

COLLECTION CONSTRUCTION

PROFESSIONAL DEVELOPMENT
CONTINUING EDUCATION COURSE



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A second certificate of completion for a second State Agency \$50 processing fee.

Most of our students prefer to do the assignment in Word and e-mail or fax the assignment back to us. We also teach this course in a conventional hands-on class. Call us and schedule a class today.

Responsibility

This course contains EPA's federal rule requirements. Please be aware that each state implements collections/wastewater/safety regulations that may be more stringent than EPA's or OSHA's regulations. Check with your state environmental agency for more information. You are solely responsible in ensuring that you abide with your jurisdiction or agency's rules and regulations.

Important Information about this Manual

This manual has been prepared to educate employees in the general awareness of dealing with complex wastewater collection procedures and requirements for safely handling hazardous and toxic materials.

The scope of the problem is quite large, requiring a major effort to bring it under control. Employee health and safety, as well as that of the public, depend upon careful application of safe sewer collection procedures.

This manual will cover general laws, regulations, required procedures and generally accepted policies relating to wastewater collection systems. It should be noted, however, that the regulation of wastewater and other hazardous materials is an ongoing process and subject to change over time. For this reason, a list of resources is provided to assist in obtaining the most up-to-date information on various subjects.

This manual is not a guidance document for employees who are involved with pollution control or wastewater treatment. It is not designed to meet the requirements of the United States Environmental Protection Agency (EPA) or Department of Labor-Occupational Safety and Health Administration (OSHA) or state environmental or health departments.

This course manual will provide general educational training guidance of Wastewater Collection. This document is not a detailed wastewater collection or treatment textbook or a comprehensive source book on occupational safety and health.

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It cannot be assumed that this manual contains all measures and concepts required for specific conditions or circumstances. This document should be used for educational guidance and is not considered a legal document.

Individuals who are responsible for the collection of wastewater or the health and safety of workers at wastewater sewer facilities should obtain and comply with the most recent federal, state, and local regulations relevant to these sites and are urged to consult with OSHA, EPA, and other appropriate federal, state, health, and local agencies.

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Technical Learning College's Scope and Function

Welcome to the Program,

Technical Learning College (TLC) offers affordable continuing education for today's working professionals who need to maintain licenses or certifications. TLC holds several different governmental agency approvals for granting of continuing education credit.

TLC's delivery method of continuing education can include traditional types of classroom lectures and distance-based courses or independent study. TLC's distance based or independent study courses are offered in a print - based distance educational format. We will beat any other training competitor's price for the same CEU material or classroom training.

Our courses are designed to be flexible and for you to finish the material at your convenience. Students can also receive course materials through the mail. The CEU course or e-manual will contain all your lessons, activities and instruction to obtain the assignments. All of TLC's CEU courses allow students to submit assignments using e-mail or fax, or by postal mail. (See the course description for more information.)

Students have direct contact with their instructor—primarily by e-mail or telephone. TLC's CEU courses may use such technologies as the World Wide Web, e-mail, CD-ROMs, videotapes and hard copies. (See the course description.) Make sure you have access to the necessary equipment before enrolling; i.e., printer, Microsoft Word and/or Adobe Acrobat Reader. Some courses may require proctored closed-book exams, depending upon your state or employer requirements.

Flexible Learning

At TLC, there are no scheduled online sessions or passwords you need contend with, nor are you required to participate in learning teams or groups designed for the "typical" younger campus based student. You will work at your own pace, completing assignments in time frames that work best for you. TLC's method of flexible individualized instruction is designed to provide each student the guidance and support needed for successful course completion.

Course Structure

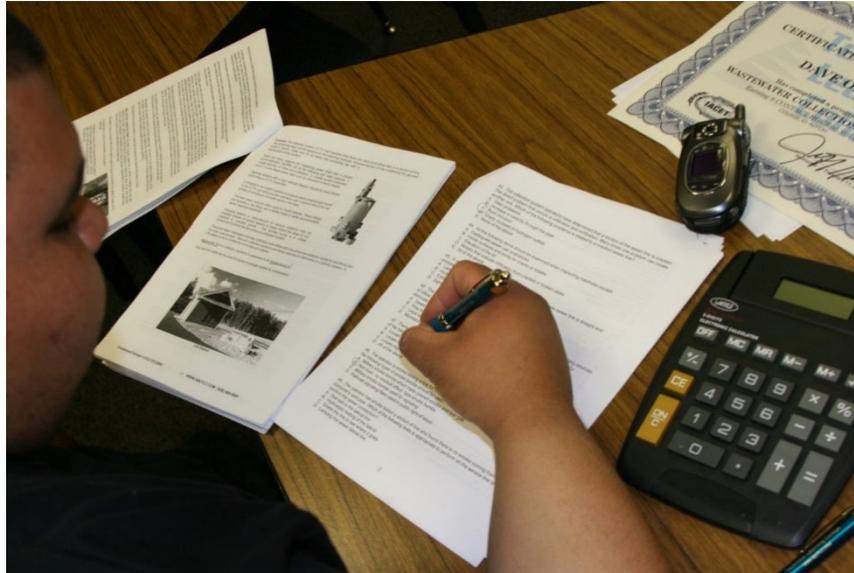
TLC's online courses combine the best of online delivery and traditional university textbooks. You can easily find the course syllabus, course content, assignments, and the post-exam (Assignment). This student-friendly course design allows you the most flexibility in choosing when and where you will study.

Classroom of One

TLC offers you the best of both worlds. You learn on your own terms, on your own time, but you are never on your own. Once enrolled, you will be assigned a personal Student Service Representative who works with you on an individualized basis throughout your program of study. Course specific faculty members (S.M.E.) are assigned at the beginning of each course providing the academic support you need to successfully complete each course. Please call or email us for assistance.

Satisfaction Guaranteed

We have many years of experience, dealing with thousands of students. We assure you, our customer satisfaction is second to none. This is one reason we have taught more than 40,000 students.



We welcome you to do the electronic version of the assignment and submit the answer key and registration to us either by fax or e-mail.

If you need this assignment graded and a certificate of completion within a 48-hour turn around, prepare to pay an additional rush charge of \$50.

Contact Numbers
Fax (928) 468-0675
Email Info@tlch2o.com
Telephone (866) 557-1746

CEU Course Description

Collection Construction CEU Training Course

Proper function of sanitary sewer systems is vital to protect public health, property, and waterways in the surrounding area. Most utilities have a management, operation and maintenance (MOM) plan to ensure their system is in working order.

This CEU course is designed for the continuing education, knowledge, and enhancement of Wastewater Collection system Operators, Pretreatment/Industrial Wastewater Operators and Wastewater Treatment Operators. The target audience for this course is the person interested in working in a wastewater treatment or collections facility and/or wishing to maintain CEUs for certification license or to learn how to do the job safely and effectively, and/or to meet education needs for promotion. This is not a comprehensive wastewater treatment or collections manual.

This CEU training course will review various wastewater collection methods, related construction and confined space subjects. This course is general in nature and not state specific but will contain different wastewater collection methods, rules, policies, electricity, pump, safety, operator certification and lift station information. This information is essential to properly operate any wastewater collection system. You will not need any other materials for this course.

Final Examination for Credit

Opportunity to pass the final comprehensive examination is limited to three attempts per course enrollment.

Upon Successful Completion of this Course, You Will Receive

- Up to 3 Continuing Education Units/ thirty training hours depending upon your State.
- A frameable certificate of competition.

Course Procedures for Registration and Support

All of Technical Learning College's distance learning courses have complete registration and support services offered. Delivery of services will include; e-mail, web site, telephone, fax, and mail support. TLC will attempt immediate and prompt service.

When a student registers for a correspondence course, he/she is assigned a start date and an end date.

It is the student's responsibility to note dates for assignments and keep up with the course work. If a student falls behind, he/she must contact TLC and request an end date extension in order to complete the course. It is the prerogative of TLC to decide whether to grant the request. All students will be tracked by a unique number assigned to the student.

Instructions for Written Assignments

The Collection Construction CEU Training course uses a multiple choice style answer key. You can write your answers in this manual or type out your own answer key. TLC would prefer that you fill out and fax, or e-mail the final examinations to TLC, but it is not required.

Feedback Mechanism (Examination Procedures)

Each student will receive a feedback form as part of their study packet. You will be able to find this form in the front of the assignment or lesson.

Security and Integrity

All students are required to do their own work. All lesson sheets and final exams are not returned to the student to discourage sharing of answers. Any fraud or deceit and the student will forfeit all fees and the appropriate agency will be notified.

Grading Criteria

TLC will offer the student either pass/fail or a standard letter grading assignment. If TLC is not notified, you will only receive a pass/fail notice.

Required Texts

The Collection Construction CEU training course will not require any other materials. This course comes complete. No other materials are needed.

Environmental Terms, Abbreviations, and Acronyms

TLC provides a glossary that defines, in non-technical language, commonly used environmental terms appearing in publications and materials. It also explains abbreviations and acronyms used throughout EPA and other agencies. You can find the glossary in the rear of the manual.

Recordkeeping and Reporting Practices

TLC will keep all student records for a minimum of seven years. It is your responsibility to give the completion certificate to the appropriate agencies. TLC will mail a copy to any State that requires a copy from the Training Provider.

ADA Compliance

TLC will make reasonable accommodations for persons with documented disabilities. Students should notify TLC and their instructors of any special needs. Course content may vary from this outline to meet the needs of this particular group.

Prerequisites: None

Note to Students

Keep a copy of everything that you submit. If your work is lost you can submit your copy for grading. If you do not receive your certificate of completion or quiz results within two or three weeks after submitting it, please contact your instructor. We expect every student to produce his/her original, independent work.

Any student whose work indicates a violation of the Academic Misconduct Policy (cheating, plagiarism) can expect penalties as specified in the Student Handbook, which is available through Student Services; contact them at (928) 468-0665. A student who registers for a Distance Learning course is assigned a "**start date**" and an "**end date.**" It is the student's responsibility to note due dates for assignments and to keep up with the course work. If a student falls behind, she/he must contact the instructor and request an extension of her/his **end date** in order to complete the course. It is the prerogative of the instructor to decide whether or not to grant the request.

Continuing Education Units

You will have 90 days from receipt of this manual to complete it in order to receive your Continuing Education Units (CEUs) or Professional Development Hours (PDHs). A score of 70% is necessary to pass this course. If you should need any assistance, please visit our Assistance Page on the website. Please e-mail all concerns and the final test to info@tlch2o.com.

Educational Mission

The educational mission of TLC is:

To provide TLC students with comprehensive and ongoing training in the theory and skills needed for the environmental education field,

To provide TLC students with opportunities to apply and understand the theory and skills needed for operator certification,

To provide opportunities for TLC students to learn and practice environmental educational skills with members of the community for the purpose of sharing diverse perspectives and experience,

To provide a forum in which students can exchange experiences and ideas related to environmental education,

To provide a forum for the collection and dissemination of current information related to environmental education, and to maintain an environment that nurtures academic and personal growth.

Course Objective: To provide up to thirty hours of continuing education training in effective and efficient wastewater collection methods, cleaning, construction and confined space entry.



Using chain nubbars to cut pipe.

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Hyperlink to the Glossary and Appendix

<http://www.abctlc.com/downloads/PDF/WWTGlossary.pdf>

Topic Legend – Need-to-Know Criteria

This CEU course covers several educational topics/functions/purposes of conventional wastewater collection operations. The topics listed below are to assist in determining which educational area is covered in a specific topic area:

CO: Having to do with the wastewater collections system. Could be regular or emergency work. This is O&M training for collection operators.

CRAO: The regulatory and compliance component. May be a requirement of the NPDES or discharge permit, compliance, non-compliance, process control and local limits. This along with the EPA information is to satisfy the regulatory portion of your operator training.

ELECTRICAL (SPARK): This section has to do with electrical principles and difficult math calculations. Maybe good for credit for those who hold an electrician or instrumentation certification. This may be considered O&M training for many operators.

FLUID MECHANICS (FM): Having to do with hydraulic or fluid mechanics. A highly technical and specialized engineering field. This may be considered O&M training for many operators or credit for pump engineers or pump mechanics.

MOTOR: Having to do with the electrical-mechanical portion of moving water. This may be considered O&M training for many operators. Maybe good for credit for those who hold an electrician or instrumentation certification.

O&M: This area is for normal operation and/or maintenance of the plant or sewer collection system. O&M training for many operators.

PUMP ENGINEERING (PE): The technical science of pumping and pump performance principles. May be a law or theory or calculation related to pumping. Information that a pump engineer or collection operator may need.

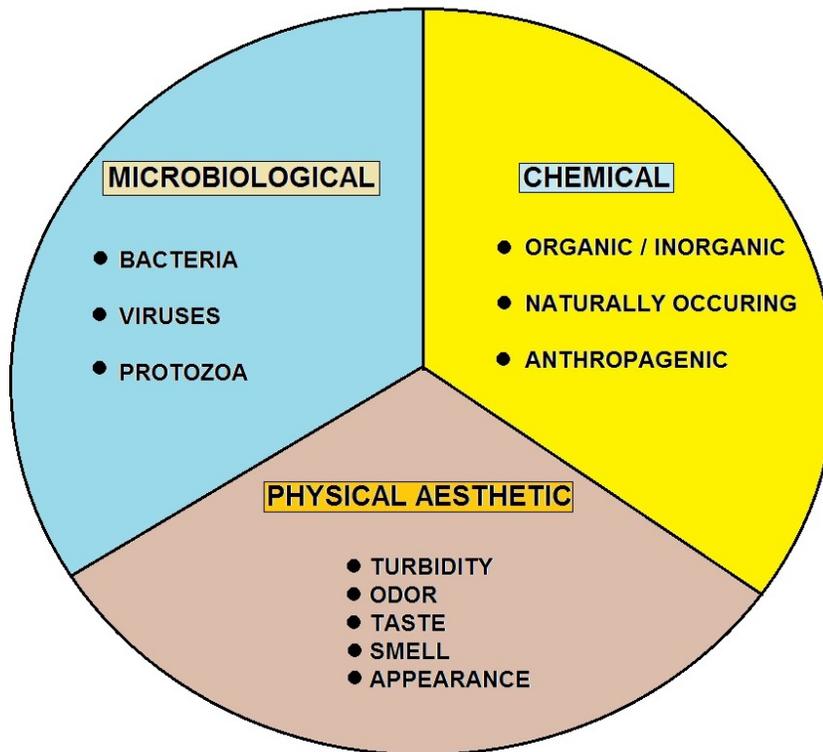
SAFETY: This area is describing process safety procedures. Safety or general training for many operators.

SCADA: Having to do with data acquisition and control methods. Remote operation of pumps and motors from a distant location or cell phone. Maybe good for credit for those who hold an electrician or instrumentation certification.

SCIENCE (SCI): Having to do with scientific principles, laws or theories. A principle that can be observed or repeated in the Laboratory. May be good for laboratory or engineering credit.

TECHNICAL: The mechanical or physical treatment process/component. O&M training for many operators.

WQ: Having to do with water quality or pollutants. May be a requirement of your NPDES or discharge permit. This along with the EPA information is to satisfy the regulatory portion of your operator training.



WATER QUALITY BROKEN DOWN INTO 3 BROAD CATEGORIES

Sewage and Pollution

Sewage contains nutrients of every type; phosphorus, nitrogen, sodium, potassium, iron, calcium and compounds such as fats, sugars and proteins. Microorganisms use these substances as a “food” source for energy, for the synthesis of cell components and to maintain life processes.

Many types of microorganisms can be found in the wastewater treatment system. However, the types of organisms that will dominate will be the ones that are best suited to the “environment” or conditions in the system. Wastewater treatment systems are designed to foster an “environment” that suits a certain type of microorganism. These microorganisms not only remove organic wastes from the water, but they also “settle out” as solid material for easy removal. Wastewater treatment operators are required to maintain the right conditions in the treatment system for the right type of microorganisms.

While there are many different microbes used in sewage treatment, there are three well-known microbes that play an instrumental role in keeping sewage clean. Each of these types of bacteria help the treatment process in a unique way to ensure there is little to no impact on the surrounding environment.

List of Collection Acronyms used in this Course

Acronym	Full Phrase
AA	<u>Approval Authority</u>
AO	<u>Administrative Order</u>
BAT	<u>Best Available Technology Economically Achievable</u>
BCT	<u>Best Conventional Pollutant Control Technology</u>
BMP	<u>Best Management Practices</u>
BMR	<u>Baseline Monitoring Report</u>
BOD5	<u>5-day Biochemical Oxygen Demand</u>
BPJ	<u>Best Professional Judgment</u>
BPT	<u>Best Practicable Control Technology Currently Available</u>
CA	<u>Control Authority</u>
CFR	<u>Code of Federal Regulations</u>
CIU	<u>Categorical Industrial User</u>
CSO	<u>Combined Sewer Overflow</u>
CWA	<u>Clean Water Act (formerly referred to as the Federal Water Pollution Control Act or Federal Water Pollution Control Act Amendments of 1972) Pub. L. 92-500, as amended by Pub. L. 95-217, Pub. L. 95-576, Pub. L. 96-483, Pub. L. 97-117, and Pub. L. 100-4, 33 U.S.C. 1251 et seq.</u>
CWF	<u>Combined Wastestream Formula</u>
CWT	<u>Centralized Waste Treater</u>
DMR	<u>Discharge Monitoring Report</u>
DSE	<u>Domestic Sewage Exclusion</u>
DSS	<u>Domestic Sewage Study</u>
ELG	<u>Effluent Limitations Guideline</u>
EPA	<u>Environmental Protection Agency</u>
EPCRA	<u>Emergency Preparedness and Community Right to Know Act</u>
ERP	<u>Enforcement Response Plan</u>
FDL	<u>Fundamentally Different Factors</u>
FR	<u>Federal Register</u>
FWA	<u>Flow Weighted Average</u>
GPD	<u>Gallons per Day</u>
IU	<u>Industrial User</u>
LEL	<u>Lower Explosive Limit</u>
MAHL	<u>Maximum Allowable Headworks Loading</u>
MAIL	<u>Maximum Allowable Industrial Loading</u>
MGD	<u>Million Gallons per Day</u>
MSDS	<u>Material Safety Data Sheet</u>
NAICS	<u>North American Industry Classification System (replaces SIC 1998)</u>
NOV	<u>Notice of Violation</u>
NPDES	<u>National Pollutant Discharge Elimination System</u>
NRDC	<u>Natural Resources Defense Council</u>
NSPS	<u>New Source Performance Standard</u>
O&G	<u>Oil and Grease</u>
O&M	<u>Operations and Maintenance</u>

<u>OCPSF</u>	<u>Organic Chemicals, Plastics, and Synthetic Fibers</u>
<u>P2</u>	<u>Pollution Prevention</u>
<u>PCI</u>	<u>Pretreatment Compliance Inspection</u>
<u>PCS</u>	<u>Permit Compliance System</u>
<u>PIRT</u>	<u>Pretreatment Implementation Review Task Force</u>
<u>POTW</u>	<u>Publicly Owned Treatment Works</u>
<u>PSES</u>	<u>Pretreatment Standards for Existing Sources</u>
<u>PSNS</u>	<u>Pretreatment Standards for New Sources</u>
<u>QA/QC</u>	<u>Quality Assurance/Quality Control</u>
<u>RCRA</u>	<u>Resource Conservation and Recovery Act</u>
<u>SIC</u>	<u>Standard Industrial Classification</u>
<u>SIU</u>	<u>Significant Industrial User</u>
<u>SPCC</u>	<u>Spill Prevention Control and Countermeasures</u>
<u>SNC</u>	<u>Significant Noncompliance</u>
<u>SSO</u>	<u>Sanitary Sewer Overflow</u>
<u>SUO</u>	<u>Sewer Use Ordinance</u>
<u>TCLP</u>	<u>Toxicity Characteristic Leaching Procedure</u>
<u>TIE</u>	<u>Toxicity Identification Evaluation</u>
<u>TOMP</u>	<u>Toxic Organic Management Program</u>
<u>TRE</u>	<u>Toxicity Reduction Evaluation</u>
<u>TRI</u>	<u>Toxic Release Inventory</u>
<u>TSS</u>	<u>Total Suspended Solids</u>
<u>TTO</u>	<u>Total Toxic Organics</u>
<u>USC</u>	<u>United States Code</u>
<u>UST</u>	<u>Underground Storage Tank</u>
<u>WET</u>	<u>Whole Effluent Toxicity</u>
<u>WWTP</u>	<u>Wastewater Treatment Plant</u>

Strange Stories from the Collections System



"City battles giant sewer blob" — this straight-out-of-science-fiction headline got us thinking about what goes on after we flush.

LEWISTON, Maine -- A large, mysterious blob has taken over a major sewer line in the city of Lewiston, leaving public works crews stumped as to how to budge it. According to city officials, the stretch of 12-inch pipe on Main Street backed up on Jan. 13, and the city has been trying unsuccessfully to clear the line ever since.

Deputy Public Services Director Kevin Gagne told News 8 the doughy, 90-foot mass is comprised of grease, flour and rags. Gagne said the city has chosen to replace the 170-foot line at a cost of between \$40,000 and \$60,000. Work is expected to begin this week.

Alligators

Search tells us that, for the most part, the idea that alligators live in city sewers is an urban legend. Homeowners concerned about the state of their own pipes search for sewer cleaning and sewer cameras, while vacationers seek sewer tourism and other forms of urban exploration. Forget about alligators and rats; raccoons rule several sewers.

Comments: Believe it or not there is a grain of truth behind this legend, namely the documented capture of an eight-foot alligator at the bottom of an East Harlem manhole in 1935, though no one assumed that it actually lived down there. It was theorized at the time that the creature must have tumbled off a steamer visiting the northeast "from the mysterious Everglades, or thereabouts," and swam up the Harlem River. It met an unfortunate end at the hands of the teenage boys who found it.

Birth of an urban legend

The earliest published reference to alligators in the sewer -- in what Jan Harold Brunvand refers to as the "standardized" form of the urban legend ("baby alligator pets, flushed, thrived in sewers") -- can be found in the 1959 book, *The World Beneath the City*, a history of public utilities in New York City written by Robert Daley. Daley's source was a retired sewer official named Teddy May, who claimed that during his tenure in the 1930s he personally investigated workers' reports of subterranean saurians and saw a colony of them with his own eyes. He also claimed to have supervised their eradication. May was a colorful storyteller, if not a particularly reliable one.

'New York White'

The tale was well known throughout the United States by the late 1960s, when, according to folklorist Richard M. Dorson, it came to be associated with another icon of sewer lore, the mythical "New York White" -- an especially potent, albino strain of marijuana growing wild from seeds spilled out of baggies hastily flushed down toilets during drug raids. Not that anyone had ever actually seen the stuff, much less smoked it. It was impossible to harvest, you see, because of all the alligators down there.

The reason we speak of all this as folklore, not fact, is that herpetologists pooh-pooh the very idea of alligators thriving in the New York City sewer system. It's cold down there most of the time, they point out -- freezing cold during the winter -- and alligators require a warm environment year-round to survive, much less reproduce and burgeon into colonies. And if the cold didn't kill them off, the polluted sewer water certainly would.

Actual New York City gator sightings:

Adding fodder to the legend is the intriguing fact that wayward alligators -- escaped or abandoned pets, we assume -- do occasionally turn up in the streets of New York City, never failing to cause a ruckus.

For example:

November 2006 - A two-foot-long caiman is captured outside an apartment building in Brooklyn. Police say it "snapped and hissed" at them.

June 2001 - A small alligator (actually a caiman, as it turned out) was spotted and eventually captured in Central Park.

The experts speak:

"I would bring leftovers from lunch, a long line and a hook, and spend a part of each day in the sewers looking for alligators. I saw rats, cockroaches — probably caught a lot of sicknesses — but I never saw anything like an alligator."

— *Frank Indiviglio, herpetologist*

"It's like the Loch Ness Monster or the Big Foot. People believe in those stories up to a point that it does make sense."

— *Esteban Rodriguez, NYC sewer worker*

Wastewater Collection Pre-Quiz *Answers are at the end of Quiz.*

1. Your collection system requires a new sewer main line. Who would be the best source of information for instructions on how to lay and join new sewer pipes?

- A. Manufacturer
- B. A local plumbing contractor
- C. Utility inspector
- D. Grading and drainage inspector

2. In many sewer installations, low pressure air testing is necessary to determine the tightness of the pipe. In instances where ground water levels are higher than the sewer lines, the new pipes are usually tested around _____ to _____ psi above any outside water pressure on the pipe.

- A. 3, 5
- B. 7, 10
- C. 10, 14
- D. 15, 22

3. A good manager will establish a good record-keeping system to help in analyzing many problems that occur. Records such as outside services versus in-house personnel costs could result in saving money by hiring personnel to handle jobs typically farmed out. For the purposes of budgeting and justifying the costs the manager will:

- A. Present all bills to the board
- B. Hide the excessive costs in other lines of the budget
- C. Beg for budget increases by verbal communication only
- D. Plot the costs to ease understanding the need for personnel
- E. None of the above, at least at my yard

4. Managers and supervisors maintain a personnel file on each employee. These files contain information about the employee. Which of the following should not be found in the employee file?

- A. Accident reports
- B. Budget requirement to justifying employee hiring
- C. Attendance analysis
- D. Performance evaluations

5. Sewer lines made of _____ types of pipe should be tested with a mandrel to measure for _____ and joint offsets.

- A. flexible, deflection
- B. ductile iron, tightness
- C. clay, stress cracks
- D. cement, thickness

6. What is the one most important reason for having a wastewater collection system?

- A. Prevent disease
- B. Keep the waste out of sight
- C. To allow for gravity feed
- D. To alleviate the foul smell
- E. Both C & D



7. Many public agencies are having a difficult time stretching their financial resources to meet all the demands they face from both internal and external sources. What is the best thing a collection system operator can do to help in meeting these challenges?
- A. Provide good collection system maintenance, operation, and inspection
 - B. Agree to work only 4 hours of overtime a week
 - C. Donate unused vacation and sick time back to the utility
 - D. None of the above
8. An operator should have a good understanding of the terms used in wastewater collection systems. What description best explains the term "*combined wastewater*"?
- A. A mixture of surface runoff and industrial wastewater
 - B. A mix of domestic wastewater and storm water
 - C. A blend of domestic and industrial wastewater
 - D. Both A and B
 - E. None of the above
9. A term used often in a collection system is the term "*grade ring*". What best describes a grade ring as used in the collection system?
- A. The bell end of the pipe that must be placed down slope
 - B. A precast concrete ring of various heights to raise the manhole cover
 - C. A surveyors tool used to mark grade along the trench
 - D. None of the above
10. Two words are used to describe a collection system; they are the words '*sanitary*' and '*wastewater*'. Which is the correct definition of the term '*sanitary collection system*'?
- A. The pipe system prior to being used
 - B. The combination of domestic and industrial waste
 - C. A collection system used only for storm water
 - D. A collection system used only for domestic waste
11. Ideally wastewater collection systems are designed and constructed to provide a minimum velocity of _____ ft per second to ensure the waste is maintained in suspension.
- A. 4.32
 - B. 6.20
 - C. 2.00
 - D. 8.25
12. A ball is traveling down a 12 inch sewer line and you see it at your manhole at 1:52:00 p.m. Your partner, at the next manhole 350 feet away, said the ball went past her at 1:55:02 p.m. The estimated surface velocity in the sewer is:
- A. 9.65 ft/sec
 - B. 1.9 ft/sec
 - C. 116.7 ft/sec
 - D. 3.97 ft/sec
13. Which of the following types of pipe materials would not be suitable for use in a wastewater collection system?
- A. Asbestos cement pipe
 - B. Uncoated black iron pipe
 - C. Polyethylene

14. Channel corrections are usually required for _____ and _____ in older manholes to reduce the causes of turbulent flows and restrictions to flow in the incoming lines.
- A. Tee intersections, basin channels
 - B. Wye channels, ell turns
 - C. Lateral flows, sweeping turns
 - D. Flat bottoms, low steps
15. The coefficient value used to represent the channel or pipe roughness in Manning's formula for computing flows in gravity sewers is called the:
- A. "R" factor
 - B. "N" factor
 - C. Abrasion value
 - D. Both A and B
16. The type of waste that can generally be consumed by bacteria and other small organisms is called:
- A. Microbes
 - B. Organic waste
 - C. Inorganic waste
 - D. Mineral waste
 - E. None of the above
17. What is the name given to a chamber, connected to the flow in the main channel by a small inlet, where the liquid level is measured to determine the flow in the main channel?
- A. Flow meter
 - B. Measuring well
 - C. Stilling well
 - D. Venturi chamber
18. The primary purpose of lubrication in the maintenance of equipment is to reduce the _____ and _____ between two surfaces.
- A. Galling, bonding
 - B. Wear, tear
 - C. Friction, heat
 - D. Roughness, friction
19. One important point to remember when using a portable centrifugal trash pump is to:
- A. Always locate the pump as close as possible to the water surface being pumped.
 - B. Always locate the pump as close as possible to the discharge pond
 - C. A high suction lift will dramatically increase the discharge volume
 - D. A high discharge head will decrease the need for a high suction lift
20. The two terms that are frequently used to describe the incoming and outgoing conductors of circuit breakers, motor starters, and other devices are called?
- A. Hot lead, ground wire
 - B. Amperage in, voltage out
 - C. Line side, load side
 - D. Time delay fuse, circuit breaker

Answers to Quiz

1. A
2. A
3. D
4. B
5. A
6. A
7. A
8. D
9. B
10. D
11. C
12. B
13. B
14. A
15. D
16. B
17. C
18. C
19. A
20. C



Installation of grinder pump for a low-pressure system.



Low-Pressure System

Inside a grinder pump found outside a home, the inlet is 3 inches and outlet is only 1½ inches.

Chapter 1- WASTEWATER COLLECTION SECTION

Section Focus: You will learn the basics of the wastewater collection. At the end of this section, you the student will be able to describe the basics of the gravity collection system. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.

Scope/Background: As a collection system operator, you will need knowledge of many different concerns of the collections system in order to properly identify the problems. Master's level knowledge of the collection system is essential for all pretreatment inspectors.



Collection System and its Purpose

Every house, restaurant, business, and industry produces waste. Wastewater collection protects public health and the environment by removing this infectious waste and recycling the water. A network of interconnected pipes accepts the flow from each building's sewer connection and delivers it to the treatment facilities. In addition to what homes and businesses flush down the drain, the system also collects excess groundwater, infiltration liquids, and inflow water. Wastewater collection is therefore a comprehensive liquid waste removal system.

The fluid waste distributed through this system is about 98% water. The waste floats on, is carried along by, and goes into suspension or solution in water. Possible waste includes anything that can be flushed down the drain--human excretion, body fluids, paper products, soaps and detergents, foods, fats, oil, grease, paints, chemicals, hazardous materials, solvents, disposable and flushable items; the list is almost infinite. This mixture of water and wastes is called "*wastewater*." In the past, it was known as "*sewage*," but this term is now falling out of favor because it refers specifically to domestic sanitary wastewater, like toilet flushing, which represents only a portion of the entire fluid waste content.

"*Wastewater*" is a more accurate description and has become the standard term for this fluid waste because it encompasses the total slurry of wastes in water that is gathered from homes and businesses.

Collection System Defined

A system composed of gravity pipes, manholes, tanks, lift stations, control structures, and force mains that gather used water from residential and nonresidential customers and convey the flow to the wastewater treatment plant.

Wastewater systems collect and dispose of household wastewater generated from toilet use, bathing, laundry, and kitchen and cleaning activities.

Any structure with running water, such as a house or office, must be connected to one of the following wastewater disposal systems:

- **Centralized** systems are *public sewer systems* that serve established towns and cities and transport wastewater to a central location for treatment.
- **Decentralized** systems do not connect to a public sewer system. Wastewater may be treated on site or may be discharged to a private treatment plant.

Centralized Systems

Large-scale public sewer systems (municipal wastewater treatment plants) are centralized systems. These systems generally serve established cities and towns and may provide treatment and disposal services for neighboring sewer districts. Where appropriate, centralized systems are preferred to decentralized systems, as one centralized system can take the place of several decentralized systems. Centralized systems are more economical, allow for greater control, require fewer people, and produce only one discharge to monitor instead of several. However, decentralized systems can be useful, and this option should be evaluated on a case-by-case basis.

Decentralized Systems

Homes and other buildings that are not served by public sewer systems depend on decentralized septic systems to treat and dispose of wastewater. Most decentralized systems are on-site systems (wastewater is treated underground near where it is generated).

On-site systems are the most common wastewater treatment system used in rural areas. These systems can be a single septic system and drainfield serving one residence or a large soil absorption system serving an entire subdivision. Wastewater in decentralized systems can also be treated by a small, private wastewater treatment plant. These plants can have similar treatment processes and equipment as centralized systems but on a smaller scale.

Sewer Main

In a centralized wastewater treatment system, the sewer to which sewer connections are made from individual residences.

Trunk Lines

Sewer pipes measuring more than 12 inches in diameter and having a capacity of 1 to 10 million gallons per day. Trunk lines connect smaller sewer pipes, or collectors, to the largest transport pipes or interceptors.

Collectors

Small sewer pipes measuring twelve inches or less in diameter.

Gravity Sewage Collection System

Publicly owned treatment works (POTWs) collect wastewater from homes, commercial buildings, and industrial facilities and transport it via a series of pipes, known as a collection system, to the treatment plant.

Collection systems may flow entirely by gravity, or may include lift stations that pump the wastewater via a force main to a higher elevation where the wastewater can then continue on via gravity. Ultimately, the collection system delivers this sewage to the treatment plant facility. Here, the POTW removes harmful organisms and other contaminants from the sewage so it can be discharged safely into the receiving stream.



New sewer manhole with sewer mains before final burial.

Without treatment, sewage creates bad odors, contaminates water supplies, and spreads disease. Today, more than 16,000 sewage treatment plants exist in the U.S. treating more than 32 billion gallons per day of wastewater.



Modern sewer vector or Camel. It is wise to make friends with the collection crews. The collection crews can greatly assist you in your enforcement efforts and can tell you lots of information, only if you develop a relationship with them.

Combined Sewer Overflows (CSOs)

Combined sewer systems are designed to collect both sanitary wastewater and storm water runoff. During dry weather, combined sewers carry sanitary waste to a POTW. During wet weather, the combined sanitary waste and storm water can overflow and discharge untreated wastewater directly to a surface water through a combined sewer overflow (CSO).

In 1994, the EPA published a CSO Control Policy (59 FR 18688). CSOs are regulated as point sources, and require NPDES permits.

The CSO Control Policy includes Nine Minimum Controls (NMC) for CSO management, which are requirements for any CSO NPDES Permit:

- ✓ Proper operation and regular maintenance programs for the sewer system and the CSOs;
- ✓ Maximum use of the collection system for storage;
- ✓ Review and modification of pretreatment requirements to ensure that CSO impacts are minimized;
- ✓ Maximization of flow to the POTW for treatment;
- ✓ Prohibition of CSOs during dry weather;
- ✓ Control of solid and floatable materials in CSOs;
- ✓ Establishment of pollution prevention programs;
- ✓ Public notification to ensure that the public receives adequate notification of CSO occurrences and CSO impacts;
- ✓ Monitoring to effectively characterize CSO impacts and the efficacy of CSO controls.

Development of a Long Term Control Plan (LTCP) is also required for management of CSOs. For more information, visit the EPA Wet Weather information page, which includes a graphic representation of Urban Wet Weather Flows.



A Vactor clearing a Manhole.

Collection System Operators' Purpose

Collection system operators are charged with protecting public health and the environment, and therefore must have documented proof of their certifications in the respective wastewater management systems. These professionals ensure that the system pipes remain clear and open. They eliminate obstructions and are constantly striving to improve flow characteristics. They keep the wastewater moving underground, unseen and unheard. Because this wastewater collection system and the professionals who maintain it operate at such a high level of efficiency, problems are very infrequent. So much so that the public often takes the wastewater collection system for granted. In truth, these operators must work hard to keep it functioning properly.

Centralized sewer systems are generally broken out into three different categories: sanitary sewers, storm sewers, and combined sewers. Sanitary sewers carry wastewater or sewage from homes and businesses to treatment plants. Underground sanitary sewer pipes can clog or break, causing unintentional "overflows" of raw sewage that flood basements and streets. Storm sewers are designed to quickly get rainwater off the streets during rain events.

Chemical, trash and debris from lawns, parking lots, and streets are washed by the rain into the storm sewer drains. Most storm sewers do not connect with a treatment plant, but instead drain directly into nearby rivers, lakes, or oceans. Combined sewers carry both wastewater and storm water in the same pipe. Most of the time, combined sewers transport the wastewater and storm water to a treatment plant.

However, when there is too much rain, combined sewer systems cannot handle the extra volume and designed "overflows" of raw sewage into streams and rivers occur. The great majority of sewer systems have separated, not combined, sanitary and storm water pipes.

Leaking, overflowing, and insufficient wastewater collection systems can release untreated wastewater into receiving waters. Outdated pump stations, undersized to carry sewage from newly developed subdivisions or commercial areas, can also create a potential overflow hazard, adversely affecting human health and degrading the water quality of receiving waters. The maintenance of the sewer system is therefore a continuous, never-ending cycle.

As sections of the system age, problems such as corroded concrete pipe, cracked tile, lost joint integrity, grease, and heavy root intrusion must be constantly monitored and repaired. Technology has improved collection system maintenance with such tools as television camera assisted line inspection equipment, jet-cleaning trucks, and improvements in pump design. Because of the increasing complexity of wastewater collection systems, collection system maintenance is evolving into a highly skilled trade.

According to a recent Clean Water Needs Survey conducted by the USEPA, the U.S. will have to invest more than \$10 billion to upgrade existing wastewater collection systems, over \$20 billion for new sewer construction, and nearly \$44 billion to improve sewer overflows, to effectively serve the projected population. As the infrastructure in the United States and other parts of the world ages, increasing importance is being placed on rehabilitating wastewater collection systems. Cracks, settling, tree root intrusion, and other disturbances that develop over time deteriorate pipelines and other conveyance structures that comprise wastewater collection systems, including stormwater, sanitary, and combined sewers.

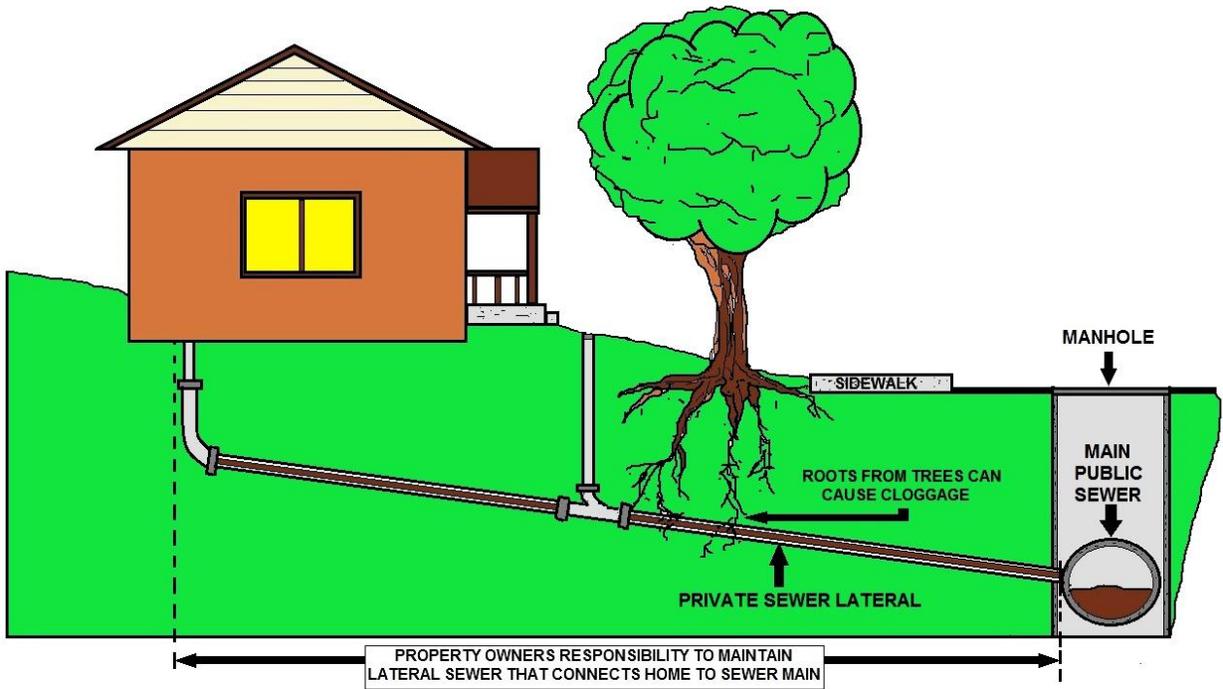
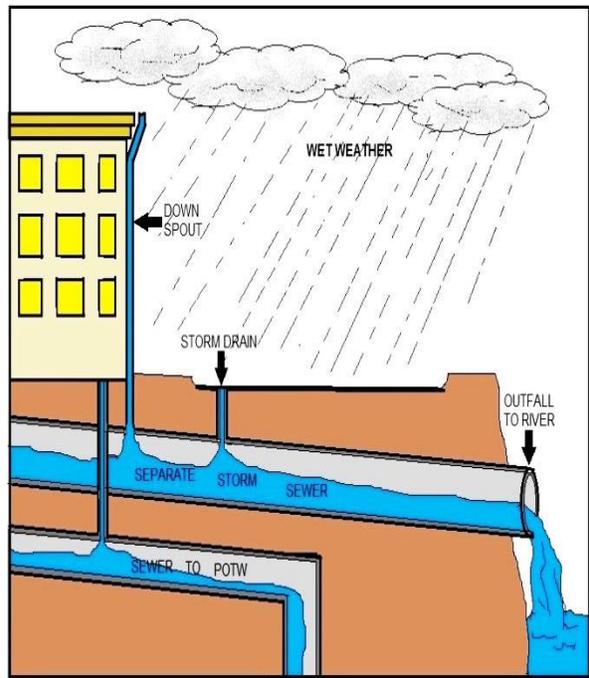
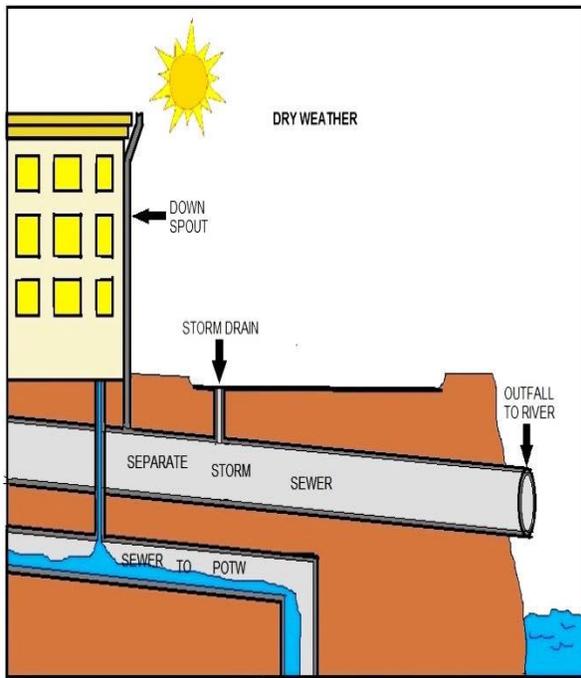


DIAGRAM OF SEWER LATERAL





Collections Daily Operations

The Sewer Cleaning Truck above is 38 feet long and 9 feet wide. The attached tank has a capacity of 1500 gallons and can hold 10 cubic yards of debris. The truck is equipped with a high pressure cleaning head that can move 800 feet down a sanitary line at 2500 PSI.

Out of sight, out of mind—that's your sanitary sewer collection system. Until there comes that inevitable emergency call due to a stoppage, then you have upset residents with sewage backed up in their toilets. A very economical and quick method of determining if a new sewer line is straight and unobstructed is called "*Lamping*" and can be done with a mirror and a bright source of light, for example a headlight at night or sunlight.

Video inspection coupled with a good cleaning program can be a highly effective maintenance tool. By cleaning and root sawing your lines, restrictions caused by debris, roots and grease buildup can be prevented—thus drastically reducing the number of emergency backups and surcharge calls.

Sewage collection systems that have video inspection closed circuit television (CCTV) and cleaning programs, report drastic reductions in the number of emergency calls because the system was cleaned and potential trouble spots were located prior to problems occurring.



Top photograph, new manhole. Bottom, a repaired sewer main after being damaged by the water distribution department using a backhoe without locates.



Rule to Protect Communities from Overflowing Sewers

The Environmental Protection Agency (EPA) has clarified and expanded permit requirements under the Clean Water Act for 19,000 municipal sanitary sewer collection systems in order to reduce sanitary sewer overflows.

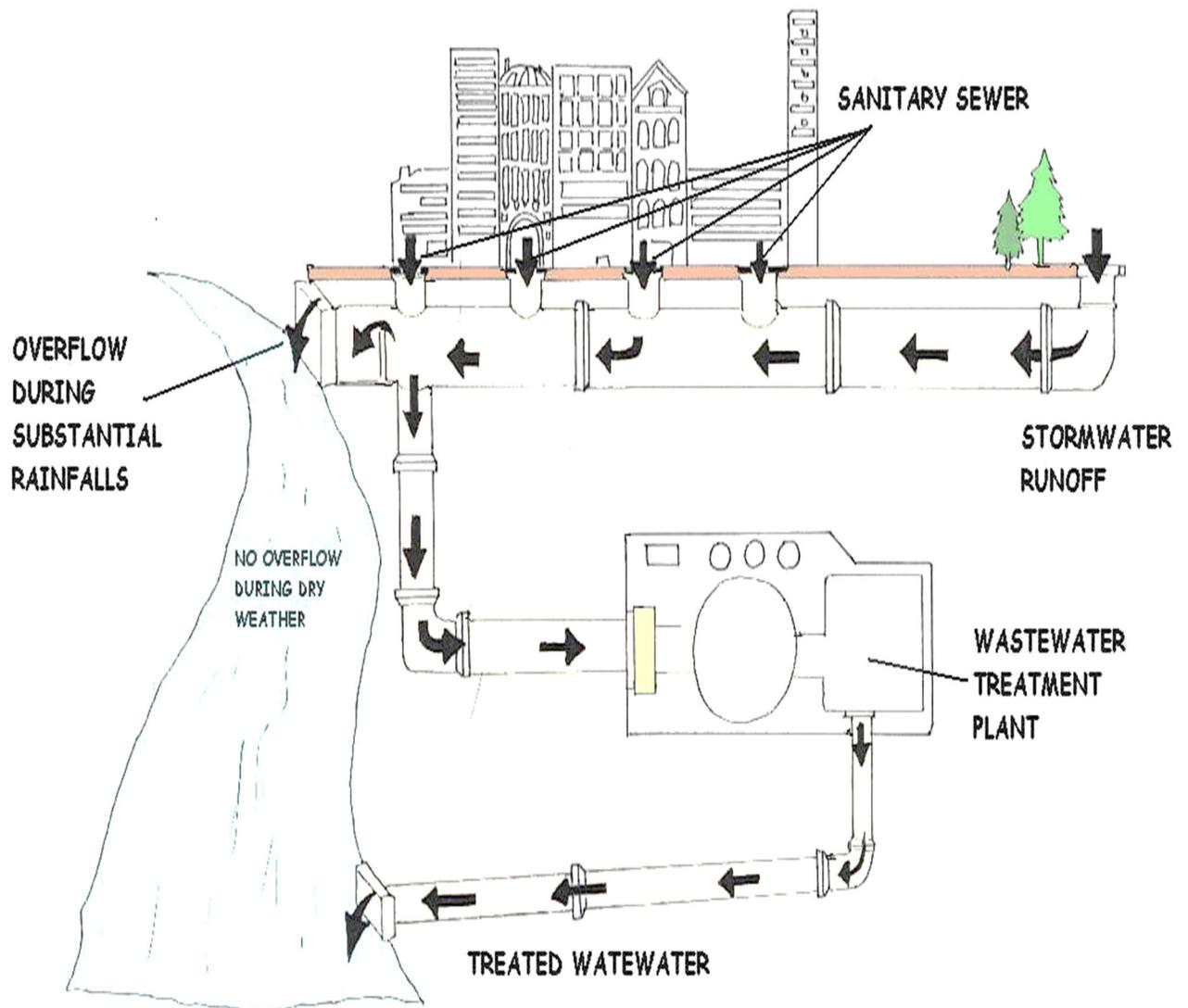
The requirements will help communities improve some of our Nation's most valuable infrastructure –our wastewater collection systems–by requiring facilities to develop and implement new capacity, management, operation, and maintenance programs and public notification programs.

The 19,000 systems covered by this rule include 4,800 municipal satellite collection systems that will be directly regulated under the Clean Water Act for the first time. These requirements will result in fewer sewer overflows, leading to healthier communities, fewer beach closures, and fish and shellfish that are safer to eat.



Various damage from undesirable materials in the sewer system. Bottom, heavy grease from not being regularly pumped. Photograph credit John Bougham.





The complexity and expense associated with a utility's CMOM or MOM programs is specific to the size and complexity of the Publicly Owned Treatment Works (POTW) and related infrastructure. Factors such as population growth rate and soil/groundwater conditions also dictate the level of investment that should be made.

Understanding the Gravity Sanitary Sewer System

A Sanitary Sewer has Two Main Functions:

- To convey the designed peak discharge.
- Transport solids so that the deposits are kept at a minimum.

Sanitary sewers are designed to transport the wastewater by utilizing the potential energy provided by the natural elevation of the earth resulting in a downstream flow. This energy, if not designed properly, can cause losses due to free falls, turbulent junctions, and sharp bends. Sewer systems are designed to maintain proper flow velocities with minimum head loss. However, higher elevations in the system may find it necessary to dissipate excess potential energy.

Design flows are based on the quantity of wastewater to be transported. Flow is determined largely by population served, density of population, and water consumption. Sanitary sewers should be designed for peak flow of population. Stormwater inflow is highly discouraged and should be designed separate from the sanitary system.

Gravity-flow sanitary sewers are usually designed to follow the topography of the land and to flow full or nearly full at peak rates of flow and partly full at lesser flows. Most of the time the flow surface is exposed to the atmosphere within the sewer and it functions as an open channel. At extreme peak flows the wastewater will surcharge back into the manholes. This surcharge produces low pressure in the sewer system.

In order to design a sewer system, many factors are considered. The purpose of this topic is to aid in the understanding of flow velocities and design depths of flow. The ultimate goal for our industry is to protect the health of the customers we serve. This is achieved by prevention of sewer manhole overflows.

Sewer System Capacity Evaluation - Testing and Inspection

The collection system owner or operator should have a program in place to periodically evaluate the capacity of the sewer system in both wet and dry weather flows and ensure the capacity is maintained as it was designed. The capacity evaluation program builds upon ongoing activities and the everyday preventive maintenance that takes place in a system.

The capacity evaluation begins with an inventory and characterization of the system components. The inventory should include the following basic information about the system:

- Population served
- Total system size (feet or miles)
- Inventory of pipe length, size, material and age, and interior and exterior condition as available
- Inventory of appurtenances such as bypasses, siphons, diversions, pump stations, tide or flood gates and manholes, etc., including size or capacity, material and age, and condition as available
- Force main locations, length, size and materials, and condition as available
- Pipe slopes and inverts
- Location of house laterals - both upper and lower

The system then undergoes general inspection which serves to continuously update and add to the inventory information.

Capacity Limitations

The next step in the capacity evaluation is to identify the location of wet weather related SSOs, surcharged lines, basement backups, and any other areas of known capacity limitations. These areas warrant further investigation in the form of flow and rainfall monitoring and inspection procedures to identify and quantify the problem. The reviewer should ensure that the capacity evaluation includes an estimate of peak flows experienced in the system, an estimate of the capacity of key system components, and identification of the major sources of I/I that contribute to hydraulic overloading events.

The capacity evaluation should also make use of a hydraulic model. This model will help identify areas where there is a need to alleviate capacity limitations. Short and long term alternatives to address hydraulic deficiencies should be identified, prioritized, and scheduled for implementation. A sewer inspection is an important part of a sewer system capacity evaluation and determining your options or alternatives.

Flow Monitoring

Fundamental information about the collection system is obtained by flow monitoring. Flow monitoring provides information on dry weather flows as well as areas of the collection system potentially affected by I/I. Flow measurement may also be performed for billing purposes, to assess the need for new sewers in a certain area, or to calibrate a model.

There are three techniques commonly used for monitoring flow rates:

- (1) permanent and long-term,
- (2) temporary, and
- (3) instantaneous.

Permanent installations are done at key points in the collection system such as the discharge point of a satellite collection system, pump stations, and key junctions. Temporary monitoring consists of flow meters typically installed for 30-90 days. Instantaneous flow metering is performed by collection system personnel, one reading is taken and then the measuring device is removed. The collection system owner or operator should have a flow monitoring plan that describes their flow monitoring strategy, or should at least be able to provide the following information:

- Purpose of the flow monitoring
- Location of all flow meters
- Type of flow meters
- Flow meter inspection and calibration frequency

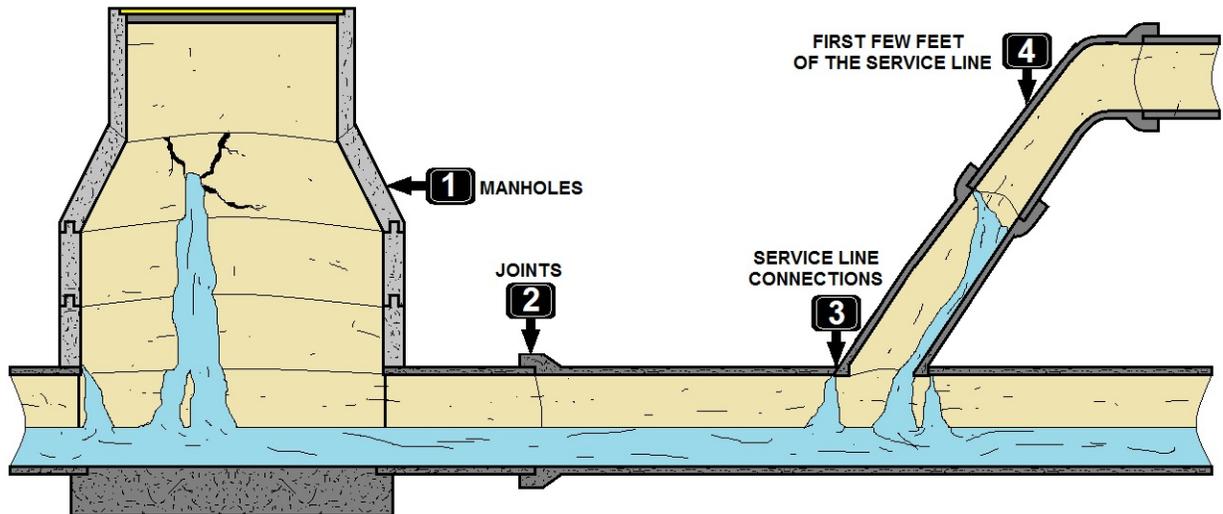
Flow Monitoring Plan

A flow monitoring plan should provide for routine inspection, service, and calibration checks (as opposed to actual calibration). In some cases, the data is calibrated rather than the flow meter. Checks should include taking independent water levels (and ideally velocity readings), cleaning accumulated debris and silt from the flow meter area, downloading data (sometimes only once per month), and checking the desiccant and battery state. Records of each inspection should be maintained.

Infiltration and Inflow Sub-Section

What is Infiltration/Inflow (I/I)?

Infiltration occurs when groundwater enters the sewer system through cracks, holes, faulty connections, or other openings. Inflow occurs when surface water such as storm water enters the sewer system through roof downspout connections, holes in manhole covers, illegal plumbing connections, or other defects.



INFLOW INTO SEWER SYSTEM EXAMPLE

The sanitary sewer collection system and treatment plants have a maximum flow capacity of wastewater that can be handled. I/I, which is essentially clean water, takes up this capacity and can result in sewer overflows into streets and waterways, sewer backups in homes, and unnecessary costs for treatment of this water. It can even lead to unnecessary expansion of the treatment plants to handle the extra capacity. These costs are passed on to the consumer.

I&I (Infiltration and Inflow)

- Infiltration is water (typically groundwater) entering the sewer underground through cracks or openings in joints.
- Inflow is water (typically stormwater or surface runoff) that enters the sewer from grates or unsealed manholes exposed to the surface.

Determining I/I

Flow monitoring and flow modeling provide measurements and data used to determine estimates of I/I. Flow meters are placed at varying locations throughout the sewer collection system to take measurements and identify general I/I source areas. Measurements taken before and after a precipitation event indicate the extent that I/I is increasing total flow. Both infiltration and inflow increase with precipitation. Infiltration increases when groundwater rises from precipitation, and inflow is mainly stormwater and rainwater. Rainfall monitoring is also performed to correlate this data.

Identifying Sources of I/I

A Sewer System Evaluation Survey (SSES) involves inspection of the sewer system using several methods to identify sources of I/I:

Visual inspection - accessible pipes, gutter and plumbing connections, and manholes are visually inspected for faults.

Smoke testing – smoke is pumped into sewer pipes. Its reappearance aboveground indicates points of I/I. These points can be on public property such as along street cracks or around manholes, or on private property such as along house foundations or in yards where sewer pipes lay underground.

TV inspection – camera equipment is used to do internal pipe inspections. The City will usually have one 2-3 person crew that can perform TV inspection on over 20 miles of sewer pipe per year.

Dye testing – Dye is used at suspected I/I sources. The source is confirmed if the dye appears in the sewer system.

Sources of I/I are also sometimes identified when sewer backups or overflows bring attention to that part of the system. The purpose of the SSES is to reduce these incidences by finding sources before they cause a problem.

I/I Source Treatments

Repair techniques include manhole wall spraying, trenchless sewer pipe relining, manhole frame and lid replacement, and disconnecting illegal plumbing, drains, and roof downspouts.

Structural problems can cause major headaches. CCTV is one of the best tools available to check the condition of your buried assets. During CCTV field inspections, pipe defects and maintenance issues are discovered and classified using a standardized coding system. Following data analysis, structural condition information is used to estimate a pipe's performance, remaining useful life and to plan for the future and make decisions about pipe repair or replacement.

CCTV inspections also reveal maintenance issues, which aid the manager in making any necessary operation or maintenance changes.

- Collapses
- Fractures
- Sags
- Infiltration
- Inflow

Hydraulic Capacity

Hydraulic capacity is a primary performance measure for a wastewater collection system. Capacity (both hydraulic and treatment) can be taken up by clean water entering the sewer collection system. It may be obvious, based on dry weather and wet weather flows, that rainwater or groundwater inflow or infiltration (I/I) is a problem.

CCTV evaluation can determine the specific location and cause of I/I in many cases, however, flow data gathered by flow meters has been used to guide sewer system capacity management for decades.

Flow data can be used as a tool in condition assessment either to identify areas for further CCTV inspection or to quantify the severity of I/I identified during CCTV work.

- Excess flow
- Infiltration
- Inflow

Fortunately, there are several actions you can take after a manhole inspection reveals I&I. Here are a few:

1. Replace the manhole covers.

- a. Cost – approximately \$200 per cover.
- b. I&I reduction could be \$350 per year or more if the covers are submerged during rain events.

2. Chemical grouting to seal up leaky joints.

- a. Cost – \$500 and up.
- b. Reduction could be as much as \$5,000 per year per manhole.

3. Line the manhole.

- a. Cost – approximately \$3,000.
- b. Could reduce costs by \$20,000 per year per manhole.

Efficient Identification of Excessive I/I

The owner or operator should have in place a program for the efficient identification of excessive I/I. The program should look at the wastewater treatment plant, pump stations, permanent meter flows, and rainfall data to characterize peaking factors for the whole system and major drainage basins. The reviewer should evaluate the program, including procedures and records associated with the flow monitoring plan. Temporary meters should be used on a “roving” basis to identify areas with high wet weather flows. Areas with high wet weather flows should then be subject to inspection and rehabilitation activities.

Sewer System Testing

Sewer system testing techniques are often used to identify leaks which allow unwanted infiltration into the sewer system and determine the location of illicit connections and other sources of stormwater inflow.

Two commonly implemented techniques include smoke testing and dyed water testing. Regardless of the program(s) implemented by the owner or operator, the reviewer should evaluate any procedures and records that have been established for these programs.

The reviewer should also evaluate any public relations program and assess how the owner or operator communicates with the public during these tests (i.e., when there is a possibility of smoke entering a home or building).



Smoke testing is a relatively inexpensive and quick method of detecting sources of inflow in sewer systems, such as down spouts, or driveway and yard drains, and works best for detecting cross connections and point source inflow leaks.

Smoke testing is not typically used on a routine basis, but rather when evidence of excessive I/I already exists. With each end of the sewer of interest plugged, smoke is introduced into the test section. Sources of inflow can then be identified when smoke escapes through them.

Areas Usually Smoke Tested

- Drainage paths
- Ponding areas
- Cellars
- Roof leaders
- Yard and area drains
- Fountain drains
- Faulty service connections
- Abandoned building sewers

If the collection system owner or operator implements a regular program of smoke testing, the program should include a public notification procedure.

The owner or operator should also have procedures to define:

- How line segments are isolated.
- The maximum amount of line to be smoked at one time.
- The weather conditions in which smoke testing is conducted (i.e., no rain or snow, little wind and daylight only).

The results of positive smoke tests should be documented with carefully labeled photographs. Building inspections are sometimes conducted as part of a smoke testing program and, in some cases, may be the only way to find illegal connections. If properly connected to the sanitary sewer system, smoke should exit the vent stacks of the surrounding properties.

If traces of the smoke or its odor enter the building, it is an indication that gases from the sewer system may also be entering. Building inspections can be labor intensive and require advanced preparation and communication with the public.

Inflow and Infiltration Calculation/Determination Terms

Average Annual Flow - The total annual volume divided by 365 days. This value is approximated by the mean of the twelve monthly average flows.

Average Annual Infiltration - The average of the monthly minimum flows.

Average Annual Inflow - From the average annual flow, subtract the base sanitary flow and average annual infiltration.

Average Dry Weather Flow (ADW) - Flow during a period of extended dry weather (7 to 14 days) and seasonally high groundwater. Flow includes sanitary flow and infiltration, and excludes significant industrial and commercial flows (assumes no inflow during dry weather conditions).

Base Sanitary Flow (BSF) - The portion of wastewater which includes domestic, commercial, institutional, and industrial sewage and specifically excludes infiltration and inflow. (See Estimating Base Flow, below).

Delayed Inflow volume - The portion of total inflow which is generated from indirect connections to the collection system or connections which produce inflow after a significant time delay from the beginning of a storm. Delayed inflow sources include: sump pumps, foundation drains, indirect sewer/drain cross-connections, etc. Rainfall induced infiltration cannot be distinguished from delayed inflow and is therefore included as part of delayed inflow. Delayed inflow sources have a gradual impact on the collection system and flow decreases gradually upon conclusion of the rainfall event, and after peak inflow caused by direct connections.

Direct Inflow Volume- The portion of total inflow volume which is from direct connections to the collection system such as catch basins, roof leaders, manhole covers, etc. These inflow sources allow stormwater runoff to rapidly impact the collection system.

Dry Weather Flow (DWF) - All flow in a sewer (includes sanitary flow and infiltration) except that caused directly by rainfall. Measured during a period of extended dry weather (7 to 14 days) and seasonally high groundwater. Groundwater

Infiltration (GWI) – Measured during average dry weather flow period (see above). The average of the low nighttime flows (midnight to 6 am) per day for the same time period, minus significant industrial or commercial nighttime flows.

Hydrograph - A graph showing stage (the height of a water surface above an established datum plane), flow, velocity, or other property of water with respect to time. Infiltration - Water other than sanitary wastewater that enters a sewer system from the ground through defective pipes, pipe joints, connections, or manholes. Infiltration does not include inflow.

Inflow - Water other than sanitary wastewater that enters a sewer system from sources such as roof leaders, cellar/foundation drains, yard drains, area drains, drains 4 from springs and swampy areas, manhole covers, cross connections between storm sewers and sanitary sewers, and catch basins. Inflow does not include infiltration.

Inflow volume - The total volume of inflow from a single storm event including both direct and delayed inflow. Total inflow is the area between the storm event hydrograph and the dry weather hydrograph.

Maximum Daily Flow - The highest flow during a 24 hour period.

Maximum Daily Infiltration - The highest daily flow at seasonal high groundwater after a dry period of three days or more minus the base sanitary flow.

Maximum Weekly Infiltration - The highest 7 day average flow at high groundwater after a dry period of three or more days minus the base sanitary flow.

Maximum Monthly Infiltration - The highest monthly average flow during dry or minimal rain period minus the base sanitary flow.

Maximum Daily Inflow - The highest daily wet weather flow minus the base sanitary flow and the infiltration prior to the rain event.

Maximum Weekly Inflow (includes delayed infiltration) - The highest 7 day average wet weather flow minus the base sanitary flow and the infiltration prior to the rain event.

Maximum Monthly Inflow - The highest monthly flow after subtracting the base sanitary flow and infiltration.

Peak Hourly Dry Weather Flow - The highest one hour flow after a dry period of three or more days.

Peak Hourly Inflow - The highest one hour flow rate during wet weather minus the base sanitary flow and the infiltration prior to the rain event.

Peak Hourly Wet Weather Flow – The highest one hour flow during a significant rain event.

Peak Infiltration- The highest nighttime (midnight to 6 am) flow during high groundwater (usually in early spring).

Peak Instantaneous Wet Weather Flow - The peak flow during a significant rain event day when the ground water is seasonally high.

Peaking Factor - The ratio of peak hourly flow to average daily flow.

Rainfall-Induced Infiltration - The short-term increase in infiltration which is the result of a rain event. Rainfall-induced infiltration is a portion of delayed inflow.

Wet Weather Flow- The highest daily flow during and immediately after a significant storm event. Includes sanitary flow, infiltration and inflow.

Monitoring Flows

The sanitary portion of the wastewater flow can be estimated through two methods, which can be used to 'check' each other - flow meter data and water consumption (if all sewer customers are on metered water). The first method is to analyze the wastewater flow data at the treatment facility during a dry weather period of 7 to 14 days. It is useful to choose the dry weather period during seasonal high water as you will be able to determine the peak infiltration rate at the same time.

From the flow data, calculate the average daily flow for the dry weather period (Average Dry Weather – ADW - flow). The base sanitary flow (BSF) can be estimated by subtracting the groundwater infiltration (GWI) flow from the average daily dry weather wastewater (ADW) flow. (See Estimating Infiltration below).

In the second method, water usage records can be used to estimate the base sanitary flow for the sewered population. The best time to estimate flow using this method would be when outdoor water uses are low and wastewater from a residential area can be assumed to be the same as the billed water use. In the northeast, this would typically be in the winter months prior to landscaping and swimming pool use. Groundwater infiltration can be estimated as the difference between the monitored wastewater flow and the billed water use.

Estimating Infiltration

Groundwater infiltration (GWI) can be estimated from influent flow data collected during a dry weather period at high groundwater. The dry weather period selected should be the same period as for estimating the BSF, however, it is more important to estimate GWI during high seasonal ground water. Dry weather is defined as when it has been at least three days without a rain event. During dry weather, inflow is expected to be zero.

During seasonal high groundwater, which usually occurs after snow melt and soil thaw, infiltration will be at its highest. During this period, the infiltration rate can be quantified by averaging the nighttime flows (midnight to 6 am) over several days, during dry weather conditions. The nighttime flows can be assumed to be mostly groundwater (after subtracting significant industrial or commercial nighttime flows). In most cases, the GWI rate will approximate the maximum weekly infiltration. The maximum daily infiltration will be higher and maximum monthly infiltration will be lower.

Estimating Inflow

Inflow represents the influence of wet weather on the sewer system and is calculated by subtracting out the sanitary wastewater and infiltration flow during a time that the system has been influence by rain.

Flow data during a significant storm event should be compared to the dry weather data immediately preceding the storm when groundwater conditions are similar. The rate and volume of inflow can be estimated by subtracting the base sanitary flow and infiltration flow data from the wet weather flow data. The peak inflow rate and the total inflow volume can be calculated from the flow records.

The peak inflow rate is the largest rate difference, over a one hour period, between the storm event flow data and the dry weather flow prior to the event.

The total inflow volume from a storm event can be apportioned into two components: direct inflow and delayed inflow.

Direct inflow is the portion of the inflow which rapidly increases soon after the start of the storm and decreases swiftly upon conclusion of the event. The time it takes for inflow from the nearest sub-basin to reach the treatment facility can be estimated as the time difference between initiation of the storm event and the increase in observed flow. The direct inflow ends at a time after the conclusion of the storm approximately equal to the inflow response time from the furthest sub-basin.

Delayed inflow is the portion of the inflow which decreases gradually upon conclusion of the storm and after the peak inflow caused by direct connections.

Delayed inflow is the inflow beginning at the conclusion of direct inflow and ending at a time when dry weather flow resumes. It is expected that a portion of the delayed inflow includes rainfall-induced infiltration.

In some cases, a second storm will impact the flow data before dry weather flow resumes. When this occurs, the expected delayed inflow can be extrapolated from the flow data collected prior to the second storm.

Estimating Infiltration and Inflow (I&I)

Maximum monthly I&I rate can be estimated by subtracting the BSF from the maximum monthly average flow. Average annual I&I rate can be estimated by subtracting the BSF rate from average annual flow rate. Annual I&I volume can be estimated by multiplying the average annual I&I rate by 365 days.

Sewer Flow Capacity

Most sewers are designed with the capacity to flow half full for less than 15 inches in diameter; larger sewers are designed to flow at three-fourths flow. The velocity is based on calculated peak flow, which is commonly considered to be twice the average daily flow. Accepted standards dictate that the minimum design velocity should not be less than 2 fps (0.60 m/sec) or generally greater than 10 fps (3.5 m/sec) at peak flow.

A velocity in excess of 10 fps (3.5 m/sec) can be tolerated with proper consideration of pipe material, abrasive characteristics of the wastewater, turbulence, and thrust at changes of direction. The minimum velocity is necessary to prevent the deposition of solids.

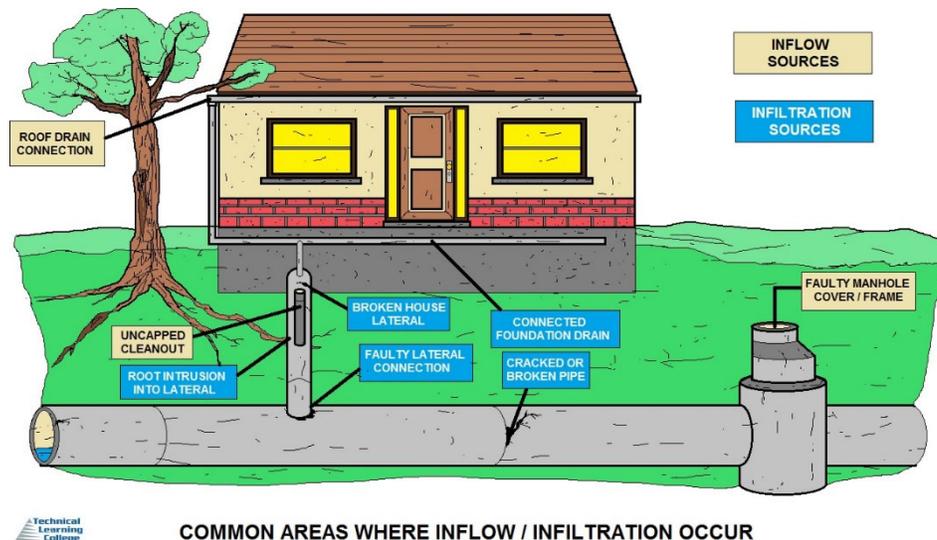
Summary

Sewers and treatment facilities are designed around expected average and maximum flows. Excess storm and groundwater entering the sewer system through I&I robs the system of its valuable capacity, puts a burden on operation and maintenance, and reduces the life expectancy of the treatment facility.

Sewer surcharging, back-ups and overflows all require emergency response and contribute to disruption of operations. Integrating I&I investigation and corrective action into a municipality's normal public works budget can allow an incremental approach to continuous improvement and help defer capacity expansion projects.

Dye Testing

Dyed water testing may be used to establish the connection of a fixture or appurtenance to the sewer. It is often used to confirm smoke testing or to test fixtures that did not smoke. As is the case with smoke testing, it is not used on a routine basis, but rather in areas that have displayed high wet weather flows. Dyed water testing can be used to identify structurally damaged manholes that might create potential I/I problems. This is accomplished by flooding the area close to the suspected manholes with dyed water and checking for entry of dyed water at the frame-chimney area, cone or corbel, and walls of the manhole.

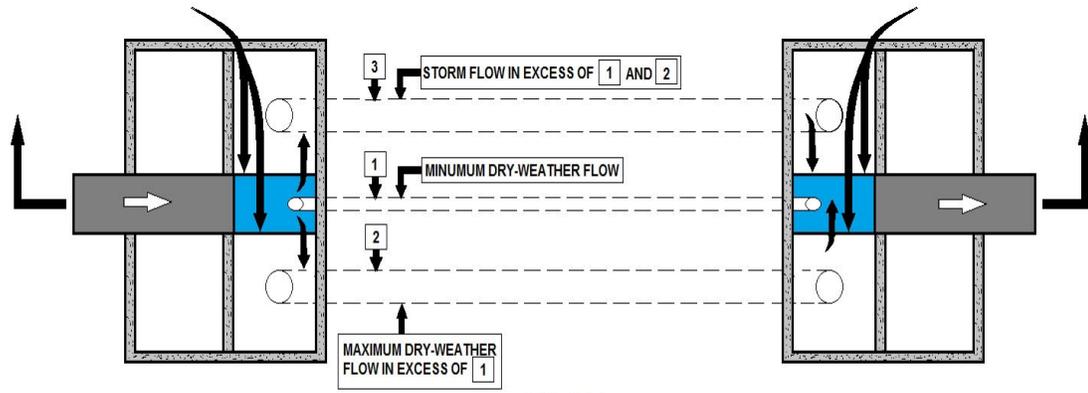


Sewer System Inspection

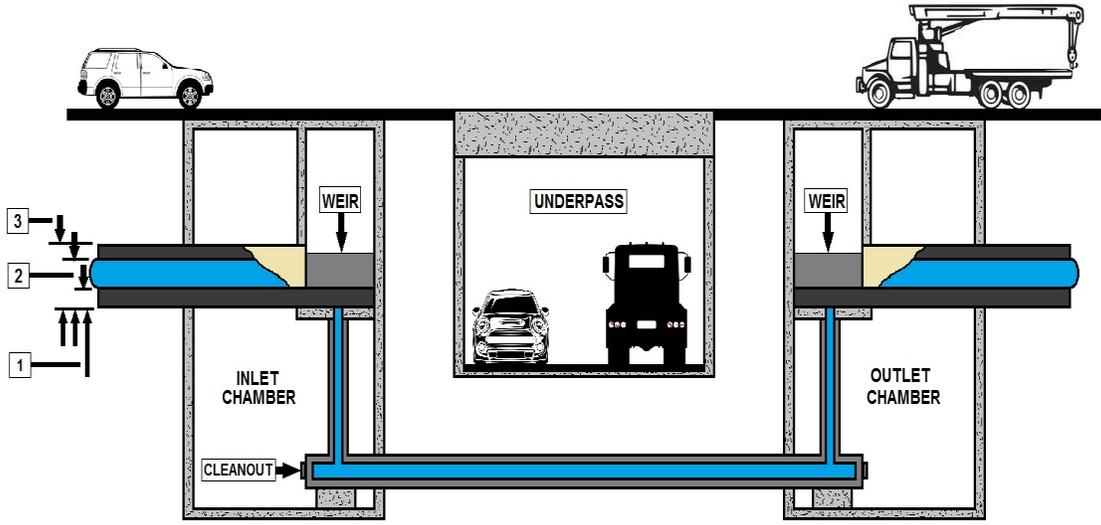
Visual inspection of manholes and pipelines is the first line of defense in the identification of existing or potential problem areas. Visual inspections should take place on both a scheduled basis and as part of any preventive or corrective maintenance activity. Visual inspections provide additional information concerning the accuracy of system mapping, the presence and degree of I/I problems, and the physical state-of-repair of the system. By observing the manhole directly and the incoming and outgoing lines with a mirror, it is possible to determine structural condition, the presence of roots, condition of joints, depth of debris in the line, and depth of flow.

The reviewer should examine the records of visual inspections to ensure that the following information is recorded:

- Manhole identification number and location.
- Cracks or breaks in the manhole or pipe (inspection sheets and/or logs should record details on defects.)
- Accumulations of grease, debris, or grit
- Wastewater flow characteristics (e.g., flowing freely or backed up.)
- Inflow - Infiltration (presence of clear water in or flowing through the manhole.)
- Presence of corrosion.
- Offsets or misalignments.
- Condition of the frame.
- Evidence of surcharge.
- Atmospheric hazard measurements (especially hydrogen sulfide.)
- If repair is necessary, a notation as to whether a work order has been issued.



PLAN



INVERTED SIPHON or SURPRESSED SEWER
(For Combined Sewage)



Low-Pressure System Description and Operation

Vacuum Sewers

Wastewater from one or more homes flows by gravity to a holding tank known as the valve pit. When the wastewater level reaches a certain level, sensors within the holding tank open a vacuum valve that allows the contents of the tank to be sucked into the network of collection piping. There are no manholes with a vacuum system; instead, access can be obtained at each valve pit. The vacuum or draw within the system is created at a vacuum station. Vacuum stations are small buildings that house a large storage tank and a system of vacuum pumps.

Vacuum sewer systems are limited to an extent by elevation changes of the land. Rolling terrain with small elevation changes can be accommodated, yet steep terrain would require the addition of lift stations like those used for conventional sewer systems. It is generally recommended that there be at least 75 properties per pump station for the use of a vacuum sewer system to be cost effective.

This minimum property requirement tends to make vacuum sewers most conducive for small communities with a relatively high density of properties per acre. The maintenance and operation of this system requires a full-time system operator with the necessary training. This can make the operation and maintenance costs of vacuum sewers exceed those of other systems.

Applications

Vacuum collection and transportation systems can provide significant capital and ongoing operating cost advantages over conventional gravity systems, particularly in flat terrain, high water table, or hard rock areas. Vacuum sewer systems are installed at shallow depths, significantly reducing excavation, shoring and restoration requirements, and minimizing the disruption to the community. The alignment of vacuum mains is extremely flexible, without the need for manholes at changes in grade or direction.

Vacuum sewer mains can skip over and around other services or obstacles and can be used to achieve uphill flow. Turbulent velocities of 5 to 6m/sec are developed as the sewage and air passes through the interface valve. This disintegrates solids and reduces the risks of sewer blockages in a correctly designed and constructed vacuum system.

No electricity is required at the interface valve, enabling the system to be installed in virtually any location. Fractures in gravity systems may go undetected for a long time. A leak in a vacuum main will raise an alarm within minutes of the break. The mains have to be repaired for sewage transport to continue, ensuring up to date maintenance and eliminating deterioration and infiltration.

Due to the shallow depth of the installation, additional connections can be quickly and simply made by a small construction crew, thus reducing the disruption and restoration work normally required for conventional gravity sewers. Vacuum collection and transport systems have many applications in industry for collecting all forms of liquid waste, including toxic and radioactive fluids. Collection pipes may be installed above ground, overhead or in utility ducts.

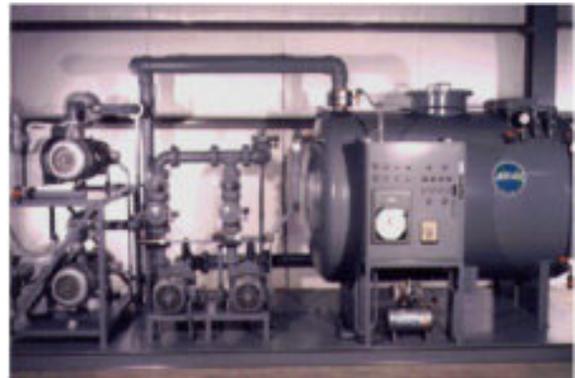
The versatility of the vacuum sewer system can be employed in a variety of locations and situations, such as:

- Rural community sewerage schemes.

- Industrial redevelopments.
- Camping and caravan sites.
- New residential and industrial developments.
- Existing towns (especially where narrow streets or congested service corridors occur).
- Diversion of small sea outfalls.
- Hospital effluent collection.
- Airports/Shopping centers.
- Railway services.
- Replacement of failed gravity systems.
- Petrol-chemical industry.
- Food processing plants.
- Roof drainage.
- Retrofitting factories for the management of segregated wastestreams.
- Collection of toxic and radioactive waste.
- Condensate collection systems.
- Factory sewerage.
- Leachate from landfills.
- Spillage around tank farms.
- Collecting used oil and fluids.
- River and lakeside communities.
- Quayside redevelopments.
- Arctic communities.

Vacuum Interface Valves

There is an interface between the vacuum within the vacuum mains and the atmospheric pressure is maintained within the vacuum interface chamber. When sewage is entering the system from a source and the sewage level in the chamber rises, it pressurizes air in the 63mm sensor line. This air pressure is transmitted by a hose to the controller/sensor unit, which opens the valve and the wastewater is rapidly drawn into the vacuum main. This suction of the sewer creates a vortex in the sump and air is drawn into the sewer with the sewage.



As the valve opens, a pneumatic timer in the controller/sensor unit starts a pre-set time cycle. The timer holds the valve open for sufficient time to draw all the sewage out of the sump and allows a designated amount of air to enter the system. The interface valve is capable of serving at least four equivalent tenements, and multiple valve chambers may be installed to serve higher flow rates. No electricity is required at the valve chamber. The vacuum valve is automatically operated by the pressure generated with the rising sewage level and the pneumatic timer, and actuated by the vacuum in the sewer.

Differential air pressure is the driving force in vacuum sewer systems. The vacuum sewer lines are under a vacuum of 16"-20" Hg (-0.5 to -0.7 bar) created by vacuum pumps located at the vacuum station. The pressure differential between the atmospheric pressure and the vacuum in the sewer lines of 7 to 10 psi (0.5 - 0.7 bar) provides the energy required to open the vacuum

interface valves and to transport the sewage. Sewage flows by gravity from homes into a collection sump.

When 10 gallons (40 liters) accumulates in the sump, the vacuum interface valve located above the sump automatically opens and differential air pressure propels the sewage through the valve and into the vacuum main. Sewage flows through the vacuum lines and into the collection tank at the vacuum station.

Sewage pumps transfer the sewage from the collection tank to the wastewater treatment facility or nearby gravity manhole. There are no electrical connections required at the home. Power is necessary only at the vacuum station.

Valve Pit Package

The Valve Pit Package connects the homes to the vacuum sewer system. Raw sewage flows by gravity from up to four homes into a sealed fiberglass sump. Located above the sewage sump and surrounded by a fiberglass valve pit is a 3" (90 mm) vacuum interface valve, which is pneumatically controlled and operated. Vacuum from the sewer line opens the valve and outside air from a breather pipe closes it.

Sewage level sensing is remarkably simple. As the sewage level rises, air trapped in the empty 2" (50 mm) diameter sensor pipe pushes on a diaphragm in the valve's controller/sensor unit, signaling the valve to open. When ten gallons of sewage accumulates in the sump the valve automatically opens. The differential air pressure propels the sewage at velocities of 15-18 feet per second (4.5 - 5.5 m/s), disintegrating solids while being transported to the vacuum station. The valve stays open for four to six seconds during this cycle.

Atmospheric air used for transport enters through the 4" (100 mm) screened air intake on the gravity line. There are no odors at this air inlet due to the small volumes of sewage (10 gallons - 40 liters) and short detention times in the sump. The valve is 3" and designed for handling nominal 3" (75 mm) solids. Homes connected to vacuum sewers don't require any special plumbing fixtures. Typically one valve pit package serves two homes. Install the valve pit package in the street, if desired. With the optional traffic cast iron cover the valve pit package has a water loading rating.

Vacuum Lines

Vacuum sewer lines are installed in narrow trenches in a saw tooth profile for grade and uphill transport. Vacuum lines follow grade for downhill transport. Vacuum lines are slightly sloped (0.2%) towards the collection station. Unlike gravity sewers that must be laid at a minimum slope to obtain a 2 ft./sec. (0.6 m/s) scouring velocity, vacuum has a flatter slope since a high scouring velocity is a feature of vacuum sewage transport.

Line Sizes

The vacuum service line from the valve to the main in the street is 3" diameter (90 mm). The vacuum mains are 4", 6", 8" and 10" diameter (110 mm to 250 mm) schedule 40 or SDR 21 gasketed PVC pipe. PE pipe can also be used. In general, a potential vacuum loss is associated with every lift. This limits the length of each vacuum line to about 2 to 3 miles (3 to 5 km) in flat terrain. Elevation changes can extend or reduce this range. Longer distances are possible depending on local topography.

Vacuum Station

The vacuum station is similar in function to a lift station in a gravity sewer system. Sewage pumps transfer the sewage from the collection tank, through a force main, to the treatment plant. Unlike a lift station, the vacuum station has two vacuum pumps that create vacuum in the sewer lines and an enclosed collection tank.

Vacuum Pumps

The vacuum pumps maintain the system vacuum in the 16" to 20" mercury vacuum (-0.5 to -0.7 bar) operating range. Vacuum pumps typically run 2 to 3 hours each per day (4 to 6 hours total) and don't need to run continuously since the vacuum interface valves are normally closed. As sewage enters the system, driven by air at atmospheric pressure, the system vacuum will slowly decrease from 20" to 16" Hg. The vacuum pumps are sized to increase the system vacuum from 16" to 20" Hg in three minutes or less.

Typical vacuum pump sizes are 10, 15, and 25 horsepower (7.5, 11 and 18.6 kw). Busch rotary vane vacuum pumps are standard. The two non-clog sewage pumps are each sized for peak flow. The collection tank is steel or fiberglass and is sized according to flow, with typical sizes ranging from 1,000 to 4,000 gallons (3.8 to 15 cubic meters). The incoming vacuum lines connect individually to the collection tank, effectively dividing the system into zones. A stand-by generator keeps the vacuum sewer system in operation during extended power outages. An automatic telephone dialer alerts the operator to alarm conditions.

Review

Pressure Sewers

Instead of relying on gravity, pressure sewers utilize the force supplied by pumps, which deliver the wastewater to the system from each property. Since pressure sewers do not rely on gravity, the system's network of piping can be laid in very shallow trenches that follow the contour of the land.

There are two kinds of pressure sewer systems, based upon the type of pump used to provide the pressure. Systems that use a septic tank/effluent pump combination are referred to as STEP pressure sewers.

Like the small diameter gravity system, STEP pressure sewers utilize septic tanks to settle out the solids; this allows for the use of piping that is extremely narrow in diameter. The effluent pump delivers the wastewater to the sewer pipes and provides the necessary pressure to move it through the system. The other type of pressure sewer uses a grinder pump.

Wastewater from each property goes to a tank containing a pump with grinder blades that shred the solids into tiny particles. Both solids and liquids are then pumped into the sewer system. Because the effluent contains a mixture of solids as well as liquids, the diameter of the pipes must be slightly larger. However, grinder pumps eliminate the need to periodically pump the septic tanks for all the properties connected to the system.

Both the STEP and grinder systems are installed with high water alarms. Because of the addition of the pumps, pressure sewers tend to require more operation and maintenance than small diameter gravity sewers.

Operators can usually be hired on a part time basis, as long as someone is on call at all times. Operators will need training on both the plumbing and electrical aspects of the system.

Manhole Sub-Section

Manholes should undergo routine inspection typically every one to five years. There should be a baseline for manhole inspections (e.g., once every two years) with problematic manholes being inspected more frequently. The reviewer should conduct visual observation at a small but representative number of manholes for the items listed below.

There are various pipeline inspection techniques, the most common include: lamping, camera inspection, sonar, and CCTV. These will be explained further in the following sections.

Sewer System Inspection Techniques

Sewer inspection is an important component of any maintenance program. There are a number of inspection techniques that may be employed to inspect a sewer system. The reviewer should determine if an inspection program includes frequency and schedule of inspections and procedures to record the results. Sewer system cleaning should always be considered before inspection is performed in order to provide adequate clearance and inspection results.

Additionally, a reviewer should evaluate records maintained for inspection activities, including whether information is maintained on standardized logs, and should include:

- Location and identification of line being inspected.
- Pipe size and type.
- Name of personnel performing inspection.
- Distance inspected.
- Cleanliness of the line.
- Condition of the manhole with pipe defects identified by footage from the starting manhole.
- Results of inspection, including estimates of I/I.

When designing a wastewater system, the design engineer begins by first determining the types and quantities of sewage to be handled. This is accomplished through a careful study of the area to be served. The design engineer bases his design on the average daily use of water per person in the area to be served. A typical value is 100 gallons per person per day. But, the use of water is not constant.

Use is greater in the summer than in the winter and greater during the morning and evening than it is in the middle of the day or at night. Therefore, the average daily flow (based on the average utilization) is multiplied by a peak flow factor to obtain the design flow.

Typical peak flow factors range from 4 to 6 times for small areas down to 1.5 to 2.5 times for larger areas. An allowance for unavoidable infiltration of surface and subsurface water into the lines is sometimes added to the peak flow to obtain the design flow.

A typical infiltration allowance is 500 gallons per inch of pipe diameter per mile of sewer per day. From the types of sewage and the estimated design flow, the engineer can then tentatively select the types, sizes, slopes, and distances below grade of the piping to be used for the system.



Upon acceptance of the preliminary designs, final design may begin. During this phase, adjustments to the preliminary design should be made as necessary, based upon additional surveys, soil analysis, or other design factors. The final designs should include a general map of the area that shows the locations of all sewer lines and structures.

They also should include detailed plans and profiles of the sewers showing ground elevations, pipe sizes and slopes, and the locations of any appurtenances and structures, such as manholes and lift stations.

Construction plans and details are also included for those appurtenances and structures.



Newly finished Manhole and Laterals

Lead and Oakum Joint, Compression Joint and No-Hub Joints

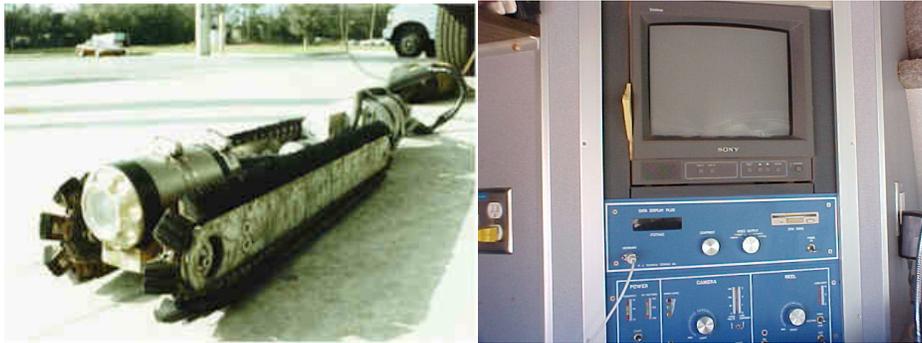
These types of joints are used to connect cast-iron soil pipes (CISP) and fittings. In lead and oakum joints, oakum (made of hemp impregnated with bituminous compound and loosely twisted or spun into a rope or yarn) is packed into the hub completely around the joint, and melted lead is poured over it. In compression joints, an assembly tool is used to force the spigot end of the pipe or fitting into the lubricated gasket inside the hub. A no-hub joint uses a gasket on the end of one pipe and a stainless steel shield and clamp assembly on the end of the other pipe.

Mortar or Bituminous Joints

This type of joint is common to vitrified clay and concrete pipes and fittings. Mortar joints may be made of grout (a mixture of cement, sand, and water).

The use of **SPEED SEAL JOINTS** (rubber rings) in joining vitrified clay pipe has become widespread. Speed seal joints eliminate the use of oakum and mortar joints for sewer mains. This type of seal is made a part of the vitrified pipe joint when manufactured. It is made of polyvinyl chloride and is called a plastisol joint connection

Closed Circuit Television (CCTV) Inspection Sub-Section



Camera Inspection

Lamping involves lowering a still camera into a manhole. The camera is lined up with the centerline of the junction of the manhole frame and sewer. A picture is taken down the pipe with a strobe-like flash. A disadvantage of this technique is that only the first 10-12 feet of the pipe can be inspected upstream and downstream of the access point. Additionally, it has limited use in small diameter sewers. The benefits of this technique include not requiring confined space entry and little equipment and set-up time is required.

Camera inspection is more comprehensive than lamping in that more of the sewer can be viewed. A still camera is mounted on a floatable raft and released into a pipe. The camera takes pictures with a strobe-like flash as it floats through the sewer pipe. This technique is often employed in larger lines where access points are far apart. Similar to lamping, portions of the pipe may still be missed using this technique.

Obviously, there also must be flow in the pipe for the raft to float. This technique also does not fully capture the invert of the pipe and its condition. Sonar is a newer technology deployed similarly to CCTV cameras, and described in more detail below.

The sonar emits a pulse which bounces off the walls of the sewer. The time it takes for this pulse to bounce back provides data and an image of the interior of the pipe, including its structural condition. A benefit of this technique is that it can be used in flooded or inaccessible sections of the sewer. The drawback is that the technique requires heavy and expensive equipment.

Sewer scanner and evaluation is an experimental technology where a 360-degree scanner produces a full digital photograph of the interior of the pipe. This technique is similar to sonar in that a more complete image of a pipe can be made than with CCTV, but not all types of sewer defects may be identified as readily (i.e., infiltration, corrosion).

Closed Circuit Television (CCTV) Inspections

Closed Circuit Television (CCTV) inspections are a helpful tool for early detection of potential problems. This technique involves a closed-circuit camera with a light which is self-propelled or pulled down the pipe. As it moves it records the interior of the pipe. CCTV inspections may be done on a routine basis as part of the preventive maintenance program, as well as part of an investigation into the cause of I/I.

CCTV, however, eliminates the hazards associated with confined space entry. The output is displayed on a monitor and videotaped. A benefit of CCTV inspection is that a permanent visual record is captured for subsequent reviews.

A remotely controlled TV camera on the top left is utilized by crews to identify and video tape problem areas within the system. By using this equipment, staff can determine what the cause of the problem is, what materials will be needed for repair, and where the problem area is.

Repairs can be made quickly without digging up large areas to find and correct a problem, as was done in the past. There are many reasons for inspecting sewer lines with a closed circuit television (CCTV). All of the following are valid reasons; locating sources of inflow and infiltration, locating buried manholes, and locating illegal sewer taps such as industrial or storm drains.



The Televising Van should be equipped with two cameras, one color camera for televising main sanitary lines and one color or black & white camera for televising house services (connection from the main sanitary line to a house).

Sewer Flow Measurements

Flow measurements performed for the purpose of quantifying I/I are typically separated into three components: base flow, infiltration, and inflow. Base flow is generally taken to mean the wastewater generated without any I/I component. Infiltration is the seepage of groundwater into pipes or manholes through defects such as cracks, broken joints, etc. Inflow is the water which enters the sewer through direct connections such as roof leaders, direct connections from storm drains or yard, area, and foundation drains, the holes in and around the rim of manhole covers, etc.

Many collection system owners or operators add a third classification: rainfall induced infiltration (RII). RII is stormwater that enters the collection system through defects that lie so close to the ground surface that they are easily reached. Although not from piped sources, RII tends to act more like inflow than infiltration.

In addition to the use of flow meters, which may be expensive for a small owner or operator, other methods of inspecting flows may be employed, such as visually monitoring manholes during low-flow periods to determine areas with excessive I/I. For a very small system, this technique may be an effective and low-cost means of identifying problem areas in the system which require further investigation.



Inside a new manhole, the Invert is the inside bottom of the pipe. The Invert is used to determine the depth which is used to determine the Rise or Slope of the pipe.

The formula for figuring the slope is: rise divided by run.



Smoke Testing is accomplished by forcing a non-toxic smoke into the sewer system and looking for locations where it is improperly exiting.

These locations are considered illegal connections in that they allow stormwater directly or indirectly to enter the sanitary sewer system.

Typical illegal connections found are roof drains tied directly into the system, abandoned customer sewer lines that were not properly capped, as well as an occasional broken sewer line.



Raising the Ring, jackhammer, install the crown, patch the street.

Sewer Flow Capacity

Most sewers are designed with the capacity to flow half full for less than 15 inches in diameter; larger sewers are designed to flow at three-fourths flow. The velocity is based on calculated peak flow, which is commonly considered to be twice the average daily flow. Accepted standards dictate that the minimum design velocity should not be less than 0.60 m/sec (2 fps) or generally greater than 3.5 m/sec (10 fps) at peak flow. A velocity in excess of 3.5 m/sec (10 fps) can be tolerated with proper consideration of pipe material, abrasive characteristics of the wastewater, turbulence, and thrust at changes of direction. The minimum velocity is necessary to prevent the deposition of solids.



Examples of various sewer flow measuring devices

The Use of a Dye at the Manhole to Determine the Velocity is Done as Follows:

1. Insert dye upstream and begin timing until the dye is first seen at the downstream manhole (t_1); and
2. Total the travel time, and the insertion time from the time the dye is no longer seen at the downstream manhole (t_2).

Once this is complete, add ($t_1 + t_2$) then divide it by 2. This will give you the total average time for the dye. In order to calculate the velocity the travel time is divided by the distance between manholes (note that the time needs to be converted to seconds):

$$\text{Velocity, ft/sec} = \frac{\text{Distance, ft}}{\text{Average time, sec}}$$

There are devices available to measure flow measurements; they all are based on the principle of the cross-sectional area of the flow in a sewer line. This is done by using the table below.

Once this has been determined, then the following equations can be used:

Q, cubic feet of flow = Area, sq ft multiplied by Velocity, ft/sec

d/D	Factor	d/D	Factor	d/D	Factor	d/D	Factor
0.01	0.0013	0.16	0.0811	0.31	0.2074	0.46	0.3527
0.02	0.0037	0.17	0.0885	0.32	0.2167	0.47	0.3627
0.03	0.0069	0.18	0.0961	0.33	0.2260	0.48	0.3727
0.04	0.0105	0.19	0.1039	0.34	0.2355	0.49	0.3827
0.05	0.0174	0.20	0.1118	0.35	0.2350	0.50	0.3927
0.06	0.0192	0.21	0.1199	0.36	0.2545	0.51	0.4027
0.07	0.0242	0.22	0.1281	0.37	0.2642	0.52	0.4127
0.08	0.0294	0.23	0.1365	0.38	0.2739	0.53	0.4227
0.09	0.0350	0.24	0.1449	0.39	0.2836	0.54	0.4327
0.10	0.0409	0.25	0.1535	0.40	0.2934	0.55	0.4426
0.11	0.0470	0.26	0.1623	0.41	0.3032	0.56	0.4526
0.12	0.0534	0.27	0.1711	0.42	0.3130	0.57	0.4625
0.13	0.0600	0.28	0.1800	0.43	0.3229	0.58	0.4724
0.14	0.0668	0.29	0.1890	0.44	0.3328	0.59	0.4822
0.15	0.0739	0.30	0.1982	0.45	0.3428	0.60	0.4920

This table works as follows:

To determine the cross-sectional flow for a 12-inch sewer main with a flow depth of 5 inches you would first:

d or depth 5 inches divided by **D** or diameter 12 inches equals 0.42 **d/D**. using the table above find the correct factor for 0.42 d/D.

The factor equals 0.3130, now calculate the cross-sectional area using the following formula:

$$\text{Pipe Cross-sectional Area, sq ft} = \frac{(\text{Factor})(\text{Diameter, in})^2}{144 \text{ sq in/sq ft}}$$

$$\frac{(0.3130)(12 \text{ in})^2}{144 \text{ sq in/sq ft}}$$

$$= 0.0313 \text{ sq ft}$$

Once the Velocity and the cross-sectional area have been determined, the calculation for flow rate is used. This formula is as followed:

$$\mathbf{Q, \text{ cubic feet per second} = (\text{Area, sq ft}) (\text{Velocity, ft/sec})}$$

Once this calculation is made, cubic feet can be converted to gallons by multiplying it by 7.48 gal/cubic feet and seconds can be converted to minutes, hours or days by multiplying the gallons with the time.

Sewer Line Mapping

The importance of maintaining accurate, current maps of the collection system cannot be overstated. Efficient collection system maintenance and repairs are unlikely if mapping is not adequate. Collection system maps should clearly indicate the information that personnel need to carry out their assignments. The collection system maps should contain information on the following:

- Main, trunk and interceptor sewers
- Building/house laterals
- Manholes
- Cleanouts
- Force mains
- Pump stations
- Service area boundaries
- Other landmarks (roads, water bodies, etc.)

Collection system maps should have a numbering system that uniquely identifies all manholes and sewer cleanouts. The system should be simple and easy to understand. Manholes and sewer cleanouts should have permanently assigned numbers and never be renumbered. Maps should also indicate the property served and reference its cleanout.



Sewer line maps should indicate the diameter, the length between the centers of manholes, and the slope or direction of flow. The dimensions of easements and property lines should be included on the maps. Other information that should be included on maps are access and overflow points, a scale, and a north arrow. All maps should have the date the map was drafted and the date of the last revision. Although optional, maps often include materials of pipe construction.

Maps may come in different sizes and scales to be used for different purposes. Detailed local maps may be used by maintenance or repair crews to perform the duties. However, these detailed local maps should be keyed to one overall map that shows the entire system.

Geographic Information System (GIS)

GIS technology has made the mapping and map updating process considerably more efficient. GIS is a computerized mapping program capable of combining mapping with detailed information about the physical structures within the collection system. If a GIS program is being used by the owner or operator, the reviewer should ask if the program is capable of accepting information from the owner or operator's management program.

Specific procedures should be established for correction of errors and updating maps and drawings. Field personnel should be properly trained to recognize discrepancies between field conditions and map data and record changes necessary to correct the existing mapping system. Reviewers should check to see that maps and plans are available to the personnel in the office and to field personnel or contractors involved in all engineering endeavors.

Key Design Characteristics

- Line locations, grades, depths, and capacities
- Maximum manhole spacing and size
- Minimum pipe size
- Pumping Station dimensions and capacities
- Drop manholes
- Flow velocities and calculations (peak flow and low-flow)
- Accessibility features
- Other technical specifications (e.g., materials, equipment)

New Sewer Construction

The owner or operator should maintain strict control over the introduction of flows into the system from new construction. New construction may be public (i.e., an expansion of the collection system) or private (i.e., a developer constructing sewers for a new development).

Quality sanitary sewer designs keep costs and problems associated with operations, maintenance, and construction to a minimum. Design flaws are difficult to correct once construction is complete.

The reviewer should be aware that this has historically not been adequately addressed in some collection systems. The owner or operator should have standards for new construction, procedures for reviewing designs and protocols for inspection, start-up, testing, and approval of new construction. The procedures should provide documentation of all activities, especially inspection.

Reviewers should examine construction inspection records and be able to answer the following:

- Does the volume of records seem reasonable given system size?
- Do records reflect that the public works inspectors are complying with procedures?

The state or other regulatory authority may also maintain standards for new construction. The standards held by the owner or operator should be at least as stringent. Start-up and testing should be in accordance with the manufacturers' recommendations where applicable, and with recognized industry practices. Each step of the review, start-up, testing, and approval procedures should be documented.

The owner or operator approval procedure should reflect future ease of maintenance concerns. After construction is complete, a procedure for construction testing and inspection should be used. Construction supervision should be provided by qualified personnel such as a registered professional engineer.



See the ladder-right on top photograph. See the collection crew under the steel plate and no shoring or trench protection. It looks like the steel plate is falling in, just another death trap for the uneducated and unsafe collection worker.





The Vector can be a very dangerous piece of equipment. Always use this equipment in the most safest manor.

Wastewater Collection Section Summary

Primary Collection System Problems

- a. Fats, oil, and greases (FOG) are a major problem; this is primarily applicable to municipal wastestreams.
- b. Odors, particularly those related to sulfides (H_2S), are a constant concern, as are other mercaptans and some indoles (skatole).
- c. In many wastewater streams, particularly in industrial ones, problems center on highly toxic anions/cations that require chemical treatment of one sort or another.
- d. Various POTW's proscribe effluent limitations on phosphates, nitrates, and various other organic entities.

Structural Sewer Problems

Structural problems can cause major headaches. CCTV is one of the best tools available to check the condition of your buried assets. During CCTV field inspections, pipe defects and maintenance issues are discovered and classified using a standardized coding system. Following data analysis, structural condition information is used to estimate a pipe's performance, remaining useful life and to plan for the future and make decisions about pipe repair or replacement.

CCTV inspections also reveal maintenance issues, which aid the manager in making any necessary operation or maintenance changes.

- Collapses
- Fractures
- Sags
- Infiltration
- Inflow

Hydraulic Capacity

Hydraulic capacity is a primary performance measure for a wastewater collection system. Capacity (both hydraulic and treatment) can be taken up by clean water entering the sewer collection system. It may be obvious, based on dry weather and wet weather flows, that rainwater or groundwater inflow or infiltration (I/I) is a problem.

CCTV evaluation can determine the specific location and cause of I/I in many cases, however, flow data gathered by flow meters has been used to guide sewer system capacity management for decades.

Flow data can be used as a tool in condition assessment either to identify areas for further CCTV inspection or to quantify the severity of I/I identified during CCTV work.

- Excess flow
- Infiltration
- Inflow

Wastewater Collection Post Quiz

Internet Link to Assignment...

<http://www.abctlc.com/downloads/PDF/Collection%20Construction.pdf>

Collection System Defined

1. Decentralized systems are public sewer systems that serve established towns and cities and transport wastewater to a central location for treatment.

A. True B. False

2. Homes and other buildings that are not served by public sewer systems depend on _____ septic systems to treat and dispose of wastewater.

3. Most decentralized systems are _____ systems (wastewater is treated underground near where it is generated).

4. Centralized systems are more inexpensive, allow for greater control, require fewer people, and produce only one discharge to monitor instead of several. However, _____ systems can be useful, and this option should be evaluated on a case-by-case basis.

5. _____ are designed to collect both sanitary wastewater and storm water runoff.

Collection System Operators' Purpose

6. Collection system operators are charged with protecting public health and the environment, and therefore must have documented proof of their certifications in the respective _____.

7. _____ and the professionals who maintain it operate at such a high level of efficiency, problems are very infrequent.

8. Collection system operators ensure that the system pipes remain clear and open. They eliminate obstructions and are constantly striving to improve flow characteristics. They keep the wastewater moving underground, unseen and unheard.

A. True B. False

9. Underground sanitary sewer pipes can clog or break, causing unplanned "overflows" of raw sewage that flood basements and streets.

A. True B. False

10. Storm sewers are not designed to quickly get rainwater off the streets during rain events.

A. True B. False

11. Combined sewers deliver both wastewater and storm water in the same pipe. Most of the time, combined sewers transport the wastewater and storm water to a treatment plant.

A. True B. False

12. The public often takes the wastewater collection system for granted. In truth, these operators must work hard to keep it functioning properly.

A. True B. False

13. When there is too much rain, combined sewer systems cannot handle the extra volume and designed "overflows" of raw sewage into streams and rivers occur. The great majority of sewer systems have separated, not combined, sanitary and storm water pipes.

A. True B. False

14. The maintenance of the sewer system is a semi-continuous cycle.

A. True B. False

15. Outdated pump stations, undersized to carry sewage from newly developed subdivisions or commercial areas, will not create any potential overflow hazards, adversely affecting human health and degrading the water quality of receiving waters.

A. True B. False

Understanding Gravity Sanitary Sewers

16. Sanitary sewers are planned to transport the wastewater by utilizing the _____ provided by the natural elevation of the earth resulting in a downstream flow.

17. Sewer systems are designed to maintain proper flow velocities with?

Sewer System Capacity Evaluation - Testing and Inspection

18. The collection system owner or operator should have a program in place to periodically evaluate this _____ in both wet and dry weather flows and ensure the capacity is maintained as it was designed.

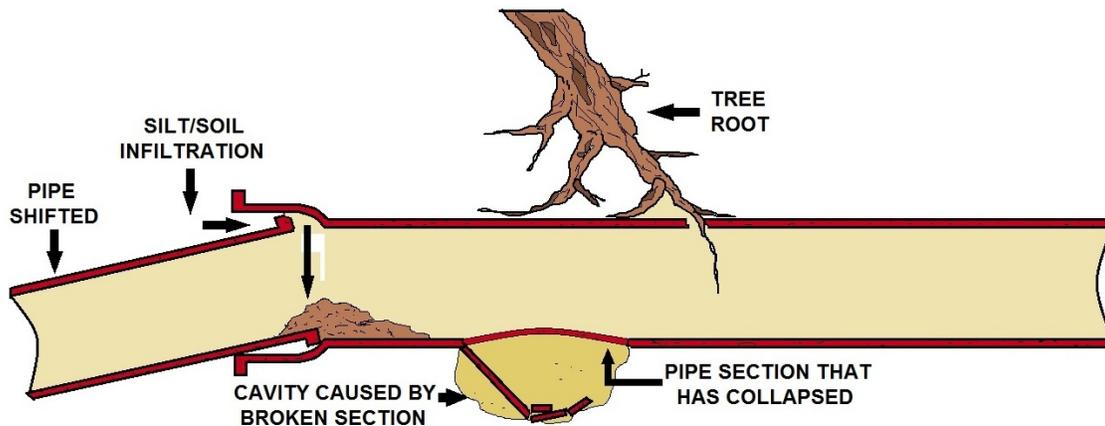
Answers

1. False, 2. Decentralized, 3. Onsite, 4. Decentralized, 5. Combined sewer systems, 6. Wastewater management system, 7. Wastewater collection system, 8. True, 9. True, 10. False, 11. True, 12. True, 13. True, 14. False, 15. False, 16. Potential energy, 17. Minimum head loss, 18. Capacity of the sewer system

Chapter 2- COLLECTION SYSTEM O&M SECTION

Section Focus: You will learn the basics of the operation and maintenance of the collection system. At the end of this section, you the student will be able to describe the basics of proper operation and maintenance of the wastewater collection system. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.

Scope/Background: As a pretreatment inspector, you will need knowledge of many different concerns of the collections and wastewater treatment systems in order to properly identify the pretreatment (pass-through or interference) problem. Master's level knowledge of the collection system is essential for all pretreatment inspectors.



BROKEN SEWER PIPE

Operation and maintenance of wastewater collection systems on a trouble or emergency basis has been the usual procedure and policy in many systems. Planned operation and preventive maintenance of the collection system has been delayed or omitted, primarily for political or financial reasons.

Routine preventative operations and maintenance activities for wastewater collection lines shall be performed by the system's personnel and outside contractors. A qualified outside contractor can also be utilized to perform hydraulic cleaning using a jet hydro-vac combination truck and mechanical cleaning using a rodding machine. Routine operations and maintenance activities including cleaning and removing roots from small and large diameter lines. The system's goal should be a minimum of cleaning between 20-30% of the sewers every year.

Closed-circuit television (CCTV) is used to assess the condition of the sewers.

There are four types of activities that the system or a CCTV contractor can also perform:

- 1) inspect new work,
- 2) inspect condition of older portions of the wastewater collection system,
- 3) routine inspection of approximately 10% of the wastewater collection, and 4) problem identification to determine the cause of selected overflow events. Manhole inspection, manhole coating (to prevent concrete deterioration) and manhole painting (for roach control) are also routinely performed.



Sewer filled with grass will damage your system, pumps, and upset the wastewater treatment system. Require your industrial users like golf courses to install grass, grease, and sand/oil interceptors.

Certain compounds and undesirable solids, like grease and grass clippings, can disturb this delicate balance and necessary process at the wastewater treatment facility.

There are compounds and mixtures that should never be introduced into a sanitary sewer system. These destructive compounds include but are not limited to: cleaning solvents, grease (both household and commercial), oils (both household and commercial), pesticides, herbicides, antifreeze and other automotive products.

Sewer Cleaning and Inspection Sub-Section

Inspection and testing are the techniques used to gather information to develop operation and maintenance programs to ensure that new and existing wastewater collection systems serve their intended purposes on a continuing basis. Inspection and testing are necessary to do the following:

- Identify existing or potential problem areas in the collection system,
- Evaluate the seriousness of detected problems,
- Locate the position of problems, and
- Provide clear, concise and meaningful reports regarding problems.

Two major purposes of inspecting and testing are to prevent leaks from developing in the wastewater collection system and to identify existing leaks so they can be corrected. The existence of leaks in a wastewater collection system is a serious and often expensive problem. When a sewer is under a water table, infiltration can take place and occupy valuable capacity in the sewer and the downstream treatment plant. Sewers located above a water table can exfiltrate, allowing raw wastewater to pollute soil and groundwater.

As sewer system networks age, the risk of deterioration, blockages, and collapses becomes a major concern. As a result, municipalities worldwide are taking proactive measures to improve performance levels of their sewer systems. Cleaning and inspecting sewer lines are essential to maintaining a properly functioning system; these activities further a community's reinvestment into its wastewater infrastructure.

Inspection Techniques

Inspection programs are required to determine current sewer conditions and to aid in planning a maintenance strategy. Ideally, sewer line inspections need to take place during low flow conditions. If the flow conditions can potentially overtop the camera, then the inspection should be performed during low flow times between midnight and 5 AM, or the sewer lines can be temporarily plugged to reduce the flow.

Most sewer lines are inspected using one or more of the following techniques:

- Closed-circuit television (CCTV).
- Cameras.
- Visual inspection.
- Lamping inspection.

Television (TV) inspections are the most frequently used, most cost efficient in the long term, and most effective method to inspect the internal condition of a sewer. CCTV inspections are recommended for sewer lines with diameters of 0.1-1.2 m (4 - 48 inches.) The CCTV camera must be assembled to keep the lens as close as possible to the center of the pipe. In larger sewers, the camera and lights are attached to a raft, which is floated through the sewer from one manhole to the next. To see details of the sewer walls, the camera and lights swivel both vertically and horizontally.

In smaller sewers, the cable and camera are attached to a sled, to which a parachute or droge is attached and floated from one manhole to the next. Documentation of inspections is very critical to a successful operation and maintenance (O&M) program.

CCTV inspections produce a video record of the inspection that can be used for future reference. In larger sewers where the surface access points are more than 300 1000 linear feet apart, camera inspections are commonly performed. This method requires less power than the CCTV, so the power cable is smaller and more manageable. Inspections using a camera are documented on Polaroid or digital still (computer jpeg) photographs that are referenced in a log book according to date, time, and location.

Visual inspections are vital in fully understanding the condition of a sewer system. Visual inspections of manholes and pipelines are comprised of surface and internal inspections. Operators should pay specific attention to sunken areas in the groundcover above a sewer line and areas with ponding water.

In addition, inspectors should thoroughly check the physical conditions of stream crossings, the conditions of manhole frames and covers or any exposed brickwork, and the visibility of manholes and other structures. For large sewer lines, a walk-through or internal inspection is recommended. This inspection requires the operator to enter a manhole, the channel, and the pipeline, and assess the condition of the manhole frame, cover, and chimney, and the sewer walls above the flow line.

When entering a manhole or sewer line, it is very important to observe the latest Occupational Safety and Health Administration confined space regulations. If entering the manhole is not feasible, mirrors can be used. Mirrors are usually placed at two adjacent manholes to reflect the interior of the sewer line. Lamping inspections are commonly used in low priority pipes, which tend to be pipes that are less than 20 years old.

Lamping

Lamping is also commonly used on sewer projects where funds are extremely limited. In the lamping technique, a camera is inserted and lowered into a maintenance hole and then positioned at the center of the junction of a manhole frame and the sewer. Visual images of the pipe interior are then recorded with the camera.

Several specialized inspection techniques have been recently developed worldwide. This includes: Light-line based and sonar-based equipment that measures the internal cross-sectional profile of sewer systems.

Sonar technology could be very useful in inspecting depressed sewers (inverted siphons), where the pipe is continually full of water under pressure. Melbourne Water and CSIRO Division of Manufacturing Technology have introduced a new technology called PIRAT, which consists of an in-pipe vehicle with a laser scanner. This instrument is capable of making a quantitative and automatic assessment of sewer conditions. The geometric data that is gathered is then used to recognize, identify, and rate defects found in the sewer lines.

Manhole Inspections - Sewer Inspections Recommendations

The information provided if employed is a good starting point for an inspection.

Manhole inspections should yield a report with the following information at a minimum:

- Exact location of the manhole;
- Diameter of the clear opening of the manhole;
- Condition of the cover and frame, including defects that would allow inflow to enter the system;
- Whether cover is subject to ponding or surface runoff;
- The potential drainage area tributary to the defects;
- Type of material and condition of the chimney corbel cone and walls;
- Condition of steps and chimney and frame-chimney joint;
- Configuration of the incoming and outgoing lines (including drops); and
- Signs of frame-chimney leakage or damage to the frame's seal

Additionally, the following data can be obtained by entering the manhole and using equipment such as portable lamps, mirrors, rulers, and probe rods:

- Type of material and condition of apron and trough;
- Any observed infiltration sources and the rate of infiltration;
- Indications of height of surcharge;
- Size and type of all incoming and outgoing lines; and
- Depth of flow indications of deposition and the characteristics of flow within all pipes.
- The condition of the manhole shaft;
- Any leakage in the channel;
- Any leakage between the manhole wall and the channel;
- Any damage or leakage where pipeline connects to the manhole; and
- Any flow obstructions.

Television Inspections

Sewer pipe inspections of small diameter sewers for infiltration are most effective when a closed circuit television camera is employed.

Television inspections should provide the following information:

- Definitions of problem(s)
- Determine if problem is in municipal sewer or private property sewer
- Effectiveness of existing cleaning program
- Future sewer cleaning requirements
- Sewer rehabilitation needs
- Ability to assess whether trenchless technology or excavation and replacement can solve the problem
- Ability to project repair budget
- Information to plan a permanent solution

Planning is Required to Define the Inspections Goals.

Inspections are performed to:

- Identify maintenance problems
- Determine general sewer conditions
- Identify extraneous flows

The following data is useful to have prior to beginning the inspection:

- Sewer map or as-built plans to locate sewer
- Site specific data
- accessibility of deploying equipment at manholes
- depth of flow in sewer
- pipe diameter
- traffic connections
- safety requirement
- sewer cleaning
- sewer backup records
- sewer cleaning records
- influence of pump station discharges
- influence of industrial discharges

If such records are not available or kept, then a system to retain such information should be established.

During the CCTV inspection the following information should be obtained:

Pipe structural condition	Pipe material	Joints
Joint interval distance	Pipe cracks	Root intrusion
Debris, sediment and/or oil and grease	Service connections	type
quadrant location	building number	active or inactive
rate of infiltration	Infiltration and inflow	Alignment
Sewer types	Sewer location	Sewer surface cover (depth)
Roadway surface material	Time of day	Weather conditions

Inspection for Sources of Inflow

- are most readily achieved through smoke testing and/or dye testing.

Smoke Testing of Sewers is Done to Determine:

- stormwater sewer connections
- proof that buildings or residences are connected to the sanitary sewer
- illegal connections such as roof leaders or downspouts, yard drains and industrial drains
- location of broken sewers due to settling of foundations, manholes and other structures
- location of uncharted manholes and diversion points

Dye testing can be used to verify connections of drains to sanitary or storm sewers. Dye testing can be used to verify the findings of smoke testing.

Suggested Inspection And Maintenance Frequencies	
Task	Frequency in Years
Video inspection/line testing (typical)	3 to 15
Video inspection/line testing (problem area)	1 to 3
Field check (problem area)	1
Walk alignment	1
Manhole/line lamping (typical)	3 to 15
Manhole/line lamping (problem area)	1 to 3
Cleaning (typical)	3 to 15
Cleaning (problem area)	0.5 to 3
System assessment	1
Source: Nelson, Richard E. "Collection System Maintenance: How Much is Enough?" Operation Forum, July 1996	

Sewer Cleaning Techniques and Schedules

To maintain its proper function, a sewer system needs a cleaning schedule. There are several traditional cleaning techniques used to clear blockages and to act as preventative maintenance tools. When cleaning sewer lines, local communities need to be aware of EPA regulations on solid and hazardous waste as defined in 40 CFR 261. In order to comply with state guidelines on testing and disposal of hazardous waste, check with the local authorities.

Hydraulic cleaning developments have also been emerging on the international frontier. France and Germany have developed several innovative flushing systems using a 'dam break' concept.

Hydrass

France has developed a flushing system called the Hydrass. The design of the Hydrass consists of a gate that pivots on a hinge to a near horizontal position. As the gate opens and releases a flow, a flush wave is generated that subsequently washes out any deposited sediments. Germany has also developed a similar system called GNA Hydroself®. This is a flushing system that requires no electricity, no maintenance and no fresh water. The Hydroself® consists of a hydraulically-operated gate and a concrete wall section constructed to store the flush water. This system can be installed into a large diameter sewer. There appears to be no limit on the flushing length, as more flush water may be stored without incurring any additional construction or operating costs.

Another example of such a technology is seen in the Brussels Sewer System. A wagon with a flushing vane physically moves along the sewer and disturbs the sediments so that they are transported with the sewer flow.

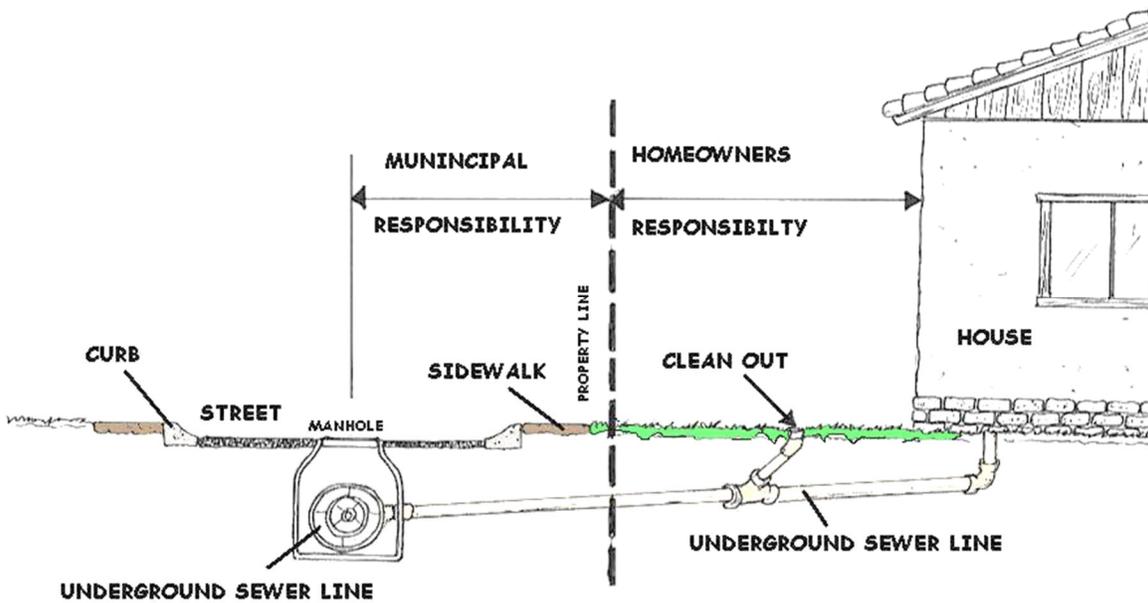
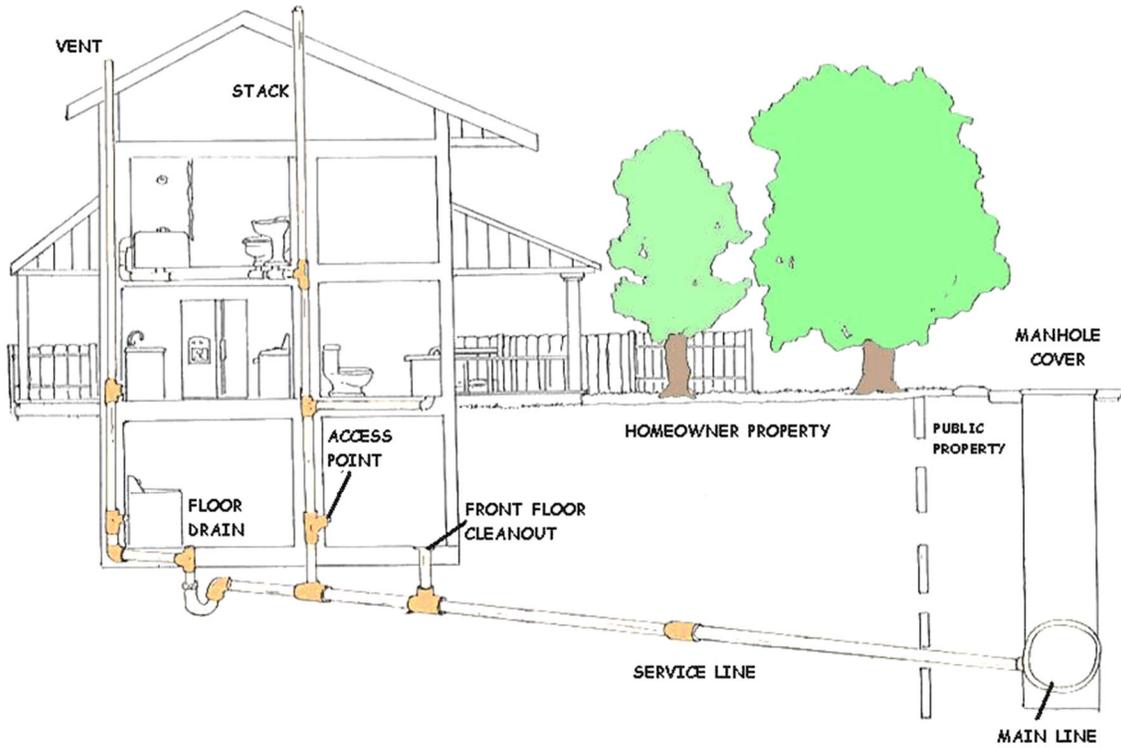
Public Education

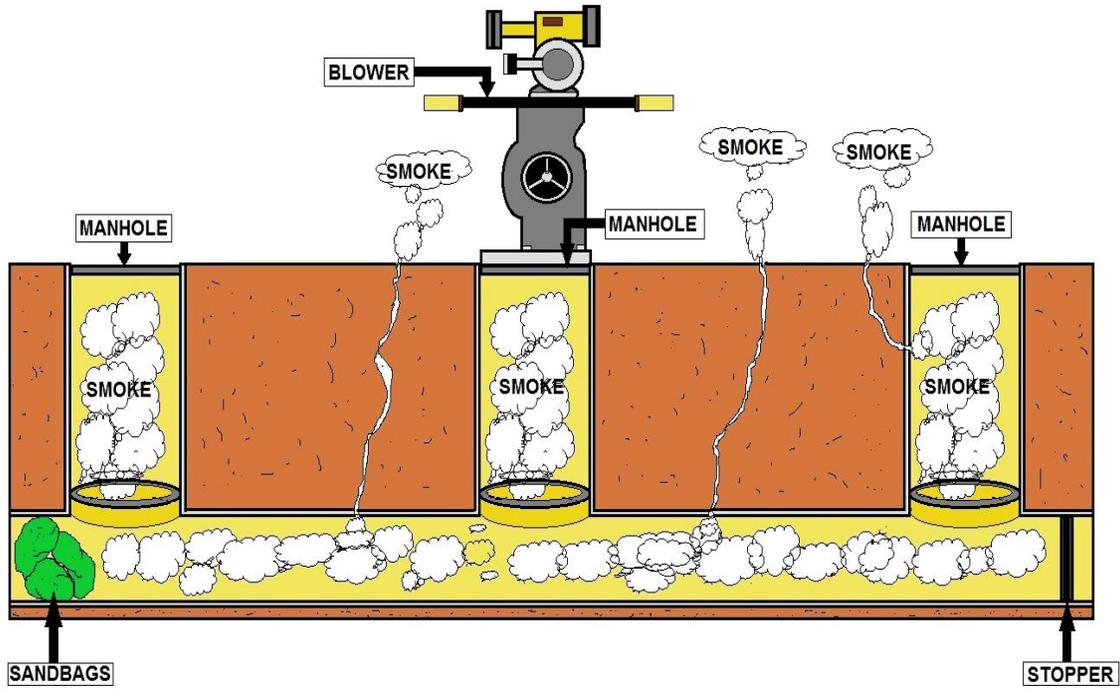
Although all of these methods have proven effective in maintaining sewer systems, the ideal method of reducing and controlling the materials found in sewer lines is education and pollution prevention. The public needs to be informed that common household substances such as grease and oil need to be disposed in the garbage in closed containers, and not into the sewer lines. This approach will not only minimize a homeowner's plumbing problems, but will also help keep the sewer lines clear.

In recent years, new methodologies and accelerated programs have been developed to take advantage of the information obtained from sewer line maintenance operations. Such programs incorporate information gathered from various maintenance activities with basic sewer evaluations to create a system that can remedy and prevent future malfunctions and failures more effectively and efficiently.

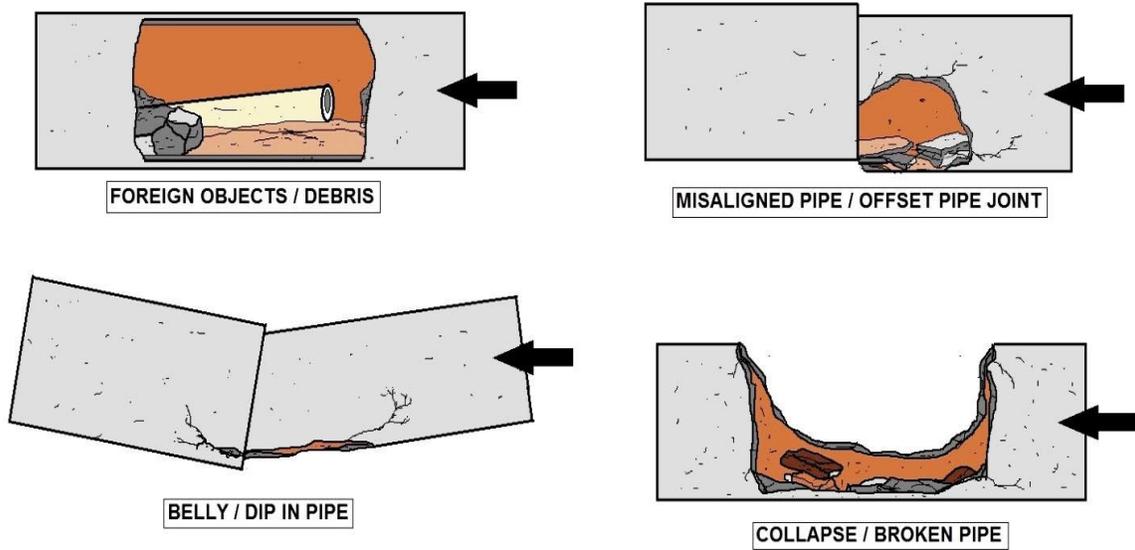
Some systems have attempted to establish a program that would optimize existing maintenance activities to reduce customer complaints, sanitary sewer overflows, time and money spent on sewer blockages, and other reactive maintenance activities. Their plan is based on maintenance frequencies, system performance, and maintenance costs over a period of time. This plan was developed using Geographical Information System (GIS) and historical data to show areas of complaints, back-ups, and general maintenance information for the area.

Homeowner Sewer Diagrams



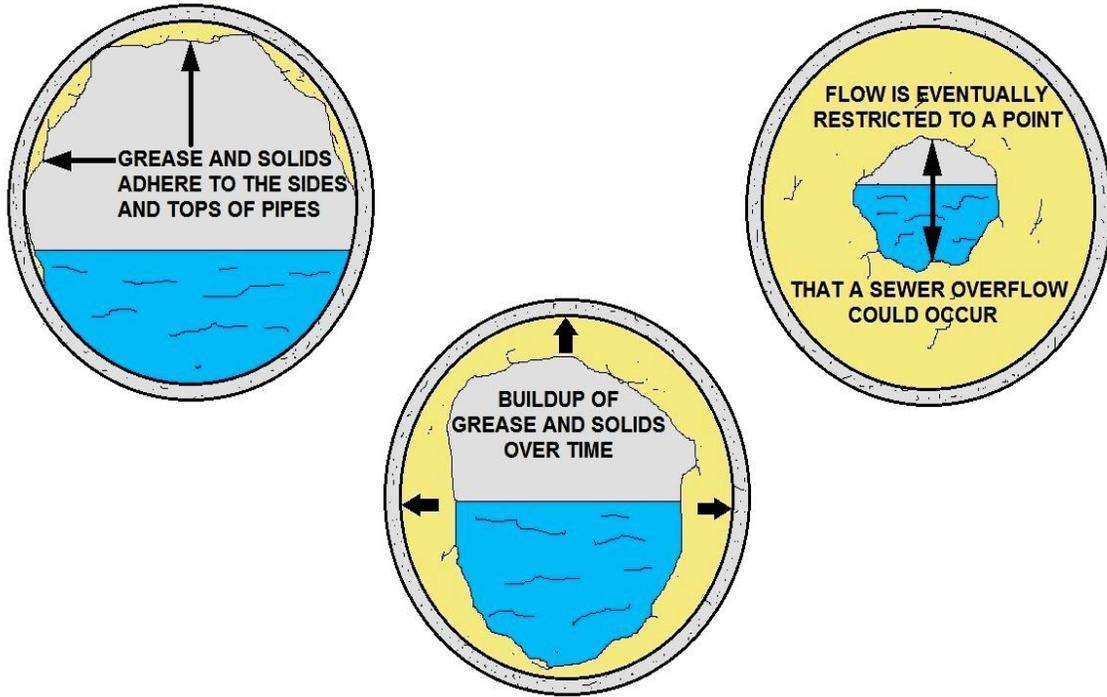


SMOKE TEST IN SEWER MAIN

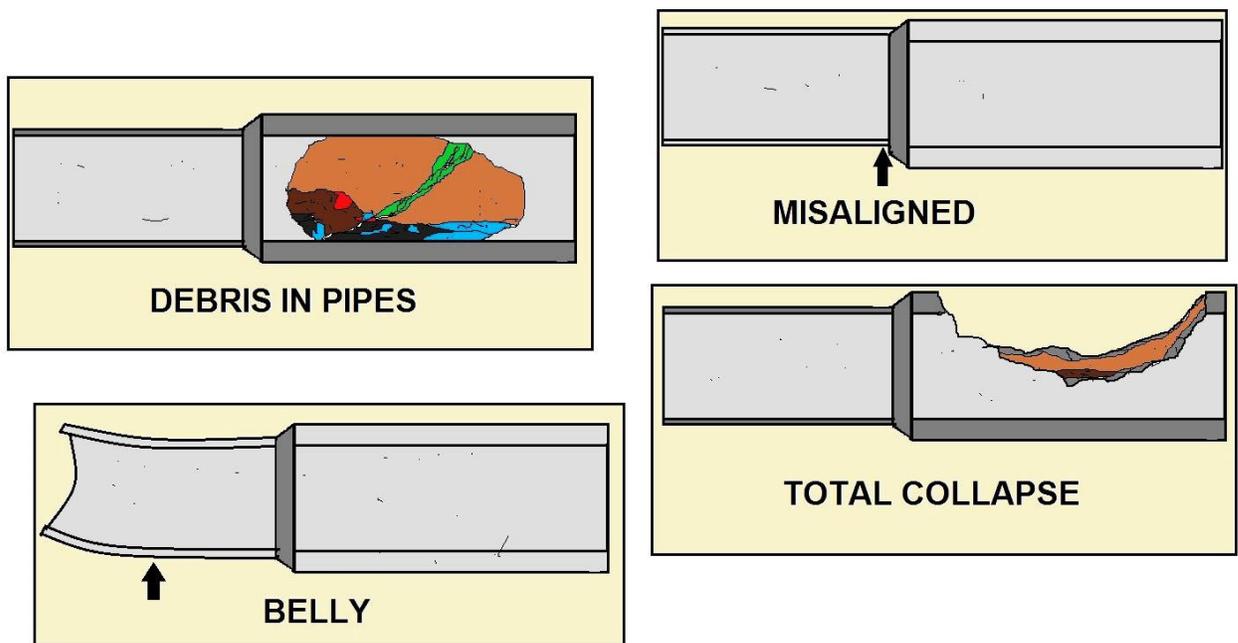


COMMON CAUSES OF SEWER LATERAL BLOCKAGES

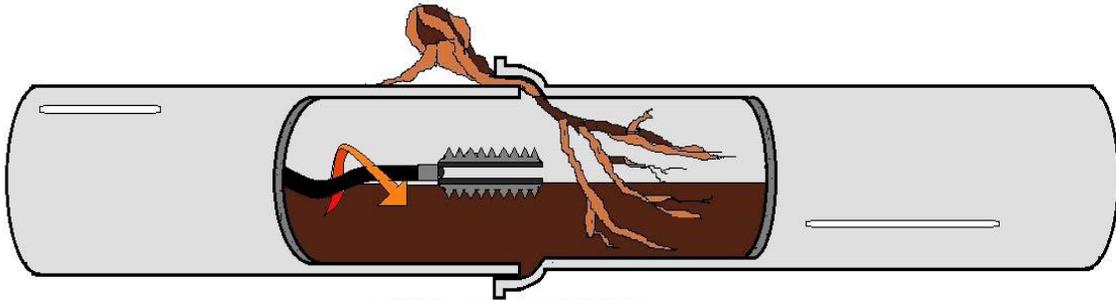
Common Sewer Problems and Solutions Diagrams



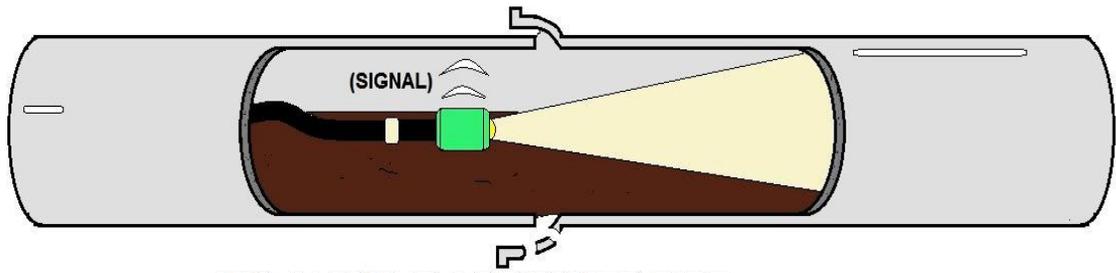
EFFECTS OF GREASE AND SOLIDS ON SEWER FLOW



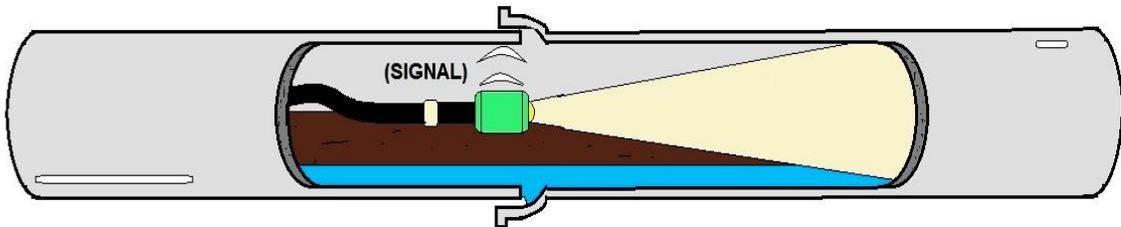
DAMAGED SEWER PIPE EXAMPLES



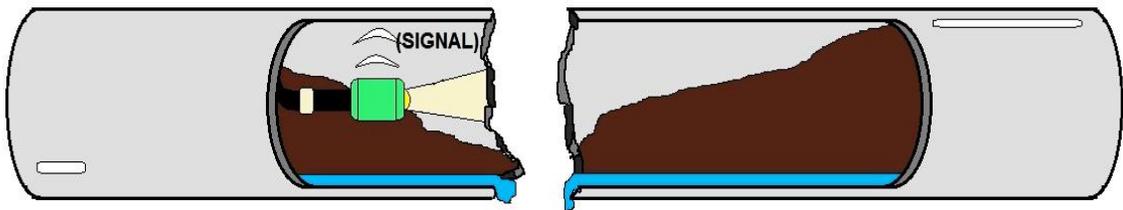
ROOT INTRUSION
(CLEANED WITH A CABLE FITTED WITH A ROOT-CUTTING BLADE)



MIS-ALIGNED / CRACKED PIPE
(A CAMERA IS USED TO SHOW THE LOCATION OF THE PROBLEM VIA A SIGNAL)

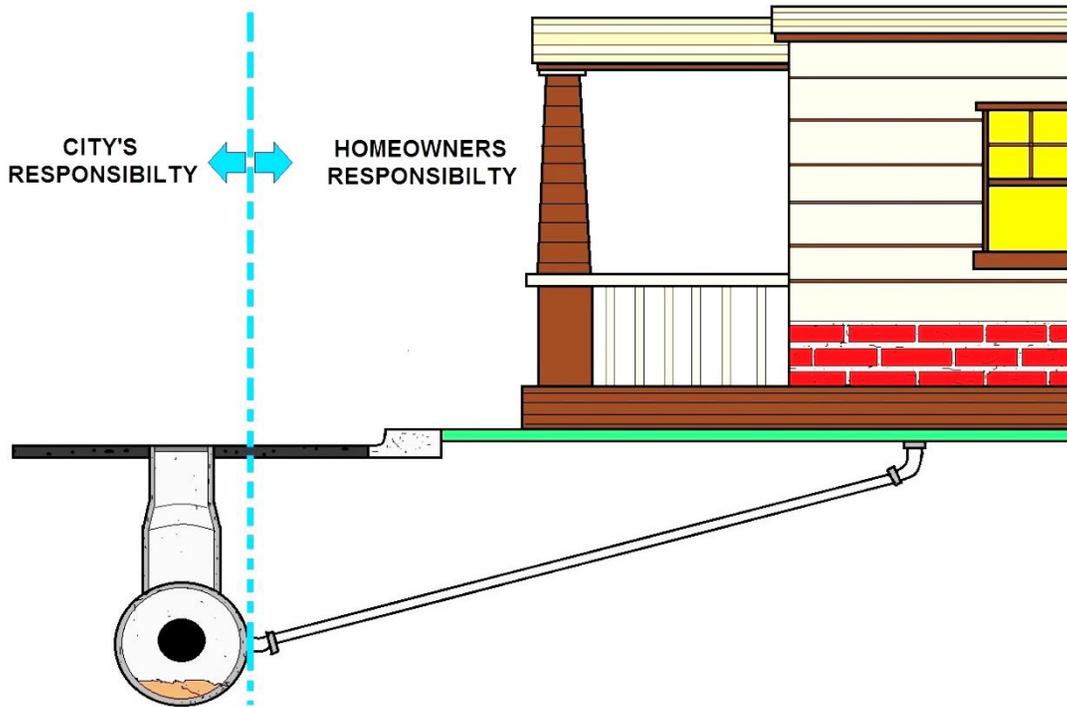


PIPE WITH A BELLY
(A CAMERA IS USED TO SHOW THE LOCATION OF THE PROBLEM VIA A SIGNAL)

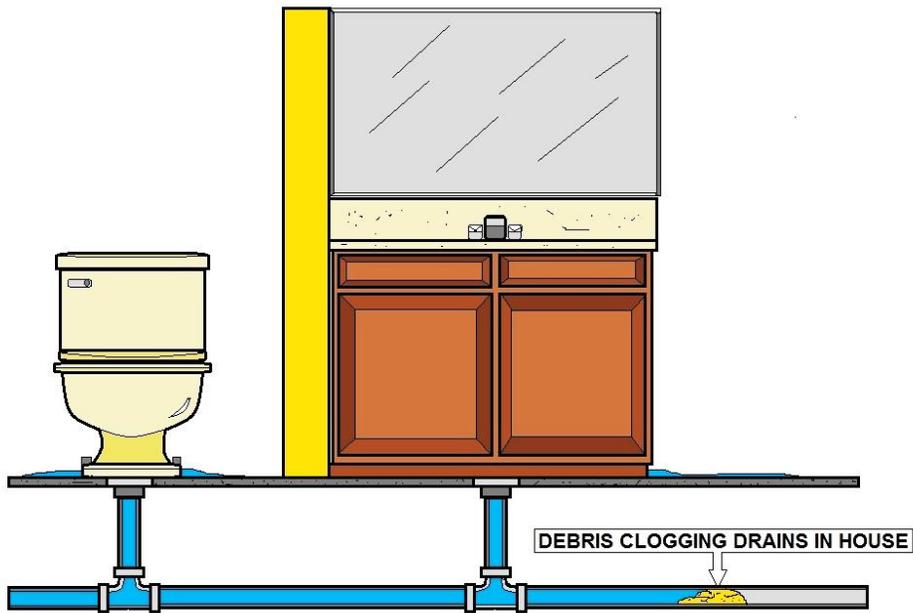


PIPE THAT HAS BEEN CRUSHED
(A CAMERA IS USED TO SHOW THE LOCATION OF THE PROBLEM VIA A SIGNAL)

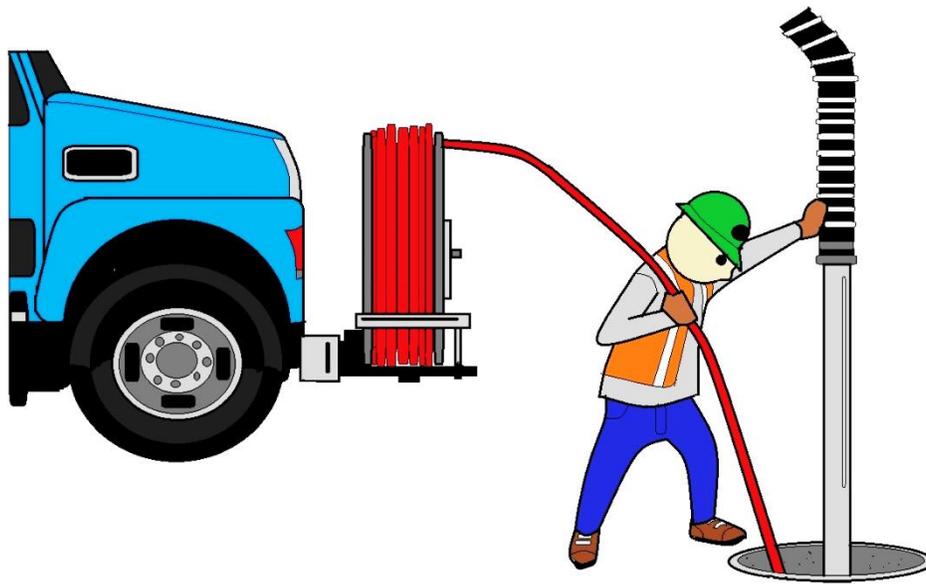
MAJOR SEWER PIPE PROBLEM DIAGRAM



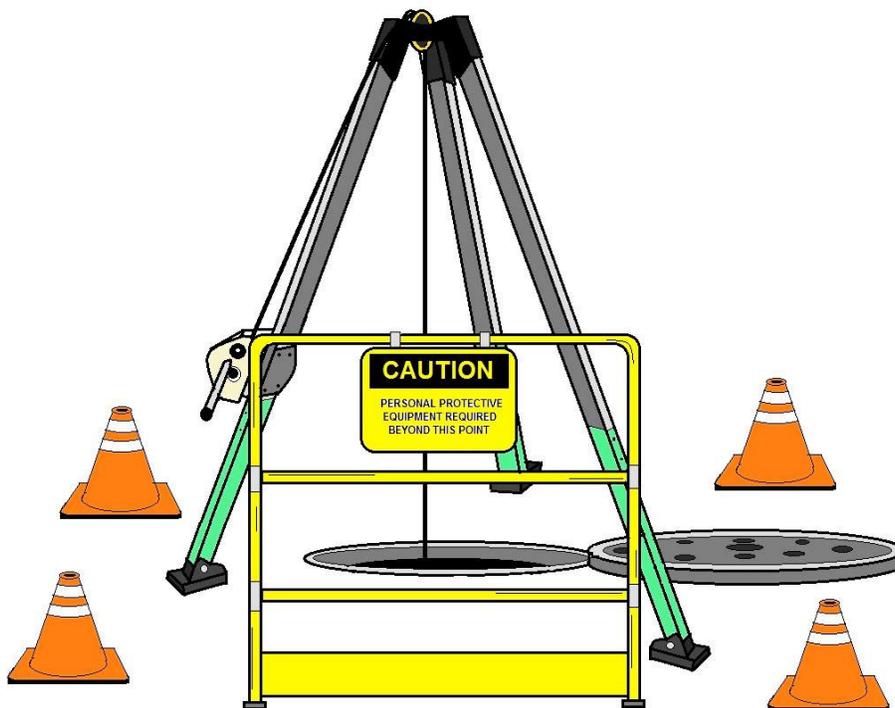
DESIGNATING SEWER MAINTENANCE RESPONSIBILITY



EXAMPLE OF A CLOGGED SEWER LINE

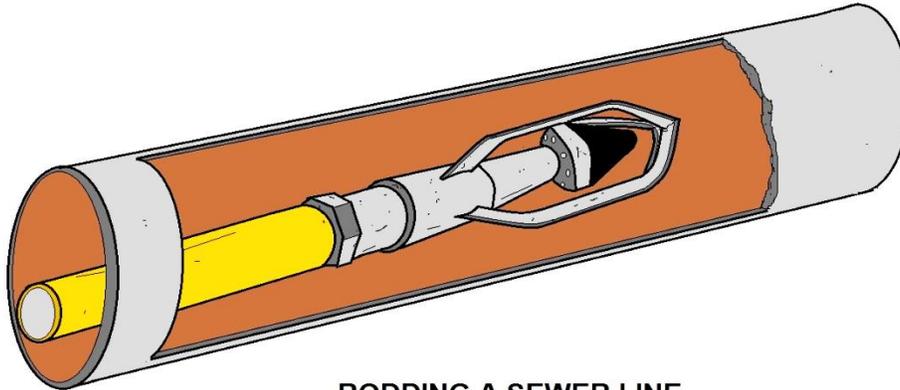


USING A VACUUM TRUCK TO CLEAN SEWER



SAFETY EQUIPMENT TO ENTER A SEWER SAFELY

Sewer Technology Uses and Applications Diagrams

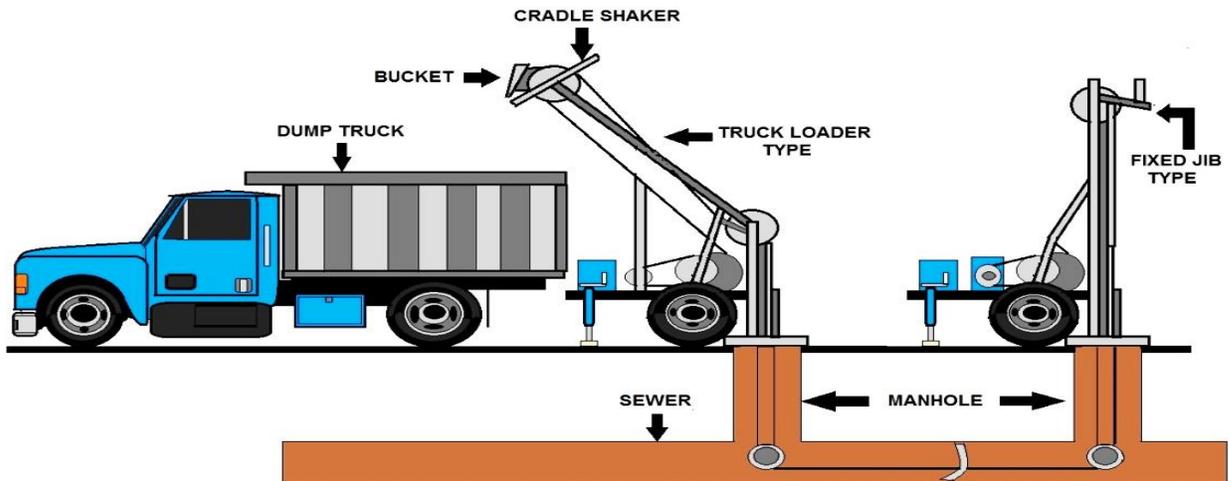


RODDING A SEWER LINE

As a collection system operator, you will need knowledge of many different concerns in order to properly identify the problem and sometimes you'll need to order the remedy, solution or correction.

Mechanical Rodding

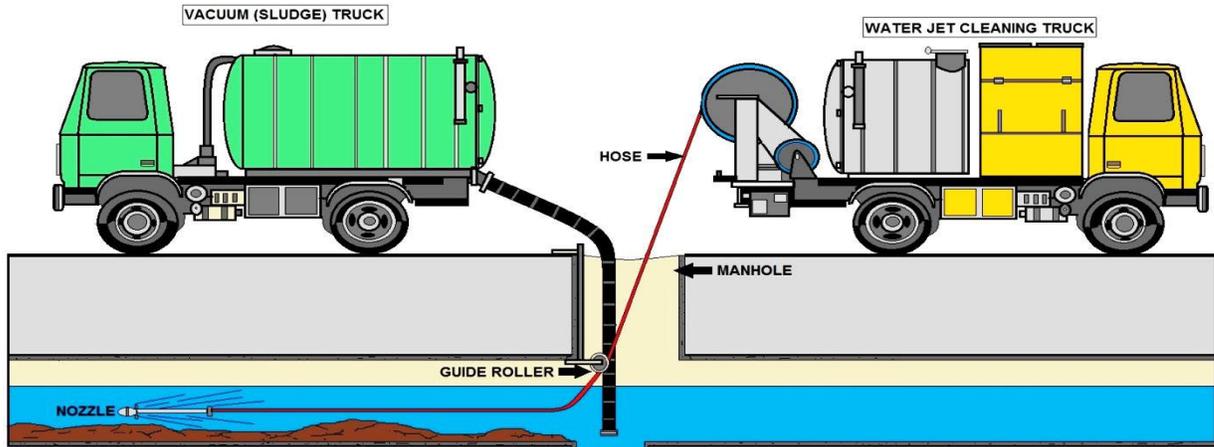
- Uses an engine and a drive unit with continuous rods or sectional rods.
- As blades rotate, they break up grease deposits, cut roots, and loosen debris.
- Rodders also help thread the cables used for TV inspections and bucket machines.
- Most effective in lines up to 12 inches in diameter.



TRAILER MOUNTED BUCKET MACHINES

Bucket Machine

- Cylindrical device, closed on one end with 2 opposing hinged jaws at the other.
- Jaws open and scrape off the material and deposit it in the bucket.
- Partially removes large deposits of silt, sand, gravel, and some types of solid waste.



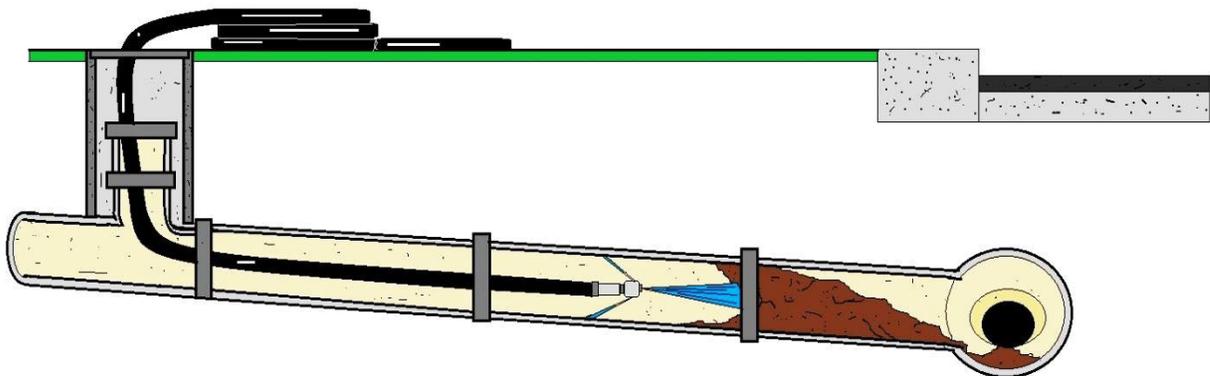
HYDRAULIC SEWER CLEANING PROCESS

Hydraulic Balling

- A threaded rubber cleaning ball that spins and scrubs the pipe interior as flow increases in the sewer line.
- Removes deposits of settled inorganic material and grease build-up.
- Most effective in sewers ranging in size from 5-24 inches.

Flushing

- Introduces a heavy flow of water into the line at a manhole.
- Removes floatables and some sand and grit.
- Most effective when used in combination with other mechanical operations, such as rodding or bucket machine cleaning.

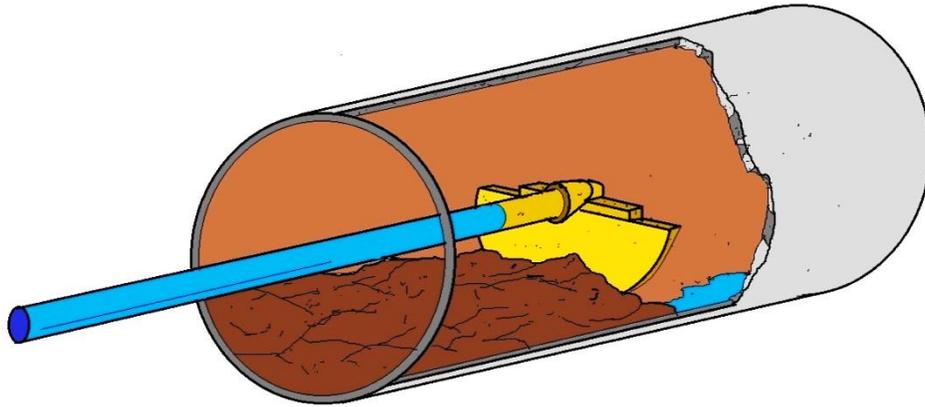


JETTING A SEWER LINE

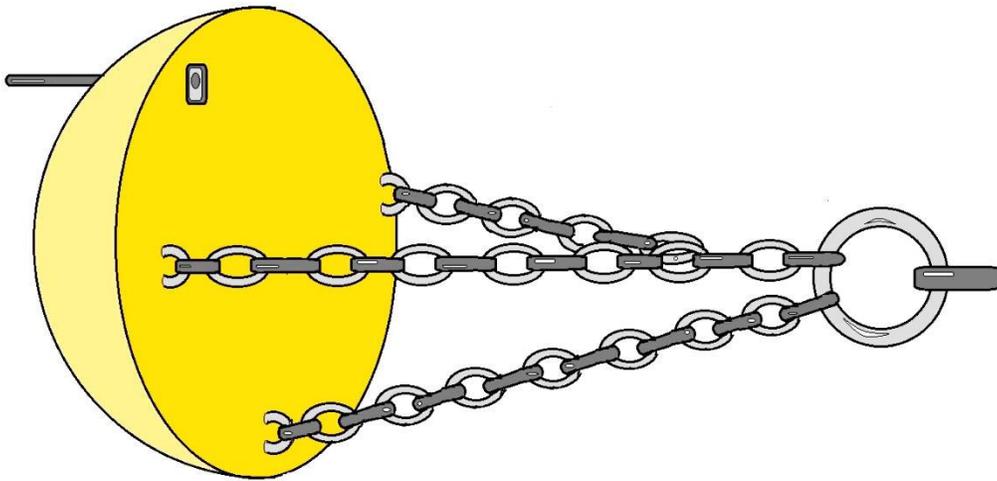
Jetting

- Directs high velocities of water against pipe walls.
- Removes debris and grease build-up, clears blockages, and cuts roots within small diameter pipes.
- Efficient for routine cleaning of small diameter, low flow sewers.

Sewer Cleaning - Technology Applications Diagrams



DROP SCRAPER



SEWER SCRAPER

Scooter

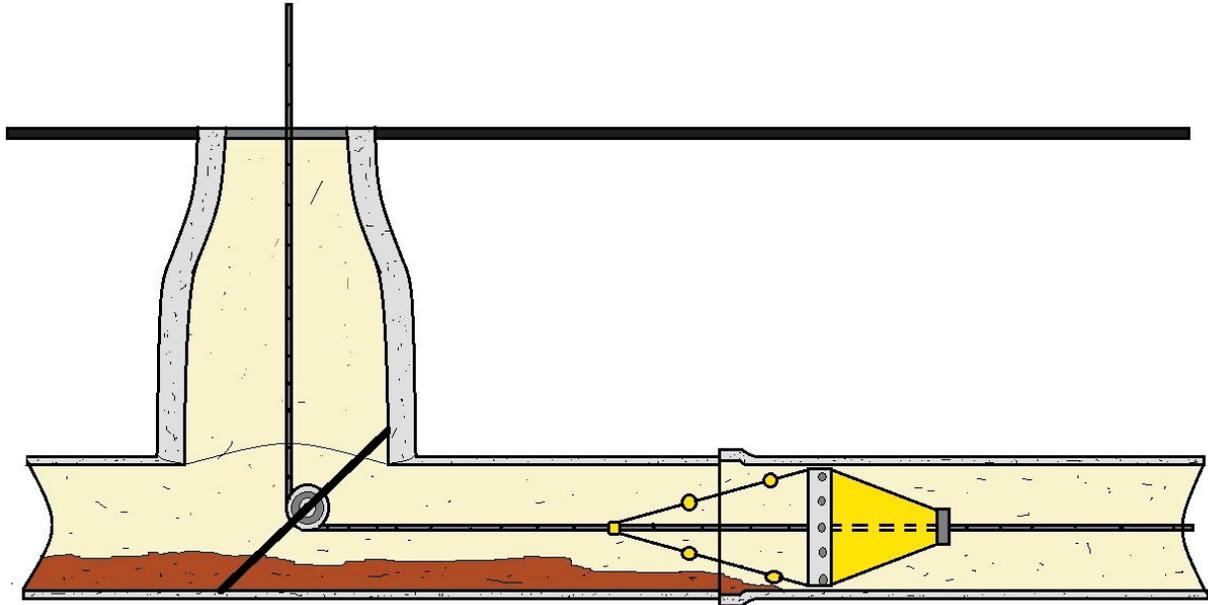
- Round, rubber-rimmed, hinged metal shield that is mounted on a steel framework on small wheels. The shield works as a plug to build a head of water.
- Scours the inner walls of the pipe lines.
- Effective in removing heavy debris and cleaning grease from line.

Kites, Bags, and Poly Pigs

- Similar in function to the ball.
- Rigid rims on bag and kite induce a scouring action.
- Effective in moving accumulations of decayed debris and grease downstream.

Silt Traps

- Collect sediments at convenient locations.
- Must be emptied on a regular basis as part of the maintenance program.



SEWER KITE DIAGRAM

Grease Traps and Sand/Oil Interceptors

- The ultimate solution to grease build-up is to trap and remove it.
- These devices are required by some uniform building codes and/or sewer-use ordinances.

Typically sand/oil interceptors are required for automotive business discharge.

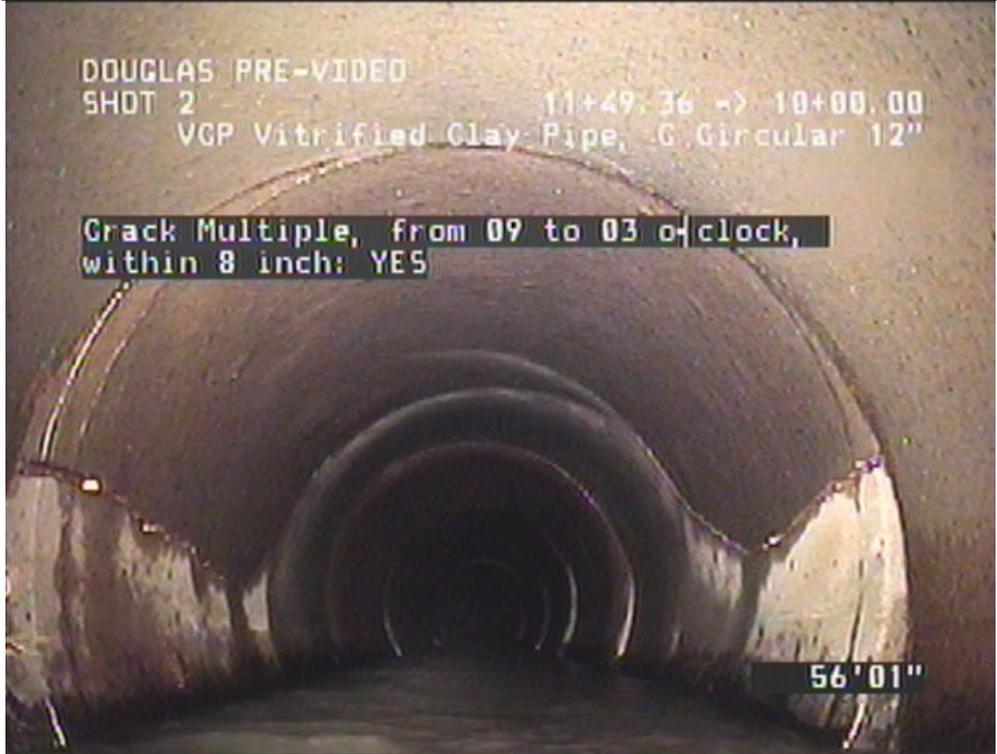
- Need to be thoroughly cleaned to function properly.
- Cleaning frequency varies from twice a month to once every 6 months, depending on the amount of grease in the discharge.
- Need to educate restaurant and automobile businesses about the need to maintain these traps.

Chemicals

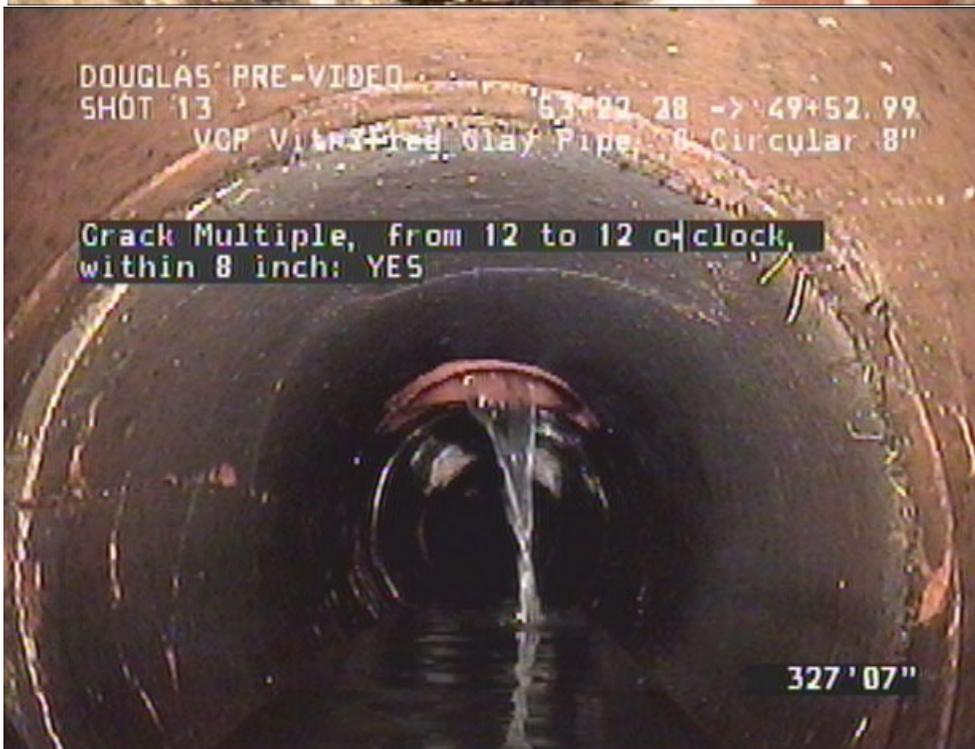
Before using these chemicals review the Safety Data Sheets (SDS) and consult the local authorities on the proper use of chemicals as per local ordinance and the proper disposal of the chemicals used in the operation. If assistance or guidance is needed regarding the application of certain chemicals, contact the U.S. EPA or state water pollution control agency.

- Used to control roots, grease, odors (H_2S gas), concrete corrosion, rodents and insects.
- *Root Control* - longer lasting effects than power rodder (approximately 2-5 years).
- *H_2S gas* - some common chemicals used are chlorine (Cl_2), hydrogen peroxide (H_2O_2), pure Oxygen (O_2), air, lime ($Ca(OH)_2$), sodium hydroxide ($NaOH$), and iron salts.
- *Grease and soap problems* - some common chemicals used are bioacids, digester, enzymes, bacteria cultures, catalysts, caustics, hydroxides, and neutralizers.

Source: Information provided by Arbour and Kerri, 1997 and Sharon, 1989.

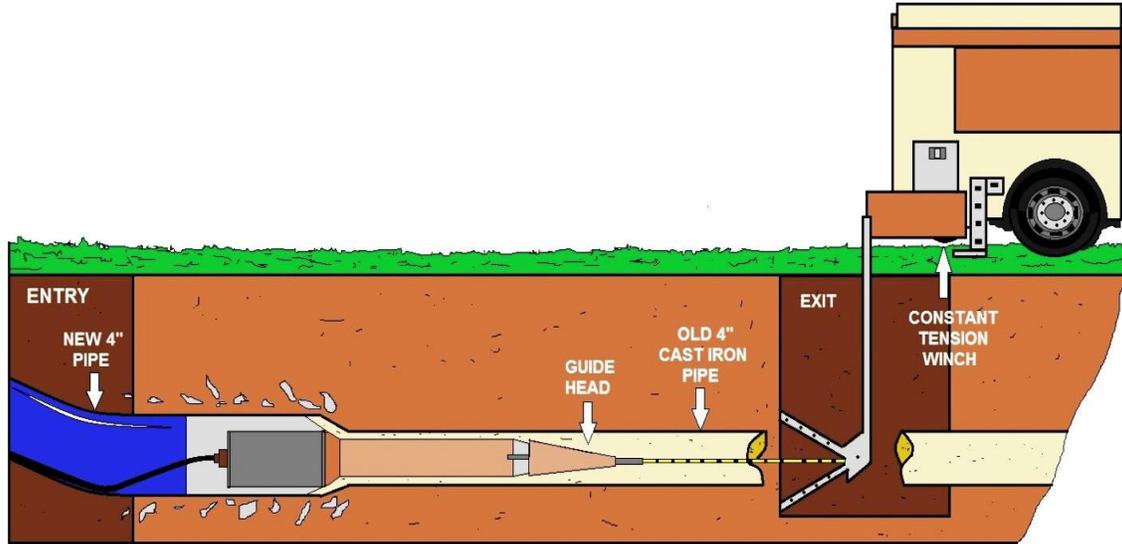


Photographs courtesy of Propipe.



Photographs courtesy of Propipe.

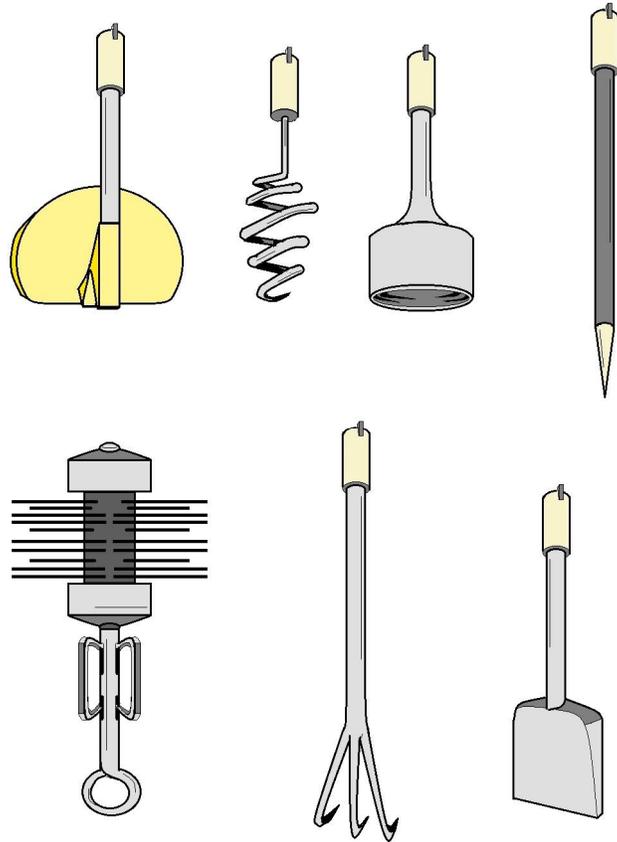
More on Sewer Cleaning Procedures



TRENCHLESS SEWER REPAIR DIAGRAM

Most cities that take advantage of sewer cleaning procedures are able to determine that as the maintenance frequency increased, there was an increase in system performance. It is recommended for 70 inspections and maintenance activities for every 30 cleanings. Inspections are considered more important because they help define and prevent future problems. A study performed by the American Society of Civil Engineers reports that the most important maintenance activities are cleaning and CCTV inspections. A maintenance plan attempts to develop a strategy and priority for maintaining pipes based on several of the following factors:

- Problems- frequency and location; 80 percent of problems occur in 25 percent of the system (Hardin and Messer, 1997).
- Age- older systems have a greater risk of deterioration than newly constructed sewers.
- Construction material- pipes constructed of materials that are susceptible to corrosion have a greater potential of deterioration and potential collapse. Non-reinforced concrete pipes, brick pipes, and asbestos cement pipes are examples of pipes susceptible to corrosion.
- Pipe diameter/volume conveyed- pipes that carry larger volumes take precedence over pipes that carry a smaller volume.
- Location- pipes located on shallow slopes or in flood prone areas have a higher priority.
- Force main vs. gravity-force mains have a higher priority than gravity, size for size, due to the complexity of the cleaning and repairs.
- Subsurface conditions- depth to groundwater, depth to bedrock, soil properties (classification, strength, porosity, compressibility, frost susceptibility, erodibility, and pH).
- Corrosion potential- Hydrogen Sulfide (H_2S) is responsible for corroding sewers, structures, and equipment used in wastewater collection systems. The interior conditions of the pipes need to be monitored and treatment needs to be implemented to prevent the growth of slime bacteria and the production of H_2S gases.



COMMON SEWER CLEANING TOOLS

Limitations of Cleaning Methods

- Sewer Cleaning and Stoppage Section- this section responds to customer complaints, pinpoints problems within the lines, and clears all blockages.
- TV Section- this section locates defects and building sewer connections (also referred to as taps) within the system.
- Preventive Maintenance Section- this section cleans and inspects the lines and also provides for Quality Assurance and Quality Control (QA/QC). Most of collection inspections use CCTV system. However, a large percent of the lines in the worst and oldest sections of the system are inspected visually. Visual inspections are also used in the most recently installed lines and manholes.

The collection system will normally utilize a variety of cleaning methods including jetting, high velocity cleaning, rodding, bucket machining, and using stop trucks (sectional rods with an attached motor).

As part of a preventive maintenance approach, most collection system operators also have been using combination trucks with both flush and vacuum systems. To control roots, most collection system operators uses a vapor rooter eradication system which can ensure that no roots return to the line for up to five years. The cleaning and inspection crews will usually consist of two members to operate each of the combination trucks and TV trucks.

Detailed Cleaning Methods

The purpose of sewer cleaning is to remove foreign material from the sewer and generally is undertaken to alleviate one of the following conditions:

- Blockages (semisolid obstructions resulting in a virtual cessation of flow). These generally are dealt with on an emergency basis, although the underlying cause can be treated preemptively.
- Hydraulic capacity. In some cases, sediment, roots, intrusions (connections or other foreign bodies), grease, encrustation and other foreign material restrict the capacity of a sewer, causing surcharge or flooding. Cleaning the sewer may alleviate these problems permanently, or at least temporarily.
- Pollution caused by either the premature operation of combined wastewater overflows because of downstream restrictions to hydraulic capacity or pollution caused by the washing through and discharge of debris from overflows during storms.
- Odor caused by the retention of solids in the system for long periods resulting in, among other things, wastewater turning septic and producing hydrogen sulfide.
- Sewer inspections, where the sewer needs to be cleaned before inspection. This requirement most often occurs when using in-sewer CCTV inspection techniques.
- Sewer rehabilitation where it is necessary to clean the sewers immediately before the sewer being rehabilitated.

Common cleaning methods include jet rodding, manual rodding, winching or dragging, cutting, and manual or mechanical digging. The method usually is determined in advance and is normally contingent on the pipe type and size and on the conditions expected in the pipe.

Jet Rodding

This method depends on the ability of high-velocity jets of water to dislodge materials from the pipe walls and transport them down the sewer. Water under high pressure (approximately 2000 psi) is fed through a hose to a nozzle containing a rosette of jets sited so the majority of flow is ejected in the opposite direction of the flow in the hose. These jets propel the hose through the sewer and dislodge the materials on the sewer walls. A range of nozzles is available to cope with the different pipe diameters and materials encountered. The hoses, nozzles, water supply and necessary pumps usually are incorporated in a purpose-built vehicle.

Rodding

This method is generally a manual push-pull technique used to clear blockages in smaller-diameter, shallow sewer systems typically not exceeding (10 in. in diameter or 6 ft. in depth. For sewer greater than 10 in. in diameter, the rods tend to wander and are not very effective. The distance from the access point is limited to approximately 60 ft.

Dragging

This is a technique where custom buckets are dragged through the sewer and the material deposited into skips.

Cutting

This method generally is used for removing roots from sewers. High-pressure water jet cutters have been developed for removing even more solid intrusions, such as intruding

connections. Care is required to eliminate damage to the existing sewer structure.

Manual or Mechanical Digging

Traditionally used in larger-diameter sewers, this method involves manually excavating the material and placing it in buckets for removal. As the sewer system can be hazardous, the technique now is used infrequently. High-pressure jet equipment also can be used manually in larger sewers.

Balling, Jetting, Scooter

In general, these methods are only successful when necessary water pressure or head is maintained without flooding basements or houses at low elevations. Jetting - The main limitation of this technique is that cautions need to be used in areas with basement fixtures and in steep-grade hill areas.

Balling

Balling cannot be used effectively in pipes with bad offset joints or protruding service connections because the ball can become distorted.

Scooter

When cleaning larger lines, the manholes need to be designed to a larger size in order to receive and retrieve the equipment. Otherwise, the scooter needs to be assembled in the manhole. Caution also needs to be used in areas with basement fixtures and in steep-grade hill areas.

Bucket Machine

This device has been known to damage sewers. The bucket machine cannot be used when the line is completely plugged because this prevents the cable from being threaded from one manhole to the next. Set-up of this equipment is time-consuming.

Flushing

This method is not very effective in removing heavy solids. Flushing does not remedy this problem because it only achieves temporary movement of debris from one section to another in the system.

High Velocity Cleaner

The efficiency and effectiveness of removing debris by this method decreases as the cross-sectional areas of the pipe increase. Backups into residences have been known to occur when this method has been used by inexperienced operators. Even experienced operators require extra time to clear pipes of roots and grease.

Kite or Bag

When using this method, use caution in locations with basement fixtures and steep-grade hill areas.

Rodding

Continuous rods are harder to retrieve and repair if broken and they are not useful in lines with a diameter of greater than 300 mm (0.984 feet) because the rods have a tendency to coil and bend. This device also does not effectively remove sand or grit, but may only loosen the material to be flushed out at a later time. Source: U.S. EPA, 1993.

Sewer – Hydraulic Cleaning Sub-Section

The purpose of sewer cleaning is to remove accumulated material from the sewer. Cleaning helps to prevent blockages and is used to prepare the sewer for inspections. Stoppages in gravity sewers are usually caused by a structural defect, poor design, poor construction, an accumulation of material in the pipe (especially grease), or root intrusion. Protruding traps (lateral sewer connections incorrectly installed so that they protrude into the main sewer) may catch debris, which then causes a further buildup of solids that eventually block the sewer.

Results of Various Flow Velocities

Velocity Result

- 2.0 ft/sec.....Very little material buildup in pipe.
- 1.4-2.0 ft/sec.....Heavier grit (sand and gravel) begin to accumulate.
- 1.0-1.4 ft/sec.....Inorganic grit and solids accumulate.
- Below 1.0 ft/sec.....Significant amounts of organic and inorganic solids accumulate.
- 1.0 to 1.4 feet per second, grit and solids can accumulate leading to a potential blockage.

Sewer Cleaning Methods

There are three major methods of sewer cleaning: hydraulic, mechanical, and chemical.

Hydraulic cleaning (also referred to as flushing) refers to any application of water to clean the pipe. Mechanical cleaning uses physical devices to scrape, cut, or pull material from the sewer.

Chemical cleaning can facilitate the control of odors, grease buildup, root growth, corrosion, and insect and rodent infestation.

Sewer Cleaning Records

The backbone of an effective sewer cleaning program is accurate recordkeeping. Accurate recordkeeping provides the collection system owner or operator with information on the areas cleaned. Typical information includes

- Date, time, and location of stoppage or routine cleaning activity
- Method of cleaning used
- Identity of cleaning crew
- Cause of stoppage
- Further actions necessary and/or initiated
- Weather conditions

The owner or operator should be able to identify problem collection system areas, preferably on a map. Potential problem areas identified should include those due to grease or industrial discharges, hydraulic bottlenecks in the collection system, areas of poor design (e.g., insufficiently sloped sewers), areas prone to root intrusion, sags, and displacements. The connection between problem areas in the collection system and the preventive maintenance cleaning schedule should be clear.

The owner or operator should also be able to identify the number of stoppages experienced per mile of sewer pipe. If the system is experiencing a steady increase in stoppages, the reviewer should try to determine the cause (i.e., lack of preventive maintenance funding, deterioration of the sewers due to age, an increase in grease producing activities, etc.).

Parts and Equipment Inventory

An inventory of spare parts, equipment, and supplies should be maintained by the collection system owner or operator. The inventory should be based on the equipment manufacturer's recommendations, supplemented by historical experience with maintenance and equipment problems. Without such an inventory, the collection system may experience long down times or periods of inefficient operation in the event of a breakdown or malfunction. Files should be maintained on all pieces of equipment and major tools. The owner or operator should have a system to assure that each crewmember has adequate and correct tools for the job.

The owner or operator should maintain a yard where equipment, supplies, and spare parts are maintained and personnel are dispatched. Very large systems may maintain more than one yard. In this case, the reviewer should perform a visual survey at the main yard. In small to medium size systems, collection system operations may share the yard with the department of public works, water department, or other municipal agencies. In this case, the reviewer should determine what percentage is being allotted for collection system items. The most important features of the yard are convenience and accessibility.

The reviewer should observe a random sampling of inspection and maintenance crew vehicles for equipment as described above. A review of the equipment and manufacturer's manuals aids will determine what spare parts should be maintained.

The owner or operator should then consider the frequency of usage of the part, how critical the part is, and finally, how difficult the part is to obtain when determining how many of the part to keep in stock. Spare parts should be kept in a clean, well-protected stock room.

Owner or Operator - Point to Note

The owner or operator should have a procedure for determining which spare parts are critical for the proper operation of the collection system. Similar to equipment and tools management, a tracking system should be in place, including Guide for Evaluating CMOM Programs at Sanitary Sewer Collection Systems procedures on logging out materials, and when maintenance personnel must use them.

The owner or operator should be able to produce the spare parts inventory and clearly identify those parts deemed critical. The reviewer should evaluate the inventory and selected items in the stockroom to determine whether the specified numbers of these parts are being maintained.



Sewer Maintenance - Advantages and Disadvantages

The primary benefit of implementing a sewer maintenance program is the reduction of SSOs, basement backups, and other releases of wastewater from the collection system due to substandard sewer conditions. Improper handling of instruments and chemicals used in inspecting and maintaining sewer lines may cause environmental harm.

Examples include:

- Improperly disposing of collected materials and chemicals from cleaning operations.
- Improperly handling chemical powdered dyes.
- Inadequately maintaining inspection devices.

Visual Inspection

In smaller sewers, the scope of problems detected is minimal because the only portion of the sewer that can be seen in detail is near the manhole. Therefore, any definitive information on cracks or other structural problems is unlikely. However, this method does provide information needed to make decisions on rehabilitation.

Camera Inspection

When performing a camera inspection in a large diameter sewer, the inspection crew is essentially taking photographs haphazardly, and as a result, the photographs tend to be less comprehensive.

Closed Circuit Television (CCTV)

This method requires late night inspection and as a result the TV operators are vulnerable to lapses in concentration. CCTV inspections are also expensive and time consuming. The video camera does not fit into the pipe and during the inspection it remains only in the maintenance hole.

Lamping Inspection

As a result, only the first 10 feet of the pipe can be viewed or inspected using this method. Source: Water Pollution Control Federation, 1989. Some instruments have a tendency to become coated with petroleum based residues and if not handled properly they can become a fire hazard. The following case study provide additional case study data for sewer cleaning methods.

Fairfax County, Virginia

The Fairfax County Sanitary Sewer System comprises over 3000 miles of sewer lines. As is the case with its sewer rehabilitation program, the county's sewer maintenance program also focuses on inspection and cleaning of sanitary sewers, especially in older areas of the system. Reorganization and streamlining of the sewer maintenance program, coupled with a renewed emphasis on increasing productivity, has resulted in very significant reductions in sewer backups and overflows during the past few years.

1998, there were a total of 49 such incidents including 25 sewer backups and 24 sewer overflows. The sewer maintenance program consists of visual inspections, scheduled sewer cleanings based on maintenance history, unscheduled sewer cleanings as determined by visual or closed circuit television inspections, and follow-up practices to determine the cause of backups and overflows.

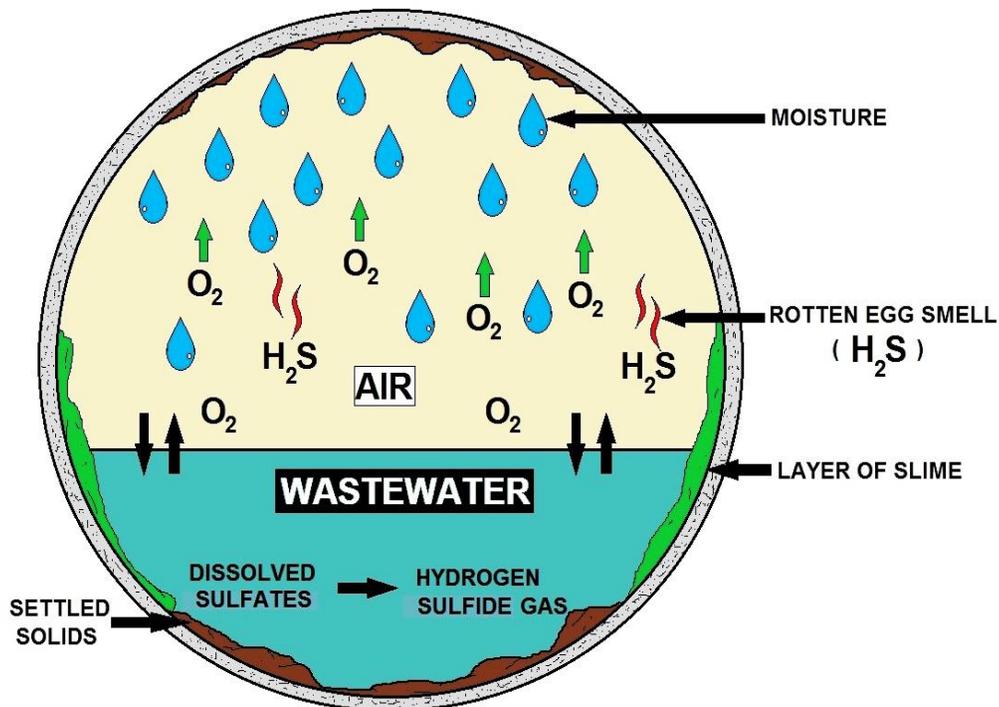
Visual inspections are carried out by using a mirror attached to a pole; however, use of portable cameras has been recently introduced to enhance the effectiveness of visual inspections.

Older areas of the sewer system are inspected every two years; whereas, the inspection of relatively new areas may be completed in 3 to 4 years. Cleaning is an important part of pipe maintenance.

Sewer line cleaning is prioritized based on the age of the pipe and the frequency of the problems within it. The county uses rodding and pressurized cleaning methods to maintain the pipes.

Bucket machines are rarely used because cleaning by this method tends to be time consuming. Many cities use mechanical, rather than chemical, methods to remove grease and roots. Introducing chemicals into the cleaning program may require hiring an expert crew, adopting a new program, and instituting a detention time to ensure the chemicals' effectiveness.

Record keeping is also vital to the success of such a maintenance program. The county has started tracking the number of times their sewer lines were inspected and cleaned and the number of overflows and backups a sewer line experienced. This information has helped the county re-prioritize sewer line maintenance and adapt a more appropriate time schedule for cleaning and inspecting the sewer lines.



HOW CORROSION FORMS IN SEWER PIPING

Sewer System Rehabilitation Sub-Section

The collection system owner or operator should have a sewer rehabilitation program. The objective of sewer rehabilitation is to maintain the overall viability of a collection system. This is done in three ways:

- (1) ensuring its structural integrity;
- (2) limiting the loss of conveyance and wastewater treatment capacity due to excessive I/I; and
- (3) limiting the potential for groundwater contamination by controlling exfiltration from the pipe network.

The rehabilitation program should build on information obtained as a result of all forms of maintenance and observations made as part of the capacity evaluation and asset inventory to assure the continued ability of the system to provide sales and service at the least cost. The reviewer should try to gain a sense of how rehabilitation is prioritized. Priorities may be stated in the written program or may be determined through interviews with system personnel.

There are many rehabilitation methods; the choice of methods depends on pipe size, type, location, dimensional changes, sewer flow, material deposition, surface conditions, severity of I/I, and other physical factors. Non-structural repairs typically involve the sealing of leaking joints in otherwise sound pipe.

Structural repairs involve either the replacement of all or a portion of a sewer line, or the lining of the sewer. These repairs can be carried out by excavating, usually for repairs limited to one or two pipe segments (these are known as point repairs) or by trenchless technologies (in which repair is carried out via existing manholes or a limited number of access excavations).

The rehabilitation program should identify the methods that have been used in the past, their success rating, and methods to be used in the future. A reviewer who wants further guidance on methods of rehabilitation may consult the owner's or operator's policies regarding service lateral rehabilitation, since service laterals can constitute a serious source of I/I.

Manholes should not be neglected in the rehabilitation program. Manhole covers can allow significant inflow to enter the system because they are often located in the path of surface runoff.

Manholes themselves can also be a significant source of infiltration from cracks in the barrel of the manhole. The owner or operator should be able to produce documentation on the location and methods used for sewer rehabilitation. The reviewer should compare the rehabilitation accomplished with that recommended by the capacity evaluation program.

When examining the collection system rehabilitation program, the reviewer should be able to answer the following questions:

- Is rehabilitation taking place before it becomes emergency maintenance?
- Are recommendations made as a result of the previously described inspections?
- Does the rehabilitation program take into account the age and condition of the sewers?



The sewer vacuum truck utilizes both a high pressure stream of water and a vacuum system to clean and remove built up debris from sewer lines. These versatile vehicles are also used to clean lift station wet wells, stormwater catch basins, and to perform excavations to locate broken water or sewer lines. It reduces repair times and costs by over 50%.



Above, various Jetter or hydraulic cleaning attachments.



Root intrusion

Tree Roots vs. Sanitary Sewer Lines

Root Growth in Pipes

Roots require oxygen to grow, they do not grow in pipes that are full of water or where high ground water conditions prevail. Roots thrive in the warm, moist, nutrient rich atmosphere above the water surface inside sanitary sewers. The flow of warm water inside the sanitary sewer service pipe causes water vapor to escape to the cold soil surrounding the pipe. Tree roots are attracted to the water vapor leaving the pipe and they follow the vapor trail to the source of the moisture, which are usually cracks or loose joints in the sewer pipe. Upon reaching the crack or pipe



joint, tree roots will penetrate the opening to reach the nutrients and moisture inside the pipe.

This phenomenon continues in winter even though trees appear to be dormant.

Problems Caused by Roots Inside Sewers

Once inside the pipe, roots will continue to grow, and if not disturbed, they will completely fill the pipe with multiple hair-like root masses at each point of entry. The root mass inside the pipe becomes matted with grease, tissue paper, and other debris discharged from the residence or business. Homeowners will notice the first signs of a slow flowing drainage system by hearing gurgling noises from toilet bowls and observing wet areas around floor drains after completing the laundry. A complete blockage will occur if no remedial action is taken to remove the roots/blockage. As roots continue to grow, they expand and exert considerable pressure at the crack or joint where they entered the pipe. The force exerted by the root growth will break the pipe and may result in total collapse of the pipe. Severe root intrusion and pipes that are structurally damaged will require replacement.

Tree Roots in Sewer

Tree roots growing inside sewer pipes are generally the most expensive sewer maintenance item experienced by City residents. Roots from trees growing on private property and on parkways throughout the City are responsible for many of the sanitary sewer service backups and damaged sewer pipes.

Homeowners should be aware of the location of their sewer service and refrain from planting certain types of trees and hedges near the sewer lines. The replacement cost of a sanitary sewer service line as a result of damage from tree roots may be very expensive.

Pipes Susceptible to Root Damage

Some pipe material is more resistant to root intrusion than others are. Clay tile pipe that was commonly installed by developers and private contractors until the late 1980's is easily penetrated and damaged by tree roots. Concrete pipe and PVC pipe may also allow root intrusions, but to a lesser extent than clay tile pipe. PVC pipe is more resistant to root intrusion because it usually has fewer joints. The tightly fitting PVC joints are less likely to leak as a result of settlement of backfill around the pipe.

Root Spread

During drought conditions and in winter, tree roots travel long distances in search of moisture. As a general rule, tree roots will extend up to 2.5 times the height of the tree, and some species of trees may have roots extending five to seven times the height of the tree.

Root Growth Control

The common method of removing roots from sanitary sewer service pipes involves the use of augers, root saws, and high pressure flushers. These tools are useful in releasing blockages in an emergency, however, cutting and tearing of roots encourages new growth. The effect is the same as pruning a hedge to promote faster, thicker, and stronger regrowth.

Roots removed by auguring are normally just a small fraction of the roots inside the pipe. To augment the cutting and auguring methods, there are products available commercially that will kill the roots inside the pipe without harming the tree. The use of products such as copper sulfate and sodium hydroxide are not recommended because of negative environmental impacts on the downstream receiving water. Also, these products may kill the roots but they do not inhibit regrowth.

The more modern method used throughout Canada and the United States for controlling root growth involves the use of an herbicide mixed with water and a foaming agent. The foam mixture is pumped into the sewer pipe to kill any roots that come into contact with the mixture. New root growth will be inhibited from three to five years after the treatment, according to the manufacturers.



FlexKid is an accessory for Ripper tools designed to clear roots and other blockages from sewer pipes. The unit readily passes through pipes and around or over typical obstructions like offset joints, hand taps and debris. Available for pipes 18 inches and larger, it features durable cable and easy attachment to the rear of any root-cutting motor. It is designed for quick setup and quick size changes in field. No underground (in-manhole) assembly is required, and no manhole modification is necessary.

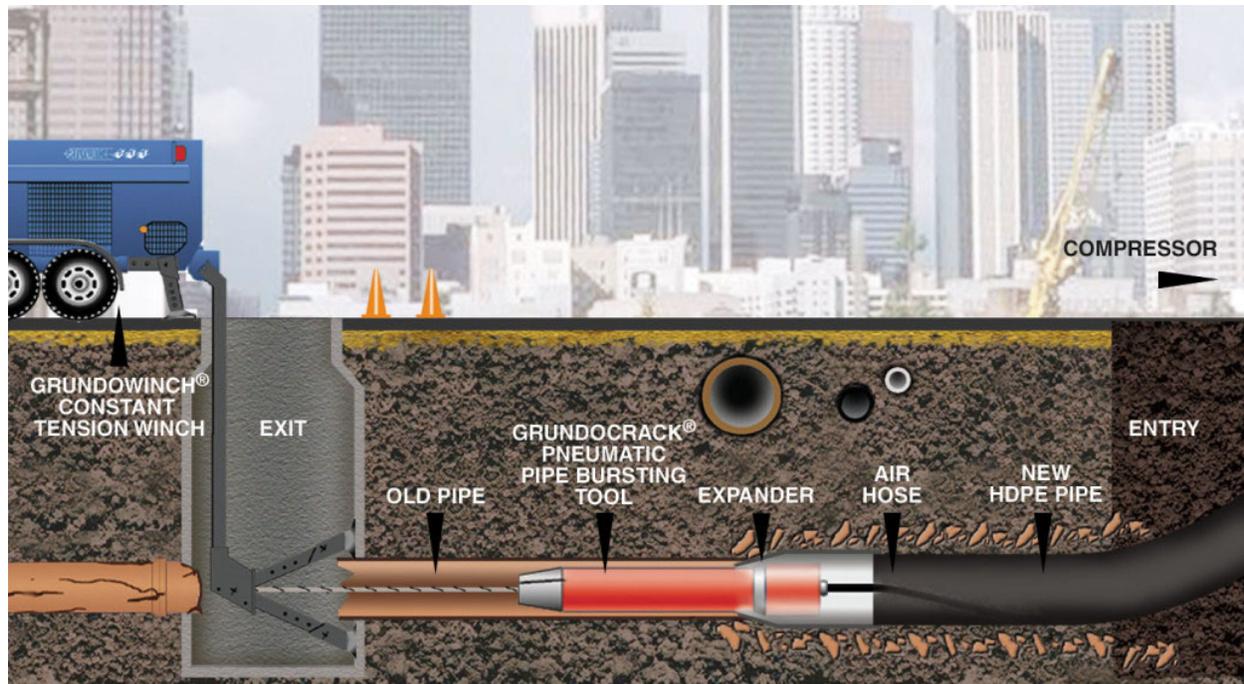
The Knocker is a chain cleaner designed to use in conjunction with The Ripper. The Ripper positions The Knocker's chain-knocking action in the center of the pipe and keeps the chain from hanging up on offsets and hand-taps. The Ripper follows up by removing loose debris - leaving pipes cleaner than any other sewer cleaning tool - period.

Courtesy of DML, LLC

419 Colford Avenue
West Chicago, IL 60185
Phone (630) 293-3653
rootripper@ameritech.net

Pipe Bursting Section

Pipe bursting can be just as effective as digging trenches and replacing the older sewer, but without the digging. With the pipe bursting method, roads, customer's yards and landscaping is spared the damage caused by digging long trenches, and repairing the damage when the job is done.



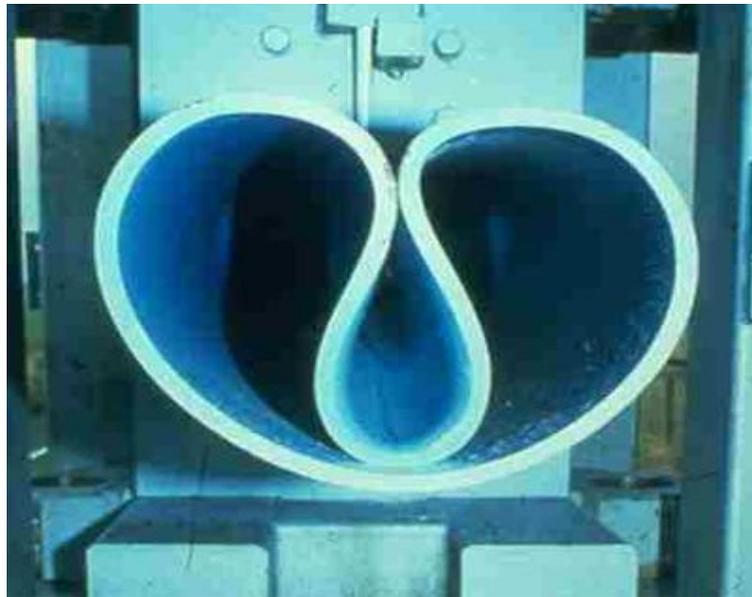
Cast iron and clay sewer lines often have more points of failure than high density polyethylene pipe or HDPE because they have more joints and joints. HDPE pipe is seamless, and so introduces fewer potential points of failure.

Bursting Pipe Procedure

- Insertion pit is excavated.
- Deteriorated host pipe is broken outward by means of an expansion tool and new pipe (black) is towed behind the bursting machine.
- Laterals reconnected by excavation after job is done.
- Pneumatic (static) head has no moving internal parts and expands existing pipe through pulling.
- New pipe can be PE, PP, PVC or GFR
- No reduction in capacity; can often upsize the new pipe
- Requires bypass or diversion of flow
- Not suitable for all materials: can replace vitrified clay, cast iron, unreinforced concrete, & some PVC



Old sewer lines are often made of cast iron and clay. These old sewer lines eventually crack and fail to drain properly. Roots and debris make their way into old sewer lines causing repeated obstructions and service calls.



Fold and Formed Pipe

- HDPE or PVC pipe is deformed in shape & inserted into host pipe
- Liner is pulled through existing line, heated and pressurized to original shape
- Bypass or diversion of flow required
- Laterals reconnected internally
- No grouting or excavation
- No joints or seams

Smoking out Sewer Leaks

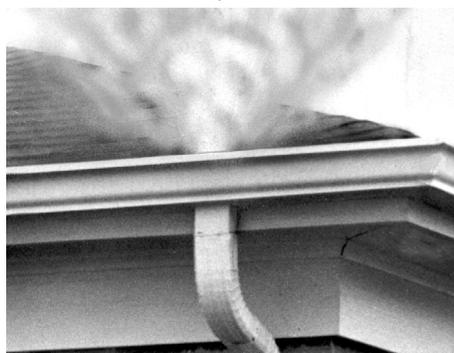
An overview of smoke testing, an important part of successful I & I studies.

By Paul Tashian, Superior Signal Company, Inc.

Used extensively for over 40 years, smoke testing has proven to be a vital ingredient of successful inflow and infiltration (I&I) studies. It is as important now as it has ever been, as growing municipalities increase demands on aging, often deteriorating collection systems. In addition, programs such as the EPA's new CMOM (capacity, management, operations, and maintenance) emphasize a focus on proactive, preventive maintenance practices. Smoke testing is an effective method of documenting sources of inflow and should be part of any CMOM program.

Just as a doctor would require the aid of several instruments to evaluate the status of one's health, various test methods should be used in performing a complete sanitary sewer evaluation survey (SSES). In addition to smoke testing, these could include dyed water testing, manhole inspection, TV inspection, flow monitoring, and more. Specializing in sanitary sewer evaluation surveys, Wade & Associates of Lawrence Kansas states a reduction of 30 to 50% in peak flows can be expected as a result of implementing these types of programs.

Smoke testing is a relatively simple process, which consists of blowing smoke mixed with larger volumes of air into the sanitary sewer line, usually induced through the manhole.



The smoke travels the path of least resistance and quickly shows up at sites that allow surface water inflow. Smoke will identify broken manholes, illegal connections (including roof drains, sump pumps, yard drains and more), uncapped lines, and will even show cracked mains and laterals providing there is a passageway for the smoke to travel to the surface.

Although video inspection and other techniques are certainly important components of an I&I survey, research has shown that approximately 65% of all extraneous stormwater inflow enters the system from somewhere other than the main line. Smoke testing is an excellent method of inspecting both the mainlines, laterals and more. Smoke travels throughout the system, identifying problems in all connected lines, even sections of line that were not known to exist, or thought to be independent or unconnected. Best results are obtained during dry weather, which allows smoke better opportunity to travel to the surface.

Necessary Equipment

Blowers; Most engineering specifications for smoke testing identify the use of a blower able to provide 1750 cfm (cubic feet of air per minute), however in today's world it seems to be the mindset that bigger is better. New smoke blowers on the market can deliver over 3000 cfm, but is this really needed? Once the manhole area is filled, the smoke only needs to travel sections of generally 8 or 10-inch pipe.

Moving the air very quickly is useless if the blower does not have the static pressure to push that air/smoke through the lines. If you've used high CFM blowers and found that smoke frequently backs up to the surface, this may be your problem.

Blowers

There are two types of blowers available for smoke testing sewers: squirrel cage and direct drive propeller. In general, squirrel cage blowers are usually larger in size, but can provide more static pressure in relation to CFM.

The output of the squirrel cage type is usually adjustable by alternating pulleys and belts to meet the demands of the job. Propeller style blowers are usually more compact and generally offer approx. 3,200 CFM.

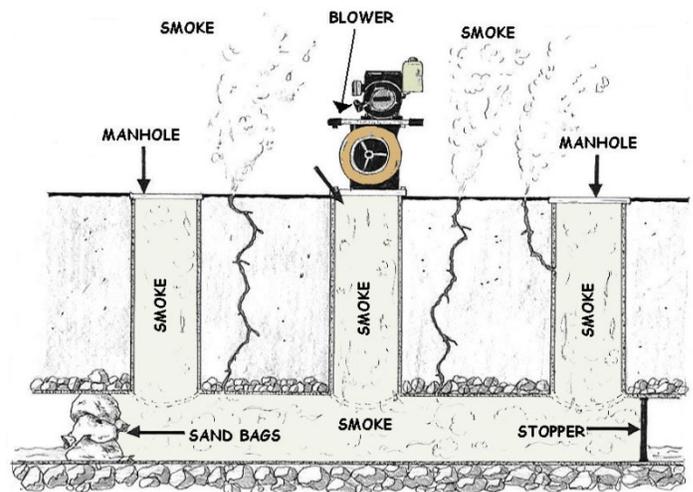
Other than reducing the engine throttle, the output is not adjustable since the fan blade is attached directly to the engine shaft. If purchasing a smoke blower you should ask the manufacturer if the CFM and static pressure output they are quoting is the specification of the propeller itself (uninstalled/free air), or if it is the actual performance when installed in the blower assembly. These two numbers can vary significantly.

Smoke Types

There are two types of smoke currently offered for smoke testing sewers, classic smoke candles and smoke fluids.

Smoke candles were first used for testing sewers when the process began its popularity back in 1961, and continue to be the most widely used. They are used by simply placing a smoke candle on the fresh air intake side of the blower. Once ignited, the exiting smoke is drawn in with the fresh air and blown down into the manhole and throughout the system.

Smoke candles are available in various sizes that can be used singularly or in combination to meet any need. This type of smoke is formed by a chemical reaction, creating a smoke which contains a high content of atmospheric moisture. It is very visible even at low concentrations, and extremely effective at finding leaks.



Another available source of smoke is a smoke fluid system. Although they have just recently been more aggressively marketed, smoke fluids became available for sewer testing shortly after smoke candles, some 30 years ago. They can certainly be used effectively, but it is important to understand how they work. This system involves injecting a smoke fluid (usually a petroleum based product) into the hot exhaust stream of the engine where it is heated within the muffler (or heating chamber) and exhausted into the air intake side of the blower. One gallon of smoke fluid is generally less expensive than one dozen smoke candles; however smoke fluids do not consistently provide the same quality of smoke.

When using smoke fluid, it is important to understand that as fluid is injected into the heating chamber (or muffler) it immediately begins to cool the unit. The heating chamber will eventually reach a point where it is not hot enough to completely convert all the fluid to smoke, thus creating thin/wet smoke. This can actually happen quickly, depending on the rate of fluid flow. If the smoke has become thin it can be especially difficult to see at greater distances.

Blocking off sections of line is usually a good idea with any type of smoke, but becomes almost a necessity when using smoke fluid. Some manufactures have taken steps to address this issue, and now offer better flow control, fluid distribution, and most importantly *insulated heating chambers* to help maintain necessary temperatures.

Safety

Maybe one of the more talked about, yet least understood aspects of smoke testing is the use and safety of these products. As manufacturers have become more competitive, some marketing programs and advertisements have implied danger in the use of competitive types of smoke products. Laboratory reports, scientific studies, and even Material Safety Data Sheets can be quite confusing to most of us who are not trained or qualified to make scientific judgments on this data. Having this information delivered to us in the form of advertising can be dangerous, as most of us tend to believe what we read.

An author of an associated industry publication once stated... "*Do not use smoke bombs, as they give off a toxic gas*". Although the author quotes no scientific literature to support this statement, competitive propaganda has made such implications. It is interesting to note that the same exact statement could be made for smoke fluids. Smoke from fluid is created in the exhaust system of the engine, which contains carbon monoxide. Is carbon monoxide not a toxic gas?

Other statements that have been made include warnings to wear a respirator while smoke testing. While certain manufacturers have issued this warning about competitive products, they do not qualify the statement, nor do they mention the fact that the same thing could be said of their own product. The fact is that a respirator should be worn whenever a person would be exposed to ANY substance in quantities that exceeded OSHA limits. The bottom line on safety is that it is important to use common sense.

All smokes, candles, and fluids can be used safely and effectively when used as directed. When planning to smoke test, it is important to develop a proactive public notice program. Ads in local papers, door hangers, mailers, as well as door to door inquiries are recommended. It is helpful to educate the public as to why the test is being performed and the positive benefits to the community. In addition, it should instruct residents on what to do and who to call if smoke should enter their homes.

It is also important to notify local police and fire departments daily, as to where and when smoke testing will be taking place. Reducing stormwater inflow into collection systems means reduced chances of overflows, less emergency maintenance and less money spent on treatment. If these are goals of your organization, consider smoke testing as a fairly easy, inexpensive, and effective way of achieving your objectives.

Paul Tashian is employed by Superior Signal Company Inc., a manufacturer of all types of smoke testing equipment, and a major contributor to the original development of smoke testing practices. Paul can be reached at (732) 251-0800, or ptashian@superiorsignal.com. Also, thanks to Wade & Associates (a company specializing in sanitary sewer evaluation surveys) for offering reference material, and providing artwork and photographs used in this article. For information on Wade's services call (785) 841-1774, or visit www.wadeinc.com.

Operation and Maintenance Summary

Maintaining wastewater collection infrastructure – pump stations, force mains, and sewers – is an integral component of the proper management of a treatment system and critical to preventing illegal wastewater releases. Effective preventive maintenance programs have been shown to significantly reduce the frequency and volume of untreated sewage discharges, help communities plan for the future and save money on emergency response.

The compelling reason to perform a condition assessment of your collection system is to preserve the existing valuable infrastructure, minimize O&M and avoid emergencies and unexpected costs. Condition assessment of your collection system is an investment in managing risk. Knowing the structural condition of your underground assets will allow you to avoid emergencies, prioritize repair and replacement projects, and plan for the future. In a condition assessment, data and information are gathered through observation, direct inspection, investigation, and monitoring.

Written Protocol

An analysis of the data and information helps determine the structural, operational, and performance status of capital infrastructure assets. A good written protocol, consistently applied, will help define the assessment. Use new data collection techniques to get the most out of your program. Implementing a pro-active program based on information and systematic assessment removes some of the politics and second-guessing from decision-making.

Performing a condition assessment has a cost, but prioritizing work by focusing on critical assets and the maintenance and replacement needs for your collection system is an essential step toward better management.

Condition Assessments

Maintenance issues are the leading cause of backups and overflows of collection systems. Condition assessment helps utilities discover maintenance and capacity issues before they become maintenance problems. Knowing how your collection system really works will identify Trouble Spots and lead to preventive maintenance decisions, rather than being reactive to the consequences of emergency incidents.

Implementing a pro-active program based on information and systematic assessment provides a manager with the tools to improve decision-making and solid information on which to base staffing and funding decisions.

- grease
- roots
- debris

Record Keeping

Record keeping of sewer maintenance, inspections and repairs meets several needs of the sewer system. Records help simplify and improve work planning and scheduling, including integrating recurring and on-demand work. Measuring and tracking of workforce productivity and developing unit costs for various activities are a few of the record keeping benefits. Records of sewer maintenance, service line maintenance, and sewer main and service line repairs should be kept and maintained. Examples of record forms are found herein.

Operations and Maintenance Post Quiz

1. The system's goal should be a minimum of cleaning between _____% of the sewers every year.

Sewer Cleaning and Inspection

2. As sewer system networks age, the risk of deterioration, this _____, and collapses becomes a major concern.

3. _____ are essential to maintaining a properly functioning system; these activities further a community's reinvestment into its wastewater infrastructure.

Identify the Cleaning Method

4. Directs high velocities of water against pipe walls. Removes debris and grease build-up, clears blockages, and cuts roots within small diameter pipes. Efficient for routine cleaning of small diameter, low flow sewers.

5. Round, rubber-rimmed, hinged metal shield that is mounted on a steel framework on small wheels. The shield works as a plug to build a head of water. Scours the inner walls of the pipe lines. Effective in removing heavy debris and cleaning grease from line.

6. Similar in function to the ball. Rigid rims on bag and kite induce a scouring action. Effective in moving accumulations of decayed debris and grease downstream.

7. Most effective in lines up to 12 inches in diameter. Uses an engine and a drive unit with continuous rods or sectional rods. As blades rotate, they break up grease deposits, cut roots, and loosen debris.

8. Partially removes large deposits of silt, sand, gravel, and some types of solid waste. Cylindrical device, closed on one end with 2 opposing hinged jaws at the other. Jaws open and scrape off the material and deposit it in the bucket.

9. A threaded rubber cleaning ball that spins and scrubs the pipe interior as flow increases in the sewer line. Removes deposits of settled inorganic material and grease build-up. Most effective in sewers ranging in size from 5-24 inches.

10. Introduces a heavy flow of water into the line at a manhole. Removes floatables and some sand and grit. Most effective when used in combination with other mechanical operations, such as rodding or bucket machine cleaning.

More on Sewer Cleaning Procedures

A maintenance plan attempts to develop a strategy and priority for maintaining pipes based on several of the following factors:

11. _____ - frequency and location; 80 percent of problems occur in 25 percent of the system.

12. Force main vs. gravity-force mains have a higher priority than gravity, size for size, due to the complexity of the _____.

13. _____ - Hydrogen Sulfide (H₂S) is responsible for corroding sewers, structures, and equipment used in wastewater collection systems. The interior conditions of the pipes need to be monitored and treatment needs to be implemented to prevent the growth of slime bacteria and the production of H₂S gases.

14. _____ - pipes that carry larger volumes take precedence over pipes that carry a smaller volume.

Limitations of Cleaning Methods

15. _____ will normally utilize a variety of cleaning methods including jetting, high velocity cleaning, rodding, bucket machining, and using stop trucks.

16. The cleaning and inspection crews will usually consist of two members to operate each of the?

Detailed Cleaning Methods

The purpose of sewer cleaning is to remove foreign material from the sewer and generally is undertaken to alleviate one of the following conditions:

17. _____ is caused by either the premature operation of combined wastewater overflows because of downstream restrictions to hydraulic capacity or pollution caused by the washing through and discharge of debris from overflows during storms.

18. _____ is caused by the retention of solids in the system for long periods resulting in, among other things, wastewater turning septic and producing hydrogen sulfide.

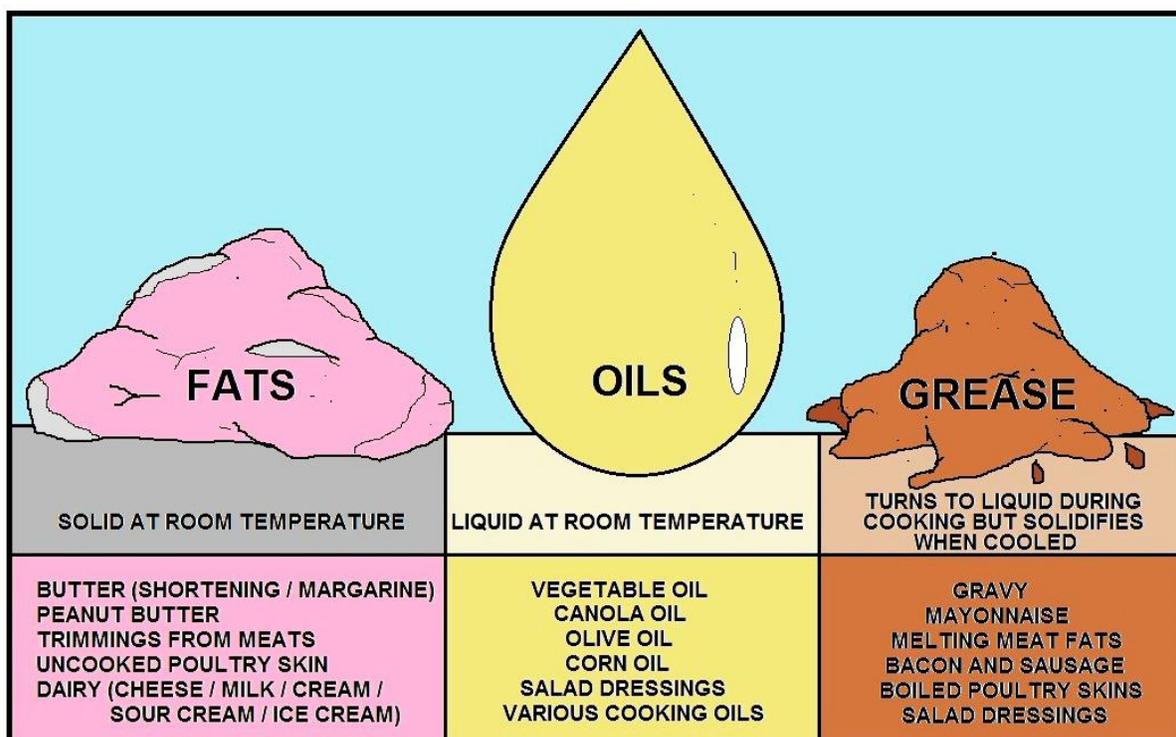
Answers

1. 20-30, 2. Blockages, 3. Cleaning and inspecting sewer lines, 4. Jetting, 5. Scooter, 6. Kites, Bags, and Poly Pigs, 7. Mechanical Rodding, 8. Bucket Machine, 9. Hydraulic Balling, 10. Flushing, 11. Problems, 12. Cleaning and repairs, 13. Corrosion potential, 14. Pipe diameter/volume conveyed, 15. The collection system, 16. Combination trucks and TV trucks, 17. Pollution, 18. Odor

Chapter 3- FATS, OILS AND GREASE SECTION

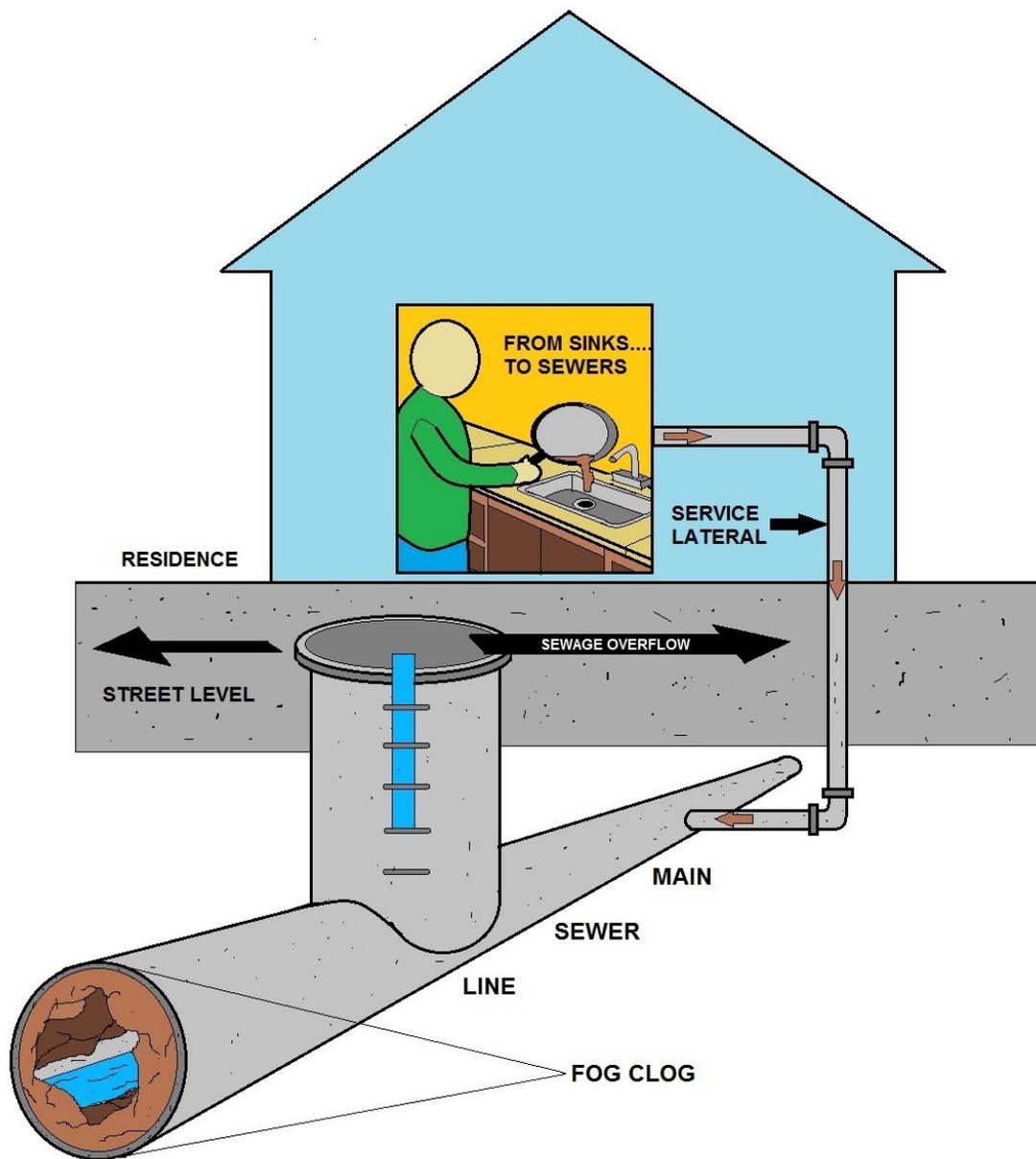
Section Focus: You will learn the basics of the Clean Water Act, the need for FOG fats, oils and grease regulation and enforcement. At the end of this section, you the student will be able to describe the need for fats, oils and grease regulation, enforcement and public education. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.

Scope/Background: The CWA made it unlawful to discharge any pollutant (FOG) from a point source into navigable waters, unless a permit was obtained. EPA's National Pollutant Discharge Elimination System (NPDES) permit program controls discharges. Food service establishments deal with large volumes of FOG on a daily basis. FOG can have a very negative impact if not handled properly. It can cause serious damage to the sewer system, your property and that of your neighbors, as well as, damage the environment and public health concerns. Cleanup of sewer overflows can be very costly and this expense translates to higher bills for sewer customers. By being aware of what FOG can do to your surroundings, it is easier to take that extra minute to do your part and prevent FOG from ending up in the sewer.



FOG (FATS/OILS/GREASE) CONTRIBUTORS

Most stoppages in the sewer system are caused by grease. It is best to have a strong FOG Ordinance that prevents restaurants from dumping grease into the system. You as the regulator will need a process of back charging the restaurants that do clog the sewers as payment for cleaning. As a pretreatment inspector, you will visit many restaurants for grease violations.

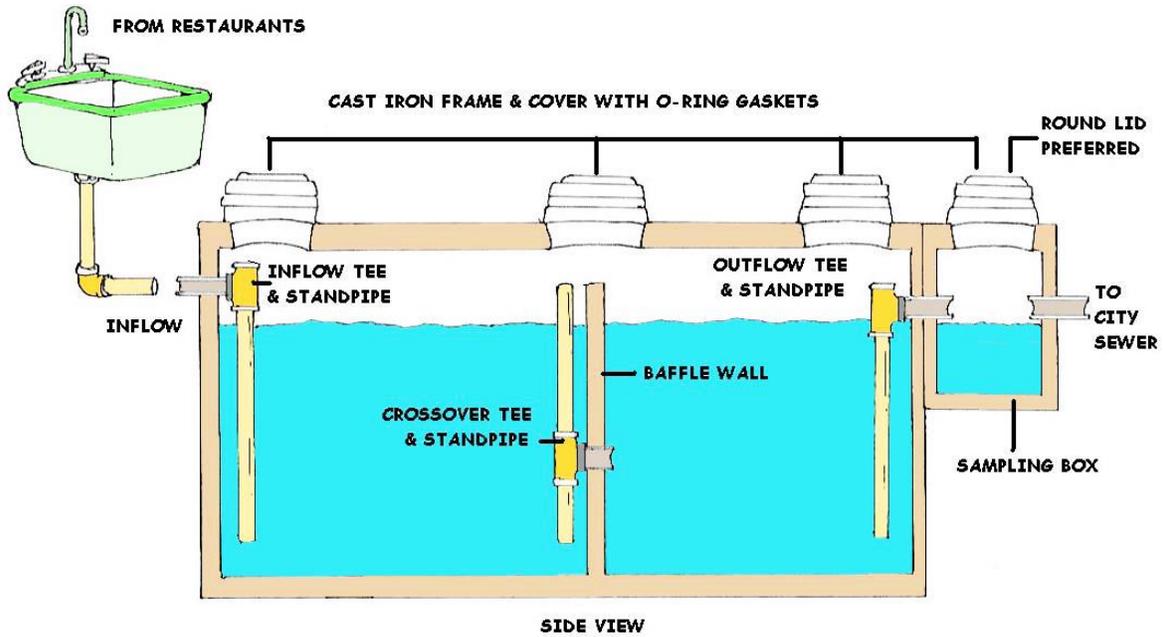


HOW SEWERS ARE CLOGGED BY GREASE DIAGRAM

Keeping Fats, Oils, and Grease out of the Sewer System

Fats, oils, and grease—FOG—comes from meat fats in food scraps, cooking oil, shortening, lard, butter and margarine, gravy, and food products such as mayonnaise, salad dressings, and sour cream.

FOG poured down kitchen drains accumulates inside sewer pipes and cause damage to the collection system. As the FOG builds up, it restricts the flow in the pipe and can cause untreated wastewater to back-up into homes and businesses, resulting in high costs for cleanup and restoration.



Cooking grease coats pipelines much like fatty foods clog human arteries. The grease clings to the insides of the pipe, eventually causing blockage and potential sewer spills. By following a few simple steps, customers can help prevent costly sewer spills in the future.

- All cooking oil (this includes salad oil, frying oil and bacon fat) should be poured into an old milk carton, frozen juice container, or other non-recyclable package, and disposed of in the garbage.
- Dishes and pots that are coated with greasy leftovers should be wiped clean with a disposable towel prior to washing or placing in the dishwasher.
- Instead of placing fat trimmings from meat down the garbage disposal, place them in a trash can.



Vactor

FOG Problems

Manholes can overflow into parks, yards, streets, and storm drains, allowing FOG to contaminate local waters, including drinking water. Exposure to untreated wastewater is a public-health hazard and is an EPA violation. FOG discharged into septic systems and drain fields can cause malfunctions, resulting in more frequent tank pump-outs and other expenses.

Restaurants, cafeterias, and fast-food establishments spend tens of thousands of dollars on plumbing emergencies each year to deal with grease blockages and pump out grease traps and interceptors. Some cities also charge businesses for the repair of sewer pipes and spill cleanup if they can attribute the blockage to a particular business.

Some cities also add a surcharge to wastewater bills if a business exceeds a specified discharge limit. These expenses can be a significant.

Communities spend billions of dollars every year unplugging or replacing grease-blocked pipes, repairing pump stations, and cleaning up costly and illegal wastewater spills. Excessive FOG in the sewer system can affect local wastewater rates. So, keeping FOG out of the sewer system helps everyone in the community.

Controlling Fats, Oils, and Grease Discharges from Food Service Establishments

FOG gets into our sewer collection system mainly from residential customers pouring the substances down their drains and from commercial food preparation establishments with inadequate grease controls. Fats, oils and grease are a byproduct of cooking and are mostly found in the following:

- ✓ Meats
- ✓ Cooking oil
- ✓ Lard or shortening
- ✓ Butter or margarine

Our sewer system is not designed to handle or treat these substances in excess. Over time, without proper disposal of fats, oils and grease, they build up in the sewer system and eventually block collection pipes and sewer lines, resulting in sewer backups and overflows on streets, properties and even in customers' homes and/or businesses. Overflows may also impact the environment negatively and can result in contamination of ponds, streams or rivers.

Food Service Establishments (FSEs)

Food Service Establishments (FSEs) are a significant source of fats, oil and grease (FOG) because of the amount of grease used in cooking. POTW Commercial FOG Programs are generally developed to assist restaurants and other FSEs with proper handling and disposal of their FOG. Through implementation of Best Management Practices (BMPs), these establishments should be able to significantly reduce the amount of FOG that goes down their drains. This will minimize back-ups and help business owners comply with the POTW's requirements.

To work effectively, sewer systems need to be properly maintained, from the drain to the treatment plant. If wastes are disposed of correctly, the POTW's sewer system can handle them without any problem.

The POTW needs businesses and individuals to do their part to maintain the system because repeated repairs are disruptive to residences and businesses alike. Furthermore, proper disposal by commercial establishments is required by law.

Grease Trap

The trap prevents excess grease from getting into the sewer system from existing plumbing lines within facilities. Traps are small and are usually installed inside a facility. Generally, they range in size from 20 gallons per minute (gpm) to 50 gpm.

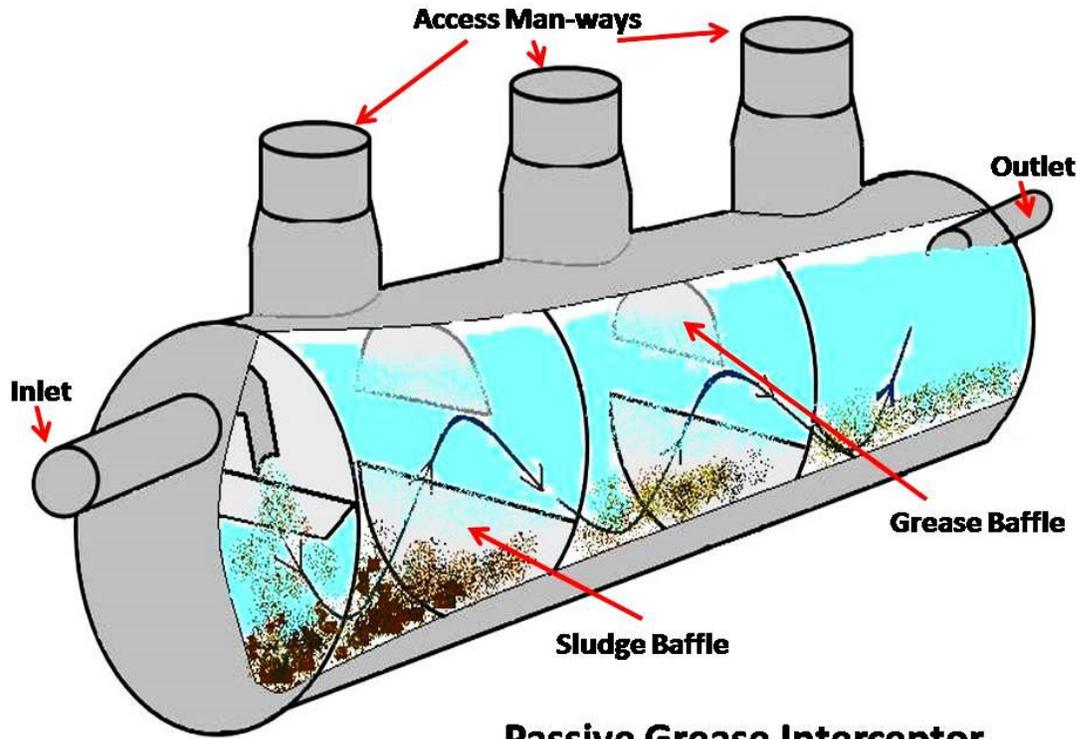


Infloor grease trap being removed and replaced with a grease interceptor.

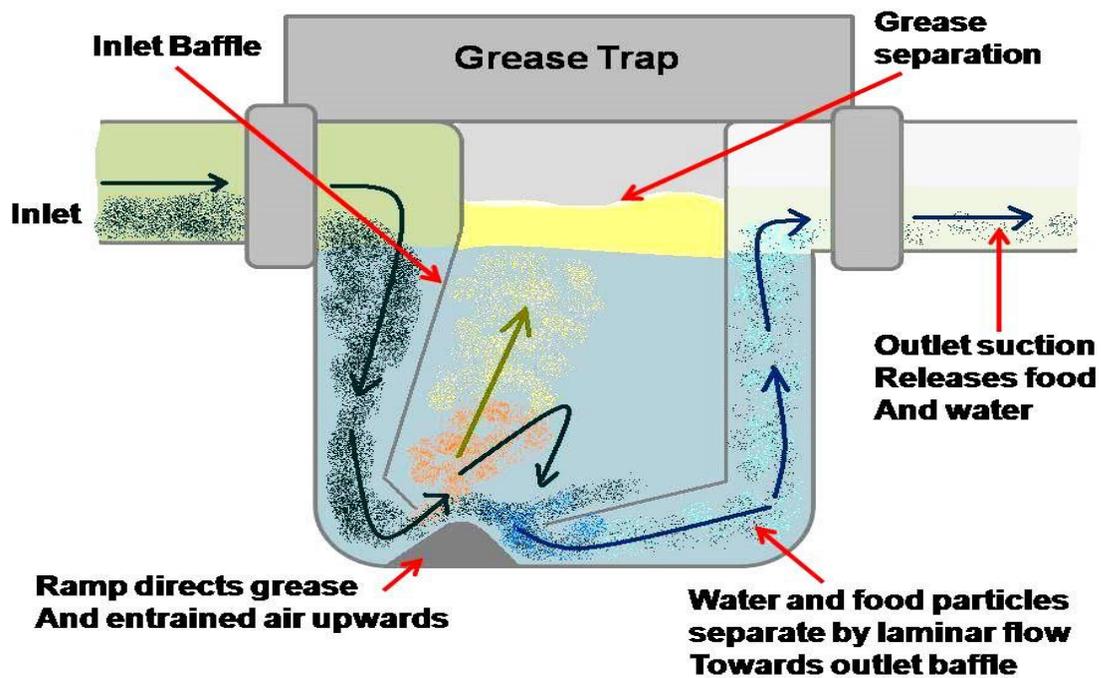


Looking down into a grease interceptor commonly used in a commercial food service operations.

Grease Interceptor Diagrams

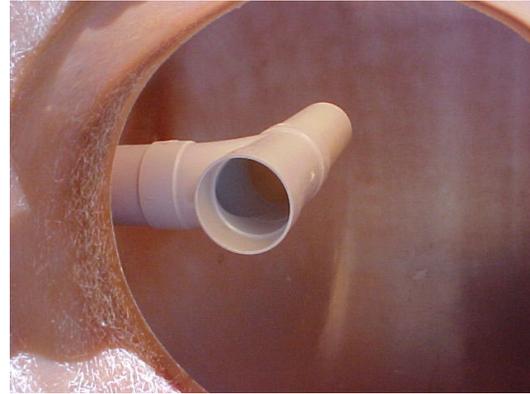


Passive Grease Interceptor



Grease Interceptor Sub-Section

High-volume or new establishments use grease interceptors that are larger than the traps and are installed underground, outside of a facility. Grease is actually "intercepted" in these concrete or fiberglass tanks before it reaches the sewer main. Grease interceptors should be accessible by three manhole covers, and a sample box. Interceptors and traps cause the flow of water to slow down, allowing the grease to naturally float to the top of the tank for easy removal.



New fiberglass three compartment grease interceptor. You will need to fill the interceptor with water before connecting it to the sewer main.

Plan Checks and Inspections

All plans for new commercial food establishments (including new construction remodels and retrofits) should receive a plan review from the POTW. This review assures that appropriate grease-removal equipment is installed during construction.

Grease Blockages

Shortly after sewer-spills caused by grease are reported or discovered, POTW inspectors investigate facilities within the immediate area. A determination is made as to which commercial facilities contributed to the blockage, and more in-depth inspections are conducted at those facilities.

Where appropriate, additional requirements and/or procedures are put in place. When requirements are made for additional grease-removal equipment, the facility is given a due date to comply.

A Notice of Violation, with an administrative fee, is issued once a facility has passed its final due date. Administrative hearings, permit revocation, and ultimately, termination of sewer service may occur for those facilities that remain out of compliance.

Regular Grease Inspection

Regular inspection and maintenance is essential to the proper operation of a grease removal device. The local ordinance should require a minimum cleaning frequency of once every six months.

However, that frequency will increase depending on the capacity of the device, the amount of grease in the wastewater, and the degree to which the facility has contributed to blockages in the past.

Regular cleaning at the appropriate interval is necessary to maintain the rated efficiency of the device. Equipment that is not regularly maintained puts the food service facility at risk of violating the sewer use ordinance, and this may not be known until an overflow and violation have occurred.

Most POTWs suggest businesses start with quarterly cleanings and should be done when 75 percent of the retention capacity of the unit is 75 percent full of accumulated grease. A large measuring stick and/or a clear piece of conduit may be used to determine the depth of the grease accumulation. You should require that restaurants contract with a licensed grease hauler to remove it from the premises for appropriate disposal.

Choosing a Grease Hauler

When you speak to a restaurant owner, inform them that while selecting a grease hauler, be aware that services and prices can vary. Minimum services should include:

- Complete pumping and cleaning of the interceptor and sample box, rather than just skimming the grease layer.
- Deodorizing and thorough cleaning of affected areas, as necessary.
- Disposal/reclamation at an approved location.
- Notes concerning the condition of the interceptor
- Complete pumping and cleaning record.

The restaurant owner and grease hauler should agree on an adequate cleaning frequency to avoid blockage of the line. Waste grease from a kitchen is recyclable for use in making soap, animal feed, etc. Grease from a grease trap or interceptor may not be reused in this way. For recyclable grease, some POTWs recommend that all facilities have waste grease containers with tight fitting lids that are either secondarily contained or kept in a bermed area to protect floor drains and storm drain inlets from spills.

Keeping up-to-date Records

Careful record keeping is one of the best ways to ensure that the grease removal device is being cleaned and maintained on a regular basis. City codes and ordinances require records be maintained for a minimum of three to five years.

Other Types of Devices

A grease trap may be approved in lieu of an interceptor for full service food service facilities only in very limited circumstances when space is not available. Grease traps may also be approved by the Industrial Pretreatment Program for facilities such as delicatessens and small bakeries that produce small quantities of oil, grease, or fat. Refer to the International Plumbing Code for requirements related to grease traps such as installation of flow-control devices, flow rates, and other structural requirements.

Please Note: Flow restrictors are required for grease traps because they increase retention time and efficiency.

Automatic grease skimming devices collect small volumes of water and remove grease into a side container at preset times each day. Usually, special approval from the Industrial Pretreatment Staff or the POTW is required to install one of these devices in lieu of a grease interceptor.

Magic Grease “Bugs” and Bacterial Additives

Manufacturers of bacterial additives claim that their products remove grease and enhance the performance of grease traps and interceptors. Such additives cannot be substituted for a grease removal device and regular inspection and maintenance.

If a customer decides to use an additive, they need to make sure the product you select is not an emulsifier, which simply keeps grease in suspension temporarily and allows it to flow to the sewer system.

Obtaining necessary permits

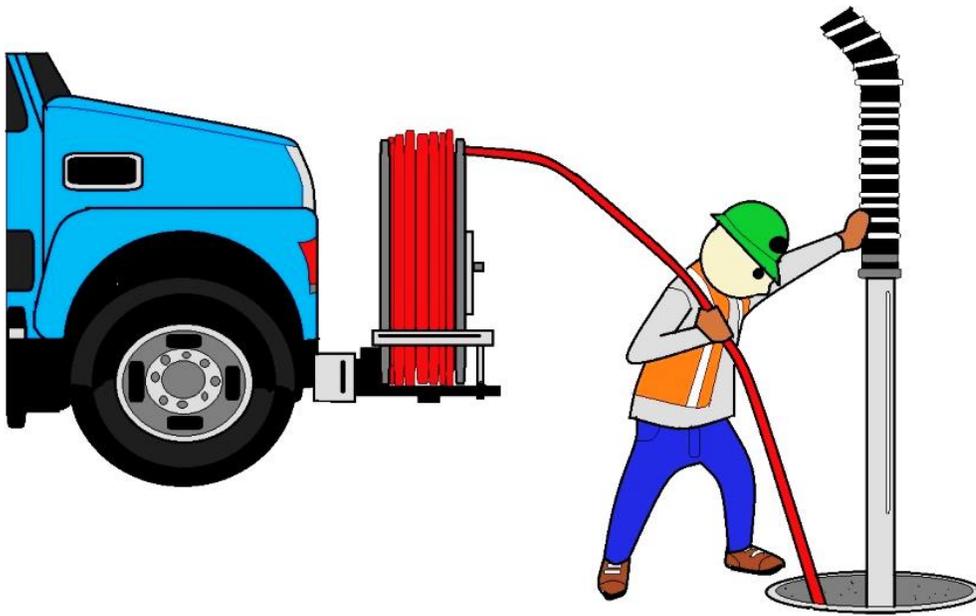
- Building departments prefer in-ground installations that drain by gravity to the sanitary sewer. Avoid pumps and other mechanical devices in your connection to the sewer if possible.
- The interceptor or grease trap needs to be properly sized in accordance with the International Plumbing Code, IAPMO, or local ordinance.

Chain Cutter

This tool is attached to the flush truck. When water pressure is applied, the 3 chains at the head spin at tremendous speeds. These spinning chains will cut roots, grease build-up, and even a protruding tap.



This is a sewer line that has a large amount of grease buildup that will be cut out. Grease gets into the sewer line by pouring grease left over from cooking, down the kitchen sink.



USING A VACUUM TRUCK TO CLEAN SEWER
Often the Vector is called out to clean out the above concerns.

Interceptors and Traps- Plan Checks and Inspections

As a collection operator, you will need knowledge of many different concerns in order to properly identify the problem.

All plans for new commercial food establishments (including new construction remodels and retrofits) should receive a plan review from the POTW. This review assures that appropriate grease-removal equipment is installed during construction.

Grease Blockages

Shortly after sewer-spills caused by grease are reported or discovered, POTW inspectors or Collection Inspectors investigate facilities within the immediate area. A determination needs to be made as to which commercial facilities contributed to the blockage, and more in-depth inspections are conducted at those facilities. Where appropriate, additional requirements and/or procedures are put into place. When requirements are made for additional grease-removal equipment, the facility is given a due date to comply. A Notice of Violation (NOV), with an administrative fee, is issued once a facility has passed its final due date. Administrative hearings, permit revocation, and ultimately, termination of sewer service may occur for those facilities that remain out of compliance.

Regular Grease Inspection

Regular inspection and maintenance is essential to the proper operation of a grease removal device. The local ordinance should require a minimum cleaning frequency of once every six months. However, that frequency will increase depending on the capacity of the device, the amount of grease in the wastewater, and the degree to which the facility has contributed to blockages in the past.

Regular cleaning at the appropriate interval is necessary to maintain the rated efficiency of the device. Equipment that is not regularly maintained puts the food service facility at risk of violating the sewer use ordinance, and this may not be known until an overflow and violation have occurred.

Most POTWs suggest businesses start with quarterly cleanings that should be done when 75 percent of the retention capacity of the unit is full of accumulated grease. A large measuring stick and/or a clear piece of conduit may be used to determine the depth of the grease accumulation.

You should contract with a licensed grease hauler to remove it from the premises for appropriate disposal.

Choosing a Grease Hauler

When the customer needs to select a grease hauler, they should be aware that services and prices can vary.

Minimum services should include:

- Complete pumping and cleaning of the interceptor and sample box, rather than just skimming the grease layer.
- Deodorizing and thorough cleaning of affected areas, as necessary.
- Disposal/reclamation at an approved location.
- Notes concerning the condition of the interceptor.

- Complete pumping and cleaning record.

The Customer and the hauler should agree on an adequate cleaning frequency to avoid blockage of the line.

Recyclable grease storage

Waste grease from a kitchen is recyclable for use in making soap, animal feed, etc. Grease from a grease trap or interceptor may not be reused in this way.

For recyclable grease, some POTWs recommend that all facilities have waste grease containers, with tight fitting lids, that are either secondarily contained or kept in a bermed area to protect floor drains and storm drain inlets from spills.

Keeping up-to-date Records

Careful record keeping is one of the best ways to ensure that your grease removal device is being cleaned and maintained on a regular basis. City codes and ordinances require records be maintained for a minimum of three to five years.

Other Types of Devices

Often but not always, a grease trap or several traps may be approved in lieu of an interceptor for full service food service facilities only in very limited circumstances when space is not available.

Grease traps may also be approved by the Industrial Pretreatment Program for facilities such as delicatessens and small bakeries that produce small quantities of oil, grease, or fat. Refer to the Plumbing Code for requirements related to grease traps such as installation of flow-control devices, flow rates, and other structural requirements.

Please Note: flow restrictors are required for grease traps because they increase retention time and efficiency. Automatic grease skimming devices collect small volumes of water and remove grease into a side container at preset times each day.

Usually, special approval from the Industrial Pretreatment Staff or the POTW is required to install one of these devices in lieu of a grease interceptor.

Magic Grease Eating “Bugs” and Bacterial Additives

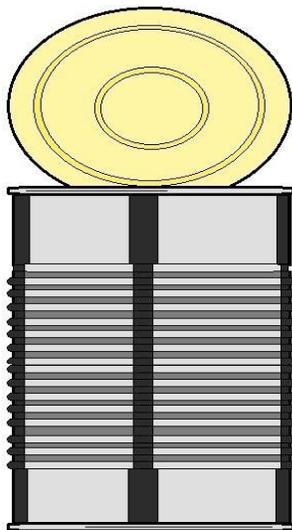
Manufacturers of bacterial additives claim that their products remove grease and enhance the performance of grease traps and interceptors. Such additives cannot be substituted for a grease removal device, cleaning, regular inspection and maintenance.

If a customer decides to use an additive, they need to make sure the product you select is not an emulsifier, which simply keeps grease in suspension temporarily and allows it to flow to the sewer system.

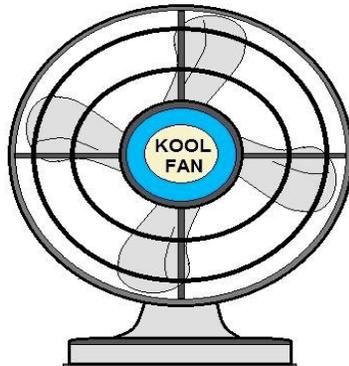
Obtaining Necessary Permits - Fixture Unit Loading Calculation

- Building departments prefer in-ground installations that drain by gravity to the sanitary sewer. Avoid pumps and other mechanical devices in your connection to the sewer if possible.
- The interceptor or grease trap needs to be properly sized (fixture unit loading) in accordance with the International Plumbing Code, IAPMO, or local ordinance.

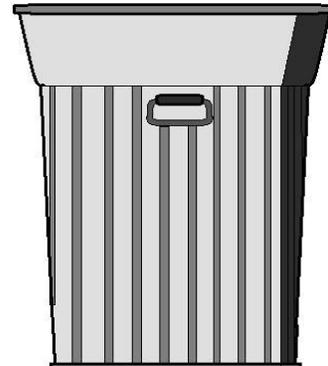
Controlling FOG Discharges



CAN IT



COOL IT



TRASH IT

METHODS OF PROPER GREASE DISPOSAL

FOG wastes are generated at FSEs as byproducts from food preparation activities. FOG captured on-site is generally classified into two broad categories: yellow grease and grease trap waste. Yellow grease is derived from used cooking oil and waste greases that are separated and collected at the point of use by the food service establishment.

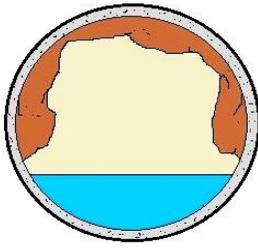
The annual production of collected grease trap waste and uncollected grease entering sewage treatment plants can be significant and ranges from 800 to 17,000 pounds/year per restaurant.

The National Pretreatment Program already provides the necessary regulatory tools and authority to local pretreatment programs for controlling interference problems. Under the provisions of Part 403.5(c)(1) & (2), in defined circumstances, a POTW must establish specific local limits for industrial users to guard against interference with the operation of the municipal treatment works.

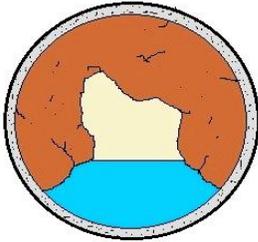
Consequently, pretreatment oversight programs should include activities designed to identify and control sources of potential interference and, in the event of actual interference, enforcement against the violator.

Food service establishments can adopt a variety of best management practices or install interceptor/collector devices to control and capture the FOG material before discharge to the collection system.

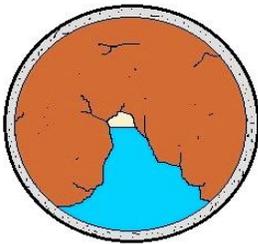
For example, instead of discharging yellow grease to POTWs, food service establishments usually accumulate this material for pick up by consolidation service companies for re-sale or re-use in the manufacture of tallow, animal feed supplements, bio-fuels, or other products. Additionally, food service establishments can install interceptor/collector devices (e.g., grease traps) in order to accumulate grease on-site and prevent it from entering the POTW collection system.



THE START OF BLOCKED PIPE BEGINS WITH SOLIDS AND GREASE COLLECTING ON TOP AND SIDES OF PIPE INTERIOR.



OVER TIME, THE BUILD-UP INCREASES WHEN GREASE AND DEBRIS ARE WASHED DOWN A DRAIN.



EXCESSIVE ACCUMULATION RESTRICTS THE FLOW OF WASTEWATER THAT CAN RESULT IN AN OVERFLOW OF SANITARY SEWER

HOW SEWER BLOCKAGES FORM

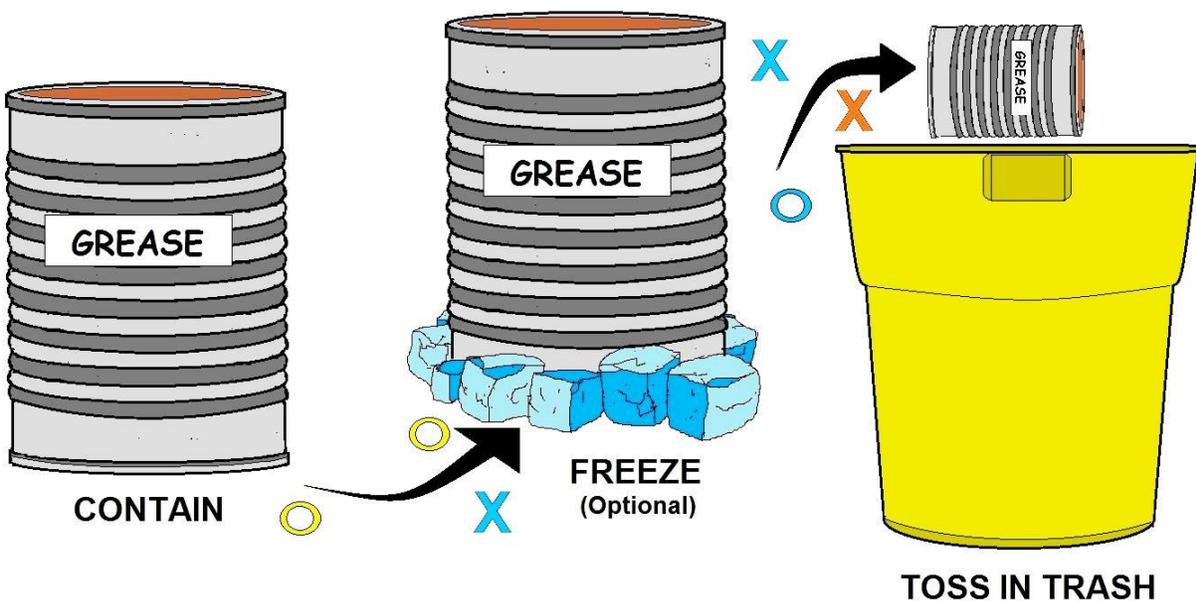
POTWs control methods for FOG discharges from FSEs

Proper design, installation, and maintenance procedures are critical for these devices to control and capture the FOG.

For example,

- ✓ Interceptor/collector devices must be designed and sized appropriately to allow FOG to cool and separate in a non-turbulent environment.
- ✓ FSE must be diligent in having their interceptor/ collector devices serviced at regular intervals.

Methods of Recycling FOG



**THE SINK SHOULD NEVER BE USED TO DISPOSE OF:
OILS , FATS OR GREASE**

FOG Customers and Violators Should be Encouraged or Written Up to...

Rendering FOG

Liquid fats and solid meat products can be used as raw materials in the rendering industry, which converts them into animal food, cosmetics, soap, and other products. Many companies will provide storage barrels and free pick-up service.

Converting FOG to Biodiesel

FOG are collected and converted by a local manufacturer into environmentally friendly biodiesel fuel. Biodiesel is an alternative fuel produced from renewable resources such as virgin oils (soybean, canola, palm), waste cooking oil, or other bio-waste feedstock.

Biodiesel significantly reduces greenhouse gases, sulfur dioxide in air emissions, and asthma-causing soot. Along with creating less pollution, biodiesel is simple to use, biodegradable and nontoxic.

Inspection Checklists

Pretreatment programs are developing and using inspection checklists for both food service establishments and municipal pretreatment inspectors to control FOG discharges.

Additionally, EPA identified typical numeric local limits controlling oil and grease in the range of 50 mg/L to 450 mg/L with 100 mg/L as the most common reported numeric pretreatment limit.

EPA expects that blockages from FOG discharges will decrease as POTWs incorporate FOG reduction activities into their Capacity, Management, Operations, and Maintenance (CMOM) program and daily practices.

CMOM programs are comprehensive, dynamic, utility specific programs for better managing, operating and maintaining sanitary sewer collection systems, investigating capacity constrained areas of the collection system, and responding to SSOs.

Collection system owners or operators who adopt FOG reduction activities as part of their CMOM program activities are likely to reduce the occurrence of sewer overflows and improve their operations and customer service.

Industrial Uses (Fats, Oils, and Grease)

Fats, Oils, and Grease Resources

Liquid fats and solid meat products are materials that should not be sent to landfills or disposed of in the sanitary sewer system. Fats, oils, and grease (FOG) can clog pipes and pumps both in the public sewer lines as well as in wastewater treatment facilities. This prevents combined sewer overflows, which protects water quality and lowers bills. FOG should be sent to the rendering industry to be made into another product, converted to biofuels, or sent to an anaerobic digester.

Proper Disposal Methods

Ways in which you as a customer can reduce the amounts of FOG that enters the sewer system is by doing the following:

- ✓ Have grease interceptors or traps inspected, maintained and cleaned regularly. (Usually every 6 months they should be pumped out).
- ✓ Scrape grease and food residue from dishes and pans into a garbage bag before placing them into your dishwasher or sink.
- ✓ Allow grease to cool to a safe temperature after cooking before disposal.
- ✓ Only dispose of fat and grease in an approved container or by an approved method.
- ✓ Recycle used cooking or motor oil at a recycling center.
- ✓ First freeze the grease or oil and then throw the hardened oil away on trash day.
- ✓ Mix oils with unscented kitty litter, sawdust or sand to solidify the oil (Avoid scented or disinfectant types of kitty litter as they can react with the oil and cause a fire).
- ✓ Use a paper towel to wipe small amounts of cooking oil, such as meat drippings, and throw the paper towel in the trash.
- ✓ Install “No Grease” signs around sinks to remind employees to avoid dumping fry grease and other fat products down the drain.
- ✓ Frying oils can generally be stored for up to six months and also can be reused for up to six hours of frying time. Store oil in the original container after cooling and strain for foreign materials as it is being poured back into the container.

Methods that should be avoided:

- ✓ Pouring household grease into sinks, garbage disposals or other drains. This is one of the major contributors to sewer stoppages.
- ✓ Flushing grease, diapers, sanitary napkins, newspapers, soiled rags, and/or paper towels down toilets.
- ✓ Pouring oil or grease into a storm drain; it is the same as pouring it directly into a lake.
- ✓ Ignoring your grease trap maintenance schedule.

National Pretreatment Program's Tools

The National Pretreatment Program provides regulatory tools and authority to state and local POTW pretreatment programs for eliminating pollutant discharges that cause interference at POTWs, including interference caused by the discharge of Fats, Oils, and Grease (FOG) from food service establishments (FSE).

More specifically, the Pretreatment Program regulations at 40 CFR 403.5(b)(3) prohibit "solid or viscous pollutants in amounts which will cause obstruction" in the POTW and its collection system.

EPA's Report to Congress on combined sewer overflows (CSOs) and sanitary sewer overflows (SSOs) identified that "grease from restaurants, homes, and industrial sources are the most common cause (47%) of reported blockages.

Grease is problematic because it solidifies, reduces conveyance capacity, and blocks flow."

Controlling FOG discharges will help POTWs prevent blockages that impact CSOs and SSOs, which cause public health and water quality problems.

Controlling FOG discharges from FSEs is an essential element in controlling CSOs and SSOs and ensuring the proper operations for many POTWs. The interference incidents identified in CSO/SSO report to Congress may indicate the need for additional oversight and enforcement of existing regulations and controls.

Best Management Practices (BMPs)

The required maintenance frequency for interceptor/collector devices depends greatly on the amount of FOG a facility generates as well as any best management practices (BMPs) that the establishment implements to reduce the FOG discharged into its sanitary sewer system. In many cases, an establishment that implements BMPs will realize financial benefit through a reduction in their required grease interceptor and trap maintenance frequency.

A growing number of control authorities are using their existing authority (e.g., general pretreatment standards in Part 403 or local authority) to establish and enforce more FOG regulatory controls (e.g., numeric pretreatment limits, best management practices including the use of interceptor/collector devices) for food service establishments to reduce interferences with POTW operations (e.g., blockages from fats, oils, and greases discharges, POTW treatment interference from *Nocardia filamentous* foaming, damage to collection system from hydrogen sulfide generation).

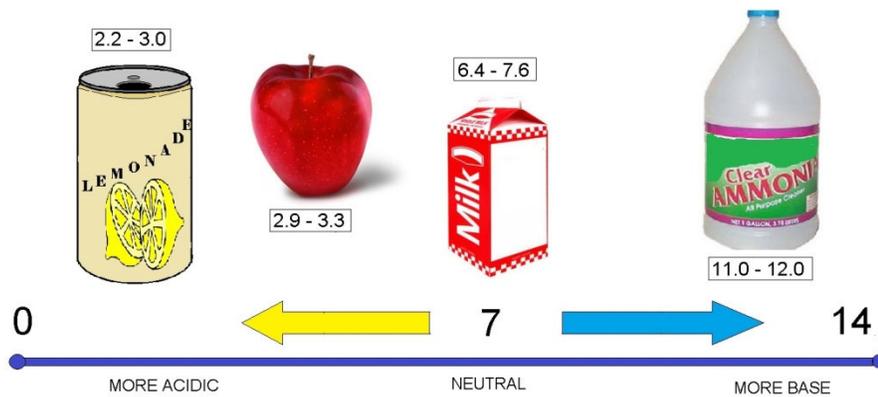
Non-Compliance Rate Example

For example, since identifying a 73% non-compliance rate with its grease trap ordinance among restaurants, New York POTW has instituted a \$1,000-per-day fine for FOG violations. Likewise, more and more municipal wastewater authorities are addressing FOG discharges by imposing mandatory measures of assorted kinds, including inspections, periodic grease pumping, stiff penalties, and even criminal citations for violators, along with 'strong waste' monthly surcharges added to restaurant sewer bills. Surcharges are reportedly ranging from \$100 to as high as \$700 and more, the fees being deemed necessary to cover the cost of inspections and upgraded infrastructure.

FOG Customers Using Best Management Practices Can:

- Lessen the likelihood of customer's losing revenue to emergency shutdowns caused by sewage backups and expensive bills for plumbing and property repairs.
- Lessen the likelihood of customer's lawsuits by nearby businesses over sewer problems caused by negligence.
- Lessen the likelihood of customer's lawsuits from workers or the public exposed to raw sewage during a backup.
- Reduce the number of times customers have to pump and clean your grease interceptors or traps.
- Lessen the likelihood of surcharges from the local sewer authority, or chargebacks for repairs to sewer pipes attributable customer's FOG.
- Reduce testing customer's requirements imposed due to a history of violations.
- Lessen the likelihood of customer's enforcement action by POTW authorities due to violations of ordinances.

pH Testing Sub-Section



pH SCALE

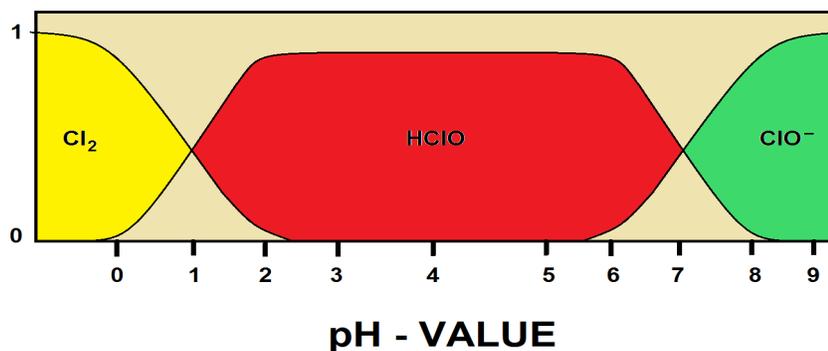
Because of FOG, it will lower the pH of the wastewater to very acidic conditions. You may be asked to test the pH of the wastewater to ensure the acid is not strong enough to cause corrosion to the sewer system.

In water and wastewater processes, **pH** is a measure of the acidity or basicity of an aqueous solution. Solutions with a pH greater than 7 are basic or alkaline and solution or samples with a pH less than 7 are said to be acidic. Pure water has a pH very close to 7.

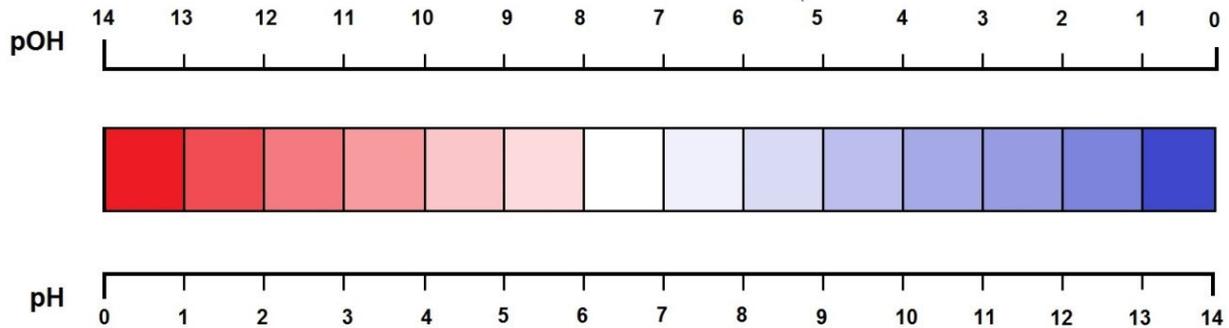
Primary pH standard values are determined using a concentration cell with transference, by measuring the potential difference between a hydrogen electrode and a standard electrode such as the silver chloride electrode. The pH scale is traceable to a set of standard solutions whose pH is established by international agreement.

Measurement of pH for aqueous solutions can be done with a glass electrode and a pH meter, or using indicators like strip test paper.

pH measurements are important in water and wastewater processes (sampling) but also in medicine, biology, chemistry, agriculture, forestry, food science, environmental science, oceanography, civil engineering, chemical engineering, nutrition, water treatment & water purification, and many other applications.



Mathematically, pH is the measurement of hydroxyl ion activity and expressed as the negative logarithm of the activity of the (solvated) hydronium ion, more often expressed as the measure of the hydronium ion concentration.



IN RELATION BETWEEN p(OH) AND p(H) (red= ACIDIC / blue= BASIC)

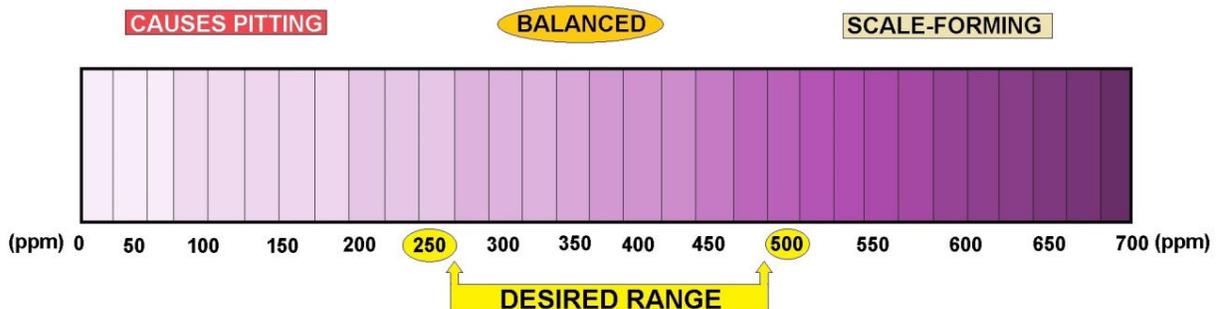
Contents

History

The scientific discovery of the p[H] concept of was first introduced by Danish chemist Søren Peder Lauritz Sørensen at the Carlsberg Laboratory back in 1909 and revised to the modern pH in 1924 to accommodate definitions and measurements in terms of electrochemical cells. In the first papers, the notation had the "H" as a subscript to the lowercase "p", as so: pH.

Alkalinity

Alkalinity is the quantitative capacity of an aqueous solution to neutralize an acid. Measuring alkalinity is important in determining a stream's ability to neutralize acidic pollution from rainfall or wastewater. It is one of the best measures of the sensitivity of the stream to acid inputs. There can be long-term changes in the alkalinity of rivers and streams in response to human disturbances.



CALCIUM HARDNESS MEASUREMENT

Reference. Bates, Roger G. *Determination of pH: theory and practice*. Wiley, 1973.

pH Definition and Measurements

CONCENTRATION OF HYDROGEN IONS COMPARED TO DISTILLED H ₂ O	1/10,000,000	14	LIQUID DRAIN CLEANER CAUSTIC SODA	EXAMPLES OF SOLUTIONS AND THEIR RESPECTIVE pH
	1/1,000,000	13	BLEACHES OVEN CLEANERS	
	1/100,000	12	SOAPY WATER	
	1/10,000	11	HOUSEHOLD AMMONIA (11.9)	
	1/1,000	10	MILK OF MAGNESIUM (10.5)	
	1/100	9	TOOTHPASTE (9.9)	
	1/10	8	BAKING SODA (8.4) / SEA WATER EGGS	
	0	7	"PURE" WATER (7)	
	10	6	URINE (6) / MILK (6.6)	
	100	5	ACID RAIN (5.6) BLACK COFFEE (5)	
	1000	4	TOMATO JUICE (4.1)	
	10,000	3	GRAPEFRUIT & ORANGE JUICE SOFT DRINK	
	100,000	2	LEMON JUICE (2.3) VINEGAR (2.9)	
	1,000,000	1	HYDROCHLORIC ACID SECRETED FROM STOMACH LINING (1)	
	10,000,000	0	BATTERY ACID	

pH Scale

Technical Definition of pH

In technical terms, pH is defined as the decimal logarithm of the reciprocal of the hydrogen ion activity, a_{H^+} , in a solution.

$$pH = -\log_{10}(a_{H^+}) = \log_{10}\left(\frac{1}{a_{H^+}}\right)$$

Ion-selective electrodes are often used to measure pH, respond to activity.

In this calculation of electrode potential, E , follows the Nernst equation, which, for the hydrogen ion can be written as

$$E = E^0 + \frac{RT}{F} \ln(a_{H^+}) = E^0 - \frac{2.303RT}{F} pH$$

where E is a measured potential, E^0 is the standard electrode potential, R is the gas constant, T is the temperature in kelvin, F is the Faraday constant.

For H^+ number of electrons transferred is one. It follows that electrode potential is proportional to pH when pH is defined in terms of activity.

International Standard ISO 31-8 is the standard for the precise measurement of pH as follows: A galvanic cell is set up to measure the electromotive force (EMF) between a reference electrode and an electrode sensitive to the hydrogen ion activity when they are both immersed in the same aqueous solution.

The reference electrode may be a silver chloride electrode or a calomel electrode. The hydrogen-ion selective electrode is a standard hydrogen electrode.

Reference electrode | concentrated solution of KCl || test solution | H₂ | Pt

Firstly, the cell is filled with a solution of known hydrogen ion activity and the emf, E_s , is measured. Then the emf, E_x , of the same cell containing the solution of unknown pH is measured.

$$pH(X) = pH(S) + \frac{E_s - E_x}{Z}$$

The difference between the two measured emf values is proportional to pH. This method of calibration avoids the need to know the standard electrode potential. The proportionality

constant, $1/z$ is ideally equal to $\frac{1}{2.303RT/F}$ the "Nernstian slope".

If you were to apply this practice the above calculation, a glass electrode is used rather than the cumbersome hydrogen electrode. A combined glass electrode has an in-built reference electrode. It is calibrated against buffer solutions of known hydrogen ion activity. IUPAC has proposed the use of a set of buffer solutions of known H⁺ activity.

Two or more buffer solutions should be used in order to accommodate the fact that the "slope" may differ slightly from ideal.

The electrode is first immersed in a standard solution and the reading on a pH meter is adjusted to be equal to the standard buffer's value, to implement the proper calibration. The reading from a second standard buffer solution is then adjusted, using the "slope" control, to be equal to the pH for that solution. Further details, are given in the IUPAC recommendations.

When more than two buffer solutions are used the electrode is calibrated by fitting observed pH values to a straight line with respect to standard buffer values. Commercial standard buffer solutions usually come with information on the value at 25 °C and a correction factor to be applied for other temperatures.

The pH scale is logarithmic and pH is a dimensionless quantity.

pH Indicators

Visual comparison of the color of a test solution with a standard color chart provides a means to measure pH accurate to the nearest whole number. Indicators may be used to measure pH, by making use of the fact that their color changes with pH. More precise measurements are possible if the color is measured spectrophotometrically, using a colorimeter or spectrophotometer. Universal indicator consists of a mixture of indicators such that there is a continuous color change from about pH 2 to pH 10. Universal indicator paper is made from absorbent paper that has been impregnated with universal indicator.

pOH

pOH is sometimes used as a measure of the concentration of hydroxide ions, OH^- , or alkalinity. pOH values are derived from pH measurements. The concentration of hydroxide ions in water is related to the concentration of hydrogen ions by

$$[\text{OH}^-] = \frac{K_w}{[\text{H}^+]}$$

where K_w is the self-ionization constant of water. Taking logarithms

$$\text{pOH} = \text{p}K_w - \text{pH}$$

So, at room temperature $\text{pOH} \approx 14 - \text{pH}$. However this relationship is not strictly valid in other circumstances, such as in measurements of soil alkalinity.

Extremes of pH

Measurement of pH below about 2.5 (ca. $0.003 \text{ mol dm}^{-3}$ acid) and above about 10.5 (ca. $0.0003 \text{ mol dm}^{-3}$ alkali) requires special procedures because, when using the glass electrode, the Nernst law breaks down under those conditions.

Extreme pH measurements imply that the solution may be concentrated, so electrode potentials are affected by ionic strength variation. At high pH the glass electrode may be affected by "alkaline error", because the electrode becomes sensitive to the concentration of cations such as Na^+ and K^+ in the solution. Specially constructed electrodes are available which partly overcome these problems. Runoff from industrial outfalls, restaurant grease, mines or mine tailings can produce some very low pH values.

Non-Aqueous Solutions

Hydrogen ion concentrations (activities) can be measured in non-aqueous solvents. pH values based on these measurements belong to a different scale from aqueous pH values, because activities relate to different standard states. Hydrogen ion activity, a_{H^+} , can be defined as:

$$a_{\text{H}^+} = \exp\left(\frac{\mu_{\text{H}^+} - \mu_{\text{H}^+}^\ominus}{RT}\right)$$

where μ_{H^+} is the chemical potential of the hydrogen ion, $\mu_{\text{H}^+}^\ominus$ is its chemical potential in the chosen standard state, R is the gas constant and T is the thermodynamic temperature. Therefore pH values on the different scales cannot be compared directly, requiring an intersolvent scale which involves the transfer activity coefficient of hydrolyonium ion.

pH is an example of an acidity function. Other acidity functions can be defined. For example, the Hammett acidity function, H_0 , has been developed in connection with superacids.

The concept of "Unified pH scale" has been developed on the basis of the absolute chemical potential of the proton. This scale applies to liquids, gases and even solids.

Applications

Water has a pH of $pK_w/2$, so the pH of pure water is about 7 at 25 °C; this value varies with temperature. When an acid is dissolved in water, the pH will be less than that of pure water. When a base, or alkali, is dissolved in water, the pH will be greater than that of pure water.

A solution of a strong acid, such as hydrochloric acid, at concentration 1 mol dm⁻³ has a pH of 0.

A solution of a strong alkali, such as sodium hydroxide, at concentration 1 mol dm⁻³, has a pH of 14. Thus, measured pH values will lie mostly in the range 0 to 14, though negative pH values and values above 14 are entirely possible.

Since pH is a logarithmic scale, a difference of one pH unit is equivalent to a tenfold difference in hydrogen ion concentration.

The pH of an aqueous solution of pure water is slightly different from that of, a salt such as sodium chloride even though the salt is neither acidic nor basic. In this case, the hydrogen and hydroxide ions' activity is dependent on ionic strength, so K_w varies with ionic strength.

The pH of pure water decreases with increasing temperatures. One example is the pH of pure water at 50 °C is 6.55.

Seawater

The pH of seawater plays an important role in the ocean's carbon cycle, and there is evidence of ongoing ocean acidification caused by carbon dioxide emissions. pH measurement can be complicated by the chemical properties of seawater, and several distinct pH scales exist in chemical oceanography.

As part of its operational definition of the pH scale, the IUPAC defines a series of buffer solutions across a range of pH values (often denoted with NBS or NIST designation).

These solutions have a relatively low ionic strength (~0.1) compared to that of seawater (~0.7), and, as a consequence, are not recommended for use in characterizing the pH of seawater, since the ionic strength differences cause changes in electrode potential.

To resolve this problem, an alternative series of buffers based on artificial seawater was developed. This new series resolves the problem of ionic strength differences between samples and the buffers.

The newest pH scale is referred to as the **total scale**, often denoted as **pH_T**.

pH Calculations

The calculation of the pH of a solution containing acids and/or bases is an example of a chemical speciation calculation, that is, a mathematical procedure for calculating the concentrations of all chemical species that are present in the solution.

The complexity of the procedure depends on the nature of the solution.

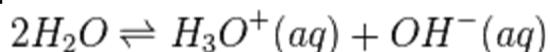
If the pH of a solution contains a weak acid requires the solution of a quadratic equation.

If the pH of a solution contains a weak base may require the solution of a cubic equation.

For strong acids and bases no calculations are necessary except in extreme situations.

The general case requires the solution of a set of non-linear simultaneous equations.

A complicating factor is that water itself is a weak acid and a weak base. It dissociates according to the equilibrium



with a dissociation constant, K_w defined as

$$K_w = [H^+][OH^-]$$

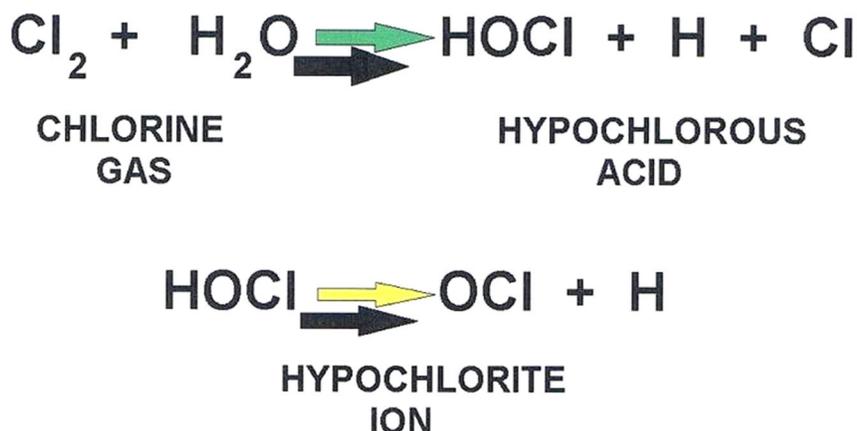
where $[H^+]$ represents for the concentration of the aquated hydronium ion and $[OH^-]$ stands for the concentration of the hydroxide ion. K_w has a value of about 10^{-14} at 25 °C, so pure water has a pH of approximately 7.

This equilibrium needs to be considered at high pH and when the solute concentration is extremely low.

Hydrogen Ion pH Comparison Chart

pH	Hydrogen Ion Concentration, mmol/L
14	0.000000000000001
13	0.00000000000001
12	0.0000000000001
11	0.000000000001
10	0.0000000001
9	0.000000001
8	0.00000001
7	0.0000001
6	0.000001
5	0.00001
4	0.0001
3	0.001
2	0.01
1	0.1

Strong Acids and Bases



Strong Acids and Bases

Strong acids and bases are compounds that, for practical purposes, are completely dissociated in water. Under normal circumstances this means that the concentration of hydrogen ions in acidic solution can be taken to be equal to the concentration of the acid. The pH is then equal to minus the logarithm of the concentration value.

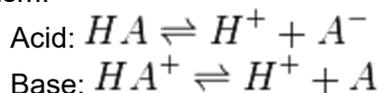
Hydrochloric acid (HCl) is an example of a strong acid. The pH of a 0.01M solution of HCl is equal to $-\log_{10}(0.01)$, that is, $\text{pH} = 2$.

Sodium hydroxide, NaOH, is an example of a strong base. The p[OH] value of a 0.01M solution of NaOH is equal to $-\log_{10}(0.01)$, that is, $\text{p[OH]} = 2$.

From the definition of p[OH] above, this means that the pH is equal to about 12. For solutions of sodium hydroxide at higher concentrations the self-ionization equilibrium must be taken into account.

Weak Acids and Bases

A weak acid or the conjugate acid of a weak base can be treated using the same formalism.



First, an acid dissociation constant is defined as follows. Electrical charges are omitted from subsequent equations for the sake of generality

$$K_a = \frac{[H][A]}{[HA]}$$

and its value is assumed to have been determined by experiment. This being so, there are three unknown concentrations, [HA], [H⁺] and [A⁻] to determine by calculation. Two additional equations are needed.

FOG Summary

Reducing Fats, Oils, and Grease in Your Commercial Kitchen

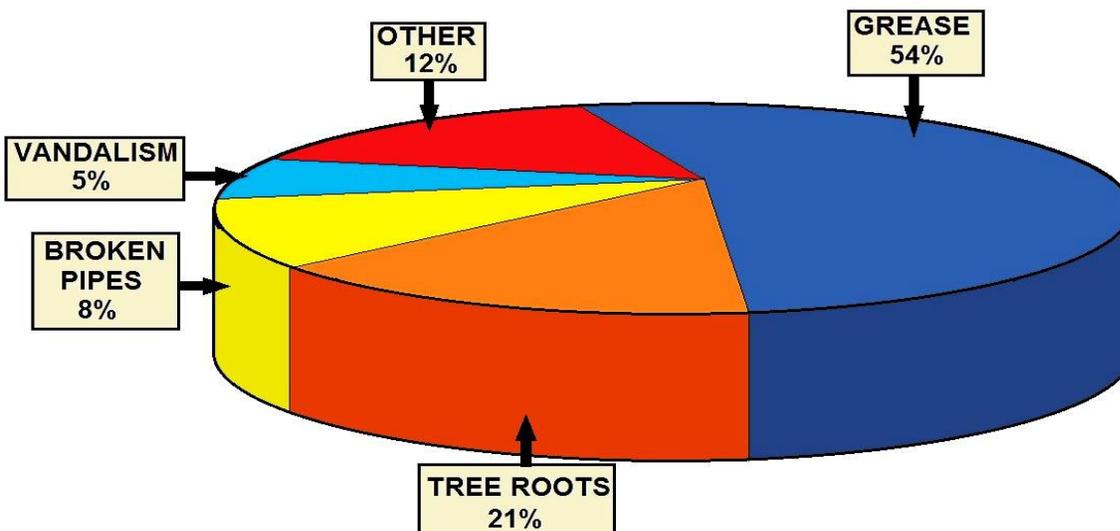
Any business or institution with a commercial kitchen has to deal with fats, oils, and grease (FOG). Commercial kitchens are found in restaurants, hospitals, churches, hotels, nursing homes, mobile food preparation facilities, etc.

Environmental problem with FOG sewers

FOG that enters the sewer system eventually solidifies and forms grease balls. These grease balls can range in size from marbles to the size of cantaloupes and must be removed periodically. Since the sewer system is unable to handle or treat these substances effectively, this incurs greater expenditures on the maintenance of the collection systems and/or treatment plants which in turn can lead to higher customer rates.

Sewer backups can also cost customers thousands of dollars for the repair or replacement of their damaged property.

Controlling FOG Discharges



CAUSES OF SANITARY SEWER OVERFLOWS

FOG wastes are generated at FSEs as by-products from food preparation activities. FOG captured on-site is generally classified into two broad categories: yellow grease and grease trap waste. Yellow grease is derived from used cooking oil and waste greases that are separated and collected at the point of use by the food service establishment.

The annual production of collected grease trap waste and uncollected grease entering sewage treatment plants can be significant and ranges from 800 to 17,000 pounds/year per restaurant. The National Pretreatment Program already provides the necessary regulatory tools and authority to local pretreatment programs for controlling interference problems. Under the provisions of Part 403.5(c)(1) & (2), in defined circumstances, a POTW must establish specific local limits for industrial users to guard against interference with the operation of the municipal treatment works.

Consequently, pretreatment oversight programs should include activities designed to identify and control sources of potential interference and, in the event of actual interference, enforcement against the violator.

Food service establishments can adopt a variety of best management practices or install interceptor/collector devices to control and capture the FOG material before discharge to the collection system. For example, instead of discharging yellow grease to POTWs, food service establishments usually accumulate this material for pick up by consolidation service companies for re-sale or re-use in the manufacture of tallow, animal feed supplements, bio-fuels, or other products.

Additionally, food service establishments can install interceptor/collector devices (e.g., grease traps) in order to accumulate grease on-site and prevent it from entering the POTW collection system.

Residential and Commercial Guidelines

The fats, oil and grease (FOG) found in food ingredients such as meat, cooking oil, shortening, butter, margarine, baked goods, sauces and dairy products is a major concern for POTW's sewers. When not disposed of properly, FOG builds up in the sewer system constricting flow, which can cause sewer back-ups into homes and overflow discharges onto streets. It can also interfere with sewage treatment processes at the POTW's Wastewater Treatment Plants.

To remediate this problem, many control authorities have developed an outreach program aimed at eliminating FOG from the sewer system. FOG buildup in sewer lines has many harmful and costly effects.

Sewer backups into homes create a health hazard as well as an unpleasant mess that can cost hundreds and sometimes thousands of dollars to clean up. In certain parts of the POTW, FOG can enter storm drains and flow directly into water bodies and onto beaches creating serious environmental and health conditions.

In addition to problems caused by cooking oils, petroleum-based oils can also cause sewer-related problems. POTW residents or customers may not be aware of or understand their role in these sewer-related problems or pollution, but they can do a lot to help eliminate FOG and other contaminants from the sewer system.

For example:

- Car washing can result in soap and oil residue entering the storm sewers.
- Run-off from your sprinkler, watering hose, or from the rain can carry yard waste and fertilizer into storm sewers.
- Littering can cause trash and debris to clog catch basins and storm drains.
- A gallon of oil poured down a storm drain could contaminate up to one million gallons of water.

FOG Section Post Quiz

Food Service Establishments (FSEs)

1. Because of the amount of grease used in cooking, _____ are a significant source of fats, oil and grease (FOG).
2. To assist improper handling and disposal of their FOG _____ are generally developed to assist restaurants and other FSEs with instruction and compliance.
3. The _____ can handle properly disposed wastes, but to work effectively, sewer systems need to be properly maintained, from the drain to the treatment plant.
4. Proper sewer disposal by commercial establishments is required by _____.

Environmental problem with FOG sewers

5. The various sizes of grease balls can range in size from cantaloupes to the size of marble and must be removed periodically.
A. *True* B. *False*
6. The repair or replacement of their damaged property caused by FOG creating _____ can also cost customers thousands of dollars for the repair or replacement of their damaged property.

Controlling FOG discharges

7. FOG wastes are generated at FSEs as byproducts from food preparation activities. FOG captured on-site is generally classified into two broad categories: yellow grease and grease trap waste.
A. *True* B. *False*
8. The POTW collection system(s) will require that certain food service establishments install interceptor/collector devices (e.g., grease traps) in order to accumulate grease on-site and prevent it from entering the?

Keeping Fats, Oils, and Grease out of the Sewer System

9. Manholes can overflow into parks, yards, streets, and storm drains, allowing FOG to contaminate local waters, including drinking water. Exposure to untreated wastewater is a public-health hazard and is an EPA violation. FOG discharged into septic systems and drain fields can cause malfunctions, resulting in more frequent tank pump-outs and other expenses.
A. *True* B. *False*
10. _____ will back up into homes and businesses, resulting in high costs for cleanup and restoration?

POTWs control methods for FOG discharges from FSEs

11. FOG must be able to cool and separate in a non-turbulent environment, therefore. _____ must be designed and sized appropriately.

12. Grease interceptor/ collector devices shall be serviced at regular intervals and _____ must be diligent in providing proper maintenance and records.

Best Management Practices (BMPs)

13. The amount of FOG a facility generates as well as any best management practices (BMPs) that the establishment implements to reduce the *FOG* discharged into its sanitary sewer system.

A. True B. False

Answers

1. Food Service Establishments (FSEs), 2. POTW Commercial FOG Program, 3. POTW's sewer system, 4. Law, 5. True, 6. Sewer backup(s), 7. True, 8. POTW collection system(s), 9. True, 10. Untreated wastewater, 11. Interceptor/collector device(s), 12. FSE, 13. True

Chapter 4 – PUMPS AND LIFT STATIONS SECTION

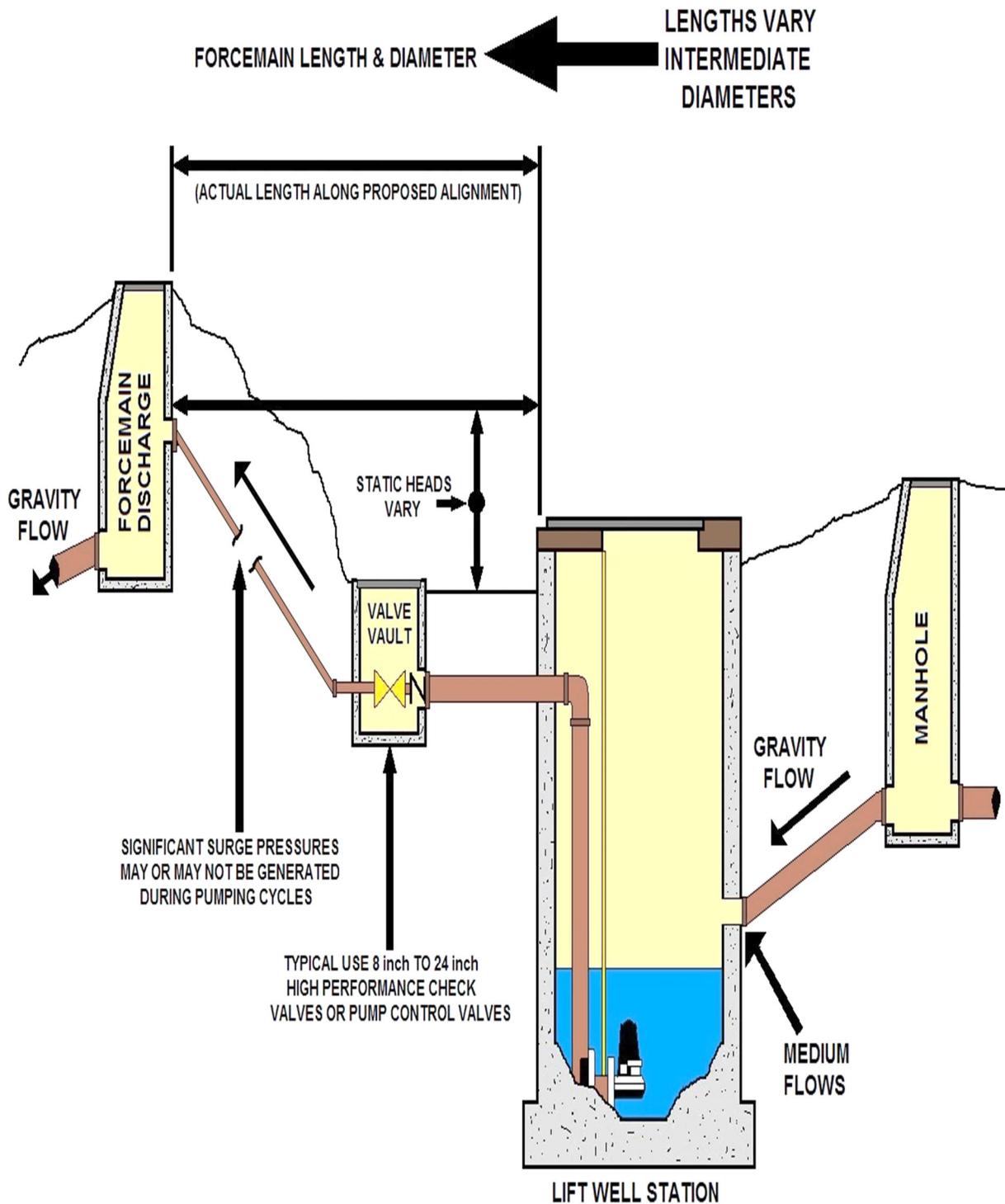
Section Focus: You will learn the Clean Water Act and the basics of the wastewater collection pumping or lift stations. At the end of this section, you the student will be able to describe the basics of the pumping station system. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.

Scope/Background: In many systems, a lift or pumping station is a major component of lifting wastewater to the onsite facility. Sewer pipes are generally gravity driven. Wastewater flows slowly downhill until it reaches a certain low point. Then, pump or "lift" stations push the wastewater back uphill to a high point where gravity can once again take over the process.



Lift Station: A facility in a sewer system consisting of a receiving chamber, pumping equipment, and associated drive and control devices which collect and lift wastewater to a higher elevation when the continuance of the sewer at reasonable slopes would involve excessive trench depths; or that collects and raises wastewater through the use of force mains from areas too low to drain into available sewers. There should not be an odor coming from a Lift Station.

Pumping Station: A relatively large sewage pumping installation designed not only to lift sewage to a higher elevation, but also to convey it through force mains to gravity flow points located relatively long distances from the pumping station.



**MEDIUM SEWAGE LIFT STATION
TYPICAL CHARACTERISTICS**

Wastewater Lift Stations

Reference EPA - EPA 832-F-00-073



Wastewater lift stations are facilities designed to move wastewater from lower to higher elevation through pipes. Key elements of lift stations include a wastewater receiving well (wet-well), often equipped with a screen or grinding to remove coarse materials; pumps and piping with associated valves; motors; a power supply system; an equipment control and alarm system; and an odor control system and ventilation system.

Lift station equipment and systems are often installed in an enclosed structure. They can be constructed on-site (custom-designed) or prefabricated.

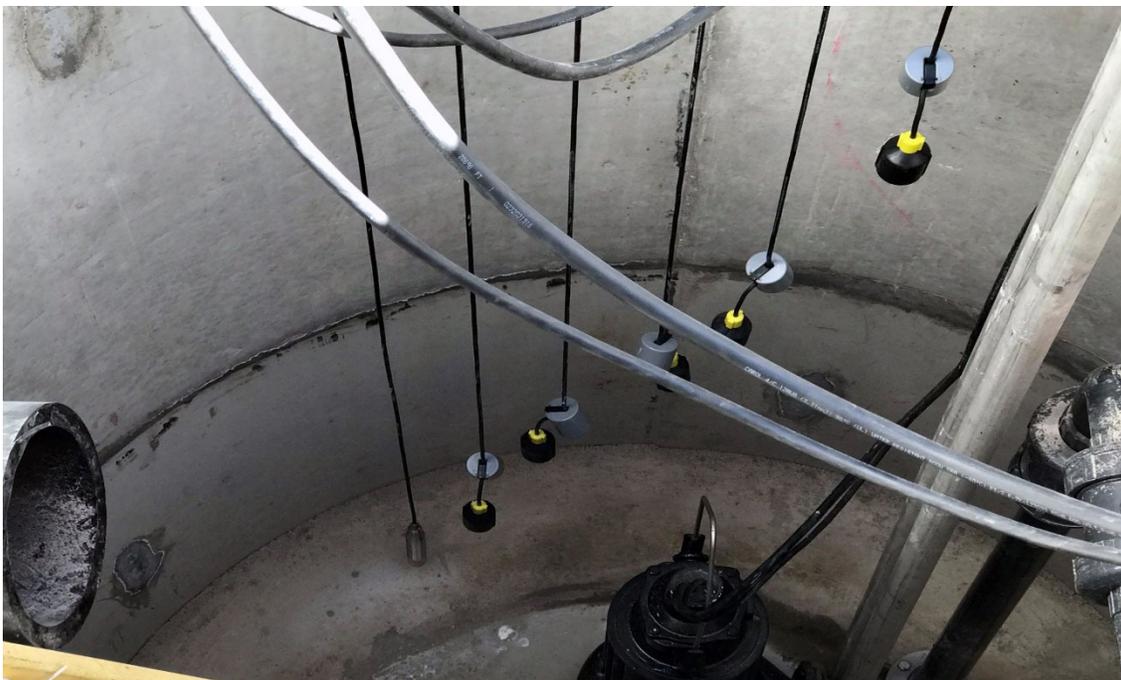
Lift station capacities range from 76 liters per minute (20 gallons per minute) to more than 378,500 liters per minute (100,000 gallons per minute).

Pre-fabricated lift stations generally have capacities of up to 38,000 liters per minute (10,000 gallons per minute).

Centrifugal pumps are commonly used in lift stations.



Top photo, Centrifugal pump is the most common wastewater lift station pump. Bottom photo, A trapped air column, or bubbler system, that senses pressure and level is commonly used for pump station control.



Other control alternatives include electrodes placed at cut-off levels, floats, mechanical clutches, and floating mercury switches.

A more sophisticated control operation involves the use of variable speed drives.

Lift stations are typically provided with equipment for easy pump removal. Floor access hatches or openings above the pump room and an overhead monorail beam, bridge crane, or portable hoist are commonly used.

The two most common types of lift stations are the dry-pit or dry-well and submersible lift stations. In dry-well lift stations, pumps and valves are housed in a pump room (dry pit or dry-well), that is easily accessible. The wet-well is a separate chamber attached or located adjacent to the dry-well (pump room) structure.

Submersible Lift Stations

Submersible lift stations do not have a separate pump room; the lift station header piping, associated valves, and flow meters are located in a separate dry vault at grade for easy access. Submersible lift stations include sealed pumps that operate submerged in the wet-well. These are removed to the surface periodically and reinstalled using guide rails and a hoist.



Prefabricated submersible lift station

A key advantage of dry-well lift stations is that they allow easy access for routine visual inspection and maintenance. In general, they are easier to repair than submersible pumps. An advantage of submersible lift stations is that they typically cost less than dry-well stations and operate without frequent pump maintenance.

Submersible lift stations do not usually include large aboveground structures and tend to blend in with their surrounding environment in residential areas. They require less space and are easier and less expensive to construct for wastewater flow capacities of 38,000 liters per minute (10,000 gallons per minute) or less.

Applicability

Lift stations are used to move wastewater from lower to higher elevation, particularly where the elevation of the source is not sufficient for gravity flow and/or when the use of gravity conveyance will result in excessive excavation depths and high sewer construction costs.

Current Status

Lift stations are widely used in wastewater conveyance systems. Dry-well lift stations have been used in the industry for many years. However, the current industry-wide trend is to replace drywell lift stations of small and medium size (typically less than 24,000 liters per minute or 6,350 gallons per minute) with submersible lift stations mainly because of lower costs, a smaller footprint, and simplified operation and maintenance.

Variable Speed Pumping

Variable speed pumping is often used to optimize pump performance and minimize power use. Several types of variable-speed pumping equipment are available, including variable voltage and frequency drives, eddy current couplings, and mechanical variable-speed drives.

Variable-speed pumping can reduce the size and cost of the wetwell and allows the pumps to operate at maximum efficiency under a variety of flow conditions. Because variable-speed pumping allows lift station discharge to match inflow, only nominal wet-well storage volume is required and the well water level is maintained at a near constant elevation.

Variable-speed pumping may allow a given flow range to be achieved with fewer pumps than a constant-speed alternative.

Variable-speed stations also minimize the number of pump starts and stops, reducing mechanical wear. Although there is significant energy saving potential for stations with large friction losses, it may not justify the additional capital costs unless the cost of power is relatively high.

Variable speed equipment also requires more room within the lift station and may produce more noise and heat than constant speed pumps.

Lift stations are complex facilities with many auxiliary systems. Therefore, they are less reliable than gravity wastewater conveyance. However, lift station reliability can be significantly improved by providing stand-by equipment (pumps and controls) and emergency power supply systems. In addition, lift station reliability is improved by using non-clog pumps suitable for the particular wastewater quality and by applying emergency alarm and automatic control systems.

Advantages and Disadvantages

Advantages

Lift stations are used to reduce the capital cost of sewer system construction. When gravity sewers are installed in trenches deeper than three meters (10 feet), the cost of sewer line installation increases significantly because of the more complex and costly excavation equipment and trench shoring techniques required. The size of the gravity sewer lines is dependent on the minimum pipe slope and flow. Pumping wastewater can convey the same flow using smaller pipeline size at shallower depth, and thereby, reducing pipeline costs.

Disadvantages

Compared to sewer lines where gravity drives wastewater flow, lift stations require a source of electric power. If the power supply is interrupted, flow conveyance is discontinued and can result in flooding upstream of the lift station. It can also interrupt the normal operation of the downstream wastewater conveyance and treatment facilities. This limitation is typically addressed by providing an emergency power supply.

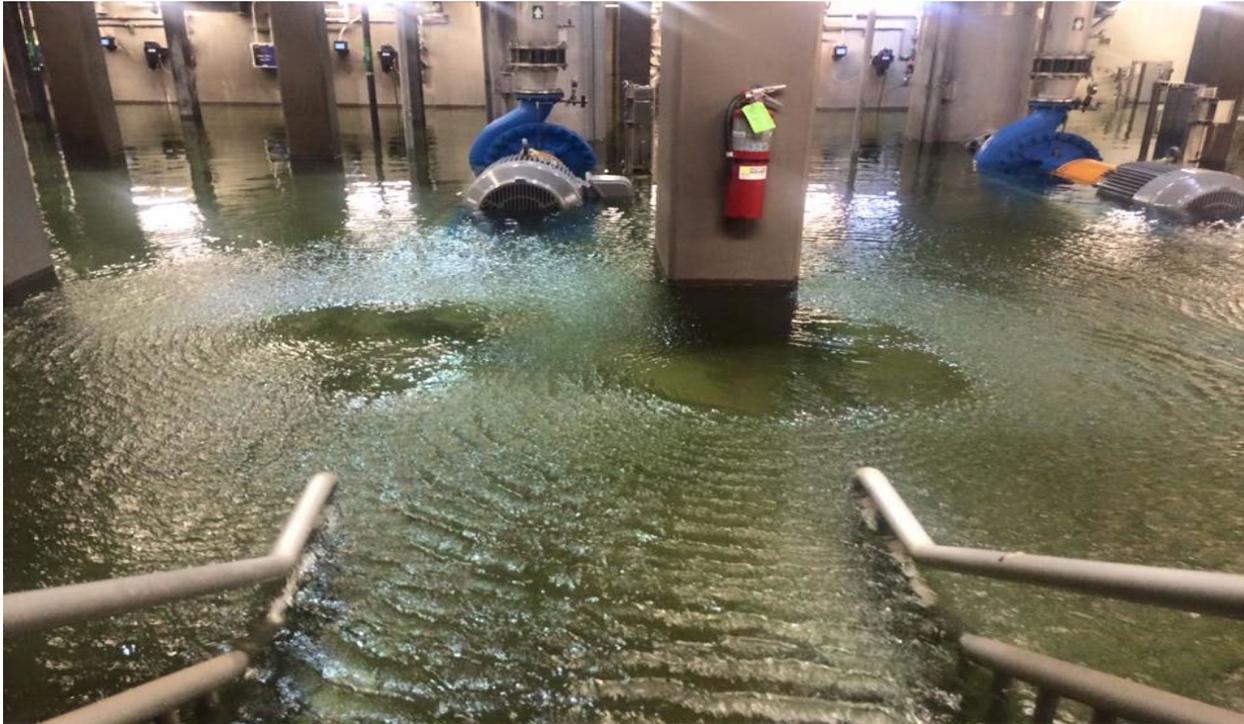
Key disadvantages of lift stations include the high cost to construct and maintain and the potential for odors and noise. Lift stations also require a significant amount of power, are sometimes expensive to upgrade, and may create public concerns and negative public reaction. The low cost of gravity wastewater conveyance and the higher costs of building, operating, and maintaining lift stations means that wastewater pumping should be avoided, if possible and technically feasible.

Wastewater pumping can be eliminated or reduced by selecting alternative sewer routes or extending a gravity sewer using direction drilling or other state-of-the-art deep excavation methods. If such alternatives are viable, a cost benefit analysis can determine if a lift station is the most viable choice.

Design Criteria

Cost effective lift stations are designed to:

- (1) match pump capacity, type, and configuration with wastewater quantity and quality;
- (2) provide reliable and uninterrupted operation;
- (3) allow for easy operation and maintenance of the installed equipment;
- (4) accommodate future capacity expansion;
- (5) avoid septic conditions and excessive release of odors in the collection system and at the lift station;
- (6) minimize environmental and landscape impacts on the surrounding residential and commercial developments; and
- (7) avoid flooding of the lift station and the surrounding areas.



Flooded pump station

The minimum recommended wet-well bottom slope is to 2:1 to allow self-cleaning and minimum deposit of debris. Effective volume of the wet-well may include sewer pipelines, especially when variable speed drives are used. Wet-wells should always hold some level of sewage to minimize odor release. Bar screens or grinders are often installed in or upstream of the wet-well to minimize pump clogging problems.

Wet Well/Dry Well Introduction

Wet-well

Wet-well design depends on the type of lift station configuration (submersible or dry-well) and the type of pump controls (constant or variable speed). Wet-wells are typically designed large enough to prevent rapid pump cycling but small enough to prevent a long detention time and associated odor release.



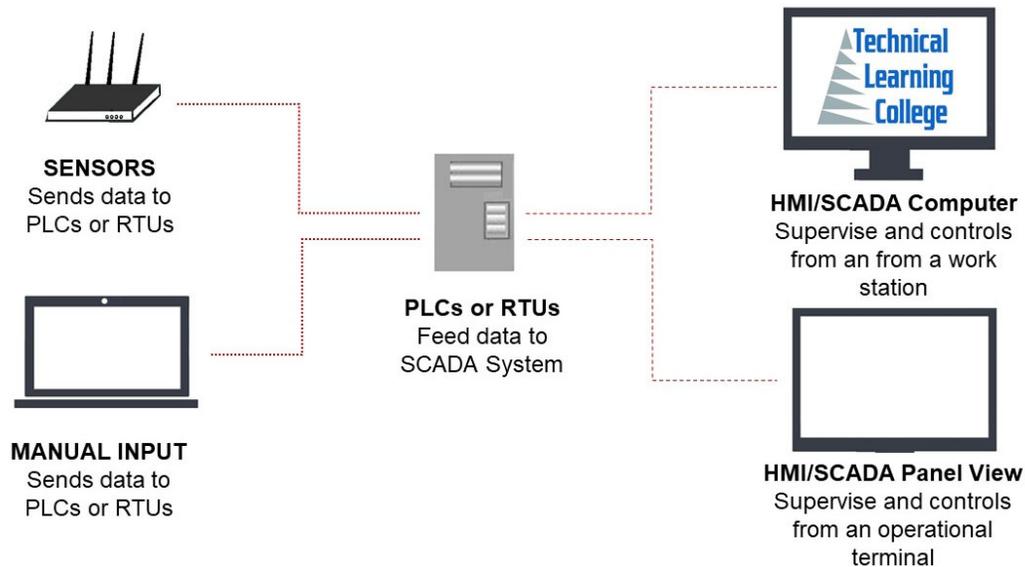
Wet-well maximum detention time in constant speed pumps is typically 20 to 30 minutes. Use of variable frequency drives for pump speed control allows wet-well detention time reduction to 5 to 15 minutes.

A Lift Station typically contains 4 main Components:

- A wet well - usually 15+ ft. in depth and 8 ft. in diameter - that houses two submersible pumps (there are some stations with up to 5 submersibles) of varying horsepower, discharging piping and floats that operate the pumps and keep a set level in the well.
- A dry well that houses the piping and valves that prevent backflow in the station, and camlock connection used to bypass the submersibles in an emergency.
- An electrical panel houses control for the submersible pumps. It also houses the telemetry used to monitor and control the station remotely.
- A "Log Book" or "Station Book" which contains the records and maps of the Lift Station's area.

Sewer pipes are generally gravity driven. Wastewater flows slowly downhill until it reaches a certain low point. Then, pump or "lift" stations push the wastewater back uphill to a high point where gravity can once again take over the process.

Lift stations are used in sanitary sewer systems where water is accumulated in wet wells and then pumped to a higher elevation. They are generally designed to operate continuously to keep sewerage from backing up through the system. That means that most lift stations have a backup electrical supply in the event that normal power is disrupted.



BASIC SCADA DIAGRAM

Most Wastewater Collection systems will have installed radio/WIFI telemetry, or SCADA systems. The telemetry system is used to monitor and control pump stations via computer at the WW Collections facility.

This type of system gives up to the minute pump station status such as wet well level, pump performance, electrical power conditions, etc. This allows wastewater technicians to prevent wastewater spills and protect public health. Using telemetry, Operators have the ability to identify potential problems instantaneously and take the proper steps to rectify the situation before it becomes a public health risk.

Odor Control

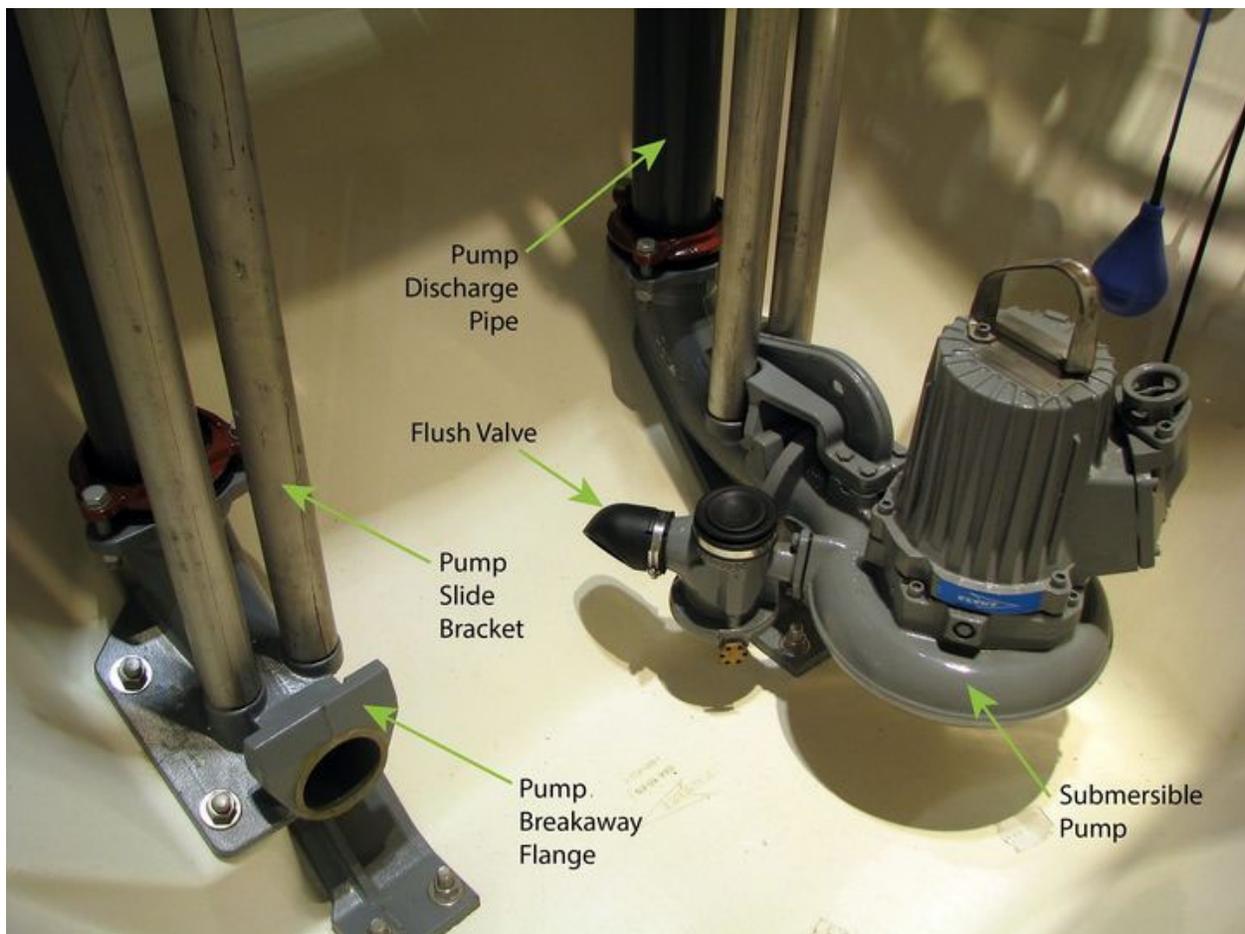
Odor control is frequently required for lift stations. A relatively simple and widely used odor control alternative is minimizing wet-well turbulence. More effective options include collection of odors generated at the lift station and treating them in scrubbers or biofilters or the addition of odor control chemicals to the sewer upstream of the lift station.

Chemicals typically used for odor control include chlorine, hydrogen peroxide, metal salts (ferric chloride and ferrous sulfate) oxygen, air, and potassium permanganate. Chemicals should be closely monitored to avoid affecting downstream treatment processes, such as extended aeration.

Wastewater Pumps- Introduction

The number of wastewater pumps and associated capacity should be selected to provide head capacity characteristics that correspond as nearly as possible to wastewater quantity fluctuations. This can be accomplished by preparing pump/pipeline system head-capacity curves showing all conditions of head (elevation of a free surface of water) and capacity under which the pumps will be required to operate.

The number of pumps to be installed in a lift station depends on the station capacity, the range of flow and the regulations. In small stations, with maximum inflows of less than 2,640 liters per minute (700 gallons per minute), two pumps are customarily installed, with each unit able to meet the maximum influent rate. For larger lift stations, the size and number of pumps should be selected so that the range of influent flow rates can be met without starting and stopping pumps too frequently and without excessive wet-well storage.



Depending on the system, the pumps are designed to run at a reduced rate. The pumps may also alternate to equalize wear and tear. Additional pumps may provide intermediate capacities better matched to typical daily flows. An alternative option is to provide flow flexibility with variable speed pumps.

For pump stations with high head-losses, the single pump flow approach is usually the most suitable.

Parallel pumping is not as effective for such stations because two pumps operating together yield only slightly higher flows than one pump. If the peak flow is to be achieved with multiple pumps in parallel, the lift station must be equipped with at least three pumps: two duty pumps that together provide peak flow and one standby pump for emergency backup.

Parallel peak pumping is typically used in large lift stations with relatively flat system head curves. Such curves allow multiple pumps to deliver substantially more flow than a single pump. The use of multiple pumps in parallel provides more flexibility.

Several types of centrifugal pumps are used in wastewater lift stations. In the straight-flow centrifugal pumps, wastewater does not change direction as it passes through the pumps and into the discharge pipe. These pumps are well suited for low-flow/high head conditions. In angle-flow pumps, wastewater enters the impeller axially and passes through the volute casing at 90 degrees to its original direction. This type of pump is appropriate for pumping against low or moderate heads.

Mixed flow pumps are most viable for pumping large quantities of wastewater at low head. In these pumps, the outside diameter of the impeller is less than an ordinary centrifugal pump, increasing flow volume.

Ventilation

Ventilation and heating are required if the lift station includes an area routinely entered by personnel. Ventilation is particularly important to prevent the collection of toxic and/or explosive gases. According to the Nation Fire Protection Association (NFPA) Section 820, all continuous ventilation systems should be fitted with flow detection devices connected to alarm systems to indicate ventilation system failure.

Dry-well ventilation codes typically require six continuous air changes per hour or 30 intermittent air changes per hour. Wet-wells typically require 12 continuous air changes per hour or 60 intermittent air changes per hour.

Motor control center (MCC) rooms should have a ventilation system adequate to provide six air changes per hour and should be air conditioned to between 13 and 32 degrees Celsius (55 to 90 degrees F).

If the control room is combined with an MCC room, the temperature should not exceed 30 degrees C or 85 degrees F.

All other spaces should be designed for 12 air changes per hour. The minimum temperature should be 13 degrees C (55 degrees F) whenever chemicals are stored or used.

Power Supply

The reliability of power for the pump motor drives is a basic design consideration. Commonly used methods of emergency power supply include electric power feed from two independent power distribution lines; an on-site standby generator; an adequate portable generator with quick connection; a stand-by engine driven pump; ready access to a suitable portable pumping unit and appropriate connections; and availability of an adequate holding facility for wastewater storage upstream of the lift station.

Performance Terms

The overall performance of a lift station depends on the performance of the pumps. All pumps have four common performance characteristics: capacity, head, power, and overall efficiency.

Capacity (flow rate) is the quantity of liquid pumped per unit of time, typically measured as gallons per minute (gpm) or million gallons per day (mgd).

Head is the energy supplied to the wastewater per unit weight, typically expressed as feet of water.

Power is the energy consumed by a pump per unit time, typically measured as kilowatt-hours.

Overall efficiency is the ratio of useful hydraulic work performed to actual work input. Efficiency reflects the pump relative power losses and is usually measured as a percentage of applied power.

Pump Performance Curves

Pump performance curves are used to define and compare the operating characteristics of a pump and to identify the best combination of performance characteristics under which a lift station pumping system will operate under typical conditions (flows and heads).

Pump systems operate at 75 to 85 percent efficiency most of the time, while overall pump efficiency depends on the type of installed pumps, their control system, and the fluctuation of influent wastewater flow.

Performance optimization strategies focus on different ways to match pump operational characteristics with system flow and head requirements. They may include the following options:

- a. adjusting system flow paths installing variable speed drives;
- b. using parallel pumps installing pumps of different sizes trimming a pump impeller;
- c. or putting a two-speed motor on one or more pumps in a lift station.

Optimizing system performance may yield significant electrical energy savings.

Common Hydraulic Terms

Head

The height of a column or body of fluid above a given point expressed in linear units. Head is often used to indicate gauge pressure. Pressure is equal to the height times the density of the liquid.

Head, Friction

The head required to overcome the friction at the interior surface of a conductor and between fluid particles in motion. It varies with flow, size, type, and conditions of conductors and fittings, and the fluid characteristics.

Head, Static

The height of a column or body of fluid above a given point.

Hydraulics

Engineering science pertaining to liquid pressure and flow.

Hydrokinetics

Engineering science pertaining to the energy of liquid flow and pressure.

Pascal's Law

A pressure applied to a confined fluid at rest is transmitted with equal intensity throughout the fluid.

Pressure

The application of continuous force by one body upon another that it is touching; compression. Force per unit area, usually expressed in pounds per square inch (Pascal or bar).

Pressure, Absolute

The pressure above zero absolute, i.e. the sum of atmospheric and gauge pressure. In vacuum related work it is usually expressed in millimeters of mercury. (mmHg).

Pressure, Atmospheric

Pressure exerted by the atmosphere at any specific location. (Sea level pressure is approximately 14.7 pounds per square inch absolute, 1 bar = 14.5psi.)

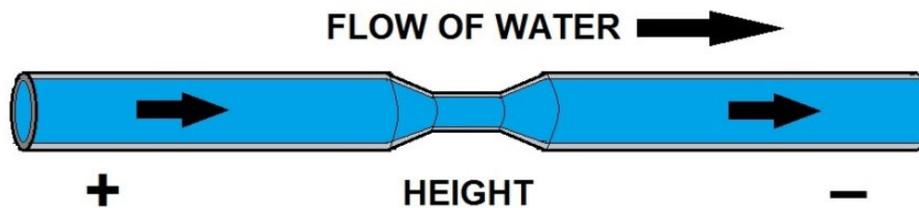
Pressure, Gauge

Pressure differential above or below ambient atmospheric pressure.

Pressure, Static

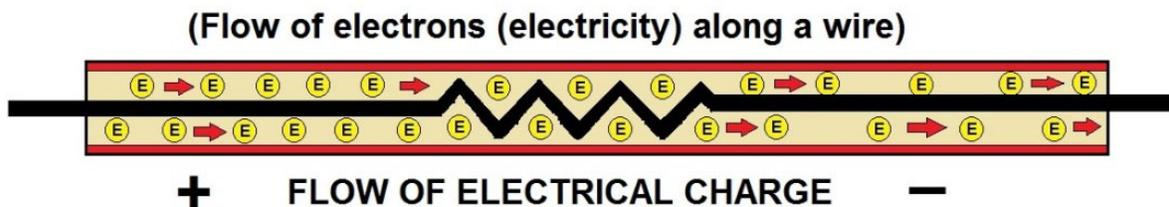
The pressure in a fluid at rest.

Hydraulic/Electrical Analogy Principles



Electricity flow can be compared to flow of water:

- When pressure is applied at one end of a pipe (or wire) then, water (or electricity) will come out the other end.

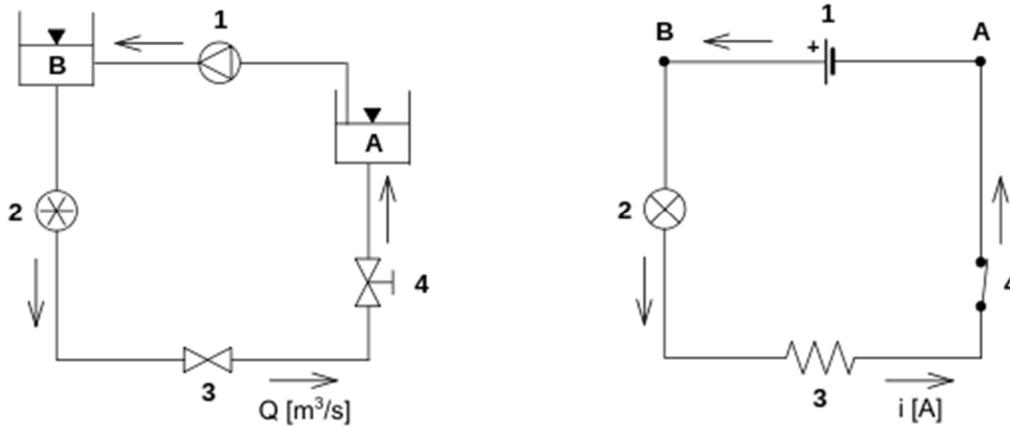


BASIC ELECTRICAL CONCEPT DIAGRAM

Water (Hydraulic) and Electrical Principles Are Very Similar

The electronic–**hydraulic analogy** (derisively referred to as the **drain-pipe theory** by Oliver Heaviside) is the most widely used analogy for "electron fluid" in a metal conductor. Since electric current is invisible and the processes at play in electronics are often difficult to demonstrate, the various electronic components are represented by hydraulic equivalents.

Electricity (as well as heat) was originally understood to be a kind of fluid, and the names of certain electric quantities (such as current) are derived from hydraulic equivalents. As all analogies, it demands an intuitive and competent understanding of the baseline paradigms (electronics and hydraulics).



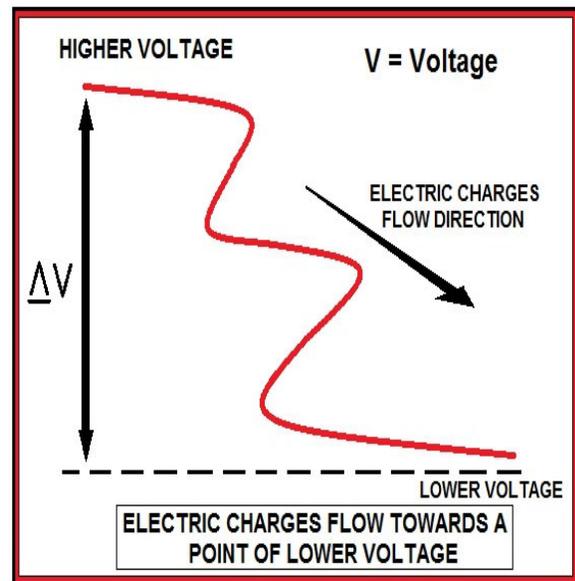
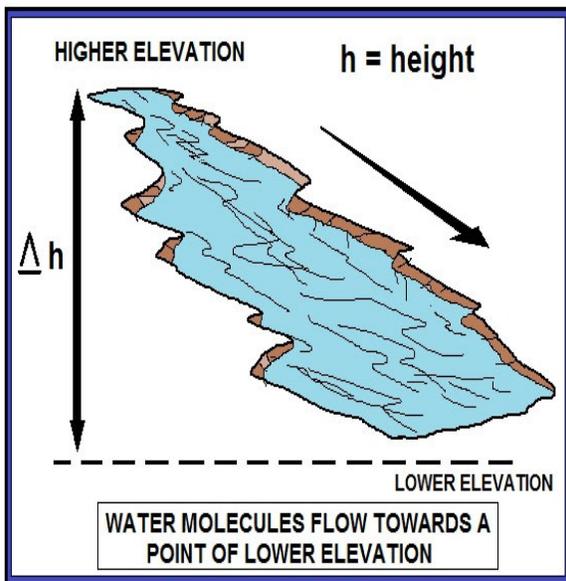
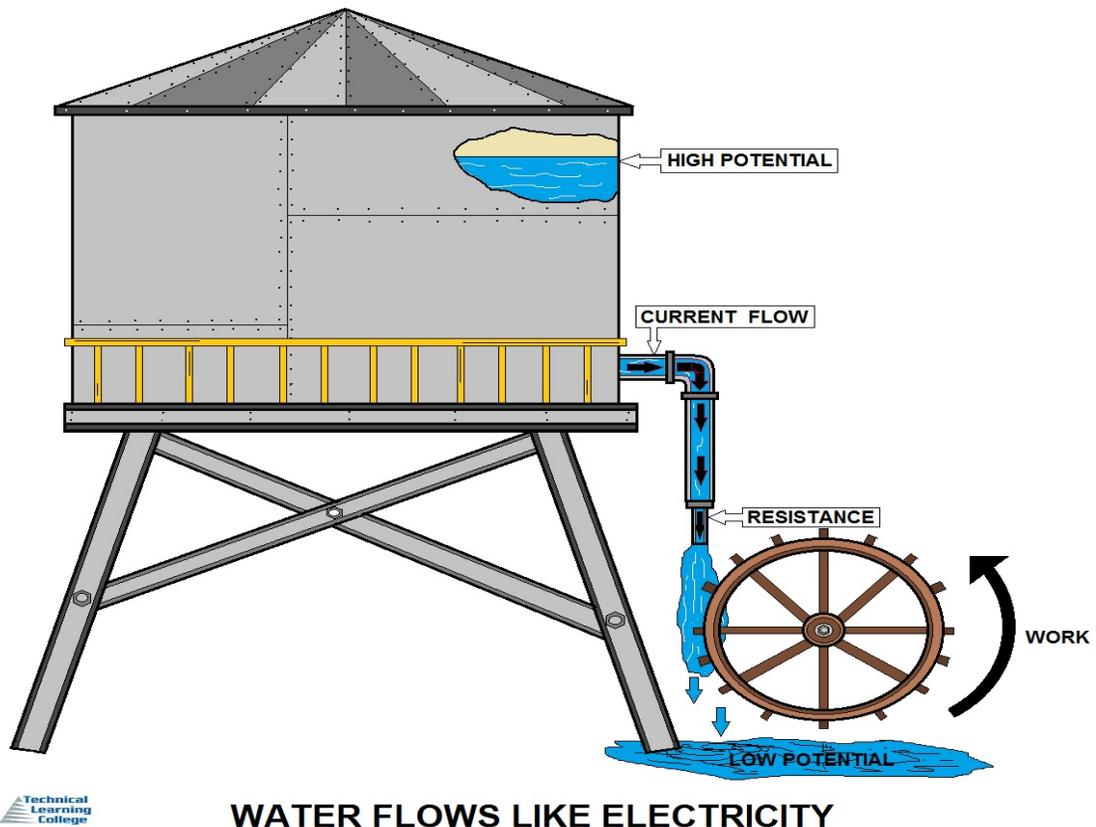
Analogy between a hydraulic circuit (left) and an electronic circuit (right).

Basic Hydraulic Ideas

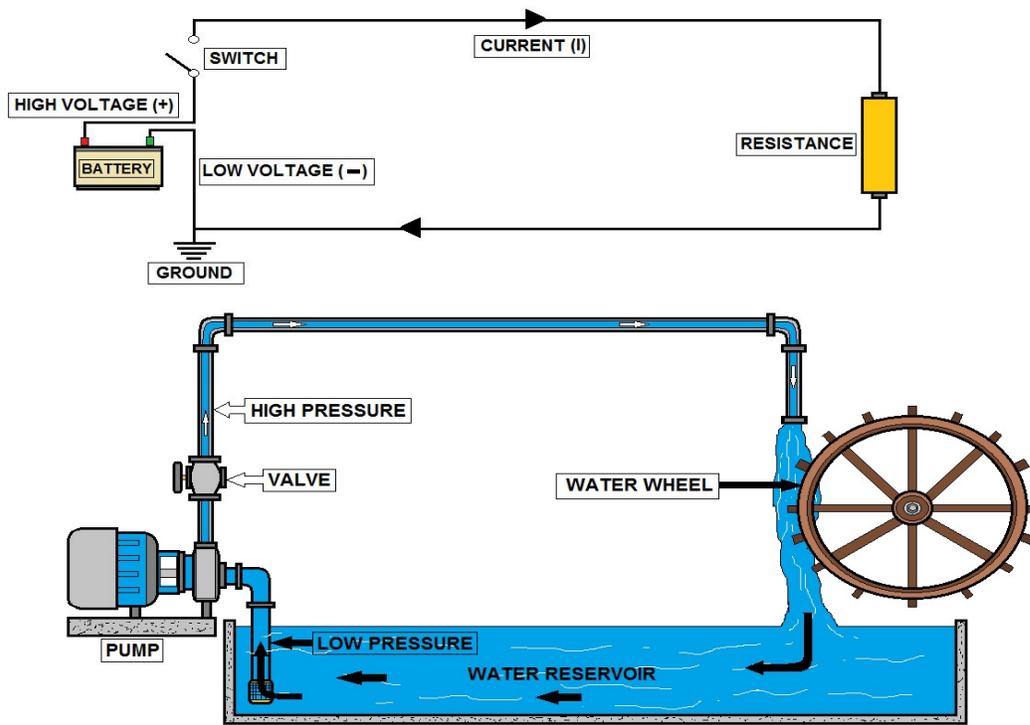
There are two basic paradigms:

- Version with pressure induced by gravity. Large tanks of water are held up high, or are filled to differing water levels, and the potential energy of the water head is the pressure source. This is reminiscent of electrical diagrams with an up arrow pointing to +V, grounded pins that otherwise are not shown connecting to anything, and so on.
- Completely enclosed version with pumps providing pressure only; no gravity. This is reminiscent of a circuit diagram with a voltage source shown and the wires actually completing a circuit.

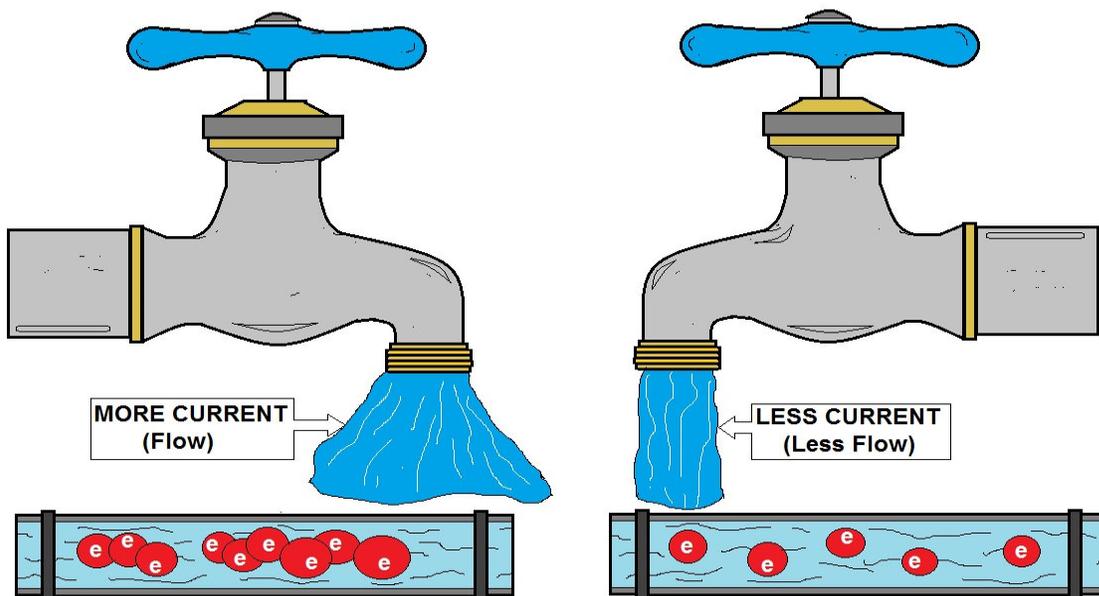
Applications: Flow and pressure variables can be calculated in fluid flow network with the use of the hydraulic ohm analogy. The method can be applied to both steady and transient flow situations.



WATER FLOWS LIKE ELECTRICITY EXAMPLE



EXAMPLE OF HOW WATER FLOWS SIMILAR TO ELECTRICITY



ELECTRIC CURRENT - WATER ANALOGY

Hydraulic Component Equivalents

Wires

A relatively wide pipe completely filled with water is equivalent to a piece of wire. When comparing to a piece of wire, the pipe should be thought of as having semi-permanent caps on the ends. Connecting one end of a wire to a circuit is equivalent to forcibly un-capping one end of the pipe and attaching it to another pipe. With few exceptions (such as a high-voltage power source), a wire with only one end attached to a circuit will do nothing; the pipe remains capped on the free end, and thus adds nothing to the circuit.

Electric potential

In general, it is equivalent to hydraulic head. In this article, it is assumed that the water is flowing horizontally, so that the force of gravity can be ignored, and then electric potential is equivalent to pressure.

Voltage

Also called voltage drop or *potential difference*. A difference in pressure between two points. Usually measured in volts.

Electric charge

Equivalent to a quantity of water.

Current

Equivalent to a hydraulic volume flow rate; that is, the volumetric quantity of flowing water over time. Usually measured in amperes.

Ideal voltage source, or ideal battery

A dynamic pump with feedback control. A pressure meter on both sides shows that regardless of the current being produced, this kind of pump produces constant pressure difference. If one terminal is kept fixed at ground, another analogy is a large body of water at a high elevation, sufficiently large that the drawn water does not affect the water level.

Ideal current source

A positive displacement pump. A current meter (little paddle wheel) shows that when this kind of pump is driven at a constant speed, it maintains a constant speed of the little paddle wheel.

Resistor

A constriction in the bore of the pipe which requires more pressure to pass the same amount of water. All pipes have some resistance to flow, just as all wires have some resistance to current.

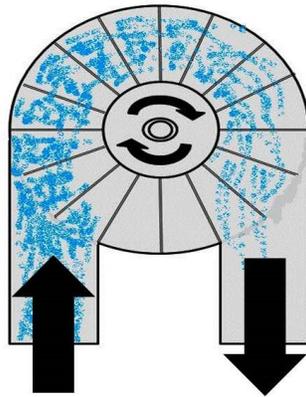
Capacitor

A tank with one connection at each end and a rubber sheet dividing the tank in two lengthwise (a hydraulic accumulator). When water is forced into one pipe, equal water is simultaneously forced out the other pipe, yet no water can penetrate the rubber diaphragm. Energy is stored by the stretching of the rubber. As more current flows "through" the capacitor, the back-pressure (voltage) becomes greater, thus current "leads" voltage in a capacitor. As the back-pressure from the stretched rubber approaches the applied pressure, the current becomes less and less. Thus capacitors "filter out" constant pressure differences and slowly varying, low-frequency pressure differences, while allowing rapid changes in pressure to pass through.

Note that the device described will pass all changes in pressure "through" equally well, regardless of rate of change, just as an electrical capacitor will. Any device in series must obey (electrical) Kirchhoff's Current Law, or its hydraulic equivalent. Considering the "filter" action, a better and more exact analogy is the hydraulic accumulator "pressure tank", as described, but with a closed, pressurized air bladder and only one water connection. Such accumulators are commonly used in hydraulic power systems exactly for the purpose of damping out pressure surges and "hammers" due to valves opening and closing.

Inductor

A heavy paddle wheel placed in the current. The mass of the wheel and the size of the blades restrict the water's ability to rapidly change its rate of flow (current) through the wheel due to the effects of inertia, but, given time, a constant flowing stream will pass mostly unimpeded through the wheel, as it turns at the same speed as the water flow. The mass and surface area of the wheel and its blades are analogous to inductance, and friction between its axle and the axle bearings corresponds to the resistance that accompanies any non-superconducting inductor.



TURBINE INDUCTOR PADDLE

Inductors are analogous to a heavy paddle wheel/turbine placed in the current.

An alternative inductor model is simply a long pipe, perhaps coiled into a spiral for convenience. This fluid-inertia device is used in real life as an essential component of a hydraulic ram. The inertia of the water flowing through the pipe produces the inductance effect; inductors "filter out" rapid changes in flow, while allowing slow variations in current to be passed through. The drag imposed by the walls of the pipe is somewhat analogous to parasitic resistance.

In either model, the pressure difference (voltage) across the device must be present before the current will start moving, thus in inductors voltage "leads" current. As the current increases, approaching the limits imposed by its own internal friction and of the current that the rest of the circuit can provide, the pressure drop across the device becomes lower and lower.

Diode

Equivalent to a one-way check valve with a slightly leaky valve seat. As with a diode, a small pressure difference is needed before the valve opens. And like a diode, too much reverse bias can damage or destroy the valve assembly.

Transistor

A valve in which a diaphragm, controlled by a low-current signal (either constant current for a BJT or constant pressure for a FET), moves a plunger which affects the current through another section of pipe.

CMOS

A combination of two MOSFET transistors. As the input pressure changes, the pistons allow the output to connect to either zero or positive pressure.

Memristor

A needle valve operated by a flow meter. As water flows through in the forward direction, the needle valve restricts flow more; as water flows the other direction, the needle valve opens further providing less resistance.

Hydraulic - Electrical Principle Equivalents**EM Wave Speed (velocity of propagation)**

Speed of sound in water. When a light switch is flipped, the electric wave travels very quickly through the wires.

Charge Flow Speed (drift velocity)

Particle speed of water. The moving charges themselves move rather slowly.

DC

Constant flow of water in a circuit of pipe.

Low Frequency AC

Water oscillating back and forth in a pipe.

Higher-Frequency AC and Transmission Lines

Sound being transmitted through the water pipes: Be aware that this does not properly mirror the cyclical reversal of alternating electric current. As described, the fluid flow conveys pressure fluctuations, but fluids "do not" reverse at high rates in hydraulic systems, which the above "low frequency" entry does accurately describe. A better concept (if sound waves are to be the phenomenon) is that of direct current with high-frequency "ripple" superimposed.

Inductive Spark

Used in induction coils, similar to water hammer, caused by the inertia of water.

Hydraulic Equation Examples

Some examples of equivalent electrical and hydraulic equations:

type	hydraulic	electric	thermal	mechanical
quantity	volume V [m ³]	charge q [C]	heat Q [J]	momentum P [Ns]
potential	pressure P [Pa=J/m ³]	potential ϕ [V=J/C]	temperature T [K=J/ k_B]	velocity v [m/s]
flux	Volumetric flow rate Φ_V [m ³ /s]	current I [A=C/s]	heat transfer rate \dot{Q} [J/s]	force F [N]
flux density	velocity v [m/s]	current density j [C/(m ² ·s) = A/m ²]	heat flux \dot{Q}'' [W/m ²]	stress σ [N/m ² = Pa]
linear model	Poiseuille's law $\Phi_V = \frac{\pi r^4}{8\eta} \frac{\Delta p^*}{\ell}$	Ohm's law $j = -\sigma \nabla \phi$	Fourier's law $\dot{Q}'' = \kappa \nabla T$	Dashpot $\sigma = c \Delta v$

If the differential equations have the same form, the response will be similar.

Limits to the Hydraulic Analogy

If taken too far, the water analogy can create misconceptions. For it to be useful, we must remain aware of the regions where electricity and water behave very differently.

Fields (Maxwell equations, Inductance)

Electrons can push or pull other distant electrons via their fields, while water molecules experience forces only from direct contact with other molecules. For this reason, waves in water travel at the speed of sound, but waves in a sea of charge will travel much faster as the forces from one electron are applied to many distant electrons and not to only the neighbors in direct contact. In a hydraulic transmission line, the energy flows as mechanical waves through the water, but in an electric transmission line the energy flows as fields in the space surrounding the wires, and does not flow inside the metal. Also, an accelerating electron will drag its neighbors along while attracting them, both because of magnetic forces.

Charge

Unlike water, movable charge carriers can be positive or negative, and conductors can exhibit an overall positive or negative net charge. The mobile carriers in electric currents are usually electrons, but sometimes they are charged positively, such as H^+ ions in proton conductors or holes in p-type semiconductors and some (very rare) conductors.

Leaking Pipes

The electric charge of an electrical circuit and its elements is usually almost equal to zero, hence it is (almost) constant. This is formalized in Kirchoff's current law, which does not have an analogy to hydraulic systems, where amount of the liquid is not usually constant. Even with incompressible liquid the system may contain such elements as pistons and open pools, so the volume of liquid contained in a part of the system can change. For this reason, continuing electric currents require closed loops rather than hydraulics' open source/sink resembling spigots and buckets.

James Thurber spoke of his maternal grandmother thus:

She came naturally by her confused and groundless fears, for her own mother lived the latter years of her life in the horrible suspicion that electricity was dripping invisibly all over the house. - My Life and Hard Times (1933).

Fluid Velocity and Resistance of Metals

As with water hoses, the carrier drift velocity in conductors is directly proportional to current. However, water only experiences drag via the pipes' inner surface, while charges are slowed at all points within a metal. Also, typical velocity of charge carriers within a conductor is less than centimeters per minute, and the "electrical friction" is extremely high. If charges ever flowed as fast as water can flow in pipes, the electric current would be immense, and the conductors would become incandescently hot and perhaps vaporize.

To model the resistance and the charge-velocity of metals, perhaps a pipe packed with sponge, or a narrow straw filled with syrup, would be a better analogy than a large-diameter water pipe. Resistance in most electrical conductors is a linear function: as current increases, voltage drop increases proportionally (Ohm's Law). Liquid resistance in pipes is not linear with volume, varying as the square of volumetric flow (see Darcy–Weisbach equation).

Quantum Mechanics

Conductors and insulators contain charges at more than one discrete level of atomic orbit energy, while the water in one region of a pipe can only have a single value of pressure. For this reason there is no hydraulic explanation for such things as a battery's charge pumping ability, a diode's voltage drop, solar cell functions, Peltier effect, etc., however equivalent devices can be designed which exhibit similar responses, although some of the mechanisms would only serve to regulate the flow curves rather than to contribute to the component's primary function.

Usefulness requires that the reader or student has a substantial understanding of the model (hydraulic) system's principles. It also requires that the principles can be transferred to the target (electrical) system. Hydraulic systems are deceptively simple: the phenomenon of pump cavitation is a known, complex problem that few people outside of the fluid power or irrigation industries would understand. For those who do, the hydraulic analogy is amusing, as no "cavitation" equivalent exists in electrical engineering. The hydraulic analogy can give a mistaken sense of understanding that will be exposed once a detailed description of electrical circuit theory is required.

One must also consider the difficulties in trying to make the analogy work. The above "electrical friction" example, where the hydraulic analog is a pipe filled with sponge material, illustrates the problem: the model must be increased in complexity beyond any realistic scenario.

Electrical Measurements and Equipment

Molecule of liquid → electron of electricity

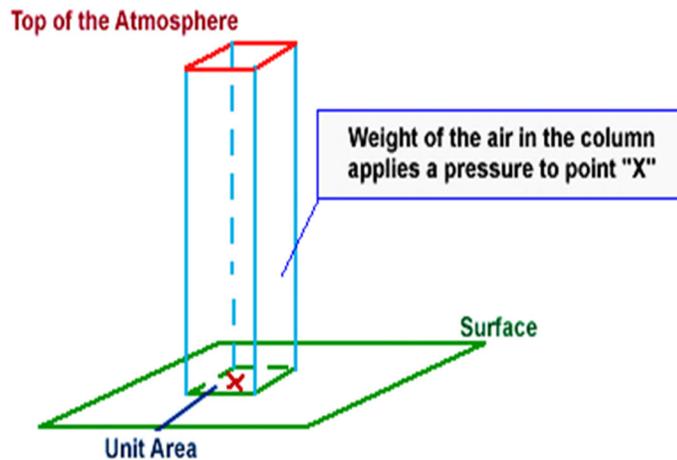
Flow rate (gpm) → current (ampere) I, A

Pressure (psi) → potential (V)

Pressure drop → voltage drop

Pump → generator

Fluid/Hydraulic Forces & Pressures Introduction



In the diagram, the pressure at point "X" increases as the weight of the air above it increases. The same can be said about decreasing pressure, where the pressure at point "X" decreases if the weight of the air above it also decreases.

Atmospheric Pressure

The atmosphere is the entire mass of air that surrounds the earth. While it extends upward for about 300 miles, the section of primary interest is the portion that rests on the earth's surface and extends upward for about 7 1/2 miles. This layer is called the troposphere.

If a column of air 1-inch square extending all the way to the "top" of the atmosphere could be weighed, this column of air would weigh approximately 14.7 pounds at sea level. Thus, atmospheric pressure at sea level is approximately 14.7 psi.

As one ascends, the atmospheric pressure decreases by approximately 1.0 psi for every 2,343 feet. However, below sea level, in excavations and depressions, atmospheric pressure increases. Pressures under water differ from those under air because the weight of the water must be added to the pressure of the air.

Atmospheric pressure can be measured by any of several methods. The common laboratory method uses the mercury column barometer. The height of the mercury column serves as an indicator of atmospheric pressure. At sea level and at a temperature of 0° Celsius (C), the height of the mercury column is approximately 30 inches, or 76 centimeters. This represents a pressure of approximately 14.7 psi. The 30-inch column is used as a reference standard.

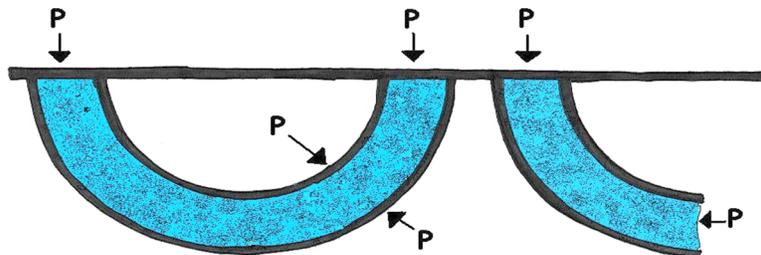
Another device used to measure atmospheric pressure is the aneroid barometer. The aneroid barometer uses the change in shape of an evacuated metal cell to measure variations in atmospheric pressure. The thin metal of the aneroid cell moves in or out with the variation of pressure on its external surface. This movement is transmitted through a system of levers to a pointer, which indicates the pressure.

The atmospheric pressure does not vary uniformly with altitude. It changes very rapidly. Atmospheric pressure is defined as the force per unit area exerted against a surface by the weight of the air above that surface.

Fluid and Pressure

By a fluid, we have a material in mind like water or air, two very common and important fluids. Water is incompressible, while air is very compressible, but both are fluids. Water has a definite volume; air does not. Water and air have low viscosity; that is, layers of them slide very easily on one another, and they quickly change their shapes when disturbed by rapid flows.

Other fluids, such as molasses, may have high viscosity and take a long time to come to equilibrium, but they are no less fluids. The coefficient of viscosity is the ratio of the shearing force to the velocity gradient. Hydrostatics deals with permanent, time-independent states of fluids, so viscosity does not appear.



EQUALITY OF PRESSURE –CURTIAN RINGS DIAGRAM

Pressure Definition

A fluid, therefore, is a substance that cannot exert any permanent forces tangential to a boundary. Any force that it exerts on a boundary must be normal perpendicular to the boundary. Such a force is proportional to the area on which it is exerted, and is called a pressure.

We can imagine any surface in a fluid as dividing the fluid into parts pressing on each other, as if it were a thin material membrane, and so think of the pressure at any point in the fluid, not just at the boundaries.

In order for any small element of the fluid to be in equilibrium, the pressure must be the same in all directions (or the element would move in the direction of least pressure), and if no other forces are acting on the body of the fluid, the pressure must be the same at all neighboring points.

Pascal's Principle

Therefore, in this case the pressure will be the same throughout the fluid, and the same in any direction at a point (Pascal's Principle). Pressure is expressed in units of force per unit area such as dyne/cm², N/cm² (pascal), pounds/in² (psi) or pounds/ft² (psf). The axiom that if a certain volume of fluid were somehow made solid, the equilibrium of forces would not be disturbed, is useful in reasoning about forces in fluids.

Equality of Pressure

On earth, fluids are also subject to the force of gravity, which acts vertically downward, and has a magnitude $\gamma = \rho g$ per unit volume, where g is the acceleration of gravity, approximately 981 cm/s² or 32.15 ft/s², ρ is the density, the mass per unit volume, expressed in g/cm³, kg/m³, or slug/ft³, and γ is the specific weight, measured in lb/in³, or lb/ft³ (pcf).

Atmospheric Pressure and its Effects

Suppose a vertical pipe is stood in a pool of water, and a vacuum pump applied to the upper end. Before we start the pump, the water levels outside and inside the pipe are equal, and the pressures on the surfaces are also equal and are equal to the atmospheric pressure.

Now start the pump. When it has sucked all the air out above the water, the pressure on the surface of the water inside the pipe is zero, and the pressure at the level of the water on the outside of the pipe is still the atmospheric pressure. There is the vapor pressure of the water to worry about if you want to be precise, but we neglect this complication in making our point.

A column of water 33.9 ft. high inside the pipe, with a vacuum above it, to balance the atmospheric pressure is required. If you were to do the same thing with liquid mercury, whose density at 0 °C is 13.5951 times that of water. The height of the column is 2.494 ft., 29.92 in, or 760.0 mm.

Standard Atmospheric Pressure

This definition of the standard atmospheric pressure was established by Regnault back in the mid-19th century. In Great Britain, 30 in. Hg (inches of mercury) had been used previously. As a real-world matter, it is convenient to measure pressure differences by measuring the height of liquid columns, a practice known as manometry.

The barometer is a familiar example of this, and atmospheric pressures are traditionally given in terms of the length of a mercury column. To make a barometer, the barometric tube, closed at one end, is filled with mercury and then inverted and placed in a mercury reservoir.

Corrections must be made for temperature, because the density of mercury depends on the temperature, and the brass scale expands for capillarity if the tube is less than about 1 cm in diameter, and even slightly for altitude, since the value of g changes with altitude.

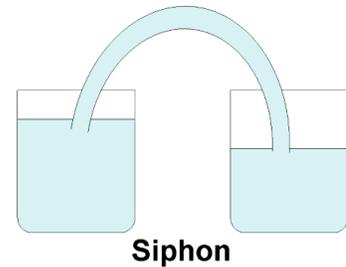
The vapor pressure of mercury is only 0.001201 mmHg at 20°C, so a correction from this source is negligible. For the usual case of a mercury column ($\alpha = 0.000181792$ per °C) and a brass scale ($\alpha = 0.0000184$ per °C) the temperature correction is -2.74 mm at 760 mm and 20°C.

Before reading the barometer scale, the mercury reservoir is raised or lowered until the surface of the mercury just touches a reference point, which is mirrored in the surface so it is easy to determine the proper position.

An aneroid barometer uses a partially evacuated chamber of thin metal that expands and contracts according to the external pressure. This movement is communicated to a needle that revolves in a dial. The materials and construction are arranged to give a low temperature coefficient. The instrument must be calibrated before use, and is usually arranged to read directly in elevations.

An aneroid barometer is much easier to use in field observations, such as in reconnaissance surveys. In a particular case, it would be read at the start of the day at the base camp, at various points in the vicinity, and then finally at the starting point, to determine the change in pressure with time.

The height differences can be calculated from $h = 60,360 \log (P/p) [1 + (T + t - 64)/986]$ feet, where P and p are in the same units, and T, t are in °F.



An absolute pressure is referring to a vacuum, while a gauge pressure is referring to the atmospheric pressure at the moment.

A negative gauge pressure is a partial vacuum. When a vacuum is stated to be so many inches, this means the pressure below the atmospheric pressure of about 30 in.

A vacuum of 25 inches is the same thing as an absolute pressure of 5 inches (of mercury).

Vacuum

The term *vacuum* indicates that the absolute pressure is less than the atmospheric pressure and that the gauge pressure is negative.

A complete or total vacuum would mean a pressure of 0 psia or -14.7 psig.

Since it is impossible to produce a total vacuum, the term vacuum, as used in this document, will mean all degrees of partial vacuum.

In a partial vacuum, the pressure would range from slightly less than 14.7 psia (0 psig) to slightly greater than 0 psia (-14.7 psig).

Again, backsiphonage results from atmospheric pressure exerted on a liquid, forcing it toward a supply system that is under a vacuum.

Barometric Loop

The barometric loop consists of a continuous section of supply piping that rises to a height of approximately 35 feet and then returns back down to the originating level. It is a loop in the piping system that effectively protects against backsiphonage. It may not be used to protect against backpressure. Backpressure refers to pressure opposed to the desired flow of a fluid in a confined place such as a pipe. It is often caused by obstructions or tight bends in the confinement vessel along which it is moving, such as piping or air vents.

The barometric loop's operation, in the protection against backsiphonage, is based upon the principle that a water column, at sea level pressure, will not rise above 33.9 feet.

Generally speaking, barometric loops are locally fabricated, and are 35 feet high.

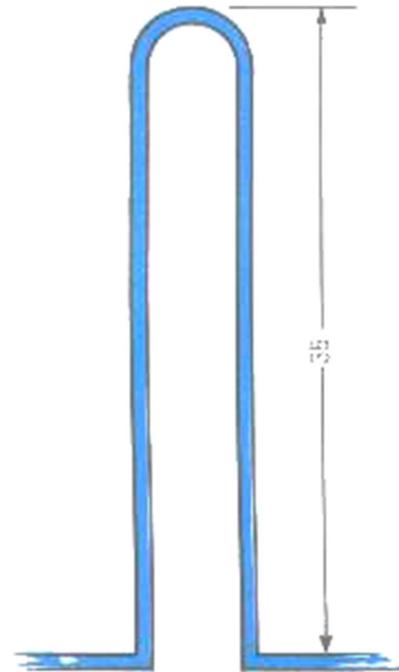
Pressure may be referred to using an absolute scale, pounds per square inch absolute (psia), or gauge scale, (psiag). Absolute pressure and gauge pressure are related.

Absolute pressure is equal to gauge pressure plus the atmospheric pressure.

At sea level, the atmospheric pressure is 14.7 psia.

Absolute pressure is the total pressure.

Gauge pressure is simply the pressure read on the gauge. If there is no pressure on the gauge other than atmospheric, the gauge will read zero. Then the absolute pressure would be equal to 14.7 psi, which is the atmospheric pressure.

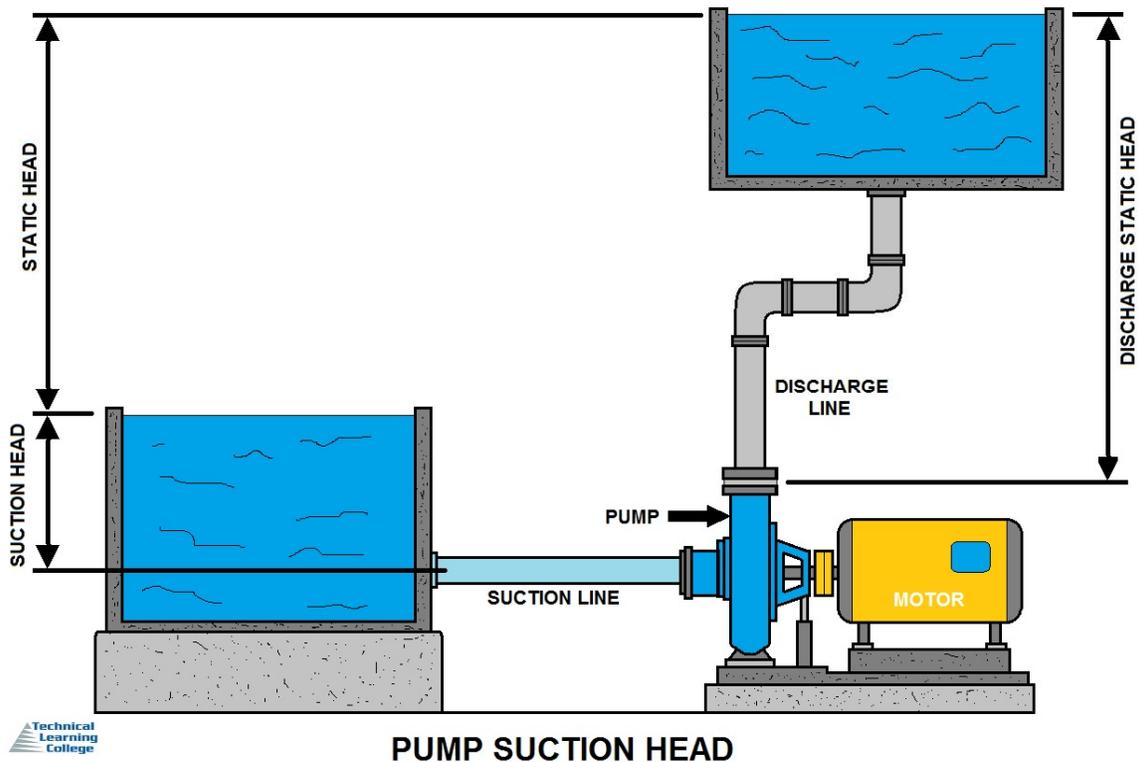


Barometric Pressure

Generally speaking, barometric pressure, or atmospheric pressure, drops as you go up in elevation. For example, at 18,000 ft. above sea level, the average barometric pressure is about half the average pressure at sea level.

Barometric pressure also varies widely with the weather (weather charts almost always show the movement of low pressure and high pressure zones), so true barometric pressure cannot simply be calculated, but must be measured.

In the United States, the National Oceanic and Atmospheric Administration provides hourly barometric readings for many locations across the country.



Pump Suction Head

A **pump's suction head** is similar to its **pump head** except it is the opposite. Rather than being a measure of the maximum discharge, it is a measure of the maximum depth from which a **pump** can raise water via **suction**.

Water Head Pressure

Water head pressure is static pressure caused by the weight of water solely due to its height above the measuring point. The pressure at the bottom of a 30-foot deep lake or a 30-foot high thin tube would be identical, since only height is involved.

The value may be expressed as pounds-per-square-inch (psi) or inches-of-water column pressure or metric. This basic calculation is widely used to solve many different practical problems involving water and other liquids of known density.

Water Head Pressure Calculation

Divide the depth in inches by **27.71-inches/psi**, or the depth in feet by **2.31-feet/psi**, which are the conversion factors. The result is the water head pressure expressed in psi.

We will cover this area (pressure) in more detail later in the course.

Pressure Sub-Section

Water Pressure

The weight of a cubic foot of water is 62.4 pounds per square foot. The base can be subdivided into 144-square inches with each subdivision being subjected to a pressure of 0.433 psig. Suppose you placed another cubic foot of water on top of the first cubic foot. The pressure on the top surface of the first cube which was originally atmospheric, or 0 psig, would now be 0.4333 psig as a result of the additional cubic foot of water. The pressure of the base of the first cubic foot would be increased by the same amount of 0.866 psig or two times the original pressure.

Pressures are very frequently stated in terms of the height of a fluid. If it is the same fluid whose pressure is being given, it is usually called "head," and the factor connecting the head and the pressure is the weight density ρg .

In the English engineering system, weight density is in pounds per cubic inch or cubic foot.

A head of 10 ft is equivalent to a pressure of 624 psf, or 4.33 psi. It can also be considered an energy availability of ft-lb per lb.

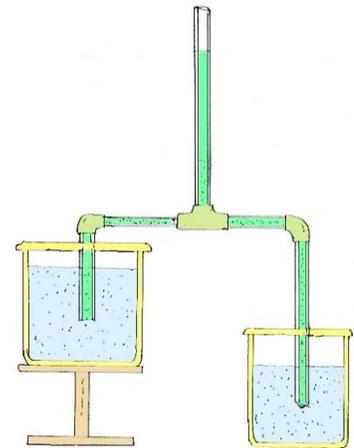
Water with a pressure head of 10 ft can furnish the same energy as an equal amount of water raised by 10 ft. Water flowing in a pipe is subject to head loss because of friction.

Take a jar and a basin of water. Fill the jar with water and invert it under the water in the basin. Raise the jar as far as you can without allowing its mouth to come above the water surface. It is always a little surprising to see that the jar does not empty itself, but the water remains with no visible means of support.

By blowing through a straw, one can put air into the jar, and as much water leaves as air enters. In fact, this is a famous method of collecting insoluble gases in the chemical laboratory, or for supplying hummingbird feeders. It is good to remind oneself of exactly the balance of forces involved.

Another application of pressure is the siphon. The name is Greek for the tube that was used for pulling wine from a cask. This is a tube filled with fluid connecting two containers of fluid, normally rising higher than the water levels in the two containers, at least to pass over their rims.

In the diagram on the right side, the two water levels are the same, so there will be no flow. When a siphon goes below the free water levels, it is called an inverted siphon.



PASCAL'S SIPHON

If the levels in the two basins are not equal, fluid flows from the basin with the higher level into the one with the lower level, until the levels are equal.

A siphon can be made by filling the tube, closing the ends, and then putting the ends under the surface on both sides.

Alternatively, the tube can be placed in one fluid and filled by sucking on it. When it is full, the other end is put in place.

The examination of the siphon is easy, and should be obvious. The pressure rises or falls as described by the barometric equation through the siphon tube.

There is obviously a maximum height for the siphon which is the same as the limit of the suction pump, about 34 feet. Inverted siphons are sometimes used in pipelines to cross valleys.

Differences in elevation are usually too great to use regular siphons to cross hills, so the fluids must be pressurized by pumps so the pressure does not fall to zero at the crests.

Liquids at Rest

In studying fluids at rest, we are concerned with the transmission of force and the factors which affect the forces in liquids. Furthermore, pressure in and on liquids and factors affecting pressure are of great importance.

Pressure and Force

Pressure is the force that pushes water through pipes. Water pressure determines the flow of water from the tap. If pressure is not sufficient then the flow can reduce to a trickle and it will take a long time to fill a kettle or a cistern.

The terms **force** and **pressure** are used extensively in the study of fluid power. It is essential that we distinguish between the terms.

Force means a total push or pull. It is the push or pull exerted against the total area of a particular surface and is expressed in pounds or grams.

Pressure means the amount of push or pull (force) applied to each unit area of the surface and is expressed in pounds per square inch (lb/in²) or grams per square centimeter (gm/cm²).

Pressure maybe exerted in one direction, in several directions, or in all directions.

Other Pressure Terms and Conditions

Everyday pressure measurements, such as for vehicle tire pressure, are usually made relative to ambient air pressure. In other cases measurements are made relative to a vacuum or to some other specific reference. When distinguishing between these zero references, the following terms are used:

- **Absolute pressure** is zero-referenced against a perfect vacuum, using an absolute scale, so it is equal to gauge pressure plus atmospheric pressure.
- **Gauge pressure** is zero-referenced against ambient air pressure, so it is equal to absolute pressure minus atmospheric pressure. Negative signs are usually omitted. To distinguish a negative pressure, the value may be appended with the word "vacuum" or the gauge may be labeled a "vacuum gauge". These are further divided into two subcategories: high and low vacuum (and sometimes ultra-high vacuum). The applicable pressure ranges of many of the techniques used to measure vacuums have an overlap. Hence, by combining several different types of gauge, it is possible to measure system pressure continuously from 10 mbar down to 10⁻¹¹ mbar.
- **Differential pressure** is the difference in pressure between two points.

For most working fluids where a fluid exists in a closed system, gauge pressure measurement prevails. Pressure instruments connected to the system will indicate pressures relative to the current atmospheric pressure. The situation changes when extreme vacuum pressures are measured, then absolute pressures are typically used instead.

Differential pressures are commonly used in industrial process systems. Differential pressure gauges have two inlet ports, each connected to one of the volumes whose pressure is to be monitored. In effect, such a gauge performs the mathematical operation of subtraction through mechanical means, obviating the need for an operator or control system to watch two separate gauges and determine the difference in readings.

Moderate vacuum pressure readings can be ambiguous without the proper context, as they may represent absolute pressure or gauge pressure without a negative sign. Thus a vacuum of 26 inHg gauge is equivalent to an absolute pressure of 4 inHg, calculated as 30 inHg (typical atmospheric pressure) – 26 inHg (gauge pressure).

Atmospheric pressure is typically about 100 kPa at sea level, but is variable with altitude and weather. If the absolute pressure of a fluid stays constant, the gauge pressure of the same fluid will vary as atmospheric pressure changes.

For example, when a car drives up a mountain, the (gauge) tire pressure goes up because atmospheric pressure goes down. The absolute pressure in the tire is essentially unchanged.

Using atmospheric pressure as reference is usually signified by a "g" for gauge after the pressure unit, e.g. 70 psig, which means that the pressure measured is the total pressure minus atmospheric pressure. There are two types of gauge reference pressure: vented gauge (vg) and sealed gauge (sg).

Gravitation

Gravitation is an example of a body force that disturbs the equality of pressure in a fluid. The presence of the gravitational body force causes the pressure to increase with depth, according to the equation $dp = \rho g dh$, in order to support the water above.

We call this relation the barometric equation, for when this equation is integrated, we find the variation of pressure with height or depth. If the fluid is incompressible, the equation can be integrated at once, and the pressure as a function of depth h is $p = \rho gh + p_0$.

The density of water is about 1 g/cm^3 , or its specific weight is 62.4 pcf.

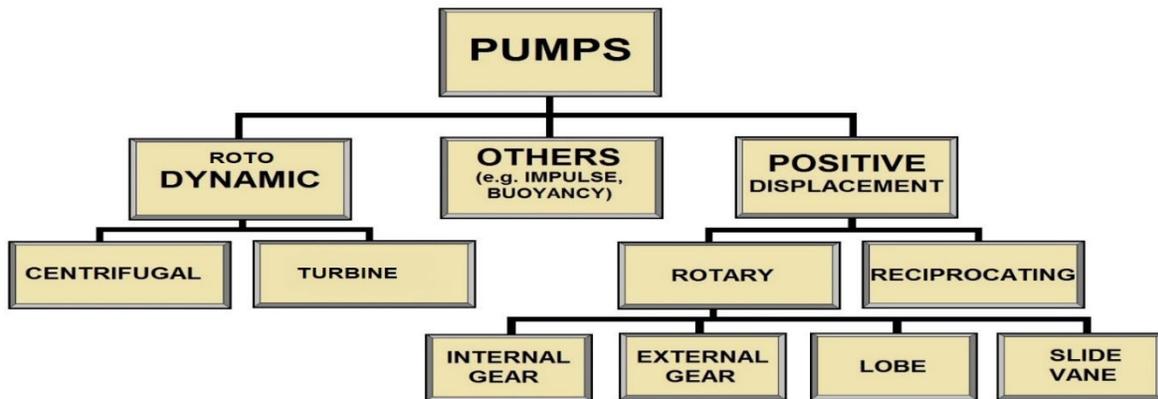
We may ask what depth of water gives the normal sea-level atmospheric pressure of 14.7 psi, or 2117 psf.

This is simply $2117 / 62.4 = 33.9$ ft of water. This is the maximum height to which water can be raised by a suction pump, or, more correctly, can be supported by atmospheric pressure.

Pumps and Pumping Water

Moving fluids plays a major role in the process of a plant. Liquid can only move on its own power from top to bottom or from a high pressure to a lower pressure system. This means that energy to the liquid must be added to move the liquid from a low to a higher level.

To add the required energy to liquids, pumps are used. There are many different definitions of a pump but it can be described as: A machine used for the purpose of transferring quantities of liquids, gases and even solids from one location to another.



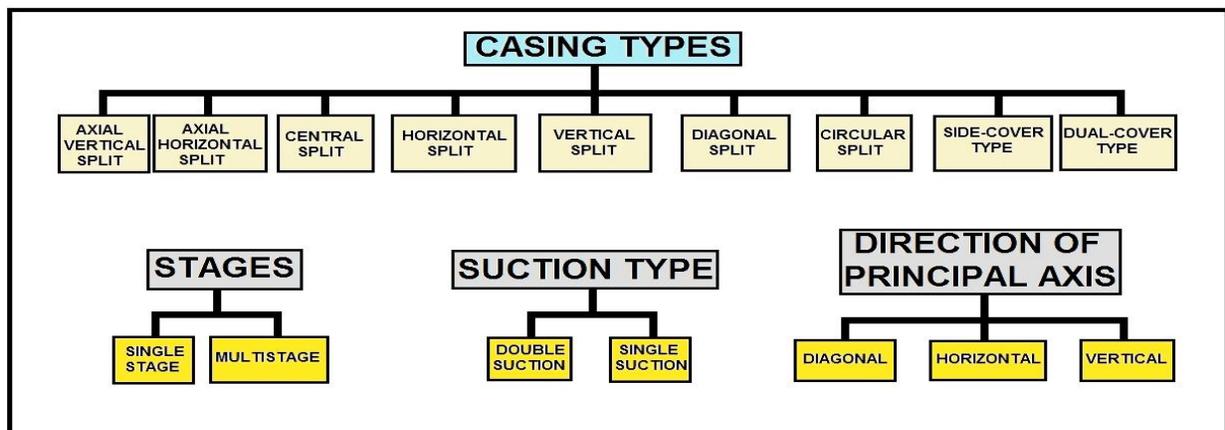
PUMP CATEGORIES

Types of Pumps

Pump types generally fall into two main categories - Rotodynamic and Positive Displacement, of which there are many forms.

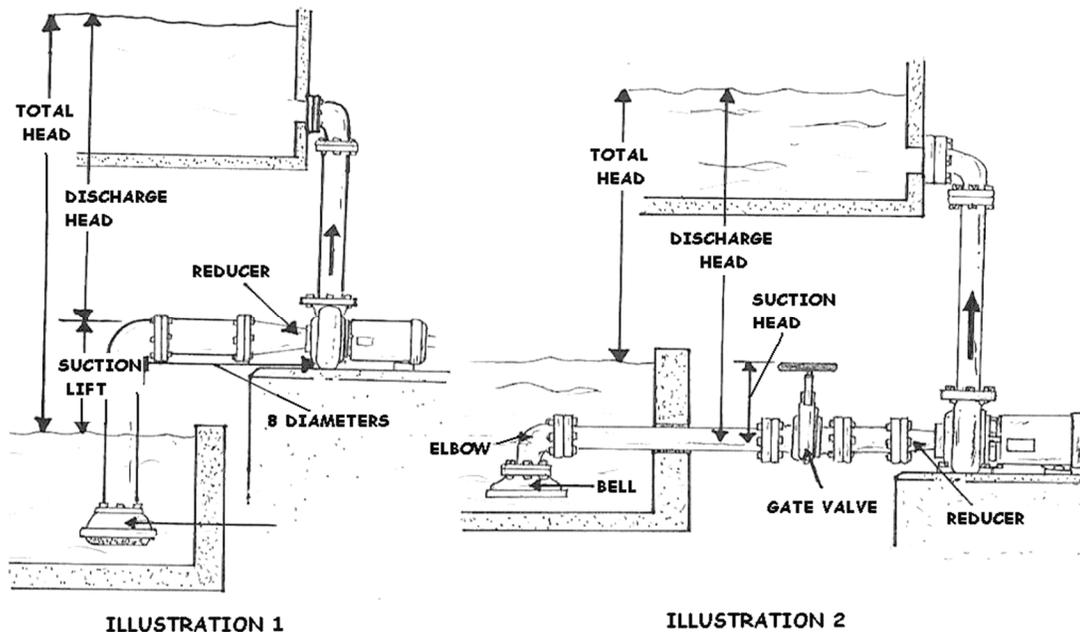
The Rotodynamic pump transfers rotating mechanical energy into kinetic energy in the form of fluid velocity and pressure. The Centrifugal and Liquid Ring pumps are types of rotodynamic pump, which utilize centrifugal force to transfer the fluid being pumped.

The Rotary Lobe pump is a type of positive displacement pump, which directly displaces the pumped fluid from pump inlet to outlet in discrete volumes.



PUMP CONFIGURATIONS

General Pumping Fundamentals



Here are the important points to consider about suction piping when the liquid being pumped is below the level of the pump:

- First, suction lift is when the level of water to be pumped is below the centerline of the pump. Sometimes suction lift is also referred to as '**negative suction head**'.
- The ability of the pump to lift water is the result of a partial vacuum created at the center of the pump.
- This works similar to sucking soda from a straw. As you gently suck on a straw, you are creating a vacuum or a pressure differential. Less pressure is exerted on the liquid inside the straw, so that the greater pressure is exerted by the atmosphere on the liquid around the outside of the straw, causing the liquid in the straw to move up. By sucking on the straw, this allows atmospheric pressure to move the liquid.
- Look at the diagram illustrated as "1". The foot valve is located at the end of the suction pipe of a pump. It opens to allow water to enter the suction side, but closes to prevent water from passing back out of the bottom end.
- The suction side of pipe should be one diameter larger than the pump inlet. The required eccentric reducer should be turned so that the top is flat and the bottom tapered.

Notice in illustration "2" that the liquid is above the level of the pump. Sometimes this is referred to as '**flooded suction**' or '**suction head**' situations.

Common Types of Water/Wastewater Pumps

The most common type of water pumps used for municipal and domestic water supplies are *variable displacement* pumps another term for dynamic pumps. A variable displacement pump will produce at different rates relative to the amount of pressure or lift the pump is working against. *Centrifugal* pumps are variable displacement pumps that are by far used the most. The water production well industry almost exclusively uses *Turbine* pumps, which are a type of centrifugal pump.

The turbine pump utilizes *impellers* enclosed in single or multiple *bowls or stages* to lift water by *centrifugal force*. The impellers may be of either a *semi-open or closed type*. Impellers are rotated by the *pump motor*, which provides the horsepower needed to overcome the pumping head. A more thorough discussion of how these and other pumps work is presented later in this section. The size and number of stages, horsepower of the motor and pumping head are the key components relating to the pump's lifting capacity.

Vertical turbine pumps are commonly used in groundwater wells but also in many other applications. These pumps are driven by a shaft rotated by a motor that is usually found on the surface. The shaft turns the impellers within the pump housing while the water moves up the column.

This type of pumping system is also called a *line-shaft turbine*. The rotating shaft in a line shaft turbine is actually housed within the column pipe that delivers the water to the surface. The size of the column, impeller, and bowls are selected based on the desired pumping rate and lift requirements.

Column pipe sections can be threaded or coupled together while the drive shaft is coupled and suspended within the column by *spider bearings*. The spider bearings provide both a seal at the column pipe joints and keep the shaft aligned within the column. The water passing through the column pipe serves as the lubricant for the bearings. Some vertical turbines are lubricated by oil rather than water. These pumps are essentially the same as water lubricated units; only the drive shaft is enclosed within an *oil tube*.

Food grade oil is supplied to the tube through a gravity feed system during operation. The oil tube is suspended within the column by *spider flanges*, while the line shaft is supported within the oil tube by *brass or redwood bearings*. A continuous supply of oil lubricates the drive shaft as it proceeds downward through the oil tube.

A small hole located at the top of the pump bow unit allows excess oil to enter the well. This results in the formation of an oil film on the water surface within oil-lubricated wells. Careful operation of oil lubricated turbines is needed to ensure that the pumping levels do not drop enough to allow oil to enter the pump. Both water and oil lubricated turbine pump units can be driven by electric or fuel powered motors. Most installations use an electric motor that is connected to the drive shaft by a keyway and nut.

However, where electricity is not readily available, fuel powered engines may be connected to the drive shaft by a right angle drive gear. Also, both oil and water lubricated systems will have a strainer attached to the intake to prevent sediment from entering the pump.

When the line shaft turbine is turned off, water will flow back down the column, turning the impellers in a reverse direction. A pump and shaft can easily be broken if the motor were to turn on during this process.

This is why a *time delay* or *ratchet* assembly is often installed on these motors to either prevent the motor from turning on before reverse rotation stops or simply not allow it to reverse at all.

Three Main Types of Diaphragm Pumps

In the first type, the diaphragm is sealed with one side in the fluid to be pumped, and the other in air or hydraulic fluid. The diaphragm is flexed, causing the volume of the pump chamber to increase and decrease. A pair of non-return check valves prevents reverse flow of the fluid.

The second type of diaphragm pump works with volumetric positive displacement, but differs in that the prime mover of the diaphragm is neither oil nor air; but is electro-mechanical, working through a crank or geared motor drive. This method flexes the diaphragm through simple mechanical action, and one side of the diaphragm is open to air.

The third type of diaphragm pump has one or more unsealed diaphragms with the fluid to be pumped on both sides. The diaphragm(s) again are flexed, causing the volume to change.

When the volume of a chamber of either type of pump is increased (the diaphragm moving up), the pressure decreases, and fluid is drawn into the chamber. When the chamber pressure later increases from decreased volume (the diaphragm moving down), the fluid previously drawn in is forced out. Finally, the diaphragm moving up once again draws fluid into the chamber, completing the cycle. This action is similar to that of the cylinder in an internal combustion engine.

Cavitation

Cavitation is defined as the phenomenon of formation of vapor bubbles of a flowing liquid in a region where the pressure of the liquid falls below its vapor pressure.

Cavitation is usually divided into two classes of behavior: inertial (or transient) cavitation and non-inertial cavitation. Inertial cavitation is the process where a void or bubble in a liquid rapidly collapses, producing a shock wave. Such cavitation often occurs in pumps, propellers, impellers, and in the vascular tissues of plants. Non-inertial cavitation is the process in which a bubble in a fluid is forced to oscillate in size or shape due to some form of energy input, such as an acoustic field. Such cavitation is often employed in ultrasonic cleaning baths and can also be observed in pumps, propellers etc.

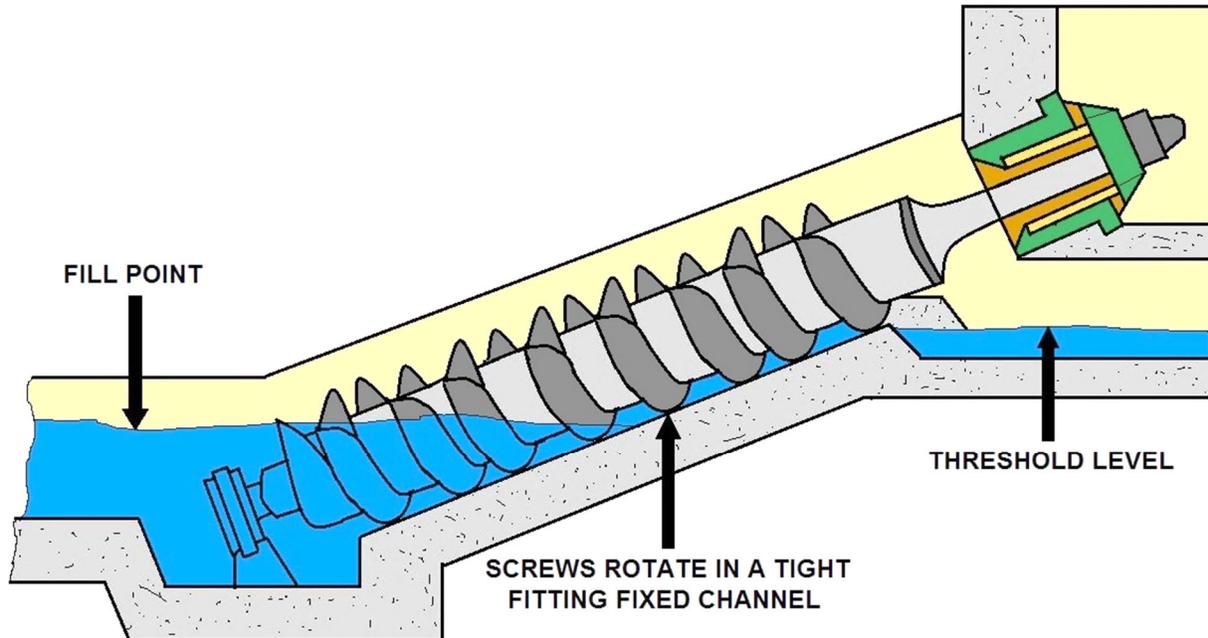
Cavitation is, in many cases, an undesirable occurrence. In devices such as propellers and pumps, cavitation causes a great deal of noise, damage to components, vibrations, and a loss of efficiency. When the cavitation bubbles collapse, they force liquid energy into very small volumes, thereby creating spots of high temperature and emitting shock waves, the latter of which are the source of rattling noise. The noise created by cavitation is a particular problem for military submarines, as it increases the chances of being detected by passive sonar.

Although the collapse of a cavity is a relatively low-energy event, highly localized collapses can erode metals, such as steel, over time. The pitting caused by the collapse of cavities produces great wear on components and can dramatically shorten a propeller's or pump's lifetime.

Simple Pumps Sub-Section

Screw or Auger Pump

The Archimedes' screw, Archimedean screw, or screw pump is a machine historically used for transferring water from a low-lying body of water into irrigation ditches. It was one of several inventions and discoveries traditionally attributed to Archimedes in the 3rd century BC.



AUGER PUMP DIAGRAM

The machine consists of a screw inside a hollow pipe. Some attribute its invention to Archimedes in the 3rd century BC, while others attribute it to Nebuchadnezzar II in the 7th century BC. A screw can be thought of as an inclined plane (another simple machine) wrapped around a cylinder.

The screw is turned (usually by a windmill or by manual labor). As the bottom end of the tube turns, it scoops up a volume of water. This amount of water will slide up in the spiral tube as the shaft is turned, until it finally pours out from the top of the tube and feeds the irrigation system.

The contact surface between the screw and the pipe does not need to be perfectly water-tight because of the relatively large amount of water being scooped at each turn with respect to the angular speed of the screw.

Also, water leaking from the top section of the screw leaks into the previous one and so on. So a sort of equilibrium is achieved while using the machine, thus preventing a decrease in efficiency.

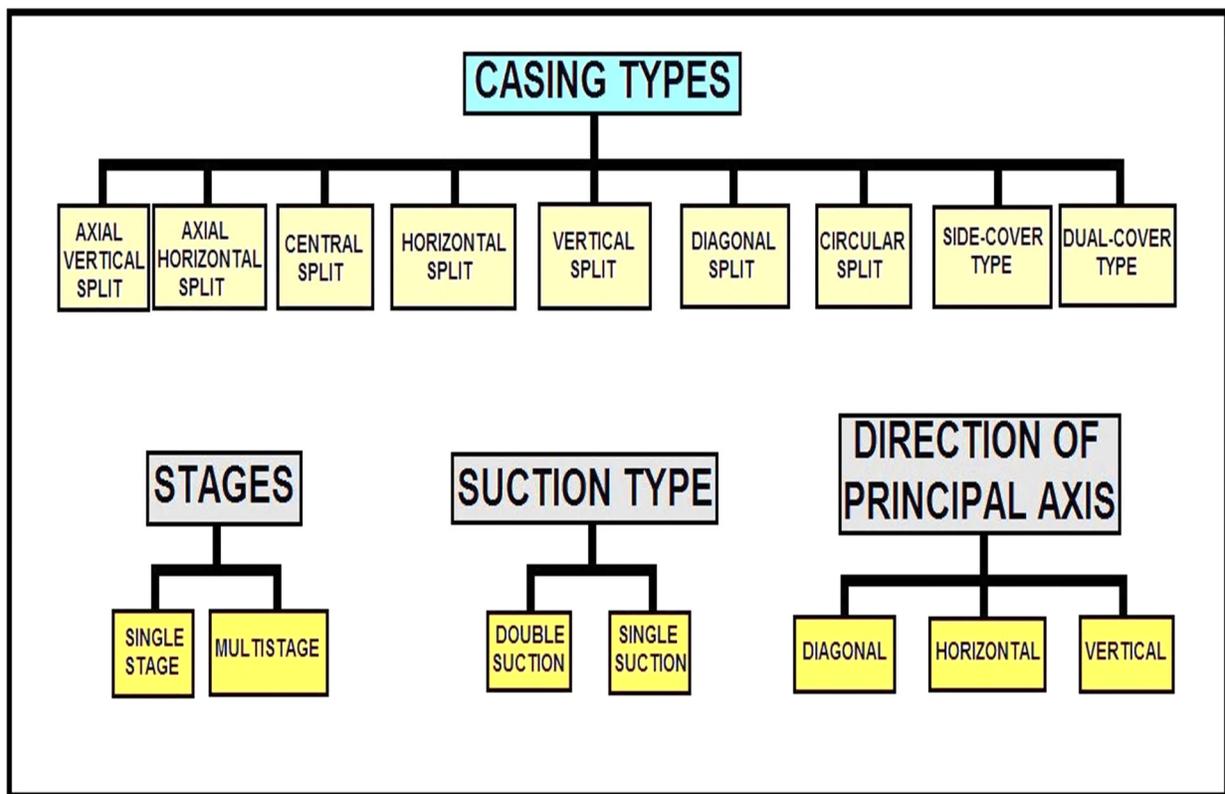
The "screw" does not necessarily need to turn inside the casing, but can be allowed to turn with it in one piece. A screw could be sealed with pitch or some other adhesive to its casing, or, cast as a single piece in bronze, as some researchers have postulated as being the devices used to irrigate Nebuchadnezzar II's Hanging Gardens of Babylon.

Depictions of Greek and Roman water screws show the screws being powered by a human treading on the outer casing to turn the entire apparatus as one piece, which would require that the casing be rigidly attached to the screw.

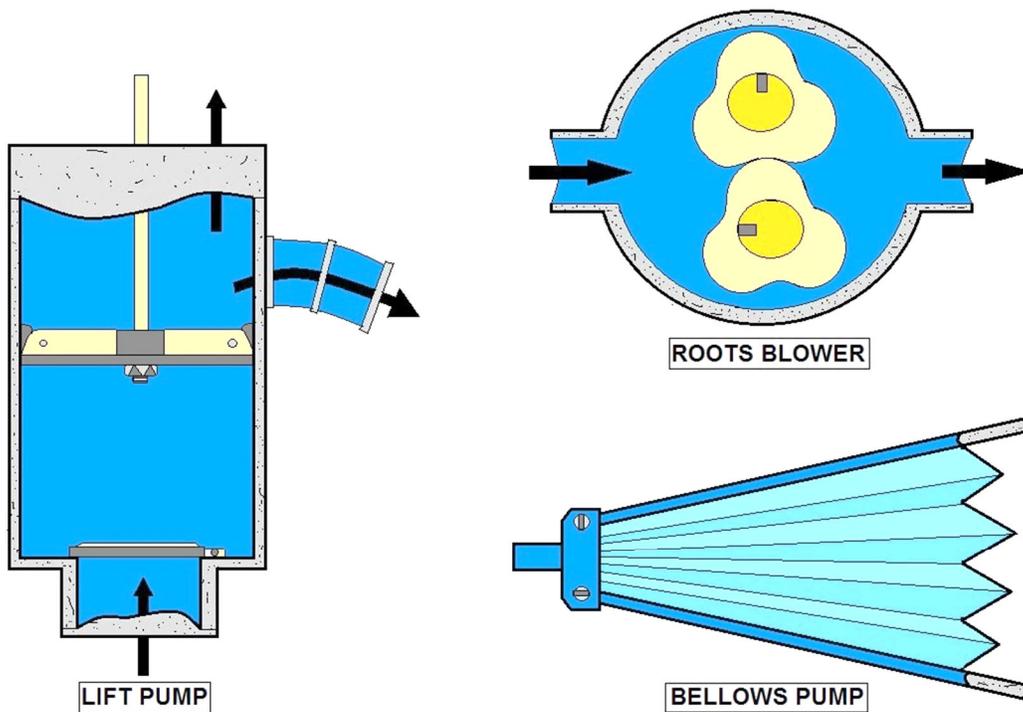
In this type of pump, a large screw provides the mechanical action to move the liquid from the suction side to the discharge side of the pump. Here are some typical characteristics of screw pumps:

- ☞ Most screw pumps rotate in the 30 to 60 rpm range, although some screw pumps are faster.
- ☞ The slope of the screw is normally either 30° or 38°.

The maximum lift for the larger diameter pumps is about 30 feet. The smaller diameter pumps have lower lift capabilities.



PUMP CONFIGURATION DIAGRAM



TYPES OF POSITIVE DISPLACEMENT PUMPS

The pump is a machine or mechanical equipment which is required to lift liquid from low level to high level or to flow liquid from low pressure area to high pressure area or as a booster in a piping network system.

Principally, pump converts mechanical energy of motor into fluid flow energy.

Pumps are used in process operations that requires a high hydraulic pressure. This can be seen in heavy duty equipment's. Often heavy duty equipment's requires a high discharge pressure and a low suction pressure. Due to low pressure at suction side of pump, fluid will lift from certain depth, whereas due to high pressure at discharge side of pump, it will push fluid to lift until reach desired height.

Classification of Pumps

Pump types generally fall into two main categories –

1. Dynamic (Centrifugal) Pumps
2. Positive Displacement Pumps

The family of pumps comprises a large number of types based on application and capabilities. The two major groups of pumps are dynamic and positive displacement.

Differences between the Dynamic and Positive Displacement Pumps

Factor	Dynamic (Centrifugal) Pump	Positive Displacement Pump
Mechanics	Impellers pass on velocity from the motor to the liquid which helps move the fluid to the discharge port (produces flow by creating pressure).	Traps confined amounts of liquid and forces it from the suction to the discharge port (produces pressure by creating flow).
Performance	Flow rate varies with a change in pressure.	Flow rate remains constant with a change in pressure.
Viscosity	Flow rate rapidly decreases with increasing viscosity, even any moderate thickness, due to frictional losses inside the pump.	Due to the internal clearances high viscosities are handled easily and flow rate increases with increasing viscosity.
Efficiency	Efficiency peaks at a specific pressure; any variations decrease efficiency dramatically. Does not operate well when run off the middle of the curve; can cause damage and cavitation.	Efficiency is less affected by pressure, but if anything tends to increase as pressure increases. Can be run at any point on their curve without damage or efficiency loss.
Suction Lift	Standard models cannot create suction lift, although self-priming designs are available and manometric suction lift is possible through a non-return valve on the suction line.	Create a vacuum on the inlet side, making them capable of creating suction lift.
Shearing	High speed motor leads to shearing of liquids. Not good for shear sensitive mediums.	Low internal velocity means little shear is applied to the pumped medium. Ideal for shear sensitive fluids.

Hyperlink to the Glossary and Appendix

<http://www.abctlc.com/downloads/PDF/PumpGlossary.pdf>

Types of Pumps

The family of pumps comprises a large number of types based on application and capabilities. The two major groups of pumps are dynamic and positive displacement.

Dynamic Pumps (Centrifugal Pump)

Centrifugal pumps are classified into three general categories:

Radial flow—a centrifugal pump in which the pressure is developed wholly by centrifugal force.

Mixed flow—a centrifugal pump in which the pressure is developed partly by centrifugal force and partly by the lift of the vanes of the impeller on the liquid.

Axial flow—a centrifugal pump in which the pressure is developed by the propelling or lifting action of the vanes of the impeller on the liquid.

Plunger Pump

The plunger pump is a positive displacement pump that uses a plunger or piston to force liquid from the suction side to the discharge side of the pump. It is used for heavy sludge. The movement of the plunger or piston inside the pump creates pressure inside the pump, so you have to be careful that this kind of pump is never operated against any closed discharge valve.

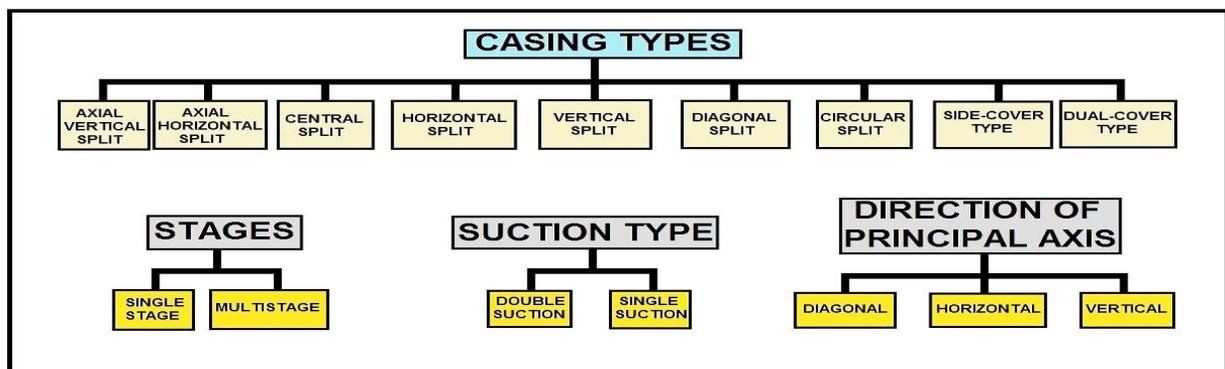
All discharge valves must be open before the pump is started, to prevent any fast build-up of pressure that could damage the pump.

Diaphragm Pumps

In this type of pump, a diaphragm provides the mechanical action used to force liquid from the suction to the discharge side of the pump. The advantage the diaphragm has over the plunger is that the diaphragm pump does not come in contact with moving metal. This can be important when pumping abrasive or corrosive materials.

There are three main types of diaphragm pumps available:

1. Diaphragm sludge pump
2. Chemical metering or proportional pump
3. Air-powered double-diaphragm pump



PUMP CONFIGURATIONS

Pump Categories

Let's cover the essentials first. The key to the whole operation is, of course, the *pump*. And regardless of what type it is (reciprocating piston, centrifugal, turbine or jet-ejector, for either shallow or deep well applications), its purpose is to move water and generate the delivery force we call pressure.

From time to time— with centrifugal pumps in particular — pressure is not referred to in pounds per square inch but rather as the equivalent in elevation, called “head”.

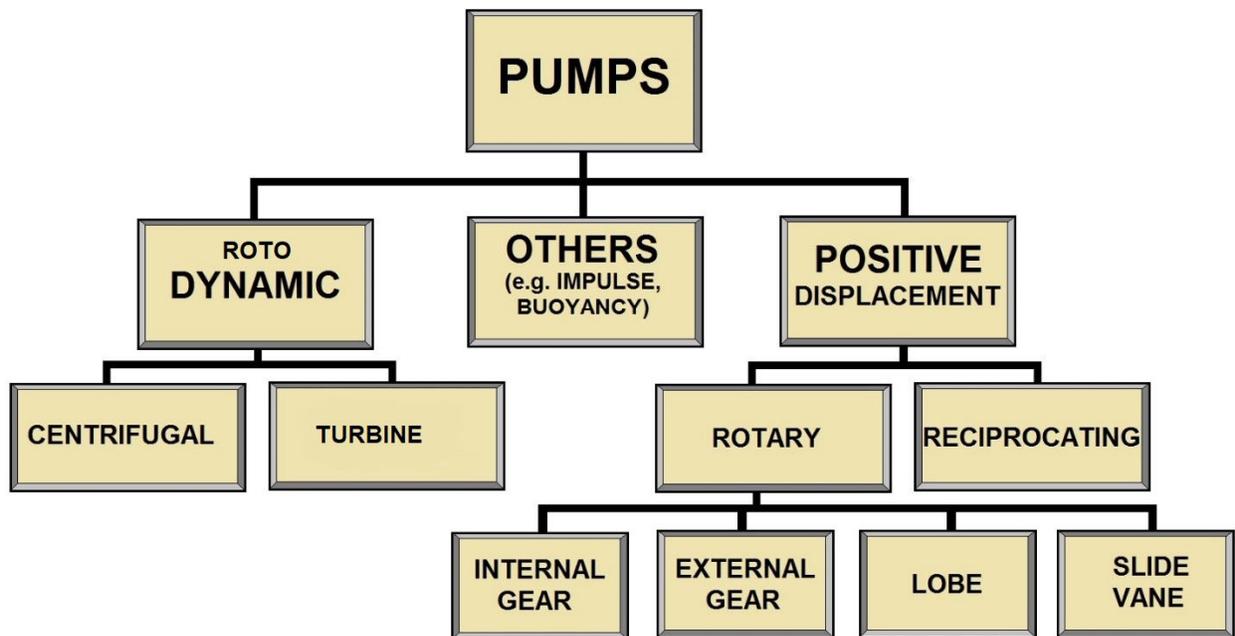
Head in feet divided by 2.31 equals pressure, so it's simple enough to establish a common figure.

Pumps may be classified on the basis of the application they serve.

All pumps may be divided into two major categories:

(1) dynamic, in which energy is continuously added to increase the fluid velocities within the machine, and

(2) displacement, in which the energy is periodically added by application of force.



PUMP CATEGORIES

Complicated Pumps - Introduction

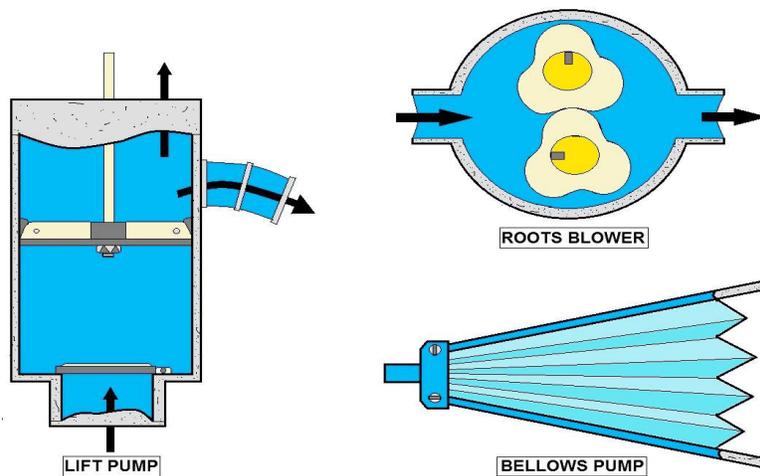
More complicated pumps have valves allowing them to work repetitively. These are usually check valves that open to allow passage in one direction, and close automatically to prevent reverse flow. There are many kinds of valves, and they are usually the most trouble-prone and complicated part of a pump. The force pump has two check valves in the cylinder, one for supply and the other for delivery. The supply valve opens when the cylinder volume increases, the delivery valve when the cylinder volume decreases.

The lift pump has a supply valve and a valve in the piston that allows the liquid to pass around it when the volume of the cylinder is reduced. The delivery in this case is from the upper part of the cylinder, which the piston does not enter.

Diaphragm pumps are force pumps in which the oscillating diaphragm takes the place of the piston. The diaphragm may be moved mechanically, or by the pressure of the fluid on one side of the diaphragm.

Some positive displacement pumps are shown below. The force and lift pumps are typically used for water. The force pump has two valves in the cylinder, while the lift pump has one valve in the cylinder and one in the piston. The maximum lift, or "suction," is determined by the atmospheric pressure, and either cylinder must be within this height of the free surface.

The force pump, however, can give an arbitrarily large pressure to the discharged fluid, as in the case of a diesel engine injector. A nozzle can be used to convert the pressure to velocity, to produce a jet, as for firefighting. Fire fighting force pumps usually have two cylinders feeding one receiver alternately. The air space in the receiver helps to make the water pressure uniform.



POSITIVE DISPLACEMENT PUMP TYPES

The three pumps above are typically used for air, but would be equally applicable to liquids. The Roots blower has no valves, their place taken by the sliding contact between the rotors and the housing.

The Roots blower (Rotary Lobe) can either exhaust a receiver or provide air under moderate pressure, in large volumes.

The Bellows is a very old device, requiring no accurate machining. The single valve is in one or both sides of the expandable chamber. Another valve can be placed at the nozzle if required. The valve can be a piece of soft leather held close to holes in the chamber.

The Bicycle pump uses the valve on the valve stem of the tire or inner tube to hold pressure in the tire. The piston, which is attached to the discharge tube, has a flexible seal that seals when the cylinder is moved to compress the air, but allows air to pass when the movement is reversed.

Diaphragm and vane pumps are not shown, but they act the same way by varying the volume of a chamber, and directing the flow with check valves.

Fluid Properties

The properties of the fluids being pumped can significantly affect the choice of pump.

Key considerations include:

- **Acidity/alkalinity (pH) and chemical composition.** Corrosive and acidic fluids can degrade pumps, and should be considered when selecting pump materials.
- **Operating temperature.** Pump materials and expansion, mechanical seal components, and packing materials need to be considered with pumped fluids that are hotter than 200°F.
- **Solids concentrations/particle sizes.** When pumping abrasive liquids such as industrial slurries, selecting a pump that will not clog or fail prematurely depends on particle size, hardness, and the volumetric percentage of solids.
- **Specific gravity.** The fluid specific gravity is the ratio of the fluid density to that of water under specified conditions. Specific gravity affects the energy required to lift and move the fluid, and must be considered when determining pump power requirements.
- **Vapor pressure.** A fluid's vapor pressure is the force per unit area that a fluid exerts in an effort to change phase from a liquid to a vapor, and depends on the fluid's chemical and physical properties. Proper consideration of the fluid's vapor pressure will help to minimize the risk of cavitation.
- **Viscosity.** The viscosity of a fluid is a measure of its resistance to motion. Since kinematic viscosity normally varies directly with temperature, the pumping system designer must know the viscosity of the fluid at the lowest anticipated pumping temperature. High viscosity fluids result in reduced centrifugal pump performance and increased power requirements. It is particularly important to consider pump suction-side line losses when pumping viscous fluids.

Environmental Considerations

Important environmental considerations include ambient temperature and humidity, elevation above sea level, and whether the pump is to be installed indoors or outdoors.

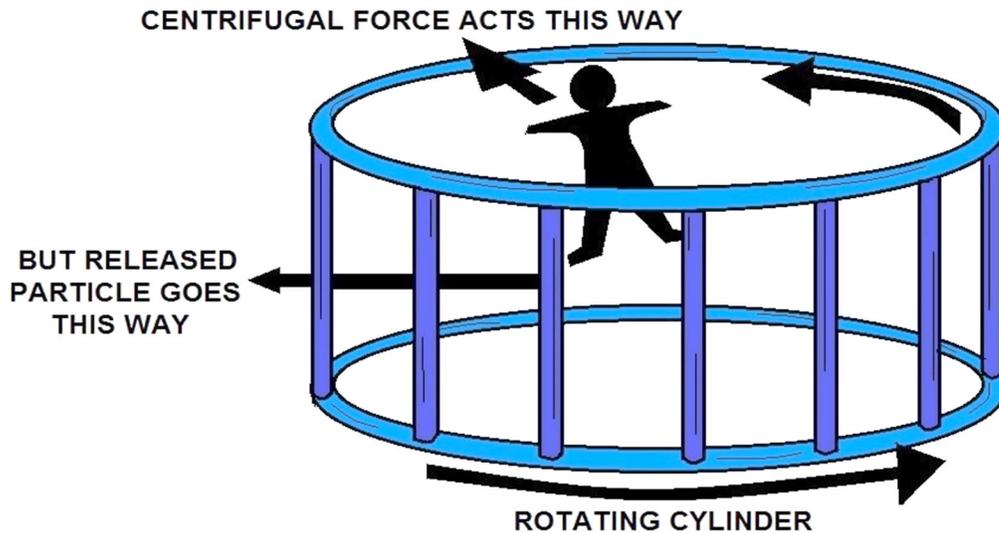
Software Tools

Most pump manufacturers have developed software or Web-based tools to assist in the pump selection process. Pump purchasers enter their fluid properties and system requirements to obtain a listing of suitable pumps. Software tools that allow you to evaluate and compare operating costs are available from private vendors.

The Basic Pump Operation

The water pump commonly found in our systems is centrifugal pumps. These pumps work by spinning water around in a circle inside a cylindrical pump housing. The pump makes the water spin by pushing it with an impeller. The blades of this impeller project outward from an axle like the arms of a turnstile and, as the impeller spins, the water spins with it. As the water spins, the pressure near the outer edge of the pump housing becomes much higher than near the center of the impeller.

There are many ways to understand this rise in pressure, and here are two:



CENTRIFUGAL PUMPING ACTION – WATER EFFECTS

First, you can view the water between the impeller blades as an object traveling in a circle. Objects do not naturally travel in a circle--they need an inward force to cause them to accelerate inward as they spin.

Without such an inward force, an object will travel in a straight line and will not complete the circle. In a centrifugal pump, that inward force is provided by high-pressure water near the outer edge of the pump housing.

The water at the edge of the pump pushes inward on the water between the impeller blades and makes it possible for that water to travel in a circle. The water pressure at the edge of the turning impeller rises until it is able to keep water circling with the impeller blades.

You can also view the water as an incompressible fluid, one that obeys Bernoulli's equation in the appropriate contexts. As water drifts outward between the impeller blades of the pump, it must move faster and faster because its circular path is getting larger and larger. The impeller blades cause the water to move faster and faster.

By the time the water has reached the outer edge of the impeller, it is moving quite fast. However, when the water leaves the impeller and arrives at the outer edge of the cylindrical pump housing, it slows down.

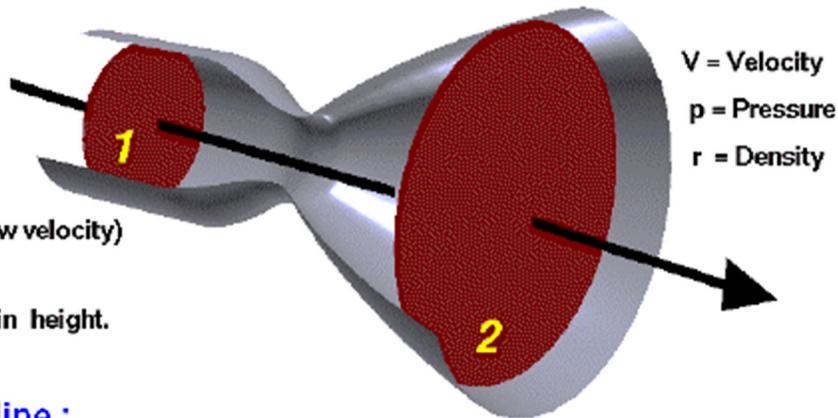


Bernoulli's Equation

Glenn
Research
Center

Restrictions :

- Inviscid
- Steady
- Incompressible (low velocity)
- No heat addition.
- Negligible change in height.



V = Velocity
 p = Pressure
 r = Density

Along a streamline :

static pressure + dynamic pressure = total pressure

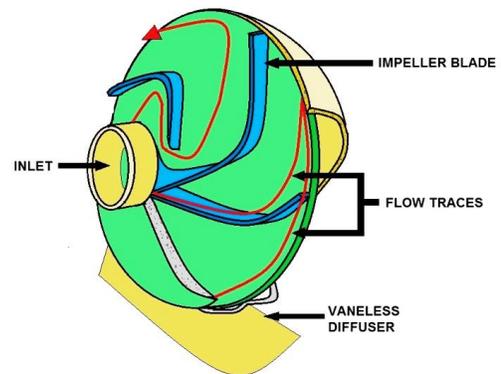
$$p_s + \frac{rV^2}{2} = p_t$$

$$\left(p_s + \frac{rV^2}{2} \right)_1 = \left(p_s + \frac{rV^2}{2} \right)_2$$

Here is where Bernoulli's equation figures in. As the water slows down and its kinetic energy decreases, that water's pressure potential energy increases (**to conserve energy**). Thus, the slowing is accompanied by a pressure rise.

That is why the water pressure at the outer edge of the pump housing is higher than the water pressure near the center of the impeller.

When water is actively flowing through the pump, arriving through a hole near the center of the impeller and leaving through a hole near the outer edge of the pump housing, the pressure rise between center and edge of the pump is not as large.



COMMON PUMP IMPELLER

Key Pump Words

NPSH: Net positive suction head - related to how much suction lift a pump can achieve by creating a partial vacuum. Atmospheric pressure then pushes liquid into the pump. A method of calculating if the pump will work or not in a given application.

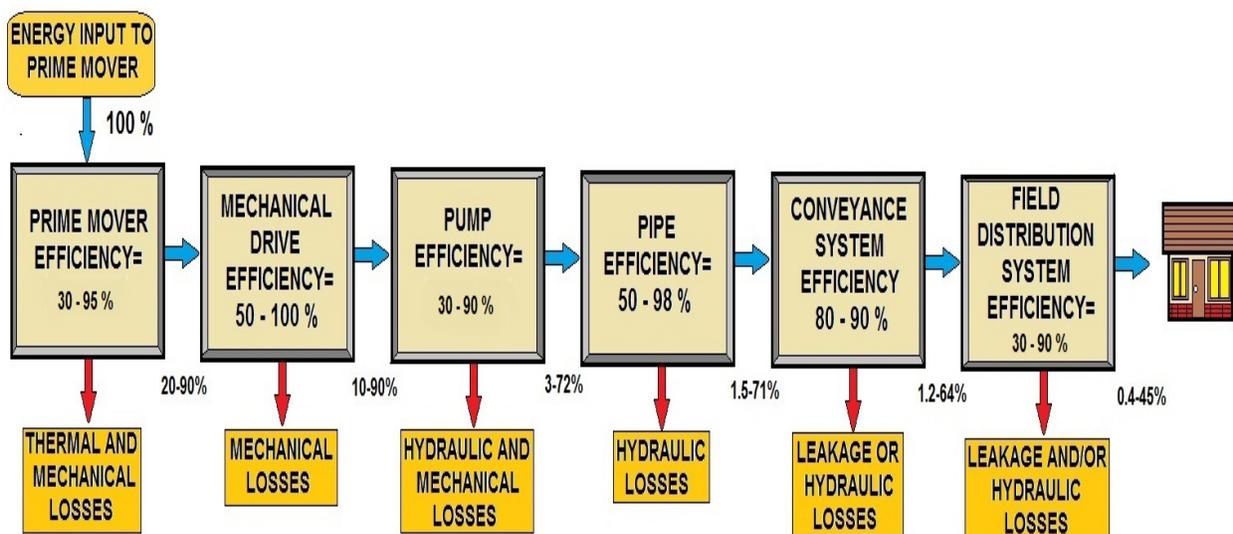
S.G.: Specific gravity. The weight of liquid in comparison to water at approx. 20 degrees C (SG = 1).

Specific Speed: A number which is the function of pump flow, head, efficiency etc. Not used in day to day pump selection, but very useful, as pumps with similar specific speed will have similar shaped curves, similar efficiency / NPSH / solids handling characteristics.

Vapor Pressure: If the vapor pressure of a liquid is greater than the surrounding air pressure, the liquid will boil.

Viscosity: A measure of a liquid's resistance to flow. i.e.: how thick it is. The viscosity determines the type of pump used, the speed it can run at, and with gear pumps, the internal clearances required.

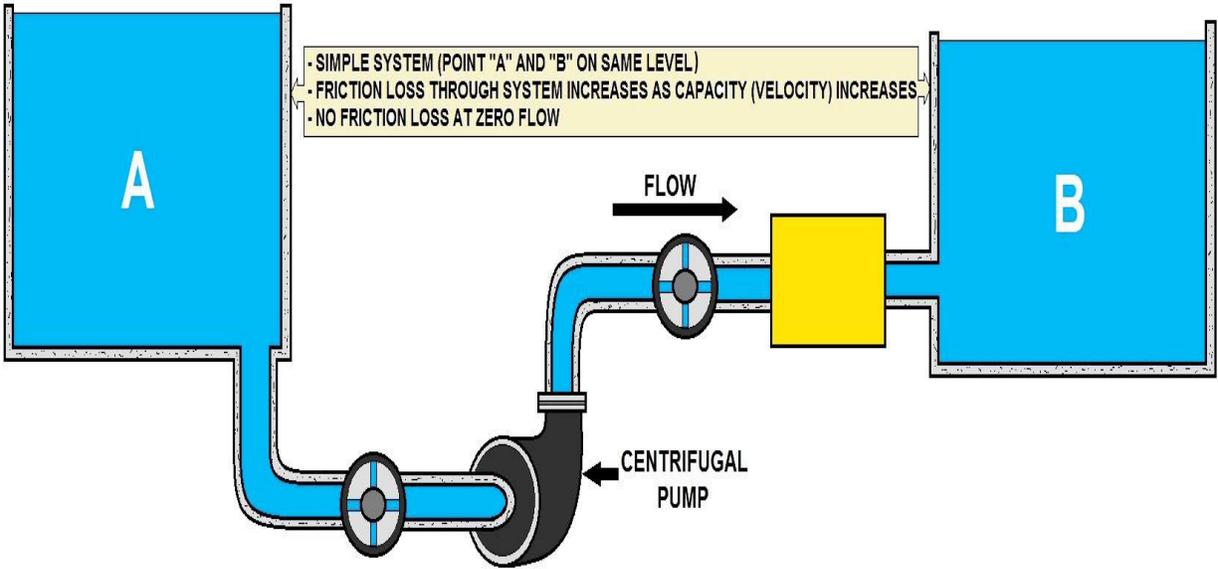
Friction Loss: The amount of pressure / head required to 'force' liquid through pipe and fittings.



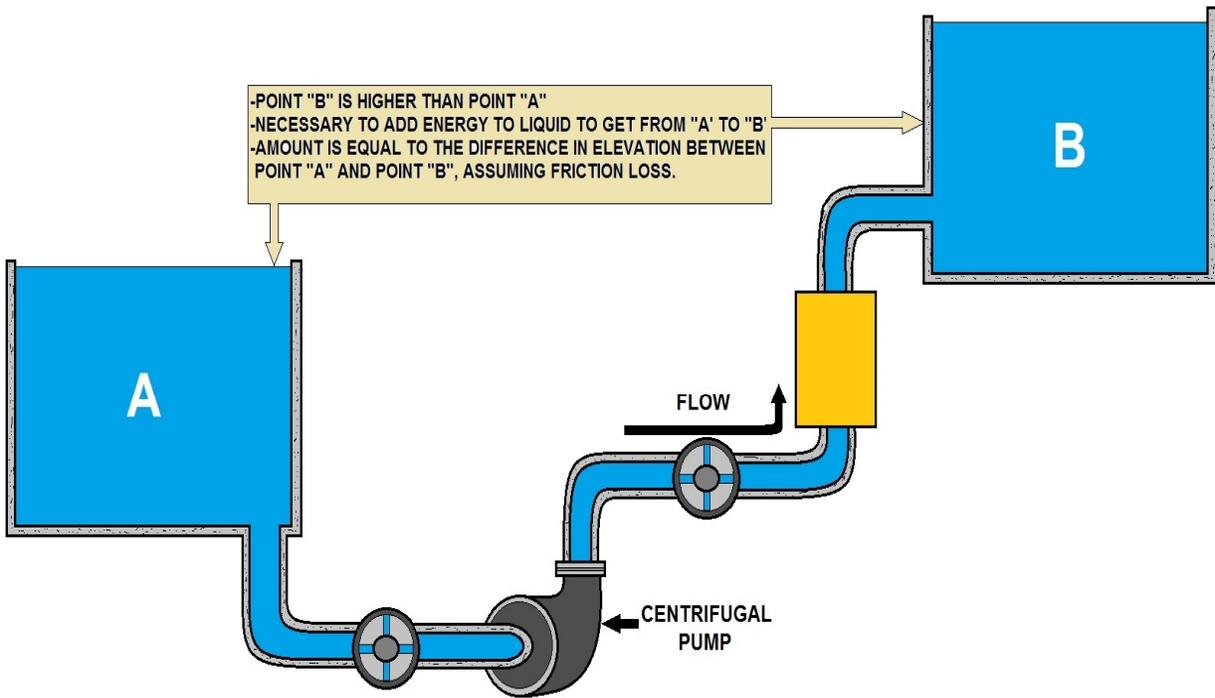
SYSTEM ENERGY EFFICIENCY LOSSES DIAGRAM

Hyperlink to the Glossary and Appendix

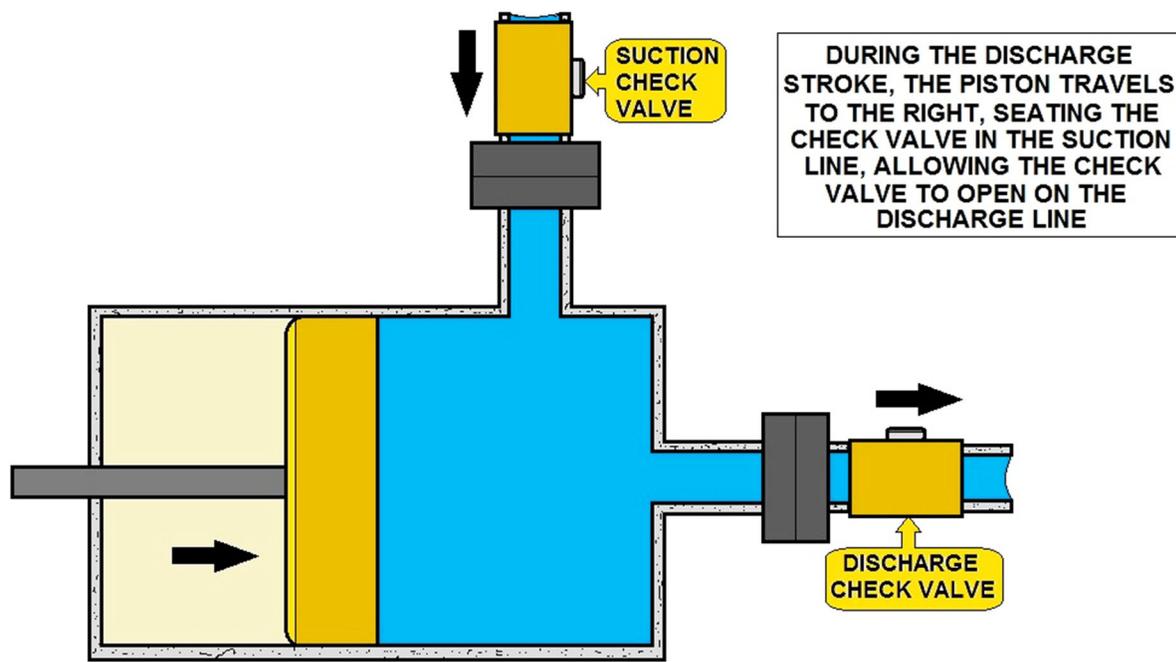
<http://www.abctlc.com/downloads/PDF/PumpGlossary.pdf>



CENTRIFUGAL PUMP CURVE CHARACTERISITICS



CENTRIFUGAL PUMP CURVE CHARACTERISITICS



PISTON TYPE –POSITIVE DISPLACEMENT PUMP

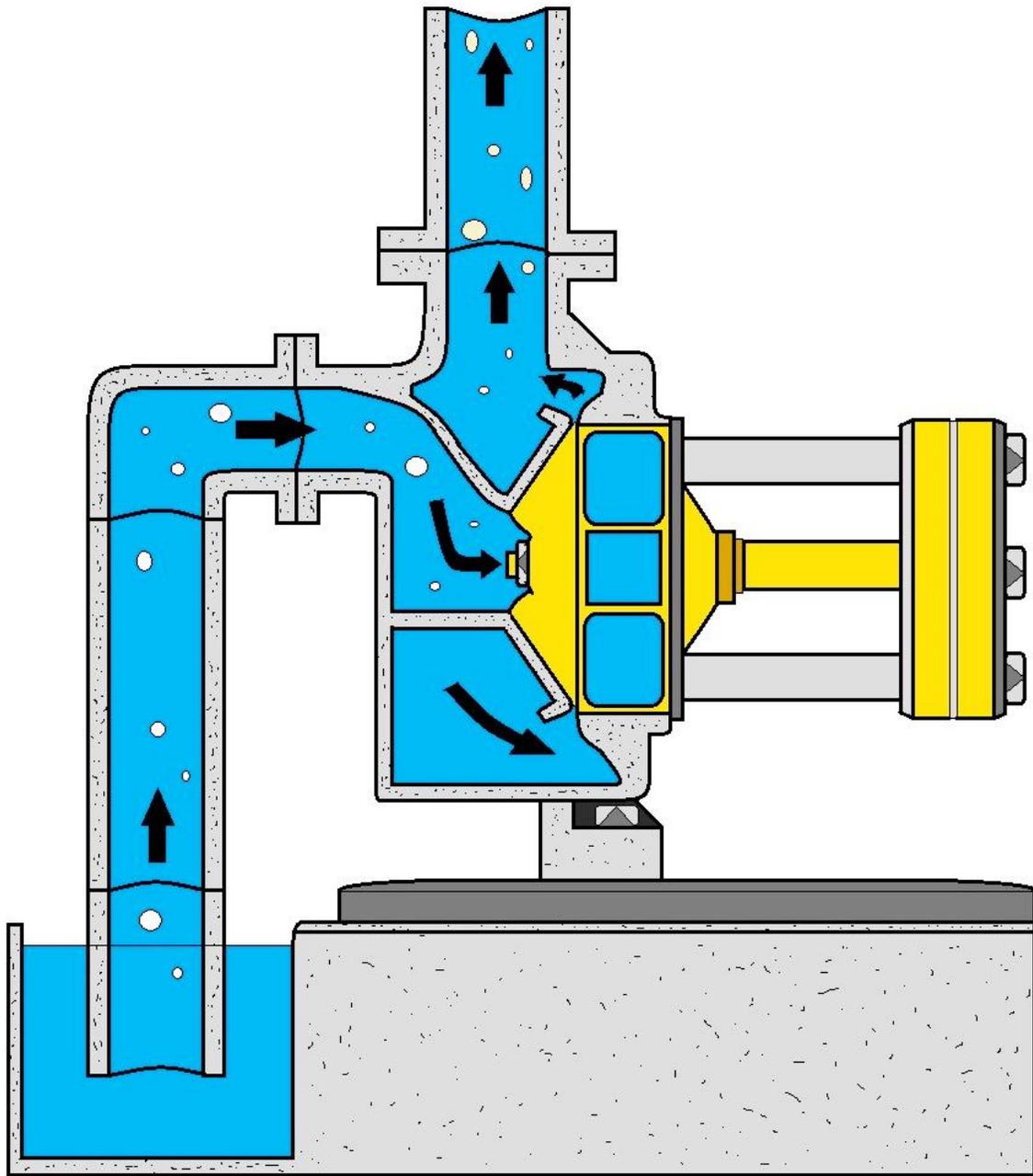
Pumping Operation

We have already seen an important example of this in the hydraulic lever or hydraulic press, which we have called quasi-static. The simplest pump is the syringe, filled by withdrawing the piston and emptied by pressing it back in, as its port is immersed in the fluid or removed from it.

More complicated pumps have valves allowing them to work repetitively. These are usually check valves that open to allow passage in one direction, and close automatically to prevent reverse flow. There are many kinds of valves, and they are usually the most trouble-prone and complicated part of a pump.

The force pump has two check valves in the cylinder, one for supply and the other for delivery. The supply valve opens when the cylinder volume increases, the delivery valve when the cylinder volume decreases.

The lift pump has a supply valve and a valve in the piston that allows the liquid to pass around it when the volume of the cylinder is reduced. The delivery in this case is from the upper part of the cylinder, which the piston does not enter.



PUMP PRIMING DIAGRAM

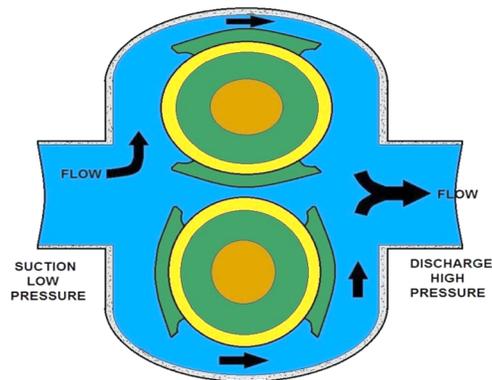
Self-Priming Pump

A pump that does not require priming or initial filling with liquid. The pump casing carries a reserve of water that helps create a vacuum that will lift the fluid from a low source.

Positive Displacement Pump Sub-Section

A positive displacement pump has an expanding cavity on the suction side of the pump and a decreasing cavity on the discharge side. Liquid is allowed to flow into the pump as the cavity on the suction side expands and the liquid is forced out of the discharge as the cavity collapses. This principle applies to all types of positive displacement pumps whether the pump is a rotary lobe, gear within a gear, piston, diaphragm, screw, progressing cavity, etc.

A positive displacement pump, unlike a centrifugal pump, will produce the same flow at a given RPM no matter what the discharge pressure is. A positive displacement pump cannot be operated against a closed valve on the discharge side of the pump, i.e. it does not have a shut-off head like a centrifugal pump does. If a positive displacement pump is allowed to operate against a closed discharge valve, it will continue to produce flow that will increase the pressure in the discharge line until either the line bursts or the pump is severely damaged or both.



POSITIVE DISPLACEMENT PUMP WITH ROTATING LOBES

Types of Positive Displacement Pumps

Single Rotor	Multiple Rotor
Vane	Gear
Piston	Lobe
Flexible Member	Circumferential Piston
Single Screw	Multiple Screw

There are many other types of positive displacement pumps. We will look at:

- ☛ Plunger pumps
- ☛ Diaphragm pumps
- ☛ Progressing cavity pumps, and
- ☛ Screw pumps

Single Rotator Positive Displacement Pump

Component	Description
Vane	The vane(s) may be blades, buckets, rollers, or slippers that cooperate with a dam to draw fluid into and out of the pump chamber.
Piston	Fluid is drawn in and out of the pump chamber by a piston(s) reciprocating within a cylinder(s) and operating port valves.
Flexible Member	Pumping and sealing depends on the elasticity of a flexible member(s) that may be a tube, vane, or a liner.
Single Screw	Fluid is carried between rotor screw threads as they mesh with internal threads on the stator.

Multiple Rotator

Component	Description
Gear	Fluid is carried between gear teeth and is expelled by the meshing of the gears that cooperate to provide continuous sealing between the pump inlet and outlet.
Lobe	Fluid is carried between rotor lobes that cooperate to provide continuous sealing between the pump inlet and outlet.
Circumferential piston	Fluid is carried in spaces between piston surfaces not requiring contacts between rotor surfaces.
Multiple Screw	Fluid is carried between rotor screw threads as they mesh.

Plunger Pump

The plunger pump is a positive displacement pump that uses a plunger or piston to force liquid from the suction side to the discharge side of the pump. It is used for heavy sludge. The movement of the plunger or piston inside the pump creates pressure inside the pump, so you have to be careful that this kind of pump is never operated against any closed discharge valve. All discharge valves must be open before the pump is started, to prevent any fast build-up of pressure that could damage the pump.

Diaphragm Pumps

In this type of pump, a diaphragm provides the mechanical action used to force liquid from the suction to the discharge side of the pump. The advantage the diaphragm has over the plunger is that the diaphragm pump does not come in contact with moving metal. This can be important when pumping abrasive or corrosive materials.

There are three main types of diaphragm pumps available:

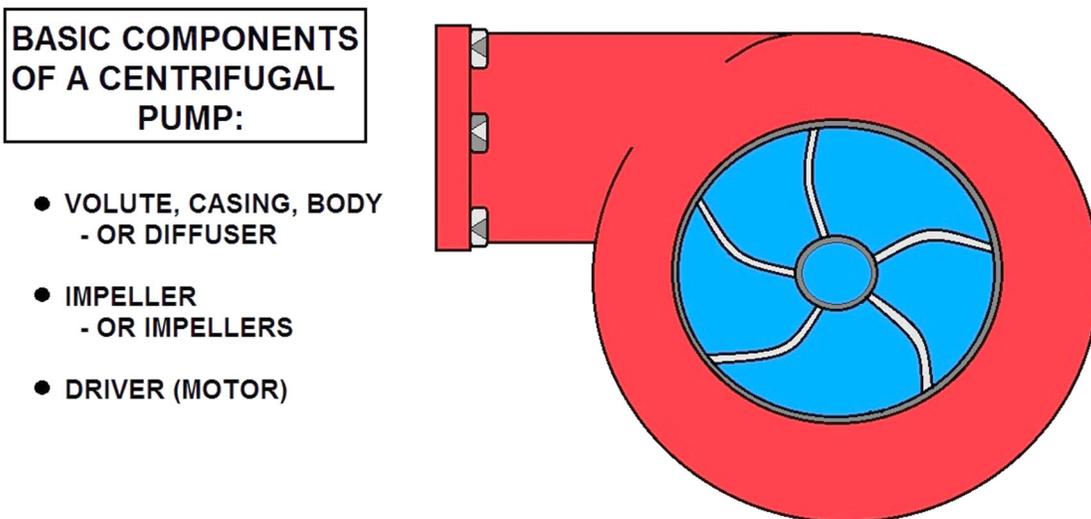
1. Diaphragm sludge pump
2. Chemical metering or proportional pump
3. Air-powered double-diaphragm pump

Centrifugal Pump Sub-Section

By definition, a centrifugal pump is a simple machine. Specifically, a pump is a machine that imparts energy to a fluid. This energy infusion can cause a liquid to flow, rise to a higher level, or both.

The centrifugal pump is an extremely simple machine. It is a member of a family known as rotary machines and consists of two basic parts: 1) the rotary element or impeller and 2) the stationary element or casing (volute). The figure at the bottom of the page is a cross section of a centrifugal pump and shows the two basic parts.

In the operation of a centrifugal pump, the pump “slings” liquid out of the impeller via centrifugal force. One fact that must always be remembered: A pump does not create pressure; it only provides flow. Pressure is just an indication of the amount of resistance to flow. Centrifugal pumps may be classified in several ways. For example, they may be either Single Stage or Multi-Stage. A single-stage pump has only one impeller. A multi-stage pump has two or more impellers housed together in one casing.



BASICS OF A CENTRIFUGAL PUMP

As a standard, each impeller acts separately, discharging to the suction of the next stage impeller. This arrangement is called series staging. Centrifugal pumps are also classified as Horizontal or Vertical, depending upon the position of the pump shaft.

The impellers used on centrifugal pumps may be classified as single suction or double suction. The single-suction impeller allows liquid to enter the eye from one side only. The double-suction impeller allows liquid to enter the eye from two directions.

Impellers are also classified as opened or closed. Closed impellers have side walls that extend from the eye to the outer edge of the vane tips. Open impellers do not have these side walls. Some small pumps with single-suction impellers have only a casing wearing ring and no impeller ring. In this type of pump, the casing wearing ring is fitted into the end plate.

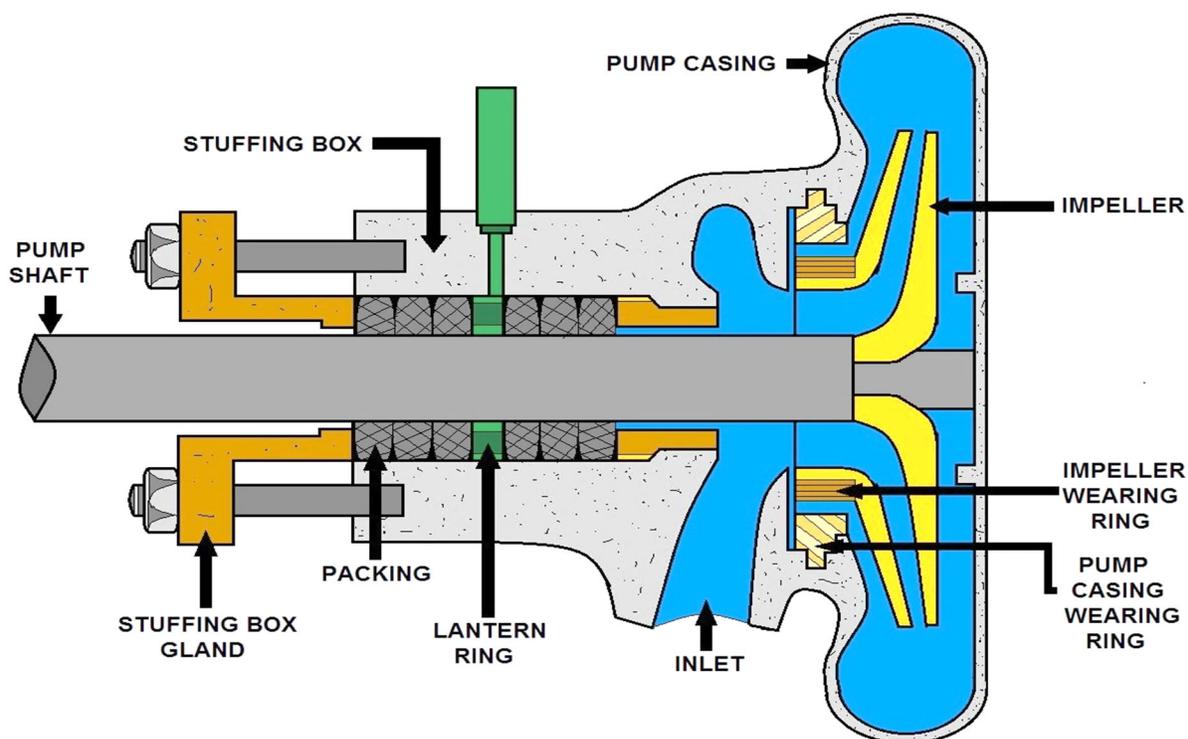
Recirculation lines are installed on some centrifugal pumps to prevent the pumps from overheating and becoming vapor bound, in case the discharge is entirely shut off or the flow of fluid is stopped for extended periods.

Seal piping is installed to cool the shaft and the packing, to lubricate the packing, and to seal the rotating joint between the shaft and the packing against air leakage. A lantern ring spacer is inserted between the rings of the packing in the stuffing box.

Seal piping leads the liquid from the discharge side of the pump to the annular space formed by the lantern ring. The web of the ring is perforated so that the water can flow in either direction along the shaft (between the shaft and the packing).

Water flinger rings may be fitted on the shaft between the packing gland and the pump bearing housing. These flingers prevent water in the stuffing box from flowing along the shaft and entering the bearing housing.

Let's Look at the Components of the Centrifugal Pump...



CENTRIFUGAL PUMP CUT-AWAY DIAGRAM #1

As the impeller rotates, it sucks the liquid into the center of the pump and throws it out under pressure through the outlet. The casing that houses the impeller is referred to as the volute, the impeller fits on the shaft inside. The volute has an inlet and outlet that carries the water as shown above.

Pump Casing

There are many variations of centrifugal pumps. The most common type is an end suction pump. Another type of pump used is the split case. There are many variations of split case, such as; two-stage, single suction, and double suction. Most of these pumps are horizontal.

There are variations of vertical centrifugal pumps. The line shaft turbine is really a multistage centrifugal pump.

Impeller

In most centrifugal pumps, the impeller looks like a number of cupped vanes on blades mounted on a disc or shaft. Notice in the picture below how the vanes of the impeller force the water into the outlet of the pipe.

The shape of the vanes of the impeller is important. As the water is being thrown out of the pump, this means you can run centrifugal pumps with the discharged valve closed for a SHORT period of time. Remember the motor sends energy along the shaft, and if the water is in the volute too long it will heat up and create steam. Not good!

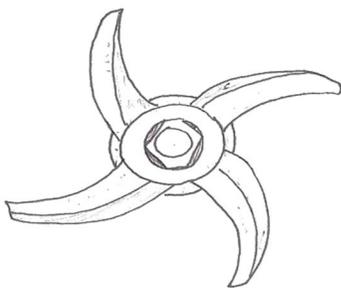
Impellers are designed in various ways. We will look at:

- Closed impellers
- Semi-open impellers
- Opened impellers, and
- Recessed impellers

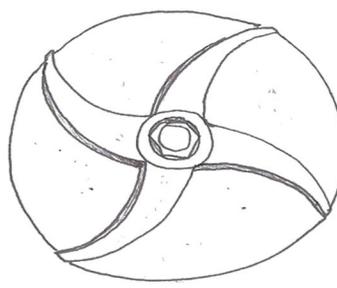
The impellers all cause a flow from the eye of the impeller to the outside of the impeller. These impellers cause what is called **radial flow**, and they can be referred to as radial flow impellers.

The **critical distance** of the impeller and how it is installed in the casing will determine if it is high volume / low pressure or the type of liquid that could be pumped.

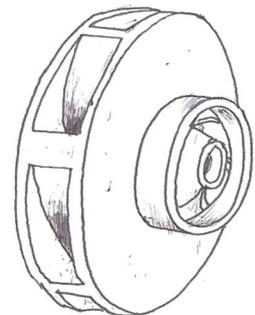
Axial flow impellers look like a propeller and create a flow that is parallel to the shaft.



OPEN



SEMI-OPEN



CLOSED

More on Centrifugal or Roto-Dynamic Pump

The centrifugal or roto-dynamic pump produce a head and a flow by increasing the velocity of the liquid through the machine with the help of a rotating vane impeller. Centrifugal pumps include radial, axial and mixed flow units.

Centrifugal Pumps Can Further be Classified As...

- ✓ end suction pumps
- ✓ in-line pumps
- ✓ double suction pumps
- ✓ vertical multistage pumps
- ✓ horizontal multistage pumps
- ✓ submersible pumps
- ✓ self-priming pumps
- ✓ axial-flow pumps
- ✓ regenerative pumps

The fact of the matter is that there are three types of problems mostly encountered with centrifugal pumps:

- ✓ design errors
- ✓ poor operation
- ✓ poor maintenance practices

Working Mechanism of a Centrifugal Pump

A centrifugal pump is one of the simplest pieces of equipment in any process plant. Its purpose is to convert energy of a prime mover (an electric motor or turbine) first into velocity or kinetic energy and then into pressure energy of a fluid that is being pumped.

The energy changes occur by virtue of two main parts of the pump, the impeller and the volute or diffuser. The impeller is the rotating part that converts driver energy into the kinetic energy. The volute or diffuser is the stationary part that converts the kinetic energy into pressure energy.

Note: All of the forms of energy involved in a liquid flow system are expressed in terms of feet of liquid i.e. head.

Generation of Centrifugal Force

The process liquid enters the suction nozzle and then into eye (center) of a revolving device known as an impeller. When the impeller rotates, it spins the liquid sitting in the cavities between the vanes outward and provides centrifugal acceleration.

As liquid leaves the eye of the impeller a low-pressure area is created causing more liquid to flow toward the inlet. Because the impeller blades are curved, the fluid is pushed in a tangential and radial direction by the centrifugal force. This force acting inside the pump is the same one that keeps water inside a bucket that is rotating at the end of a string.

Selecting between Centrifugal or Positive Displacement Pumps

Selecting between a Centrifugal Pump or a Positive Displacement Pump is not always straight forward.

Flow Rate and Pressure Head

The two types of pumps behave very differently regarding pressure head and flow rate: The centrifugal pump has varying flow depending on the system pressure or head. The positive displacement pump has more or less a constant flow regardless of the system pressure or head. positive displacement pumps generally gives more pressure than centrifugal pumps. Depending on how the measurement is taken suction lift and head may also be referred to as static or dynamic. Static indicates the measurement does not take into account the friction caused by water moving through the hose or pipes. Dynamic indicates that losses due to friction are factored into the performance. The following terms are usually used when referring to lift or head.

Static Suction Lift - The vertical distance from the water line to the centerline of the impeller.

Static Discharge Head - The vertical distance from the discharge outlet to the point of discharge or liquid level when discharging into the bottom of a water tank.

Dynamic Suction Head - The Static Suction Lift plus the friction in the suction line. Also referred to as a Total Suction Head.

Dynamic Discharge Head - The Static Discharge Head plus the friction in the discharge line. Also referred to as Total Discharge Head.

Total Dynamic Head - The Dynamic Suction Head plus the Dynamic Discharge Head. Also referred to as Total Head.

Capacity and Viscosity

Another major difference between the pump types is the effect of viscosity on the capacity:

- ✓ In the centrifugal pump the flow is reduced when the viscosity is increased.
- ✓ In the positive displacement pump the flow is increased when viscosity is increased

Liquids with high viscosity fills the clearances of a positive displacement pump causing a higher volumetric efficiency and a positive displacement pump is better suited for high viscosity applications.

A centrifugal pump becomes very inefficient at even modest viscosity.

Mechanical Efficiency

The pumps behaves different considering mechanical efficiency as well.

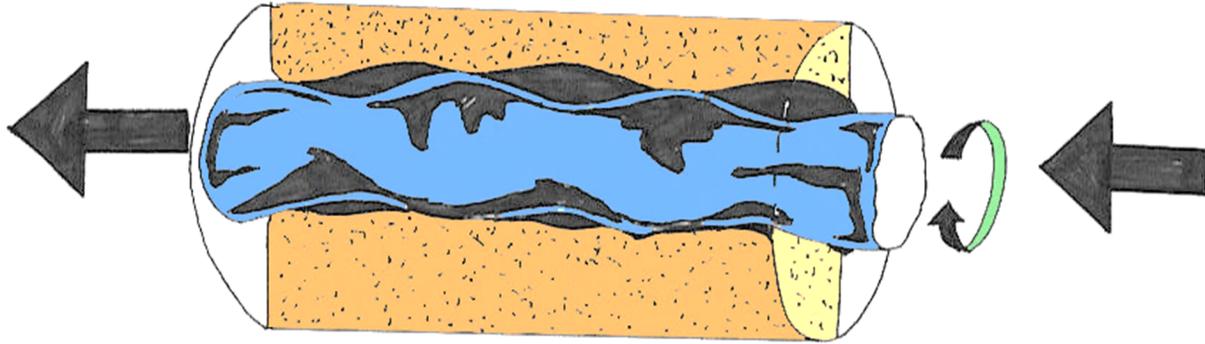
- ✓ Changing the system pressure or head has little or no effect on the flow rate in the positive displacement pump.
- ✓ Changing the system pressure or head has a dramatic effect on the flow rate in the centrifugal pump.

Net Positive Suction Head - NPSH

Another consideration is the Net Positive Suction Head NPSH.

- ✓ In a centrifugal pump, NPSH varies as a function of flow determined by pressure.
- ✓ In a positive displacement pump, NPSH varies as a function of flow determined by speed. Reducing the speed of the positive displacement pump reduces the NPSH.

Progressing Cavity Pump Sub-Section



PROGRESSING CAVITY ACTION

In this type of pump, components referred to as a rotor and an elastic stator provide the mechanical action used to force liquid from the suction side to the discharge side of the pump. As the rotor turns within the stator, cavities are formed which progress from the suction to the discharge end of the pump, conveying the pumped material.

The continuous seal between the rotor and the stator helices keeps the fluid moving steadily at a fixed flow rate proportional to the pump's rotational speed. Progressing cavity pumps are used to pump material very high in solids content. The progressive cavity pump must never be run dry, because the friction between the rotor and stator will quickly damage the pump.

More on the Progressive Cavity Pump

A progressive cavity pump is also known as a progressing cavity pump, eccentric screw pump, or even just cavity pump, and as is common in engineering generally, these pumps can often be referred to by using a generalized trademark. Hence, names can vary from industry to industry and even regionally; examples include: Mono pump, Moyno pump, Mohno pump, and Nemo pump.

This type of pump transfers fluid by means of the progress, through the pump, of a sequence of small, fixed shape, discrete cavities, as its rotor is turned. This leads to the volumetric flow rate being proportional to the rotation rate (bi-directionally) and to low levels of shearing being applied to the pumped fluid.

Therefore, these pumps have application in fluid metering and pumping of viscous or shear sensitive materials. It should be noted that the cavities taper down toward their ends and overlap with their neighbors, so that, in general, no flow pulsing is caused by the arrival of cavities at the outlet, other than that caused by compression of the fluid or pump components.

The principle of this pumping technique is frequently misunderstood; often it is believed to occur due to a dynamic effect caused by drag, or friction against the moving teeth of the screw rotor.

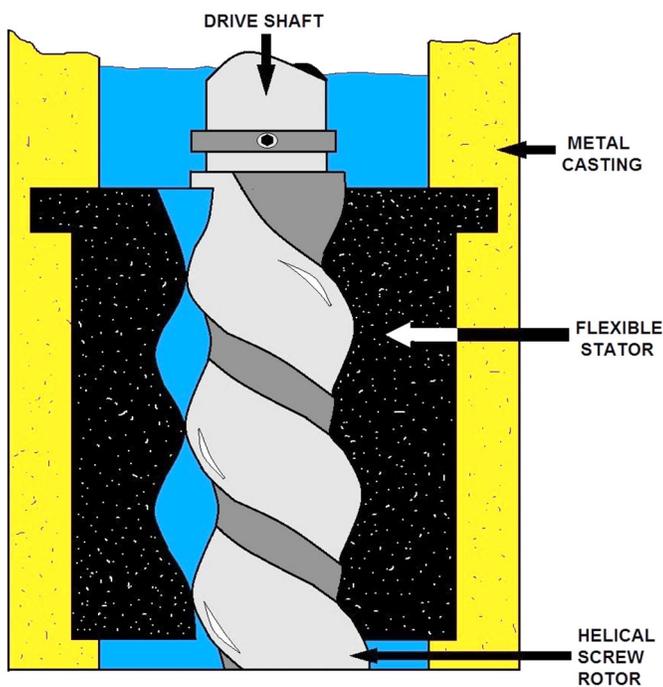
Nevertheless, in reality it is due to sealed cavities, like a piston pump, and so has similar operational characteristics, such as being able to pump at extremely low rates, even to high pressure, revealing the effect to be purely positive displacement.

The mechanical layout that causes the cavities to, uniquely, be of fixed dimensions as they move through the pump, is hard to visualize (it's essentially 3D nature renders diagrams quite ineffective for explanation), but it is accomplished by the preservation in shape of the gap formed between

a helical shaft and a two start, twice the wavelength and double the diameter, helical hole, as the shaft is "rolled" around the inside surface of the hole. The motion of the rotor being the same as the smaller gears of a planetary gears system. This form of motion gives rise to the curves called Hypocycloids.

In order to produce a seal between cavities, the rotor requires a circular cross-section and the stator an oval one. The rotor so takes a form similar to a corkscrew, and this, combined with the off-center rotary motion, leads to the name; *Eccentric screw pump*.

Different rotor shapes and rotor/stator pitch ratios exist, but are specialized in that they don't generally allow complete sealing, so reducing low speed pressure and flow rate linearity, but improving actual flow rates, for a given pump size, and/or the pump's solids handling ability.



PROGRESSIVE CAVITY PUMP

At a high enough pressure the sliding seals between cavities will leak some fluid rather than pumping it, so when pumping against high pressures a longer pump with more cavities is more effective, since each seal has only to deal with the pressure difference between adjacent cavities. Pumps with between two and a dozen or so cavities exist.

In operation, progressive cavity pumps are fundamentally fixed flow rate pumps, like piston pumps and peristaltic pumps. This type of pump needs a fundamentally different understanding to the types of pumps to which people are more commonly first introduced, namely ones that can be thought of as generating a pressure.

This can lead to the mistaken assumption that all pumps can have their flow rates adjusted by using a valve attached to their outlet, but with this type of pump this assumption is a problem, since such a valve will have practically no effect on the flow rate and completely closing it will involve very high, probably damaging, pressures being generated.

In order to prevent this, pumps are often fitted with cut-off pressure switches, burst disks (deliberately weak and easily replaced points), or a bypass pipe that allows a variable amount of a fluid to return to the inlet. With a bypass fitted, a fixed flow rate pump is effectively converted to a fixed pressure one.

At the points where the rotor touches the stator, the surfaces are generally traveling transversely, so small areas of sliding contact occur, these areas need to be lubricated by the fluid being pumped (Hydrodynamic lubrication), this can mean that more torque is required for starting, and if allowed to operate without fluid, called 'run dry', rapid deterioration of the stator can result.

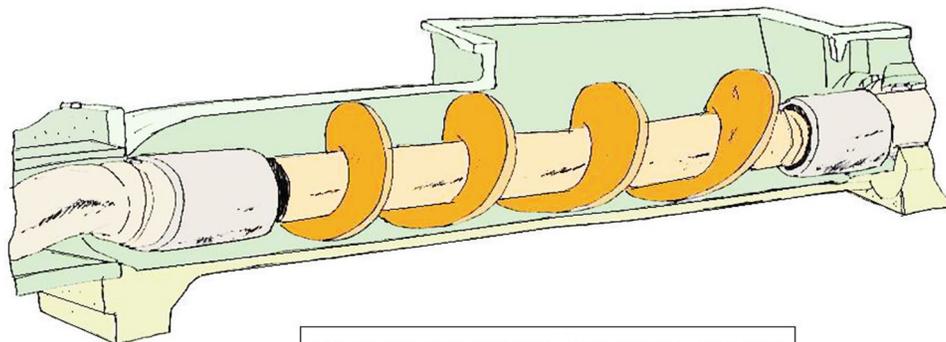
While progressive cavity pumps offer long life and reliable service transporting thick or lumpy fluids, abrasive fluids will significantly shorten the life of the stator. However, slurries (particulates in a medium) can be pumped reliably, as long as the medium is viscous enough to maintain a lubrication layer around the particles and so provide protection to the stator.

Specific designs involve the rotor of the pump being made of a steel, coated in a smooth hard surface, normally chromium, with the body (the stator) made of a molded elastomer inside a metal tube body. The Elastomer core of the stator forms the required complex cavities.

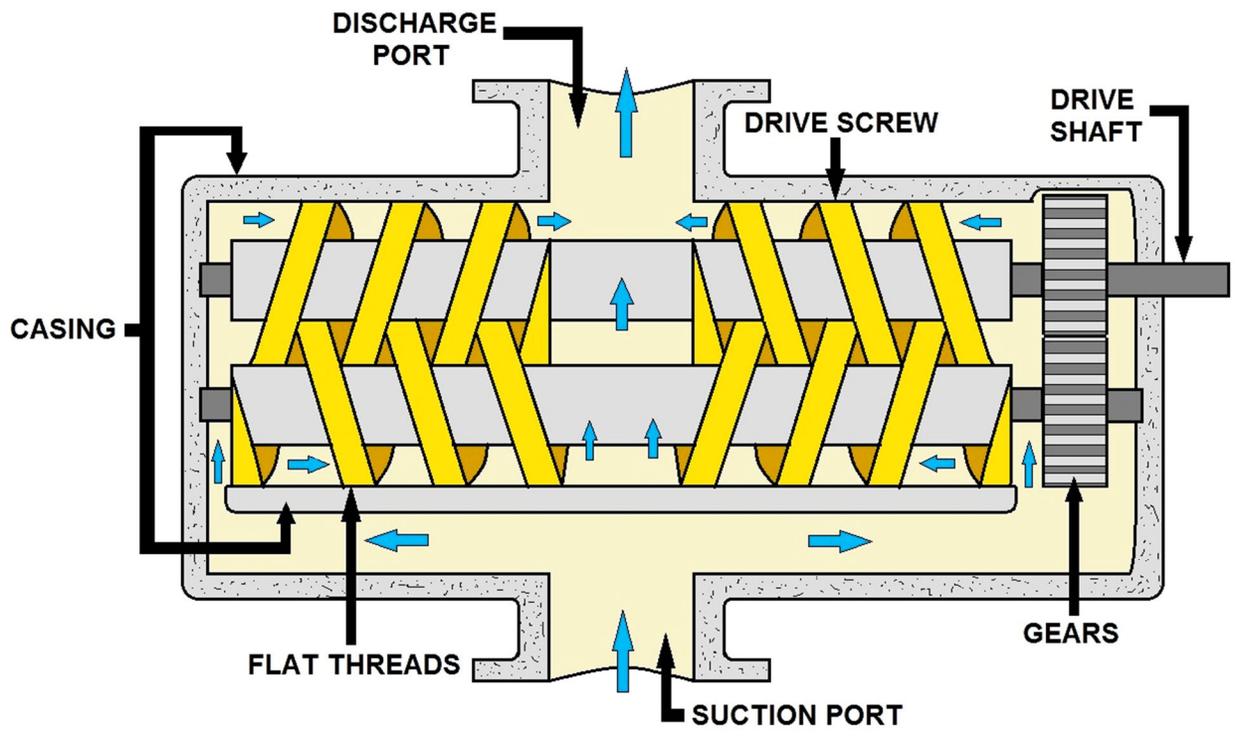
The rotor is held against the inside surface of the stator by angled link arms, bearings (which have to be within the fluid) allowing it to roll around the inner surface (un-driven).

Elastomer is used for the stator to simplify the creation of the complex internal shape, created by means of casting, and also improves the quality and longevity of the seals by progressively swelling due to absorption of water and/or other common constituents of pumped fluids. Elastomer/pumped fluid compatibility will thus need to be taken into account.

Two common designs of stator are the "Equal-walled" and the "Unequal walled". The latter, having greater elastomer wall thickness at the peaks, allows larger-sized solids to pass through because of its increased ability to distort under pressure.



PROGRESSIVE CAVITY PUMP



**POSITIVE DISPLACEMENT PUMP
SCREW TYPE**

Peristaltic Pump Sub-Section

A peristaltic pump is a type of positive displacement pump used for pumping a variety of fluids. The fluid is contained within a flexible tube fitted inside a circular pump casing (though linear peristaltic pumps have been made). A rotor with a number of "rollers", "shoes" or "wipers" attached to the external circumference compresses the flexible tube.

As the rotor turns, the part of the tube under compression closes (or "occludes") thus forcing the fluid to be pumped to move through the tube. Additionally, as the tube opens to its natural state after the passing of the cam ("restitution") fluid flow is induced to the pump. This process is called peristalsis and is used in many biological systems such as the gastrointestinal tract.



Priming a Pump

Liquid and slurry pumps can lose prime and this will require the pump to be primed by adding liquid to the pump and inlet pipes to get the pump started. Loss of "prime" is usually due to ingestion of air into the pump. The clearances and displacement ratios in pumps used for liquids and other more viscous fluids cannot displace the air due to its lower density.

Plunger Pumps

Plunger pumps are reciprocating positive displacement pumps. They consist of a cylinder with a reciprocating plunger in them. The suction and discharge valves are mounted in the head of the cylinder. In the suction stroke the plunger retracts and the suction valves open causing suction of fluid into the cylinder. In the forward stroke the plunger pushes the liquid out of the discharge valve.

Efficiency and Common Problems

With only one cylinder in plunger pumps, the fluid flow varies between maximum flow when the plunger moves through the middle positions and zero flow when the plunger is at the end positions. A lot of energy is wasted when the fluid is accelerated in the piping system. Vibration and "water hammer" may be a serious problem. In general, the problems are compensated for by using two or more cylinders not working in phase with each other.

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Compressed-Air-Powered Double-Diaphragm Pumps

One modern application of positive displacement diaphragm pumps is compressed-air-powered double-diaphragm pumps.

Run on compressed air these pumps are intrinsically safe by design, although all manufacturers offer ATEX certified models to comply with industry regulation.

Commonly seen in all areas of industry from shipping to processing, Wilden Pumps, Graco, SandPiper or ARO are generally the larger of the brands.

They are relatively inexpensive and can be used for almost any duty from pumping water out of bunds, to pumping hydrochloric acid from secure storage (dependent on how the pump is manufactured – elastomers / body construction).

Lift is normally limited to roughly 18 feet (6m) although heads can reach almost 200 Psi.



Understanding Progressing Cavity Pump Theory

Progressing cavity pumps (PCPs) are a special type of rotary positive displacement pump where the produced fluid is displaced axially at a constant rate. This characteristic enables progressing cavity pumps to produce viscous, abrasive, multiphase and gaseous fluids and slurries over a wide range of flow rates and differential pressures. Progressing cavity pumps are comprised of two helicoidal gears (rotor and stator), where the rotor is positioned inside the stator. The combination of rotational movement and geometry of the rotor inside the stator results in the formation of cavities that move axially from pump suction to pump discharge.

Rotors are typically machined from high-strength steel and then coated with a wear resistant material to resist abrasion and reduce stator/rotor friction. Stators consist of steel tubular with an elastomer core bonded to the steel. The elastomer is molded into the shape of an internal helix to match the rotor.

Progressive cavity pumps are fundamentally fixed flow rate pumps, like piston pumps and peristaltic pumps, and this type of pump needs a fundamentally different understanding to the types of pumps to which people are more commonly first introduced, namely ones that can be thought of as generating pressure.

This can lead to the mistaken assumption that all pumps can have their flow rates adjusted by using a valve attached to their outlet, but with this type of pump this assumption is a problem, since such a valve will have practically no effect on the flow rate and completely closing it will involve very high pressures being generated.

To prevent this, pumps are often fitted with cut-off pressure switches, burst disks (deliberately weak and easily replaced), or a bypass pipe that allows a variable amount a fluid to return to the inlet. With a bypass fitted, a fixed flow rate pump is effectively converted to a fixed pressure one.

At the points where the rotor touches the stator, the surfaces are generally traveling transversely, so small areas of sliding contact occur. These areas need to be lubricated by the fluid being pumped (Hydrodynamic lubrication). This can mean that more torque is required for starting, and if allowed to operate without fluid, called 'run dry', rapid deterioration of the stator can result. Progressive cavity pumps offer long life and reliable service transporting thick or lumpy substances.

Helical Rotor and a Twin Helix

The progressive cavity pump consists of a helical rotor and a twin helix, twice the wavelength and double the diameter helical hole in a rubber stator. The rotor seals tightly against the rubber stator as it rotates, forming a set of fixed-size cavities in between. The cavities move when the rotor is rotated but their shape or volume does not change. The pumped material is moved inside the cavities.

The principle of this pumping technique is frequently misunderstood. Often it is believed to occur due to a dynamic effect caused by drag, or friction against the moving teeth of the screw rotor. In reality, it is due to the sealed cavities, like a piston pump, and so has similar operational characteristics, such as being able to pump at extremely low rates, even to high pressure, revealing the effect to be purely positive displacement.

At a high enough pressure, the sliding seals between cavities will leak some fluid rather than pumping it, so when pumping against high pressures a longer pump with more cavities is more

effective, since each seal has only to deal with the pressure difference between adjacent cavities. Pumps with between two and a dozen (or so) cavities exist.

When the rotor is rotated, it rolls around the inside surface of the hole. The motion of the rotor is the same as the smaller gears of a planetary gears system. As the rotor simultaneously rotates and moves around, the combined motion of the eccentrically mounted drive shaft is in the form of a hypocycloid. In the typical case of single-helix rotor and double-helix stator, the hypocycloid is just a straight line. The rotor must be driven through a set of universal joints or other mechanisms to allow for the movement.

The rotor takes a form similar to a corkscrew, and this, combined with the off-center rotary motion, leads to the alternative name: eccentric screw pump. Different rotor shapes and rotor/stator pitch ratios exist, but are specialized in that they don't generally allow complete sealing, so reducing low speed pressure and flow rate linearity, but improving actual flow rates, for a given pump size, and/or the pump's solids handling ability

Specific designs involve the rotor of the pump being made of a steel, coated with a smooth hard surface, normally chromium, with the body (the stator) made of a molded elastomer inside a metal tube body. The elastomer core of the stator forms the required complex cavities. The rotor is held against the inside surface of the stator by angled link arms, bearings (immersed in the fluid) allowing it to roll around the inner surface (un-driven).

Elastomer

Elastomer is used for the stator to simplify the creation of the complex internal shape, created by means of casting, which also improves the quality and longevity of the seals by progressively swelling due to absorption of water and/or other common constituents of pumped fluids. Elastomer/pumped fluid compatibility will thus need to be taken into account. Two common designs of stator are the "equal-walled" and the "unequal-walled". The latter, having greater elastomer wall thickness at the peaks allows larger-sized solids to pass through because of its increased ability to distort under pressure.

The former have a constant elastomer wall thickness and therefore exceed in most other aspects such as pressure per stage, precision, heat transfer, wear and weight. They are more expensive due to the complex shape of the outer tube.

Cavities are created by the geometry of the rotor and stator where the stator has one more lobe than the rotor. The cavities are moved axially along the pump by the rotating motion of the rotor. The motion of the rotor is a combination of a clockwise rotation of the rotor along its own axis and a counterclockwise rotation of the rotor eccentrically about the axis of the stator. Because the volume of each cavity remains constant throughout the process, the pump delivers a uniform non-pulsating flow. The total pressure capability of the pump is determined by the maximum pressure that can be generated within each cavity times the total number of cavities.

PC pumps are manufactured with a variety of stator/rotor tooth combinations. Typically, artificial lift applications use a two-tooth stator and a single tooth rotor pump referred to as single-lobe pump. Higher stator/rotor tooth combinations, such as 3/2, are used to achieve higher volumetric and lift capacity although with higher torque requirements.

Understanding Pump NPSH

NPSH is an initialism for Net Positive Suction Head. In any cross-section of a generic hydraulic circuit, the NPSH parameter shows the difference between the actual pressure of a liquid in a pipeline and the liquid's vapor pressure at a given temperature. NPSH is an important parameter to take into account when designing a circuit: whenever the liquid pressure drops below the vapor pressure, liquid boiling occurs, and the final effect will be cavitation: vapor bubbles may reduce or stop the liquid flow, as well as damage the system.

Centrifugal pumps are particularly vulnerable especially when pumping heated solution near the vapor pressure, whereas positive displacement pumps are less affected by cavitation, as they are better able to pump two-phase flow (the mixture of gas and liquid), however, the resultant flow rate of the pump will be diminished because of the gas volumetrically displacing a disproportion of liquid. Careful design is required to pump high temperature liquids with a centrifugal pump when the liquid is near its boiling point.

The violent collapse of the cavitation bubble creates a shock wave that can literally carve material from internal pump components (usually the leading edge of the impeller) and creates noise often described as "pumping gravel". Additionally, the inevitable increase in vibration can cause other mechanical faults in the pump and associated equipment.

A somewhat simpler informal way to understand NPSH...

Fluid can be pushed down a pipe with a great deal of force. The only limit is the ability of the pipe to withstand the pressure. However, a liquid cannot be pulled up a pipe with much force because bubbles are created as the liquid evaporates into a gas. The greater the vacuum created, the larger the bubble, so no more liquid will flow into the pump.

Rather than thinking in terms of the pump's ability to pull the fluid, the flow is limited by the ability of gravity and air pressure to push the fluid into the pump. The atmosphere pushes down on the fluid, and if the pump is below the tank, the weight of the fluid from gravity above the pump inlet also helps. Until the fluid reaches the pump, those are the only two forces providing the push. Friction loss and vapor pressure must also be considered.

Friction loss limits the ability of gravity and air pressure to push the water toward the pump at high speed. Vapor pressure refers to the point at which bubbles form in the liquid. NPSH is a measure of how much spare pull you have before the bubbles form.

Some helpful information regarding atmospheric pressure; Atmospheric pressure is always naturally occurring and is always around us. At sea level, it equates to 101.325 kPa or approximately 14 Psi OR 10 meters of liquid pressure head. As we move higher up mountains, the air gets thinner and the atmospheric pressure reduces.

This should be taken into account when designing pumping systems. The reason there is atmospheric pressure is simply due to earth's gravity and its position in our solar system. It is a natural phenomenon and we are very lucky to have it as water wells and bores with shallow aquifers allow us to use this atmospheric pressure to our advantage.

We all know that pressure gauges exist on pumping systems and other machines to give us an indication of what performances are being achieved. We also use known pressures versus known performance in order to create a reference for system designs. An example would be an experienced pump technician or plumber knowing that a pressure of between 300 kPa and 500 kPa will provide adequate and comfortable pressure for household use.

A typical pressure gauge reads what is known as 'Gauge Pressure,' or pressure relative to atmospheric pressure. An 'Absolute Pressure' gauge displays atmospheric pressure (typically 100 kPa or 14 psi or 10 meters of liquid pressure head) before any system had been connected. Manufacturers set typical gage pressure gauges to read ZERO at sea level as a standard, assuming designers will make allowances for the atmospheric pressure calculations themselves. Knowing this simple fact can make NPSH easier to understand. If we now know that there is 100 kPa or 10 meters of head pressure, plus or minus whatever the gage pressure gauge shows, then we can safely see that this gives us an instant advantage of 10 meters of head pressure at sea level.

This means we can borrow against this and drop a maximum of 10 meters into or under the ground (or below sea level) reducing the gauge to zero and still get natural 'push' into our pump. Great for wells and bores with shallow aquifers within this depth! It is important to note that to get to exactly 10 meters may be difficult, but with the correct pipework and system design, it is possible to get very close.

Once NPSH is fully understood, sizing and controlling pumps and pumping machines is a much simpler task.

NPSH is the liquid suction force at the intake of a pump. In other words, the force of a liquid naturally "pushing" into a pump from gravity pressure plus liquid head pressure only - into a single pump intake.

This means;

NPSH = the net (left over) positive pressure of suction force into a pump intake after friction loss has occurred. Liquid head height or liquid head pressure + gravity pressure, minus friction loss, leaves a net head pressure of force into the pump. If we want to pump some amount of liquid, we have to ensure that this liquid can reach the center line of the suction point of the pump. NPSH represents the head (pressure and gravity head) of liquid in the suction line of the pump that will overcome the friction along the suction line.

NPSHR is the amount of liquid pressure required at the intake port of a pre-designed and manufactured pump. This is known as NPSHR (Net Positive Suction Head Required). The pump manufacturer will usually clearly have a NPSH curve to assist you in the correct installation.

NPSHA is the amount (A = available) to the pump intake after pipe friction losses and head pressures have been taken into account.

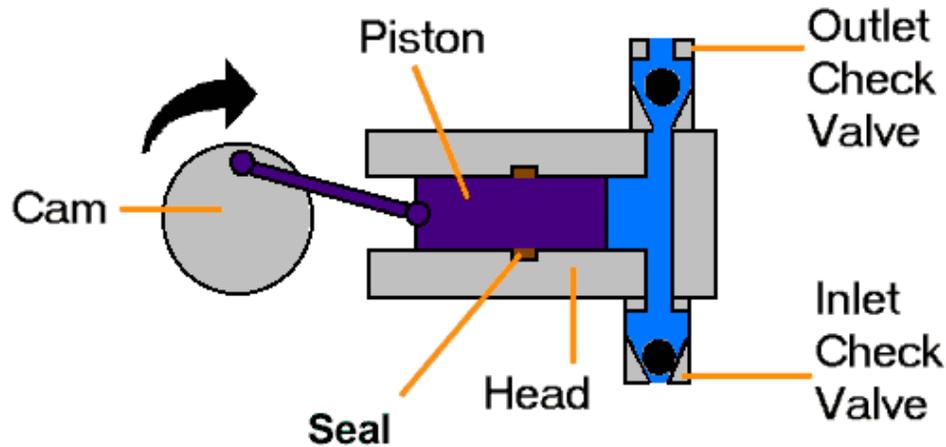
The Reason for This Requirement?

When the pump is receiving liquid at intake port and the impeller is pushing the liquid out the discharge port, they are effectively trying to tear each other apart because the pump is changing the liquid movement by a pressure increase at the impeller vanes, (general pump installations). Insufficient NPSHR will cause a low or near-vacuum pressure (negative NPSHA) to exist at the pump intake. This will cause the liquid to boil and cause cavitation, and the pump will not receive the liquid fast enough because it will be attempting to pump vapor. Cavitation will lower pump performance and damage pump internals. At low temperatures the liquid can "hold together" (remain fluid) relatively easily, hence a lower NPSH requirement. However, at higher temperatures, the higher vapor pressure starts the boiling process much quicker, hence a high NPSH requirement.

- ✓ Water will boil at lower temperatures under lower pressures. Conversely its boiling point is higher at higher pressures.

- ✓ Water boils at 100 degrees Celsius at sea level and an atmospheric pressure of 1 bar.
- ✓ Vapor Pressure is the pressure of a gas in equilibrium with its liquid phase at a given temperature. If the vapor pressure at a given temperature is greater than the pressure of the atmosphere above the liquid, then the liquid will boil. (This is why water boils at a lower temperature high in the mountains).
- ✓ At normal atmospheric pressure minus 5 psi (or -0.35 bar) water will boil at 89 degrees Celsius.
- ✓ At normal atmospheric pressure minus 10 psi (or -0.7 bar) water will boil at 69 degrees Celsius.
- ✓ At a positive pressure of +12 psi or +0.82 bar above atmospheric, water will boil at 118 degrees Celsius.

Reciprocating Pump Sub-Section



Typical reciprocating pumps are

- Plunger pumps
- Diaphragm pumps

A plunger pump consists of a cylinder with a reciprocating plunger in it. The suction and discharge valves are mounted in the head of the cylinder. In the suction stroke the plunger retracts and the suction valves open causing suction of fluid into the cylinder. In the forward stroke the plunger pushes the liquid out of the discharge valve.

With only one cylinder the fluid flow varies between maximum flow when the plunger moves through the middle positions and zero flow when the plunger is at the end positions. A lot of energy is wasted when the fluid is accelerated in the piping system. Vibration and "water hammer" may be a serious problem. In general, the problems are compensated for by using two or more cylinders not working in phase with each other.

In diaphragm pumps, the plunger pressurizes hydraulic oil which is used to flex a diaphragm in the pumping cylinder. Diaphragm valves are used to pump hazardous and toxic fluids. An example of the piston displacement pump is the common hand soap pump.

Gear Pump

This uses two meshed gears rotating in a closely fitted casing. Fluid is pumped around the outer periphery by being trapped in the tooth spaces. It does not travel back on the meshed part, since the teeth mesh closely in the center. Widely used on car engine oil pumps. It is also used in various hydraulic power packs.

Progressing Cavity Pump

Widely used for pumping difficult materials such as sewage sludge contaminated with large particles, this pump consists of a helical shaped rotor, about ten times as long as its width. This can be visualized as a central core of diameter x , with typically a curved spiral wound around of thickness half x , although of course in reality it is made from one casting. This shaft fits inside a heavy duty rubber sleeve, of wall thickness typically x also. As the shaft rotates, fluid is gradually forced up the rubber sleeve. Such pumps can develop very high pressure at quite low volumes.

Diaphragm Pumps

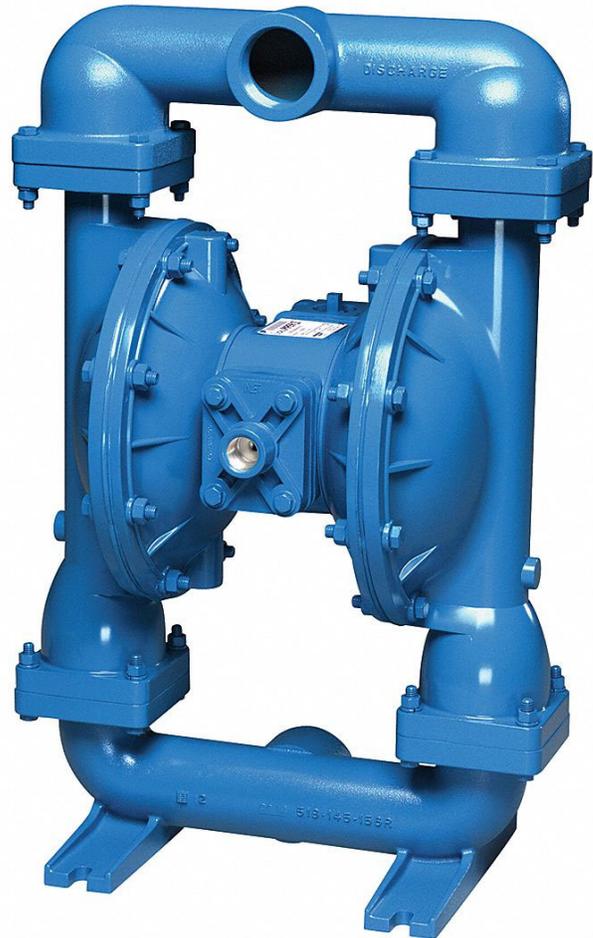
A diaphragm pump is a positive displacement pump that uses a combination of the reciprocating action of a rubber, thermoplastic or Teflon diaphragm and suitable non-return check valves to pump a fluid. Sometimes this type of pump is also called a membrane pump. Diaphragm Pumps are used extensively in many industries and can handle a very wide variety of liquids.

Diaphragm Pumps are in the category of "positive displacement" pumps because their flowrates do not vary much with the discharge "head" (or pressure) the pump is working against (for a given pump speed).

Diaphragm pumps can transfer liquids with low, medium or high viscosities and also liquids with a large solids content. They can also handle many aggressive chemicals such as acids because they can be constructed with a wide variety of body materials and diaphragms.

There are three main types of diaphragm pumps:

- ✓ Those in which the diaphragm is sealed with one side in the fluid to be pumped, and the other in air or hydraulic fluid. The diaphragm is flexed, causing the volume of the pump chamber to increase and decrease. A pair of non-return check valves prevent reverse flow of the fluid.
- ✓ Those employing volumetric positive displacement where the prime mover of the diaphragm is electro-mechanical, working through a crank or geared motor drive. This method flexes the diaphragm through simple mechanical action, and one side of the diaphragm is open to air.
- ✓ Those employing one or more unsealed diaphragms with the fluid to be pumped on both sides. The diaphragm(s) again are flexed, causing the volume to change.



When the volume of a chamber of either type of pump is increased (the diaphragm moving up), the pressure decreases, and fluid is drawn into the chamber. When the chamber pressure later increases from decreased volume (the diaphragm moving down), the fluid previously drawn in is forced out. Finally, the diaphragm moving up once again draws fluid into the chamber, completing the cycle. This action is similar to that of the cylinder in an internal combustion engine. The most popular type of diaphragm pump is the Air-Operated Diaphragm Pump.

These pumps use compressed air as their power supply. They also include two chambers with a diaphragm, inlet check valve and outlet check valve in each chamber. The air supply is shifted from one chamber to another with an air spool valve that is built into the pump. This continual

shifting of air from one chamber to another (to the backside of the diaphragm) forces liquid out of one chamber and into the discharge piping while the other chamber is being filled with liquid.

There is some pulsation of discharge flow in Air-Operated Diaphragm Pumps. This pulsating flow can be reduced somewhat by using pulsation dampeners in the discharge piping.

Characteristics Diaphragm Pumps

- ✓ have good suction lift characteristics, some are low pressure pumps with low flow rates; others are capable of higher flow rates, dependent on the effective working diameter of the diaphragm and its stroke length. They can handle sludges and slurries with a relatively high amount of grit and solid content.
- ✓ suitable for discharge pressure up to 1,200 bar.
- ✓ have good dry running characteristics.
- ✓ can be used to make artificial hearts.
- ✓ are used to make air pumps for the filters on small fish tanks.
- ✓ can be up to 97% efficient.
- ✓ have good self-priming capabilities.
- ✓ can handle highly viscous liquids.
- ✓ are available for industrial, chemical and hygienic applications.
- ✓ cause a pulsating flow that may cause water hammer.

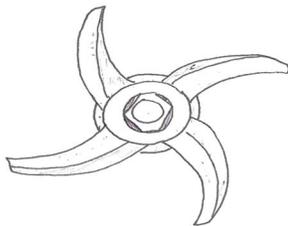
Hyperlink to the Glossary and Appendix

<http://www.abctlc.com/downloads/PDF/PumpGlossary.pdf>

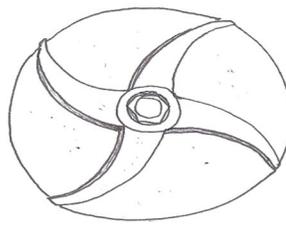
Vapor Pressure and Cavitation Sub-Section

Cavitation is the formation and then immediate implosion of cavities in a liquid – i.e. small liquid-free zones ("bubbles") – that are the consequence of forces acting upon the liquid. It usually occurs when a liquid is subjected to rapid changes of pressure that cause the formation of cavities where the pressure is relatively low.

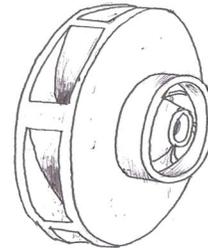
Cavitation is a significant cause of wear in some engineering contexts. When entering high pressure areas, cavitation bubbles that implode on a metal surface cause cyclic stress. These results in surface fatigue of the metal causing a type of wear also called "cavitation". The most common examples of this kind of wear are pump impellers and bends when a sudden change in the direction of liquid occurs. Cavitation is usually divided into two classes of behavior: inertial (or transient) cavitation and non-inertial cavitation.



OPEN



SEMI-OPEN



CLOSED

COMMONLY FOUND IMPELLER TYPES

Inertial Cavitation

Inertial cavitation is the process where a void or bubble in a liquid rapidly collapses, producing a shock wave. Inertial cavitation occurs in nature in the strikes of mantis shrimps and pistol shrimps, as well as in the vascular tissues of plants. In man-made objects, it can occur in control valves, pumps, propellers and impellers.

Non-Inertial Cavitation

Non-inertial cavitation is the process in which a bubble in a fluid is forced to oscillate in size or shape due to some form of energy input, such as an acoustic field. Such cavitation is often employed in ultrasonic cleaning baths and can also be observed in pumps, propellers, etc. Since the shock waves formed by cavitation are strong enough to significantly damage moving parts, cavitation is usually an undesirable phenomenon. It is specifically avoided in the design of machines such as turbines or propellers, and eliminating cavitation is a major field in the study of fluid dynamics.

To understand Cavitation, you must first understand vapor pressure. Vapor pressure is the pressure required to boil a liquid at a given temperature. Soda water is a good example of a high vapor pressure liquid. Even at room temperature the carbon dioxide entrained in the soda is released. In a closed container, the soda is pressurized, keeping the vapor entrained.

Temperature affects vapor pressure as well, raises the water's temperature to 212°F and the vapors are released because at that increased temperature the vapor pressure is greater than the atmospheric pressure.

Pump cavitation occurs when the pressure in the pump inlet drops below the vapor pressure of the liquid. Vapor bubbles form at the inlet of the pump and are moved to the discharge of the pump where they collapse, often taking small pieces of the pump with them. Cavitation is often characterized by:

- ✓ Loud noise often described as a grinding or “marbles” in the pump.
- ✓ Loss of capacity (bubbles are now taking up space where liquid should be).
- ✓ Pitting damage to parts as material is removed by the collapsing bubbles.

Noise is a nuisance and lower flows will slow your process, but pitting damage will ultimately decrease the life of the pump.

In general, cavitation performance is related to some “critical” value:

$NPSHA (=available) > NPSHc \text{ or } NPSHR (=critical \text{ or } required)$

Typical “critical” characteristics identified for centrifugal pumps:

- Incipient cavitation ($NPSHi$)
- Developed cavitation causing 3% head drop ($NPSH3\%$)
- Developed cavitation causing complete head breakdown (vapor lock).

Choice of $NPSHR$ is rather arbitrary, but usually $NPSHR=NPSH3\%$

Alternative choices:

- $NPSHR=NPSH1\%$ or $NPSHR=NPSH5\%$
- $NPSHR=NPSHi$ (cavitation free operation)

Cavitation causes or may cause:

- Performance loss (head drop)
- Material damage (cavitation erosion)
- Vibrations
- Noise
- Vapor lock (if suction pressure drops below break-off value)

The definition of $NPSHA$ is simple: Static head + surface pressure head - the vapor pressure of your product - the friction losses in the piping, valves and fittings.

But to really understand it, you first have to understand a couple of other concepts:

- ✓ Cavitation is what net positive suction head ($NPSH$) is all about, so you need to know a little about cavitation.
- ✓ Vapor Pressure is another term we will be using. The product's vapor pressure varies with the fluid's temperature.
- ✓ Specific gravity plays an important part in all calculations involving liquid. You have to be familiar with the term.
- ✓ You have to be able to read a pump curve to learn the $N.P.S.H.$ required for your pump.
- ✓ You need to understand how the liquid's velocity affects its pressure or head.
- ✓ It is important to understand why we use the term Head instead of Pressure when we make our calculations.
- ✓ Head loss is an awkward term, but you will need to understand it.

You will have to be able to calculate the head loss through piping, valves and fittings.

- ✓ You must know the difference between gage pressure and absolute pressure.
- ✓ Vacuum is often a part of the calculations, so you are going to have to be familiar with the terms we use to describe vacuum.

Let's look at each of these concepts in a little more detail

- ✓ Cavitation means cavities or holes in liquid. Another name for a hole in a liquid is a bubble, so cavitation is all about bubbles forming and collapsing.
- ✓ Bubbles take up space so the capacity of our pump drops.
- ✓ Collapsing bubbles can damage the impeller and volute. This makes cavitation a problem for both the pump and the mechanical seal.
- ✓ Vapor pressure is about liquids boiling. If I asked you, "at what temperature does water boil?" You could say 212° F. or 100° C., but that is only true at atmospheric pressure. Every product will boil (make bubbles) at some combination of pressure and temperature. If you know the temperature of your product you need to know its vapor pressure to prevent boiling and the formation of bubbles. In the charts section of this web site you will find a vapor pressure chart for several common liquids.
- ✓ Specific gravity is about the weight of the fluid. Using 4°C (39° F) as our temperature standard we assign fresh water a value of one. If the fluid floats on this fresh water it has a specific gravity is less than one. If the fluid sinks in this water the specific gravity of the fluid is greater than one.
- ✓ Look at any pump curve and make sure you can locate the values for head, capacity, best efficiency point (B.E.P.), efficiency, net positive suction head (NPSH), and horse power required. If you cannot do this, have someone show you where they are located.
- ✓ Liquid velocity is another important concept. As a liquid's velocity increases, its pressure (90° to the flow) decreases. If the velocity decreases the pressure increases. The rule is: velocity times pressure must remain a constant.
- ✓ "Head" is the term we use instead of pressure. The pump will pump any liquid to a given height or head depending upon the diameter and speed of the impeller. The amount of pressure you get depends upon the weight (specific gravity) of the liquid. The pump manufacturer does not know what liquid the pump will be pumping so he gives you only the head that the pump will generate. You have to figure out the pressure using a formula described later on in this paper.
- ✓ Head (feet) is a convenient term because when combined with capacity (gallons or pounds per minute) you come up with the conversion for horsepower (foot pounds per minute).
- ✓ "Head loss through the piping, valves and fittings" is another term we will be using. Pressure drop is a more comfortable term for most people, but the term "pressure" is not used in most pump calculations so you could substitute the term "head drop" or "loss of head" in the system. To calculate this loss, you will need to be able to read charts like those you will find in the "charts you can use" section in the home page of this web site. They are labeled Friction loss for water and Resistance coefficients for valves and fittings.
- ✓ Gage and absolute pressure. Add atmospheric pressure to the gage pressure and you get absolute pressure.
- ✓ Vacuum is a pressure less than atmospheric. At sea level atmospheric pressure is 14.7 psi. (760 mm of Mercury). Vacuum gages are normally calibrated in inches or millimeters of mercury.

Hyperlink to the Glossary and Appendix

<http://www.abctlc.com/downloads/PDF/PumpGlossary.pdf>

To calculate the net positive suction head (NPSH) of your pump and determine if you are going to have a cavitation problem, you will need access to several additional pieces of information:

- ✓ The curve for your pump. This pump curve is supplied by the pump manufacturer. Someone in your plant should have a copy. The curve is going to show you the Net Positive Suction Head (NPSH) required for your pump at a given capacity. Each pump is different so make sure you have the correct pump curve and use the numbers for the impeller diameter on your pump. Keep in mind that this NPSH required was for cold, fresh water.
- ✓ A chart or some type of publication that will give you the vapor pressure of the fluid you are pumping.
- ✓ If you would like to be a little more exact, you can use a chart to show the possible reduction in NPSH required if you are pumping hot water or light hydrocarbons.
- ✓ You need to know the specific gravity of your fluid. Keep in mind that the number is temperature sensitive. You can get this number from a published chart, ask some knowledgeable person at your plant, or take a reading on the fluid using a hydrometer.
- ✓ Charts showing the head loss through the size of piping you are using between the source and the suction eye of your pump. You will also need charts to calculate the loss in any fittings, valves, or other hardware that might have been installed in the suction piping.
- ✓ Is the tank you are pumping from at atmospheric pressure or is it pressurized in some manner? Maybe it is under a vacuum?
- ✓ You need to know the atmospheric pressure at the time you are making your calculation. We all know atmospheric pressure changes throughout the day, but you have to start somewhere.

The formulas for converting pressure to head and head back to pressure in the imperial system are as follows:

- o sg. = specific gravity
- o pressure = pounds per square inch
- o head = feet

You also need to know the formulas that show you how to convert vacuum readings to feet of head. Here are a few of them:

To convert surface pressure to feet of liquid; use one of the following formulas:

- ✓ Inches of mercury x 1.133 / specific gravity = feet of liquid
- ✓ Pounds per square inch x 2.31 / specific gravity = feet of liquid
- ✓ Millimeters of mercury / (22.4 x specific gravity) = feet of liquid

There are different ways to think about net positive suction head (NPSH) but they all have two terms in common.

- ✓ NPSHA (net positive suction head available)
- ✓ NPSHR (net positive suction head required)

Motor-Pump Coupling Sub-Section



Finger is shown pointing to a Lantern Ring. Notice the packing on both sides of the ring. The packing joints need to be staggered and the purpose of this device is to allow air to the Stuffing Box.

Motor-Pump alignment should be an important part of any maintenance program. Most pump distress events or failures) have their root cause in the misalignment of the pump to motor. Misaligned pumps can even consume up to 15% more energy input than well-aligned pumps.

Even small pumps can generate big losses when shaft misalignment imposes reaction forces on shafts, even if the flexible coupling suffers no immediate damage. The inevitable result is premature failure of shaft seals and bearings.

Performing precise alignment, therefore, pays back through preventing the costly consequences of poor alignment. Indeed, using precise alignment methods is one of the principal attributes of a reliability focused organization.

Good alignment has been demonstrated to lead to:

- Lower energy losses due to friction and vibration
- Increased productivity through time savings and repair avoidance
- Reduced parts expense and lower inventory requirements

Further, in order to insure good alignment, the alignment must be checked and correctly set when:

- A pump and drive unit are initially installed (before grouting the baseplate, after grouting the baseplate, after connecting the piping, and after the first run).

- After a unit has been serviced.
- The process operating temperature of the unit has changed.
- Changes have been made to the piping system.
- Periodically, as a preventive maintenance check of the alignment, following the plant operating procedures for scheduled checks or maintenance.

Proper shaft alignment is achieved by moving the motor. The motor is shimmed vertically to achieve the proper elevation to align it to the pump, both parallel (offset) and angular. The motor is then moved horizontally to achieve proper horizontal placement for aligning the shaft centerlines, both parallel and angular. The motor is moved horizontally by the use of jacking bolts, or by the use of pry bars, hammers, or other tools.

Motors are normally easier to move, since the motor is not piped into a process system. A short run of flexible conduit is most often used to run the electrical wiring from a local disconnect, or a rigid conduit, to the motor termination box. This allows for ease of movement of the motor.

Motor-Pump alignment is critical for these reasons:

- It minimizes the forces of misalignment acting upon the bearings and seals of both components.
- It minimizes wear of the coupling.
- It can help reduce energy costs.
- It maximizes the life of the machine components by minimizing wear, increasing time between failures, and reducing vibration.

The Pump Coupling Serves Two Main Purposes:

- It couples or joins the two shafts together to transfer the rotation from motor to impeller.
- It compensates for small amounts of misalignment between the pump and the motor.

Remember that any coupling is a device in motion. If you have a 4-inch diameter coupling rotating at 1800 rpm, its outer surface is traveling about 20 mph. With that in mind, can you think of safety considerations?

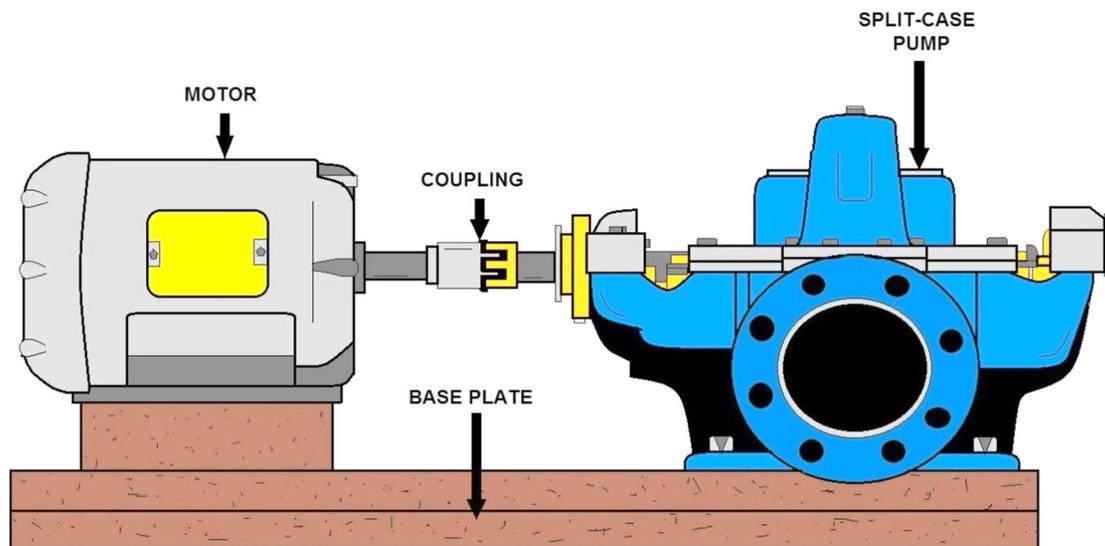
There are three commonly used types of couplings: **Rigid**, **Flexible** and **V-belts**.

Rigid Coupling

Rigid couplings are most commonly used on vertically mounted pumps. The rigid coupling is usually specially keyed or constructed for joining the coupling to the motor shaft and the pump shaft. There are two types of rigid couplings: the flanged coupling, and the split coupling.

Flexible Coupling

The flexible coupling provides the ability to compensate for small shaft misalignments. Shafts should be aligned as close as possible, regardless. The greater the misalignment, the shorter the life of the coupling. Bearing wear and life are also affected by misalignment.



FLEXIBLE COUPLED PUMP AND MOTOR DIAGRAM

Alignment of Flexible and Rigid Couplings

Both flexible and rigid couplings must be carefully aligned before they are connected. Misalignment will cause excessive heat and vibration, as well as bearing wear. Usually, the noise from the coupling will warn you of shaft misalignment problems.

Three types of shaft alignment problems are shown in the pictures below:



Different couplings will require different alignment procedures. We will look at the general procedures for aligning shafts.

1. Place the coupling on each shaft.
2. Arrange the units so they appear to be aligned. (Place shims under the legs of one of the units to raise it.)
3. Check the run-out, or difference between the driver and driven unit, by rotating the shafts by hand.
4. Turn both units so that the maximum run-out is on top.

Now you can check the units for both parallel and angular alignment. Many techniques are used, such as: straight edge, needle deflection (dial indicators), calipers, tapered wedges, and laser alignment.

V-Belt Drive Couplings

V-belt drives connect the pump to the motor. A pulley is mounted on the pump and motor shaft. One or more belts are used to connect the two pulleys. Sometimes a separately mounted third pulley is used. This idler pulley is located off centerline between the two pulleys, just enough to allow tensioning of the belts by moving the idler pulley. An advantage of driving a pump with belts is that various speed ratios can be achieved between the motor and the pump. Alignment is still important, but less critical using v-belts.

Shaft Bearings

There are three types of bearings commonly used: ball bearings, roller bearings, and sleeve bearings. Regardless of the particular type of bearings used within a system--whether it is ball bearings, a sleeve bearing, or a roller bearing--the bearings are designed to carry the loads imposed on the shaft.

Bearings must be lubricated. Without proper lubrication, bearings will overheat and seize.

Proper lubrication means using the correct type and the correct amount of lubrication. Similar to motor bearings, shaft bearings can be lubricated either by oil or by grease.

Packing Seals

How can we prevent the water from leaking along the pump shaft?

A special seal is used to prevent liquid leaking out along the shaft. There are two types of seals commonly used:

- **Packing seal**
- **Mechanical seal**



Packing Seal Leakage

During pump operation, a certain amount of leakage around the shafts and casings normally takes place.

This leakage must be controlled for two reasons:

(1) to prevent excessive fluid loss from the pump, and

(2) to prevent air from entering the area where the pump suction pressure is below atmospheric pressure.

The amount of leakage that can occur without limiting pump efficiency determines the type of shaft sealing selected. Shaft sealing systems are found in every pump. They can vary from simple packing to complicated sealing systems.

Packing is the most common and oldest method of sealing. Leakage is checked by the compression of packing rings that causes the rings to deform and seal around the pump shaft and casing.

The packing is lubricated by liquid moving through a lantern ring in the center of the packing. The sealing slows down the rate of leakage. It does not stop it completely, since a certain amount of leakage is necessary during operation.

Mechanical seals are rapidly replacing conventional packing on centrifugal pumps.

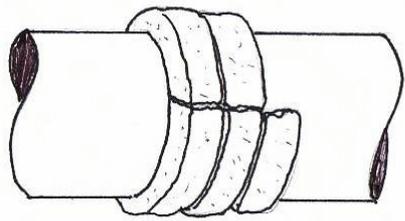
Some of the reasons for the use of mechanical seals are as follows:

1. *Leaking causes bearing failure by contaminating the oil with water. This is a major problem in engine-mounted water pumps.*

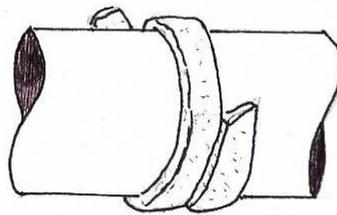
2. Properly installed mechanical seals eliminate leakoff on idle (vertical) pumps. This design prevents the leak (water) from bypassing the water flinger and entering the lower bearings. Leakoff causes two types of seal leakage:

- a. Water contamination of the engine lubrication oil.
- b. Loss of treated fresh water that causes scale buildup in the cooling system.

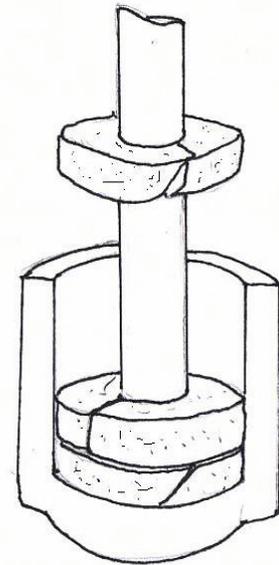
Centrifugal pumps are versatile and have many uses. This type of pump is commonly used to pump all types of water and wastewater flows, including thin sludge.



INCORRECT
(butt joint)

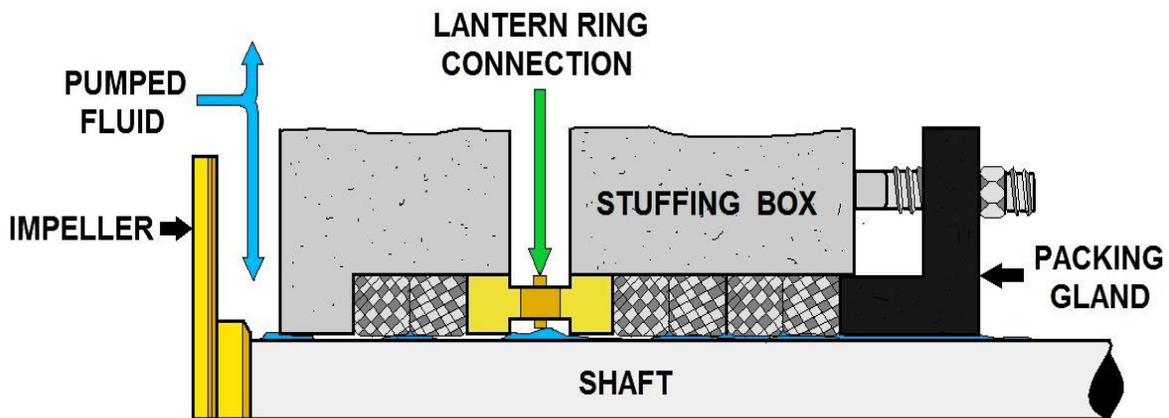


CORRECT
(skive joint)
(stagger @ 45 degree angle)



Skive Packing Procedure

Install one ring at a time: Make sure it is clean, and has not picked up any dirt in handling. If desired, lubricate the shaft inside of the stuffing box. Seat rings firmly (except PTFE filament and Graphite yarn packing, which should be snugged up very gently, then tightened gradually after the pump is on stream). Joints of successive rings should be staggered and kept at least 90° apart. Each individual ring should be firmly seated with a tamping tool. When enough rings have been individually seated so that the nose of the gland will reach them, individual tamping should be supplemented by the gland.



LANTERN RING BETWEEN PACKING FOR COOL / CLEAN FLUID BARRIER



Finger is shown pointing to a Lantern Ring. This old school method of sealing a pump is still out there. Notice the packing on both sides of the ring. The packing joints need to be staggered and the purpose of this device is to allow pressurized cooling water to the Stuffing Box.

Lantern Rings

Lantern rings are used to supply clean water along the shaft. This helps to prevent grit and air from reaching the area. Another component is the slinger ring. The slinger ring is an important part of the pump because it is used to protect the bearings. Other materials can be used to prevent this burier.

Mechanical Seals

Mechanical seals are commonly used to reduce leakage around the pump shaft. There are many types of mechanical seals. The photograph below illustrates the basic components of a mechanical seal. Similar to the packing seal, clean water is fed at a pressure greater than that of the liquid being pumped. There is little or no leakage through the mechanical seal. The wearing surface must be kept extremely clean. Even fingerprints on the wearing surface can introduce enough dirt to cause problems.



What care should be taken when storing mechanical seals?



Mechanical Seals

Wear Rings

Not all pumps have wear rings. However, when they are included, they are usually replaceable. Wear rings can be located on the suction side and head side of the volute. Wear rings could be made of the same metal but of different alloys. The wear ring on the head side is usually a harder alloy.

It's called a "**WEAR RING**" and what would be the purpose?

Mechanical Seals- Detailed

Mechanical seals are rapidly replacing conventional packing as the means of controlling leakage on rotary and positive-displacement pumps.

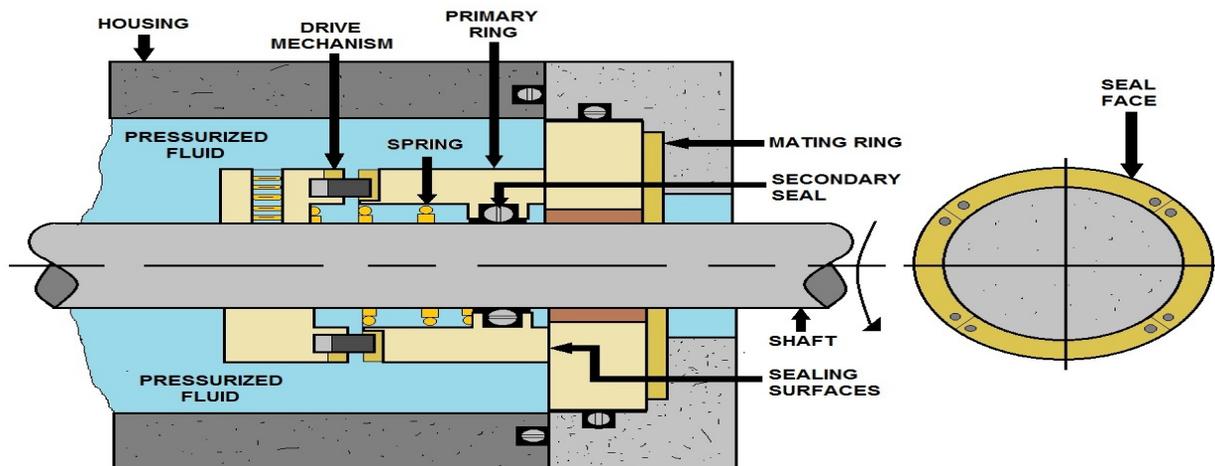
Mechanical seals eliminate the problem of excessive stuffing box leakage, which causes failure of pump and motor bearings and motor windings.

Mechanical seals are ideal for pumps that operate in closed systems (such as fuel service and air-conditioning, chilled-water, and various cooling systems). They not only conserve the fluid being pumped, but also improve system operation.

The type of material used for the seal faces will depend upon the service of the pump. Most water service pumps use a carbon material for one of the seal faces and ceramic (tungsten carbide) for the other. When the seals wear out, they are simply replaced.

You should replace a mechanical seal whenever the seal is removed from the shaft for any reason, or whenever leakage causes undesirable effects on equipment or surrounding spaces. Do not touch a new seal on the sealing face because body acid and grease or dirt will cause the seal to pit prematurely and leak.

Mechanical shaft seals are positioned on the shaft by stub or step sleeves. Shaft sleeves are chamfered (beveled) on the outboard ends for easy mechanical seal mounting. Mechanical shaft seals serve to ensure that position liquid pressure is supplied to the seal faces under all conditions of operation. They also ensure adequate circulation of the liquid at the seal faces to minimize the deposit of foreign matter on the seal parts.



MECHANICAL SEAL DIAGRAM

Pump Operating Problems

If a centrifugal pump **DOES NOT DELIVER ANY LIQUID**, the trouble may be caused by (1) insufficient priming; (2) insufficient speed of the pump; (3) excessive discharge pressure, such as might be caused by a partially closed valve or some other obstruction in the discharge line; (4) excessive suction lift; (5) clogged impeller passages; (6) the wrong direction of rotation (this may occur after motor overhaul); (7) clogged suction screen (if used); (8) ruptured suction line; or (9) loss of suction pressure.

If a centrifugal pump delivers some liquid but operates at **INSUFFICIENT CAPACITY**, the trouble may be caused by (1) air leakage into the suction line; (2) air leakage into the stuffing boxes in pumps operating at less than atmospheric pressure; (3) insufficient pump speed; (4) excessive suction lift; (5) insufficient liquid on the suction side; (6) clogged impeller passages; (7) excessive discharge pressure; or (8) mechanical defects, such as worn wearing rings, impellers, stuffing box packing, or sleeves.

If a pump **DOES NOT DEVELOP DESIGN DISCHARGE PRESSURE**, the trouble may be caused by (1) insufficient pump speed; (2) air or gas in the liquid being pumped; (3) mechanical defects, such as worn wearing rings, impellers, stuffing box packing, or sleeves; or (4) reversed rotation of the impeller (3-phase electric motor-driven pumps).

If a pump **WORKS FOR A WHILE AND THEN FAILS TO DELIVER LIQUID**, the trouble may be caused by (1) air leakage into the suction line; (2) air leakage in the stuffing boxes; (3) clogged water seal passages; (4) insufficient liquid on the suction side; or (5) excessive heat in the liquid being pumped.

If a motor-driven centrifugal pump **DRAWS TOO MUCH POWER**, the trouble will probably be indicated by overheating of the motor. The basic causes may be (1) operation of the pump to excess capacity and insufficient discharge pressure; (2) too high viscosity or specific gravity of the liquid being pumped; or (3) misalignment, a bent shaft, excessively tight stuffing box packing, worn wearing rings, or other mechanical defects.

VIBRATION of a centrifugal pump is often caused by (1) misalignment; (2) a bent shaft; (3) a clogged, eroded, or otherwise unbalanced impeller; or (4) lack of rigidity in the foundation. Insufficient suction pressure may also cause vibration and cavitation, as well as noisy operation and fluctuating discharge pressure, particularly in pumps that handle hot or volatile liquids. If the pump fails to build up pressure when the discharge valve is opened and the pump comes up to normal operating speed, proceed as follows:

1. Shut the pump discharge valve.
2. Secure the pump.
3. Open all valves in the pump suction line.
4. Prime the pump (**fill casing with the liquid being pumped**) and be sure that all air is expelled through the air cocks on the pump casing.
5. Restart the pump. If the pump is electrically driven, be sure the pump is rotating in the correct direction.
6. Open the discharge valve to “load” the pump. If the discharge pressure is not normal when the pump is up to its proper speed, the suction line may be clogged, or an impeller may be broken. It is also possible that air is being drawn into the suction line or into the casing. If any of these conditions exist, stop the pump and continue troubleshooting according to the technical manual for that unit.



Some of the operating problems you may encounter with centrifugal pumps as an Operator, together with the probable causes, are discussed in the following pages

Maintenance of Centrifugal Pumps

When properly installed, maintained and operated, centrifugal pumps are usually trouble-free. Some of the most common preventative and corrective maintenance actions that you may be required to perform are discussed in the following sections.

Repacking

Lubrication of the pump packing is extremely important. The quickest way to wear out the packing is to forget to open the water piping to the seals or stuffing boxes. If the packing is allowed to dry out, it will score the shaft. When operating a centrifugal pump, be sure there is always a slight trickle of water coming out of the stuffing box or seal. How often the packing in a centrifugal pump should be renewed depends on several factors, such as the type of pump, condition of the shaft sleeve, and hours in use.

To ensure the longest possible service from pump packing, make certain the shaft or sleeve is smooth when the packing is removed from a gland. Rapid wear of the packing will be caused by roughness of the shaft sleeve (or shaft where no sleeve is installed). If the shaft is rough, it should be sent to the machine shop for a finishing cut to smooth the surface. If it is very rough, or has deep ridges in it, it will have to be renewed.

It is absolutely necessary to use the correct packing. When replacing packing, be sure the packing fits uniformly around the stuffing box. If you have to flatten the packing with a hammer to make it fit, **YOU ARE NOT USING THE RIGHT SIZE**. Pack the box loosely, and set up the packing gland lightly. Allow a liberal leak-off for stuffing boxes that operate above atmospheric pressure.

Next, start the pump. Let it operate for about 30 minutes before you adjust the packing gland for the desired amount of leak-off. This gives the packing time to run-in and swell. You may then begin to adjust the packing gland. Tighten the adjusting nuts one flat at a time. Wait about 30 minutes between adjustments. Be sure to tighten the same amount on both adjusting nuts. If you pull up the packing gland unevenly (or cocked), it will cause the packing to overheat and score the shaft sleeves. Once you have the desired leak-off, check it regularly to make certain that sufficient flow is maintained.

Mechanical Seals

Mechanical seals are rapidly replacing conventional packing as the means of controlling leakage on rotary and positive-displacement pumps. Mechanical seals eliminate the problem of excessive stuffing box leakage, which can cause failures of pump and motor bearings and motor windings. Mechanical seals are ideal for pumps that operate in closed systems (such as fuel service and air-conditioning, chilled-water, and various cooling systems). They not only conserve the fluid being pumped, but also improve system operation.

The type of material used for the seal faces will depend upon the service of the pump. Most water service pumps use a carbon material for one of the seal faces and ceramic (tungsten carbide) for the other. When the seals wear out, they are simply replaced.

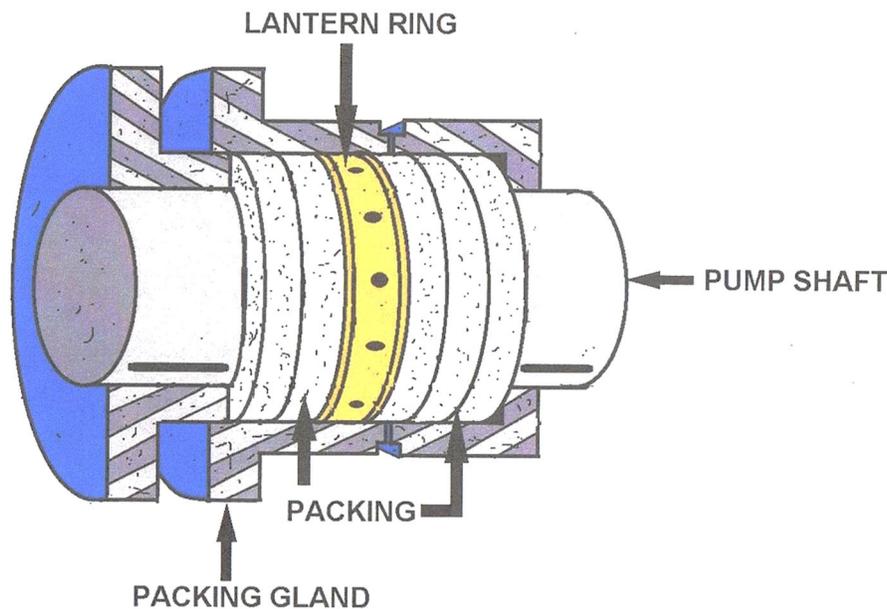


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Do not touch a new seal on the sealing face because body acid and grease or dirt will cause the seal to pit prematurely and leak.

Mechanical shaft seals are positioned on the shaft by stub or step sleeves. Mechanical shaft seals must not be positioned by setscrews. Shaft sleeves are chamfered (beveled) on outboard ends for easy mechanical seal mounting.

Mechanical shaft seals serve to ensure that liquid pressure is supplied to the seal faces under all conditions of operation. They also ensure adequate circulation of the liquid at the seal faces to minimize the deposit of foreign matter on the seal parts.



Choosing Coupling Gaskets

Using a gasket in a coupling that it was not made for is a common cause of leaky gaskets. Get the right gasket and the right kind of gasket for the fitting.

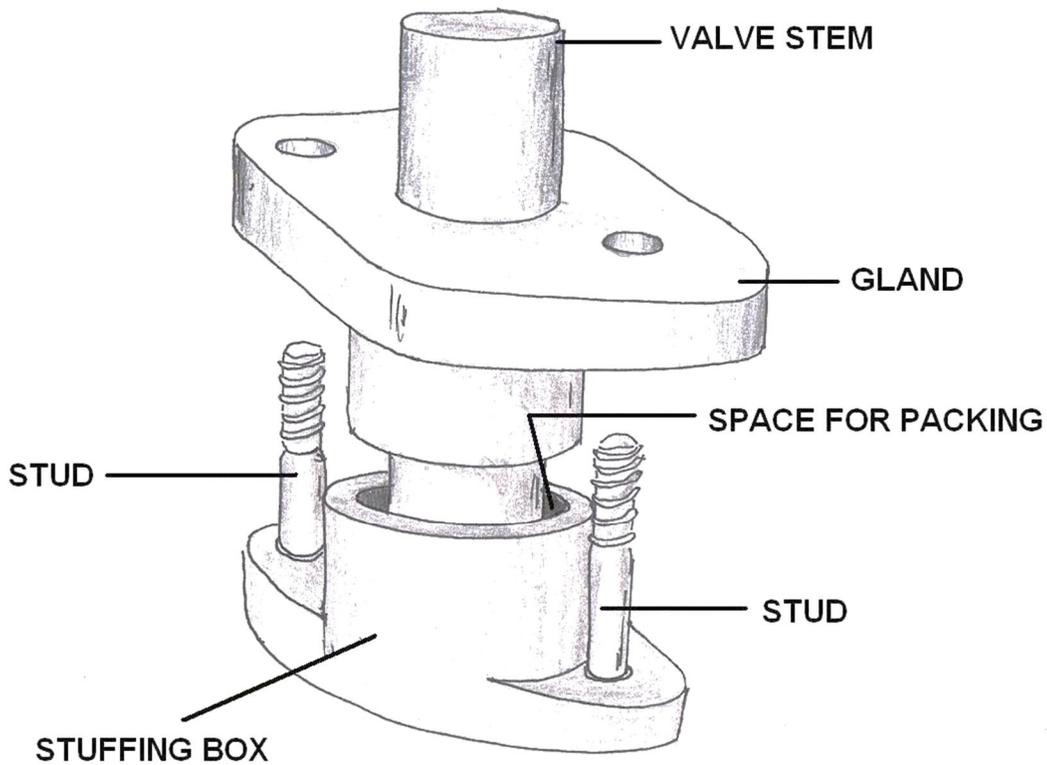
Flat Gaskets

Most are made of neoprene and are used on flanged, bolt-together fittings. They are usually not expensive. They normally fail by "creeping" out of their fitting. Look for new neoprene gaskets that contain a cotton backing sandwiched in the gasket to reduce the creeping action.

Shaped Gaskets

The three most common materials are styrene-butadiene (SBR), ethylene-propylene (EPDM), and polyethylene (poly). SBR and EPDM have much better resistance to cracking, abrasion, ozone, and weathering resistance than poly gaskets. They are more expensive than poly but will last longer. When buying shaped gaskets look for gaskets that are dull; this indicates that little or no plasticizer has been added to the gasket. Plasticizers significantly reduce gasket life.

Installation of Standard Stuffing Boxes



1. Stuffing Box

A. Slide the stuffing box over the shaft and fit into place (be sure to include the O-ring or gasket below the stuffing box flange). Bolt securely in place using the studs and nuts provided.

2. Packing

A. Insert four packing rings, fitting ends together so they contact face to face on the cut end. Turn each cut piece 90° from the previous piece. Be sure each piece is set against the piece below it.

CAUTION

Do not tamp packing tight in the stuffing box. Excessive tamping will stop the flow of fluid through the packing. This will result in the destruction of the shaft area.

3. Packing Gland

A. Thread the two studs in the threaded holes on top of the stuffing box. Insert the packing gland on top of the packing and pull snug (not tight). The packing gland nuts should be tightened together to keep equal pressure on the packing.

4. Slinger

A. Attach slinger above packing gland.

CAUTION

The stuffing box must be allowed to leak for proper operation. The proper amount of leakage can be determined by checking the temperature of the leakage. This should be cool or just lukewarm, not hot. Shutting off leakage flow from the packing will result in burned packing and a scored shaft.

Installation of Optional Stuffing Boxes

A. Stuffing Box

A. Slide the stuffing box over the shaft and fit into place (be sure to include the O-ring or gasket on the bottom

side of the stuffing box in the groove provided. Bolt securely in place using the studs and nuts.

B. Packing

a. Insert the lower lantern ring (threaded holes up) in bottom of box.

b. Insert three packing rings, fitting ends together so they contact face to face on an angle. Turn each cut piece 90° from the previous piece. Be sure each piece is set against the piece below it.

c. Insert the second lantern ring (threaded holes up) on top of the packing. The lantern ring should be aligned with the grease port.

d. Insert three more packing rings on top of the lantern ring, as before.

e. Thread two studs into the holes on top of the stuffing box.

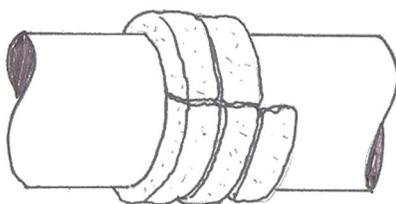
f. Insert the packing gland on top of packing, press down snug. The packing gland nuts should be tightened together to keep equal pressure on the packing.

The packing must be allowed to leak for proper operation. The proper amount of leakage can be determined by checking the temperature of the leakage. This should be cool or just lukewarm, not hot.

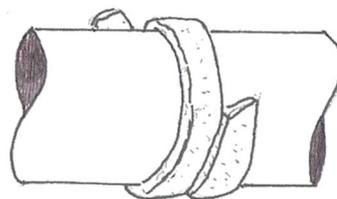
g. Insert the grease zerk and grease with a high quality grease.

C. If high pressure bypass is necessary, remove bypass plug. Install bypass line back to suction side of pump or drain.

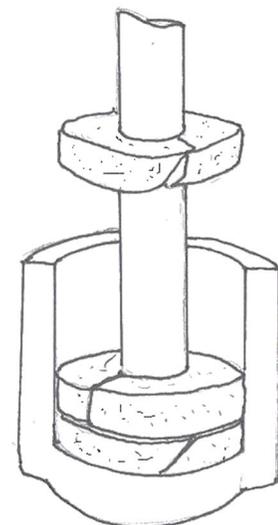
D. Attach a slinger above packing gland.



INCORRECT
(butt joint)



CORRECT
(skive joint)
(stagger @ 45 degree angle)



Installation of Mechanical Seals

1. General Information

A. Study all instructions before installing.

2. Equipment Preparation

A. Assembled Pumps

a. The throttle bushing housing is shipped assembled on the pump but without the seal installed.

b. All faces of the mechanical seal housing and the throttle bushing housing must be free from dirt and rust.

B. Unassembled Pumps

a. The mechanical seal and throttle bushing housing are packaged in the box of small parts.

b. All faces of the mechanical seal housing, throttle bushing and head must be free from dirt and rust.

c. Install the O-ring or gasket in the throttle bushing housing, slide throttle bushing housing over shaft and seat it against the discharge head. Bolt securely in place using the studs & nuts provided.

2. Seal Installation

A. Before installation of Vertical Solid Shaft Motor (VSS) or Head Shaft in Vertical Hollow Shaft (VHS) Motor Installation.

B. Assure that shaft & seal housing are clean and free of machining and handling burrs

C. Set seal in place over pump shaft. Apply teflon tape to shaft treads and lubricate to ease seal into place.

D. Using fasteners provided, secure seal gland to seal housing

E. In the case of VSS Motor Installation

1. Install pump shaft key and coupling half

2. Install coupling spacer and run down to full shaft thread length

3. Affix key and Motor coupling half to VSS Motor

F. Set VSS or VHS Motor in place and bolt to Discharge Head

G. In the case of VSS Motor

1. Rotate coupling spacer in reverse direction to installation in order to elevate coupling spacer to the appropriate impeller adjustment if contact with motor coupling half.

2. Rotate motor to align motor half coupling holes with the holes in the pump coupling half.

3. Install and tighten coupling bolts (at which point pump shaft will be elevated to the appropriate impeller adjustment.

H. In the case of VHS Motor

1. Thread shaft coupling onto pump shaft.

2. Install motor (head) shaft through opening (quill) of motor (be careful not to impact coupling threads).

3. Hold shaft coupling and thread motor shaft into coupling.

4. Rotate motor by cooling fins until the female key slot is in alignment with the motor (Head) shaft.

5. Install Gibb Key into slot presented by the motor (head) shaft and the motor coupling on the top end of the motor.

6. Install adjusting nut in top end of motor (Head) shaft.

7. Tighten adjusting nut until shaft and string is elevated to appropriate impeller adjustment.

8. Rotate adjustment nut until one of the 1/4" - 20unc holes and the motor coupling on the top end of the motor, and one of the 5/16" holes in the adjustment nut are in alignment. (Note: Rotate the adjustment in the direction that assures minimum vertical shaft movement.)

9. Install and tighten the 1/4" - 20unc bolt provided into the aligned bolt hole.
 - I. Tighten the 1/4" - 20unc Allen (grub) screws located on the mechanical seal, onto the top shaft.
 - J. Remove the 1/4" - 20unc beveled head machine screws and aluminum spacer clips and store these parts in a secure place for use upon removal of the mechanical seal.
3. Seal Removal
Reverse the above process.

Installation of Hollow Shaft Drivers

1. Clean driver mounting flange on discharge head and check for burrs or nicks on the register and mounting face. Oil lightly.
2. Remove driver clutch.
3. See No. 10 regarding the installation of motor guide bushing, if required.
4. Lift driver and clean mounting flange, checking for burrs and nicks.
5. Center motor over pump and rotate to align mounting holes.
6. Lower carefully into place making certain that the female register on the driver mates over the male register on the pump.
7. Bolt driver to discharge head.
8. Check driver manufacturer's instruction manual for special instructions including lubrication instructions and follow all "start-up" directions.
9. Electric motors should be checked for rotation at this time. Make certain the driver clutch has been removed. Make electrical connections to the job motor and momentarily check rotation. **DRIVER MUST ROTATE COUNTER CLOCKWISE** when looking down at the top end of the motor. To change the direction of rotation on a three phase motor, interchange any two line leads. To change direction of rotation on a two phase motor, interchange the leads of either phase.
10. Some electric motors will be supplied with a "lower guide bushing" which is installed at the bottom of the motor to stabilize the shaft at this point. Some motor manufacturers mount this guide bushing before shipping while others will ship the guide bushing with instructions for field mounting. Check the packing slip to see if a guide bushing is required, if so, determine if the bushing is already mounted or not and proceed accordingly. Refer to the Motor Instruction Manual.
11. Install coupling on driver being careful that it fits properly.
12. At this point, if the pump is supplied with a two-piece head shaft construction, attach the headshaft to the top shaft with a coupling and tighten the shafts (left hand threads).
13. Clean threads on top of headshaft and headshaft nut. Lubricate male threads lightly.
14. Install Gibb Key in coupling and shaft. This must be a sliding fit and may require filling and dressing. Do not force.
15. Thread adjusting nut down on shaft until it bears against coupling. (Threads on 1-11/16" and larger head shaft adjusting nuts are left-handed, all other are right-handed). Do not thread nut further at this time. See impeller adjusting instructions.

Pumping and Lift Station Chapter Highlights

Pump Stations

Proper operation, maintenance, and repair of pump stations typically requires special electrical, hydraulic, and mechanical knowledge. Pump station failure may damage equipment, the environment, or endanger public health. Variation in equipment types, pump station configuration, and geographical factors determine pump station design and O&M requirements.

The reviewer should verify that the O&M manual contains procedures in writing for the following:

- Are pumps rotated manually or automatically? If manually, how frequently?
- Are wet well operating levels set to limit pump starts and stops?
- Is there a procedure for manipulating pump operations (manually or automatically) during wet weather to increase in-line storage of wet weather flows?
- Is flow monitoring provided? How is the collected data used?
- Does the pump station have capacity-related overflows? Maintenance related overflows? Is overflow monitoring provided?
- Is there a history of power outages? Is there a source of emergency power? If the emergency power source is a generator, is it regularly exercised under load?

Operation and Maintenance (O&M) Activities

Proactive O&M initiatives are critical to effective prevention of SSOs. Nationwide, improved O&M activities such as implementation of hot spot cleaning programs, routine pipeline cleaning, and video inspections to find structural deficiencies have dramatically reduced the frequency and severity of SSOs in many cities.

Your system should conduct various types of proactive O&M activities throughout their service area.

Suggested goals of your system's wastewater collection system maintenance programs should be as follows:

- Maintain wastewater collection system flow capacity.
- Reduce the frequency and duration of overflow events.
- Optimize the use of resources.
- Optimize the life cycle of system components.
- Maintain accurate maintenance records.

Your section of the CMOM Plan shall include descriptions of maintenance facilities, mapping and data management, routine O&M activities, system repairs, and training.

Maintenance Program

Every collection system owner or operator should have a well-planned, systematic, and comprehensive maintenance program. The goals of a maintenance program should include:

- Prevention of overflows.
- Maximization of service and system reliability at minimum cost.
- Assurance of infrastructure sustainability (i.e., ensure all components reach their service life).

There should then be procedures which describe the maintenance approach for various systems. In addition, there should be detailed instructions for the maintenance and repair of individual facilities. These instructions should provide a level of detail such that any qualified collection system personnel or repair technician could perform the repair or maintenance activity.

Maintenance may be planned or unplanned. There are essentially two types of planned maintenance; predictive and preventive. Predictive maintenance is a method that tries to look for early warning signs of equipment failure such that emergency maintenance is avoided.

Preventive maintenance consists of scheduled maintenance activities performed on a regular basis. There are two types of unplanned maintenance, corrective and emergency. Corrective maintenance consists of scheduled repairs to problems identified under planned or predictive maintenance. Emergency maintenance is activities (typically repairs) performed in response to a serious equipment or line failure where action must be taken immediately. The goal of every owner or operator should be to reduce corrective and emergency maintenance through the use of planned and predictive maintenance. The reviewer should evaluate the progress of the owner or operator in achieving that goal.

The goals of the reviewer in assessment of the maintenance program are:

- Identify SSOs caused by inadequate maintenance.
- Determine maintenance trends (i.e., frequent emergency maintenance performed as opposed to predictive maintenance.)
- Identify sustainability issues (i.e., inadequate maintenance to allow system components to reach service life and/or many components nearing or at service life.)

Pump Station Inspection

Pump stations should be subject to inspection and preventive maintenance on a regular schedule. The frequency of inspection may vary from once a week, for a reliable pump station equipped with a telemetry system, to continuous staffing at a large pump station.

The basic inspection should include verification that alarm systems are operating properly, wet well levels are properly set, all indicator lights and voltage readings are within acceptable limits, suction and discharge pressures are within normal limits, that the pumps are running without excessive heat or vibration and have the required amount of lubrication, and that the emergency generator is ready if needed. Less frequent inspections may include such items as vibration analysis and internal inspection of pump components.

Pump Station Checklist

Observations and tasks performed should be recorded in a log book or on a checklist at the pump station. It is important to note how this data returns to the central maintenance data management system. At the time of the inspection, collection system personnel may perform minor repairs if necessary. If non-emergency repairs are required that are beyond the staff's training, it will probably be necessary to prepare a work order which routes a request through the proper channels to initiate the repair action. During the review the reviewer should check a random number of work orders to see how they move through the system. The reviewer should note whether repairs are being carried out promptly. In pump stations, for critical equipment (pumps, drives, power equipment, and control equipment), there should not be much backlog, unless the staff is waiting for parts.

During the review, the reviewer should also make on-site observations of representative pump stations. The reviewer should plan at least half an hour to look at the simplest two-pump prefabricated station, and one to two hours to look at a larger station. In large systems, drive time between stations may be significant. The reviewer should strive to see a range of pump station sizes and types (i.e., the largest, smallest, most remote, and any that review of work orders has indicated might be problematic).

Overall, the pump station should be clean, in good structural condition, and exhibit minimal odor. The reviewer should note the settings of the pumps (i.e., which are operating, which are on stand-by, and which are not operating and why). The operating pumps should be observed for noise, heat, and excessive vibration. The settings in the wet well should be noted (as indicated on the controls, as direct observation of the wet well by the reviewer is not recommended) and the presence of any flashing alarm lights.

Atmospheric Hazards

The reviewer is reminded of the atmospheric hazards in a pump station (make sure ventilation has been running prior to arrival) and to avoid confined space entry. If the pump station has an overflow its outlet should be observed, if possible, for signs of any recent overflows such as floatable materials or toilet paper. The reviewer should check the log book and/or checklist kept at the pump station to ensure that records are current and all maintenance activities have been performed. Below is a listing of items that indicate inadequate maintenance:

- Overall poor housekeeping and cleanliness.
- Excessive grease accumulation in wet well.
- Excessive corrosion on railings, ladders, and other metal components.
 - Sagging, worn, improperly sized, or inadequate belts.
- Excessive equipment out of service for repair or any equipment for which repair has not been ordered (i.e., a work order issued.)
 - Pumps running with excessive heat, vibration, or noise.
- Peeling paint and/or dirty equipment (the care given to equipment's outer surfaces often, but not always, mirrors internal condition.)
- Check valves not closing when pumps shut off.
- Inoperative instrumentation, alarms, and recording equipment.
 - "Jury-rigged" repairs (i.e., "temporary" repairs using inappropriate materials.)
- Leakage from pumps, piping, or valves (some types of pump seals are designed to "leak" seal water.)
- Inadequate lighting or ineffective/inoperative ventilation equipment.

Routine Preventative O&M Activities – Wastewater Lift Stations and Force Mains

Perform Regular Preventative Maintenance

The wastewater collections service technicians should perform regular preventative maintenance on the various components at the lift stations. An outside contractor may also be used to clean each lift station twice a year.

Most wastewater lift station and force main operations are typically remotely monitored and controlled through a telemetry or WIFI system that sends signals to the system's operation center. In the event of a malfunction, all of the lift stations should have redundant pump and pump monitoring systems, and all should have emergency backup power generation.

System Repairs

Deficiencies in the sewer system requiring repair are noted during cleaning and video inspections or are discovered through investigation of customer complaints. A Supervisor should arrange for all repairs; small repairs are often completed by the system's crews and larger repairs may be completed by a qualified outside contractor.

Deficiencies in lift stations and force mains requiring repair should be noted by the wastewater collections technicians during their routine visits, by alarms or through customer complaints. The Supervisor should make arrangements for all lift station and force main repairs.

Maintenance Budgeting

The cost of a maintenance program is a significant part of the annual operating budget. The collection system owner or operator should track all maintenance costs incurred throughout the year, both by internal staff and contractors, to ensure that the budget is based on representative costs from past years. Budgets should be developed from past cost records which usually are categorized according to preventive maintenance, corrective maintenance, and projected and actual major repair requirements. Annual costs should be compared to the budget periodically to control maintenance expenditures.

The reviewer should evaluate the maintenance budget, keeping in mind the system's characteristics, such as age. Costs for emergency repairs should be a relatively small percentage of the budget--five to ten percent would not be considered excessive. The establishment of an "emergency reserve" may also be included as part of the maintenance budget. This is especially useful where full replacement is not funded. The budget should also be considered in light of maintenance work order backlog.

Planned and Unplanned Maintenance

A planned maintenance program is a systematic approach to performing maintenance activities so that equipment failure is avoided. Planned maintenance is composed of predictive and preventive maintenance. In the end, a good planned maintenance program should reduce material, capital repair, and replacement costs, improve personnel utilization and morale, reduce SSOs, and sustain public confidence.

Examples of predictive maintenance includes monitoring equipment for early warning signs of impending failure, such as excess vibration, heat, dirty oil, and leakage. Assessment and inspection activities can be classified as predictive maintenance. Vibration and lubrication analyses, thermography, and ultrasonics are among the more common predictive maintenance tools.

Predictive maintenance also takes into account historical information about the system as all systems will deteriorate over time. A predictive maintenance program strives to identify potential problem areas and uncover trends that could affect equipment performance.

Predictive maintenance offers an early warning. It allows collection system personnel to detect early signs of increasing rates of wear and therefore failure, and thus shift a “corrective” task into a “planned” task. To be truly effectively predictive, however, maintenance should not spur personnel into doing the work too soon and wasting useful life and value of the equipment in question.

The reviewer should inquire as to whether tools such as vibration and lubrication analysis, thermography, or ultrasonics are used, and obtain information on the extent of the programs.

The basis of a good predictive maintenance program is recordkeeping. Only with accurate recordkeeping can baseline conditions be established, problem areas identified, and a proactive approach taken to repairs and replacement.

Effective preventive maintenance minimizes system costs and environmental impacts by reducing breakdowns and thus the need for corrective or emergency maintenance; improves reliability by minimizing the time equipment is out of service; increases the useful life of equipment, thus avoiding costly premature replacement; and avoids potential noncompliance situations.

An Effective Preventive Maintenance Program Includes:

- Trained personnel.
- Scheduling based on system specific knowledge.
- Detailed instructions related to the maintenance of various pieces of equipment.
- A system for recordkeeping.

System knowledge in the form of maps, historical knowledge and records. An effective preventive maintenance program builds on the inspection activities and predictive maintenance described above, and includes a well thought-out schedule for these activities.

The basis of the schedule for mechanical equipment maintenance (i.e., pump station components) should be the manufacturers’ recommended activities and frequencies. This schedule may then be augmented by the knowledge and experience of collection system personnel to reflect the site-specific requirements.

The schedule for sewer line cleaning, inspection, root removal, and repair activities should be based on periodic inspection data. In most systems, uniform frequencies for sewer line cleaning, inspection, and root removal are not necessary and inefficient. In many systems, a relatively small percentage of the pipe generates most of the problems.

Efficient use of inspection data allows the owner or operator to implement a schedule in the most constructive manner. In rare cases it may be appropriate to reduce maintenance frequency for a particular piece of equipment.

Lubrication

Lubrication is probably one of the most important maintenance activities for mechanical systems, such as pumps and motors. Frequencies of lubrication, choice of lubricant and lubrication procedure are all important factors in this activity. These items should closely follow manufacturer instructions, but may be modified to fit site-specific conditions and particular equipment applications. An example of a scheduling code and maintenance schedule for a pump is shown below:

Guide for Evaluating CMOM Programs at Sanitary Sewer Collection Systems

Rotary Pump Maintenance Schedule	
Frequency	Maintenance Required
D	Check packing gland assembly
D	Check discharge pressure
S	Inspect and lubricate bearings
A	Flush bearings and replace lubricant

D = Daily A = Annually S = Semiannually

Typically, there is a maintenance card or record for each piece of equipment within the collection system. These records should contain maintenance recommendations, schedule, and instructions on conducting the specific maintenance activity. The records should include documentation regarding any maintenance activities conducted to date and other observations related to that piece of equipment or system.

Maintenance records are generally kept where maintenance personnel have easy access to them. The reviewer should examine the full series of periodic work orders (i.e. weekly, monthly, semiannually, and annually) for a selection of system components (e.g., a few pump stations, several line segments).

The reviewer should then compare the recommended maintenance frequency to that which is actually performed. He or she should also look at the backlog of work; not focusing solely on the number of backlogged work orders, but on what that number represents in time. A very large system can have a hundred orders backlogged and only be one week behind. In a computerized system, a listing of all open work orders is usually very simple for collection system personnel to generate. The owner or operator should be able to explain their system for prioritizing work orders.

The reviewer needs to clearly understand the following:

- How the maintenance data management system works
- How work orders are generated and distributed
- How field crews use the work orders
- How data from the field is collected and returned
- How and on whose authority work orders are closed out

The reviewer should check to see if data entry is timely and up to date.

Unplanned Maintenance

Unplanned maintenance is that which takes place in response to equipment breakdowns or emergencies. Unplanned maintenance may be corrective or emergency maintenance. Corrective maintenance could occur as a result of preventive or predictive maintenance activities which identified a problem situation.

A work order should be issued so that the request for corrective maintenance is directed to the proper personnel. An example of non-emergency corrective maintenance could be a broken belt on a belt driven pump.

The worn belt was not detected and replaced through preventive maintenance and therefore the pump is out of service until corrective maintenance can be performed. Although the pump station may function with one pump out of service, should another pump fail, the situation may become critical during peak flow periods.

If the information can be easily generated the reviewer should select a sampling of work orders and compare them to the corrective maintenance database to determine if repairs are being made in a timely manner. Reviewers should note the current backlog of corrective maintenance work orders. A corrective maintenance backlog of two weeks or less would indicate an owner or operator in control of corrective maintenance. The owner or operator should be able to explain corrective maintenance work orders that have not been completed within six months.

Corrective Maintenance

Corrective maintenance takes resources away from predictive and preventive maintenance. When corrective maintenance becomes a predominant activity, personnel may not be able to perform planned maintenance, thus leading to more corrective maintenance and emergency situations. Emergency maintenance occurs when a piece of equipment or system fails, creating a threat to public health, the environment, or associated equipment. This type of maintenance involves repairs on short notice, of malfunctioning equipment or sewers. A broken force main, totally non-functional pump station and street cave-ins are all examples of emergency situations.

Types of Portable Emergency Equipment

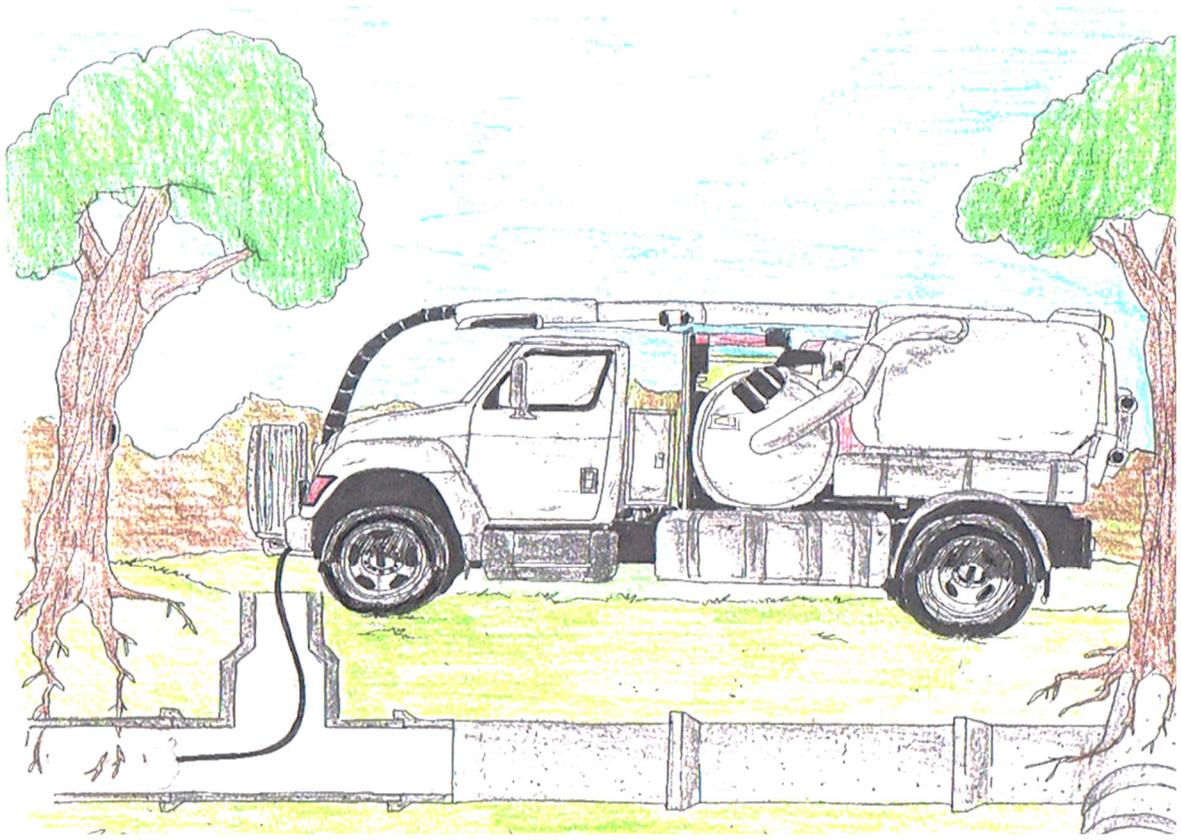
- Bypass pumps
- Portable generator
- Air compressor, trailer-mounted
- Manhole lifters and gas testing equipment
- Sewer rodder and/or flushing machine
- Portable lights and hand tools
- Chemical spray units (for insects and rodent control)
- Truck (1-ton) and trailers
- Vacuum truck
- Repair equipment for excavation (backhoe, shoring equipment, concrete mixers, gasoline operated saws, traffic control equipment, etc.)
- Confined space entry gear

Emergency Crews

Emergency crews should be geared to a 24-hour-a-day, year-round operation. Most large systems have staffed 24-hour crews; many small systems have an "on-call" system. The owner or operator should be able to produce written procedures which spell out the type of action to take in a particular type of emergency and the equipment and personnel requirements necessary to carry out the action.

The crews should have copies of these procedures and be familiar with them. Equipment must be located in an easily accessible area and be ready to move in a short period of time.

Vehicles and equipment must be ready to perform, under extreme climatic conditions if necessary. The emergency crew may need materials such as piping, pipe fittings, bedding materials, and concrete. The owner or operator should have supplies on hand to allow for two point (i.e. segment, fitting, or appurtenance) repairs of any part of its system. The reviewer should note the presence of supplies during the review of the yard where equipment and spare parts are maintained and personnel are dispatched.



The best method of controlling hydrogen sulfide is to eliminate its habitat or growth area by keeping sewers cleaner, this will harbor fewer slime bacteria.

Electrical Motor Sub-Section - Introduction

The power source of the pump is usually an electric motor. The motor is connected by a coupling to the pump shaft. The purpose of the bearings is to hold the shaft firmly in place, yet allow it to rotate. The bearing house supports the bearings and provides a reservoir for the lubricant. An impeller is connected to the shaft. The pump assembly can be a vertical or horizontal set-up; the components for both are basically the same.

Motors

The purpose of this discussion on pump motors is to identify and describe the main types of motors, starters, enclosures and motor controls, as well as to provide you with some basic maintenance and troubleshooting information. Although pumps may be driven by diesel or gasoline engines, pumps driven by electric motors are commonly used in our industry.

There are two general categories of electric motors:

- ✱ D-C motors, or direct current
- ✱ A-C motors, or alternating current

You can expect most motors at facilities to be A-C type.

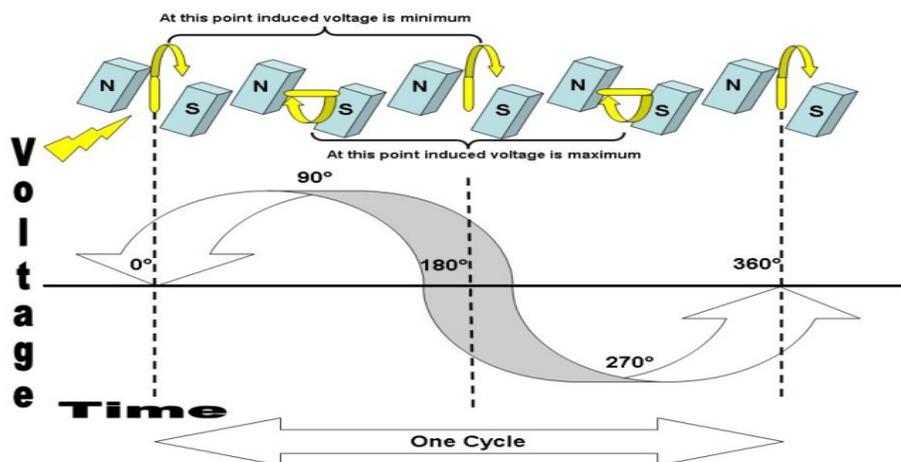
D-C Motors

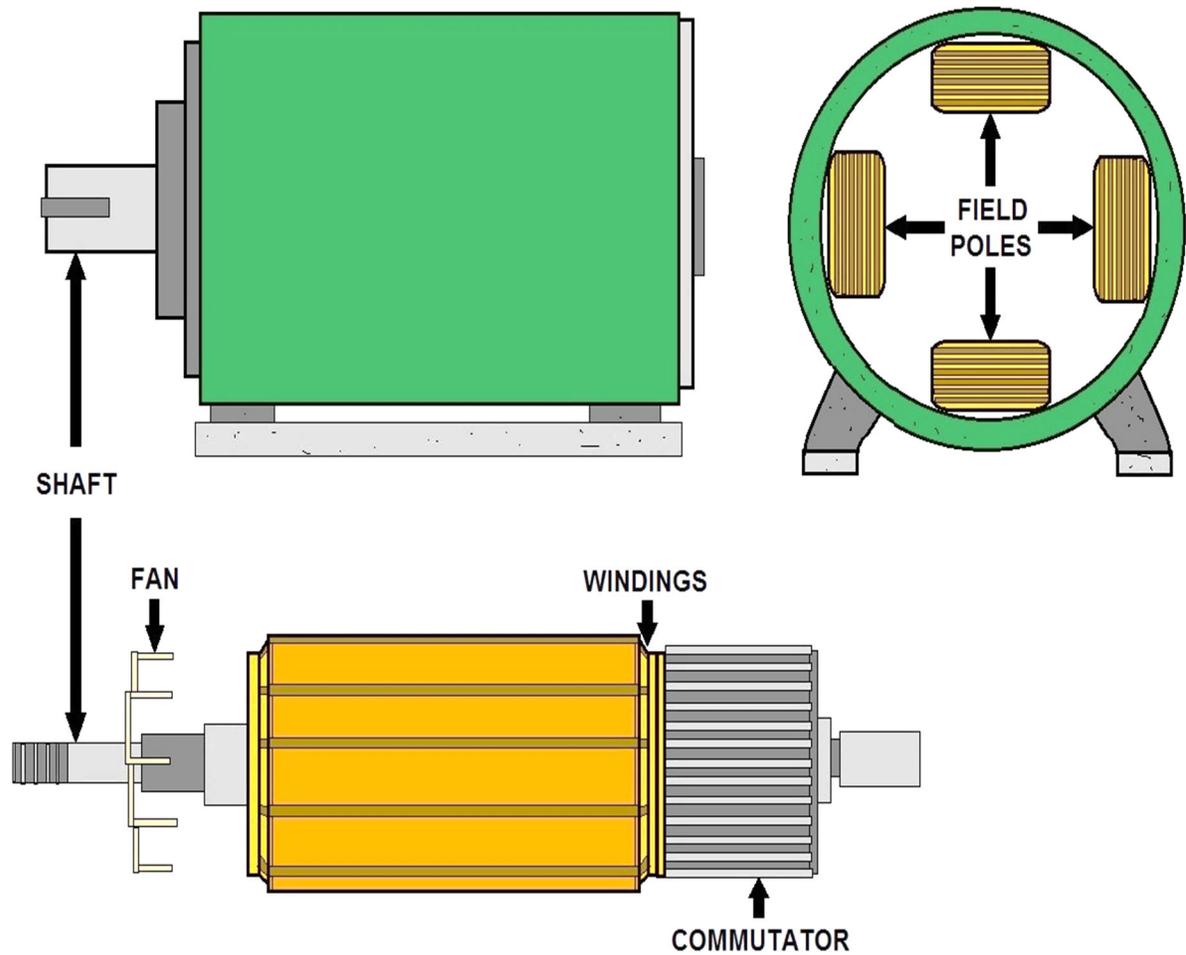
The important characteristic of the D-C motor is that its speed will vary with the amount of voltage used. There are many different kinds of D-C motors, depending on how they are wound and their speed/torque characteristics.



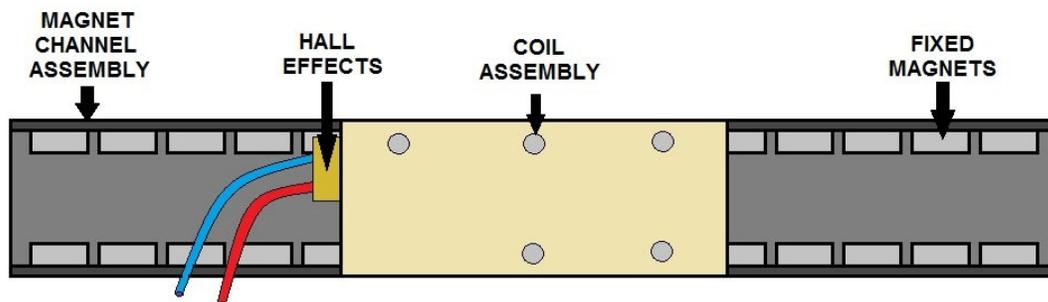
A-C Motors

There are a number of different types of alternating current motors, such as Synchronous, Induction, wound rotor, and squirrel cage. The synchronous type of A-C motor requires complex control equipment, since they use a combination of A-C and D-C. This also means that the synchronous type of A-C motor is used in large horsepower sizes, usually above 250 HP. The induction type motor uses only alternating current. The squirrel cage motor provides a relatively constant speed. The wound rotor type could be used as a variable speed motor.





DC ELECTRIC MOTOR DIAGRAM EXAMPLE



LINEAR MOTOR

Electric Induction Motor that produces Straight-Line motion by means of a Linear Stator and Rotor placed in Parallel

Define the Following Terms:

Voltage:

EMF:

Power:

Current:

Resistance:

Conductor:

Phase:

Single Phase:

Three Phase:

Hertz:

Motor Starters

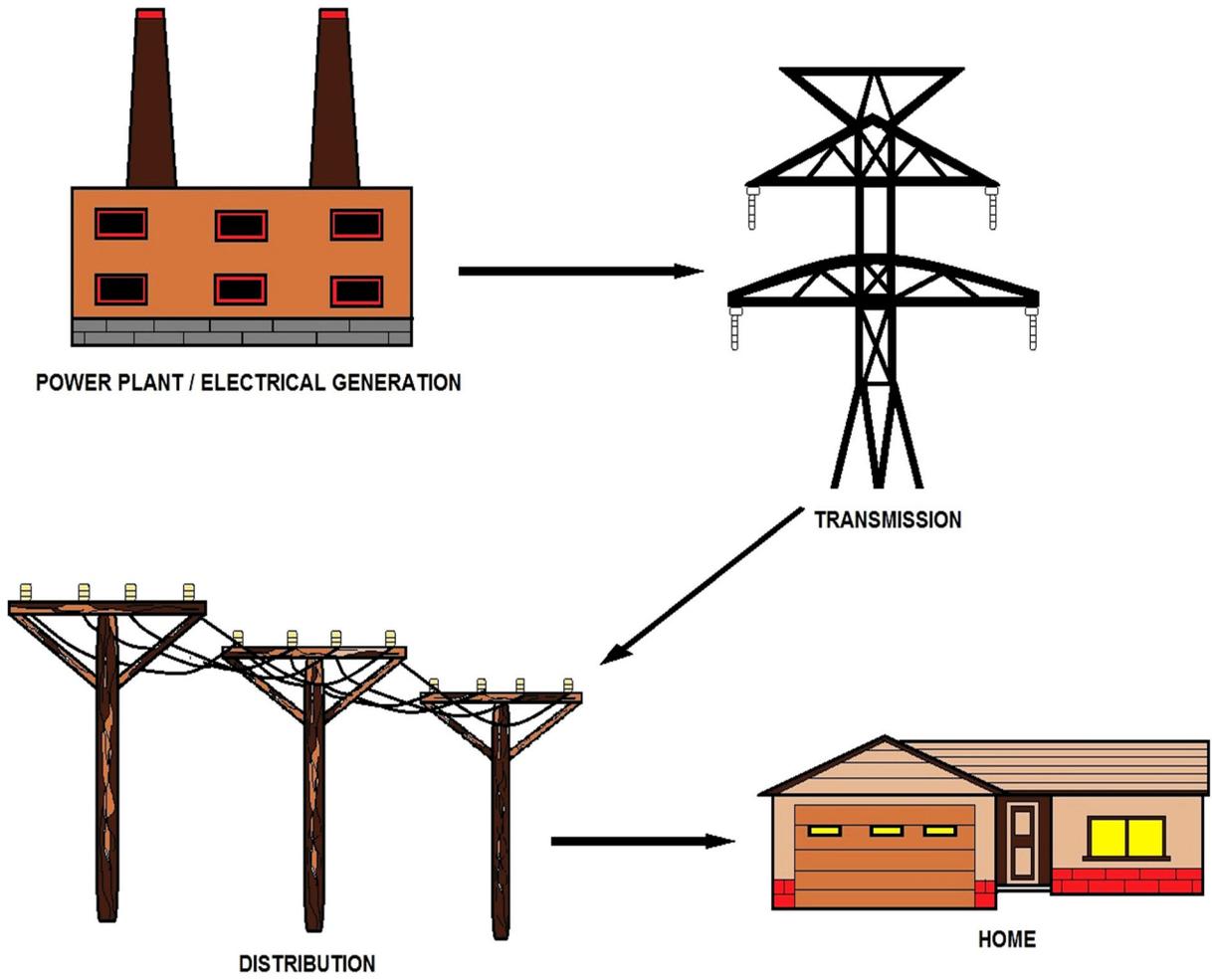
All electric motors, except very small ones such as chemical feed pumps, are equipped with starters, either full voltage or reduced voltage. This is because motors draw a much higher current when they are starting and gaining speed. The purpose of the reduced voltage starter is to prevent the load from coming on until the amperage is low enough.

Motor Enclosures

Depending on the application, motors may need special protection. Some motors are referred to as open motors. They allow air to pass through to remove heat generated when current passes through the windings. Other motors use specific enclosures for special environments or safety protection.

Can you think of any locations within your facility that requires special enclosures?





HOW ELECTRICITY GETS TO CONSUMERS (USERS)

Two Types of Totally Enclosed Motors Commonly Used

- ☞ **TENV**, or totally enclosed non-ventilated motor
- ☞ **TEFC**, or totally enclosed fan cooled motor

Totally enclosed motors include dust-proof, water-proof and explosion-proof motors. An explosion proof enclosure must be provided on any motor where dangerous gases might accumulate.

Motor Controls

All pump motors are provided with some method of control, typically a combination of manual and automatic. Manual pump controls can be located at the central control panel, at the pump, or at the suction or discharge points of the liquid being pumped.

There are a number of ways in which automatic control of a pump motor can be regulated:

- ☞ Pressure and vacuum sensors
- ☞ Preset time intervals
- ☞ Flow sensors
- ☞ Level sensors

Two typical level sensors are the float sensor and the bubbler regulator. The float sensor is pear-shaped and hangs in the wet well.

As the height increases, the float tilts, and the mercury in the glass tube flows toward the end of the tube that has two wires attached to it. When the mercury covers the wires, it closes the circuit.



For a bubbler level sensor, a low pressure air supply is allowed to escape from a bubbler pipe in the wet well. The back-pressure on the air supply will vary with the liquid level over the pipe. Sensitive air pressure switches will detect this change and use this information to control pump operation.

Motor Maintenance

Motors should be kept clean, free of moisture, and lubricated properly. Dirt, dust, and grime will plug the ventilating spaces and can actually form an insulating layer over the metal surface of the motor.

What condition would occur if the ventilation becomes blocked?



Moisture

Moisture harms the insulation on the windings to the point where they may no longer provide the required insulation for the voltage applied to the motor. In addition, moisture on windings tend to absorb acid and alkali fumes, causing damage to both insulation and metals. To reduce problems caused by moisture, the most suitable motor enclosure for the existing environment will normally be used. It is recommended to run stand by motors to dry up any condensation which accumulates in the motor.

Motor Lubrication

Friction will cause wear in all moving parts, and lubrication is needed to reduce this friction. It is very important that all your manufacturer's recommended lubrication procedures are strictly followed. You have to be careful not to add too much grease or oil, as this could cause more friction and generate heat.

To grease the motor bearings, this is the usual approach:

1. Remove the protective plugs and caps from the grease inlet and relief holes.
2. Pump grease in until fresh starts coming from the relief hole.

If fresh grease does not come out of the relief hole, this could mean that the grease has been pumped into the motor windings. The motor must then be taken apart and cleaned by a qualified service representative.

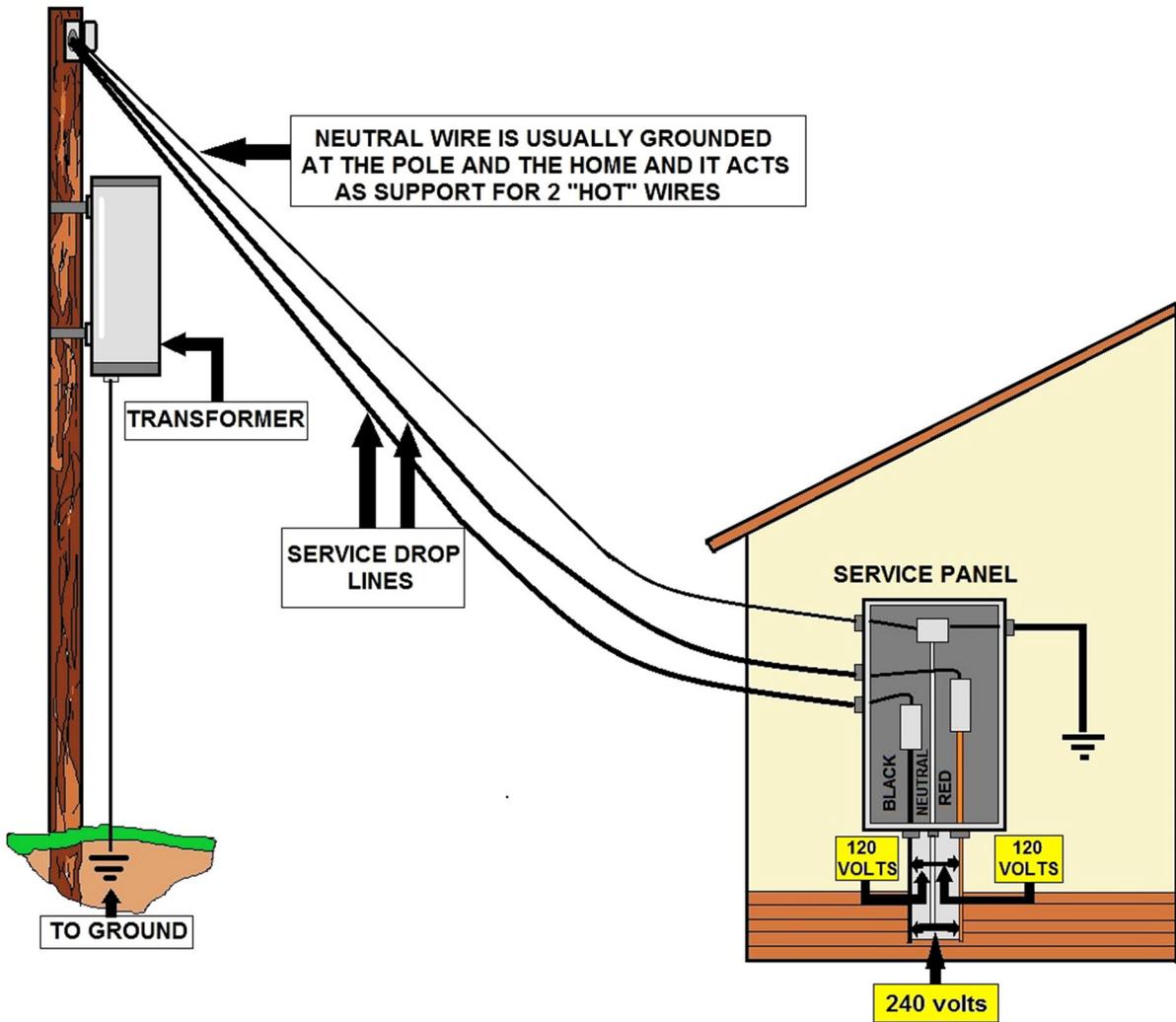
To change the oil in an oil lubricated motor, this is the usual approach:

1. Remove all plugs and let the oil drain.
2. Check for metal shearing (pieces of metal in the oil.)
3. Replace the oil drain.
4. Add new oil until it is up to the oil level plug.
5. Replace the oil level and filter plug.

Never mix oils, since the additives of different oils when combined can cause breakdown of the oil.

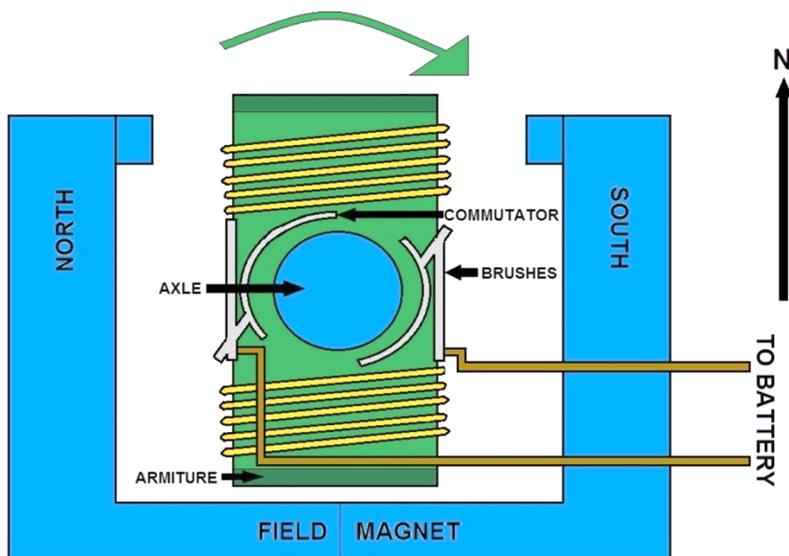
Type of Motor Commutation

Self-Commutated		Externally Commutated		
Mechanical-Commutator Motors		Electronic-Commutator (EC) Motors	Asynchronous Machines	Synchronous Machines
AC	DC	AC	AC	
<ul style="list-style-type: none"> • Universal motor (AC commutator series motor or AC/DC motor) • Repulsion motor 	<p>Electrically excited DC motor:</p> <ul style="list-style-type: none"> • Separately excited • Series • Shunt • Compound <p>PM DC motor</p>	<p>With PM rotor:</p> <ul style="list-style-type: none"> • BLDC motor <p>With ferromagnetic rotor:</p> <ul style="list-style-type: none"> • SRM 	<p>Three-phase motors:</p> <ul style="list-style-type: none"> • SCIM • WRIM <p>AC motors:</p> <ul style="list-style-type: none"> • Capacitor • Resistance • Split • Shaded-pole 	<p>Three-phase motors:</p> <ul style="list-style-type: none"> • WRSM • PMSM or BLAC motor <ul style="list-style-type: none"> ○ IPMSM ○ SPMSM • Hybrid <p>AC motors:</p> <ul style="list-style-type: none"> • Permanent-split capacitor • Hysteresis • Stepper • SyRM • SyRM-PM hybrid
Simple electronics	Rectifier, linear transistor(s) or DC chopper	More elaborate electronics	Most elaborate electronics (VFD), when provided	



**BASIC HOME ELECTRICITY
(120/240 VOLTS)**

Understanding Motors



The classic division of electric motors has been that of Direct Current (DC) types vs. Alternating Current (AC) types. This is more a de facto convention, rather than a rigid distinction. For example, many classic DC motors run happily on AC power.

The ongoing trend toward electronic control further muddles the distinction; as modern drivers have moved the commutator out of the motor shell. For this new breed of motor, driver circuits are relied upon to generate sinusoidal AC drive currents, or some approximation of. The two best examples are: the brushless DC motor and the stepping motor, both being polyphase AC motors requiring external electronic control.

There is a clearer distinction between a synchronous motor and asynchronous types. In the synchronous types, the rotor rotates in synchrony with the oscillating field or current (e.g. permanent magnet motors). In contrast, an asynchronous motor is designed to slip; the most ubiquitous example being the common AC induction motor which must slip in order to generate torque.

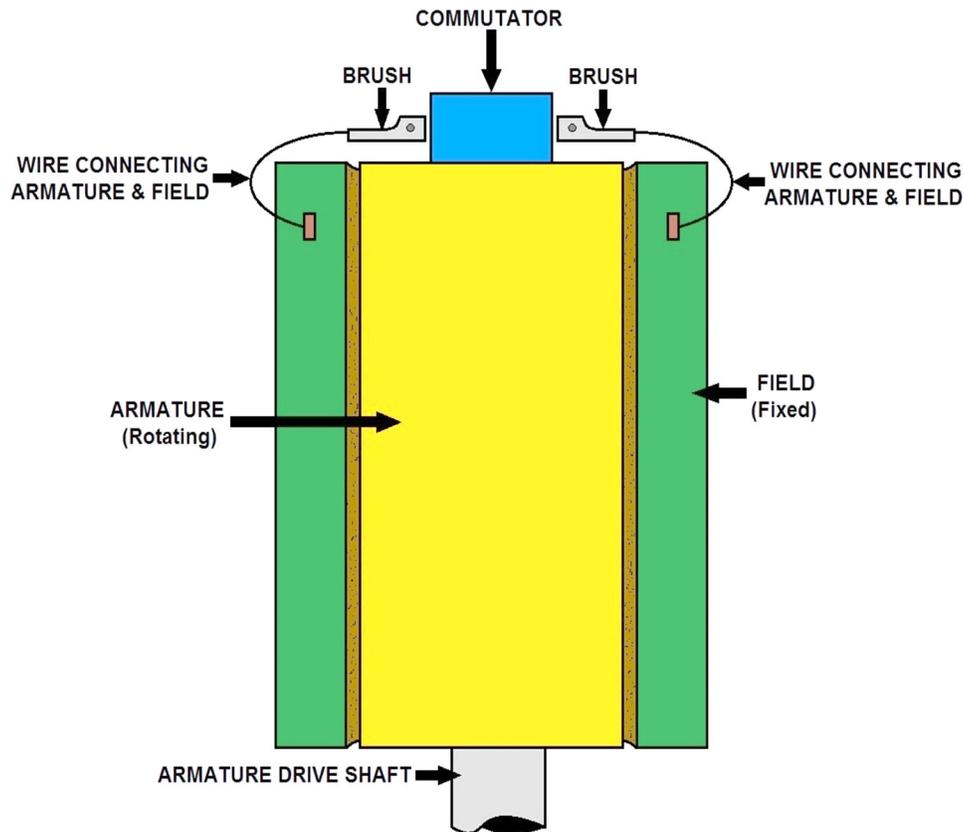
A DC motor is designed to run on DC electric power. Two examples of pure DC designs are Michael Faraday's homopolar motor (which is uncommon), and the ball bearing motor, which is (so far) a novelty. By far the most common DC motor types are the brushed and brushless types, which use internal and external commutation respectively to create an oscillating AC current from the DC source -- so they are not purely DC machines in a strict sense.

Brushed DC motors

The classic DC motor design generates an oscillating current in a wound rotor with a split ring commutator, and either a wound or permanent magnet stator. A rotor consists of a coil wound around a rotor which is then powered by any type of battery. Many of the limitations of the classic commutator DC motor are due to the need for brushes to press against the commutator. This creates friction.

At higher speeds, brushes have increasing difficulty in maintaining contact. Brushes may bounce off the irregularities in the commutator surface, creating sparks. This limits the maximum speed of the machine.

The current density per unit area of the brushes limits the output of the motor. The imperfect electric contact also causes electrical noise. Brushes eventually wear out and require replacement, and the commutator itself is subject to wear and maintenance. The commutator assembly on a large machine is a costly element, requiring precision assembly of many parts.



**DIAGRAM SHOWING MECHANICAL CONSTRUCTION
OF A DC SERIES WOUND MOTOR**

Brushless DC Motors

Some of the problems of the brushed DC motor are eliminated in the brushless design. In this motor, the mechanical "rotating switch" or commutator/brush gear assembly is replaced by an external electronic switch synchronized to the rotor's position. Brushless motors are typically 85-90% efficient, whereas DC motors with brush gear are typically 75-80% efficient.

Midway between ordinary DC motors and stepper motors lies the realm of the brushless DC motor. Built in a fashion very similar to stepper motors, these often use a permanent magnet external rotor, three phases of driving coils, one or more Hall Effect sensors to sense the position of the rotor, and the associated drive electronics.

The coils are activated one phase after the other by the drive electronics, as cued by the signals from the Hall effect sensors. In effect, they act as three-phase synchronous motors containing their own variable-frequency drive electronics. Brushless DC motors are commonly used where precise speed control is necessary, as in computer disk drives or in video cassette recorders, the spindles within CD, CD-ROM (etc.) drives, and mechanisms within office products such as fans, laser printers, and photocopiers.

They have several advantages over conventional motors:

- * Compared to AC fans using shaded-pole motors, they are very efficient, running much cooler than the equivalent AC motors. This cool operation leads to much-improved life of the fan's bearings.
- * Without a commutator to wear out, the life of a DC brushless motor can be significantly longer compared to a DC motor using brushes and a commutator. Commutation also tends to cause a great deal of electrical and RF noise; without a commutator or brushes, a brushless motor may be used in electrically sensitive devices like audio equipment or computers.
- * The same Hall Effect sensors that provide the commutation can also provide a convenient tachometer signal for closed-loop control (servo-controlled) applications. In fans, the tachometer signal can be used to derive a "fan OK" signal.
- * The motor can be easily synchronized to an internal or external clock, leading to precise speed control.
- * Brushless motors have no chance of sparking, unlike brushed motors, making them better suited to environments with volatile chemicals and fuels.
- * Brushless motors are usually used in small equipment such as computers, and are generally used to get rid of unwanted heat.
- * They are also very quiet motors, which is an advantage if being used in equipment that is affected by vibrations.

Modern DC brushless motors range in power from a fraction of a watt to many kilowatts. Larger brushless motors up to about 100 kW rating are used in electric vehicles. They also find significant use in high-performance electric model aircraft.

Coreless DC Motors

Nothing in the design of any of the motors described above requires that the iron (steel) portions of the rotor actually rotate; torque is exerted only on the windings of the electromagnets. Taking advantage of this fact is the coreless DC motor, a specialized form of a brush or brushless DC motor. Optimized for rapid acceleration, these motors have a rotor that is constructed without any iron core. The rotor can take the form of a winding-filled cylinder inside the stator magnets, a basket surrounding the stator magnets, or a flat pancake (possibly formed on a printed wiring board) running between upper and lower stator magnets.

The windings are typically stabilized by being impregnated with electrical epoxy potting systems. Filled epoxies that have moderate mixed viscosity and a long gel time. These systems are highlighted by low shrinkage and low exotherm.

Because the rotor is much lighter in weight (mass) than a conventional rotor formed from copper windings on steel laminations, the rotor can accelerate much more rapidly, often achieving a mechanical time constant under 1 ms. This is especially true if the windings use aluminum rather than the heavier copper. But because there is no metal mass in the rotor to act as a heat sink, even small coreless motors must often be cooled by forced air.

These motors were commonly used to drive the capstan(s) of magnetic tape drives and are still widely used in high-performance servo-controlled systems, like radio-controlled vehicles/aircraft, humanoid robotic systems, industrial automation, medical devices, etc.

Universal Motors

A variant of the wound field DC motor is the universal motor. The name derives from the fact that it may use AC or DC supply current, although in practice they are nearly always used with AC supplies.

The principle is that in a wound field DC motor the current in both the field and the armature (and hence the resultant magnetic fields) will alternate (reverse polarity) at the same time, and hence the mechanical force generated is always in the same direction. In practice, the motor must be specially designed to cope with the AC current (impedance must be taken into account, as must the pulsating force), and the resultant motor is generally less efficient than an equivalent pure DC motor.

Operating at normal power line frequencies, the maximum output of universal motors is limited and motors exceeding one kilowatt are rare. But universal motors also form the basis of the traditional railway traction motor in electric railways. In this application, to keep their electrical efficiency high, they were operated from very low frequency AC supplies, with 25 Hz and 16 2/3 hertz operation being common. Because they are universal motors, locomotives using this design were also commonly capable of operating from a third rail powered by DC.

The advantage of the universal motor is that AC supplies may be used on motors which have the typical characteristics of DC motors, specifically high starting torque and very compact design if high running speeds are used. The negative aspect is the maintenance and short life problems caused by the commutator. As a result, such motors are usually used in AC devices such as food mixers and power tools which are used only intermittently.

Continuous speed control of a universal motor running on AC is very easily accomplished using a thyristor circuit, while stepped speed control can be accomplished using multiple taps on the field coil. Household blenders that advertise many speeds frequently combine a field coil with several taps and a diode that can be inserted in series with the motor (causing the motor to run on half-wave rectified AC).

AC Motor Sub-Section

In 1882, Nicola Tesla identified the rotating magnetic field principle, and pioneered the use of a rotary field of force to operate machines. He exploited the principle to design a unique two-phase induction motor in 1883. In 1885, Galileo Ferraris independently researched the concept. In 1888, Ferraris published his research in a paper to the Royal Academy of Sciences in Turin.

Introduction of Tesla's motor from 1888 onwards initiated what is sometimes referred to as the Second Industrial Revolution, making possible the efficient generation and long distance distribution of electrical energy using the alternating current transmission system, also of Tesla's invention (1888). Before the invention of the rotating magnetic field, motors operated by continually passing a conductor through a stationary magnetic field (as in homopolar motors). Tesla had suggested that the commutators from a machine could be removed and the device could operate on a rotary field of force. Professor Poeschel, his teacher, stated that would be akin to building a perpetual motion machine.

Components

A typical AC motor consists of two parts:

1. An outside stationary stator having coils supplied with AC current to produce a rotating magnetic field, and;
2. An inside rotor attached to the output shaft that is given a torque by the rotating field.

Torque motors

A torque motor is a specialized form of induction motor which is capable of operating indefinitely at stall (with the rotor blocked from turning) without damage. In this mode, the motor will apply a steady stall torque to the load (hence the name).

A common application of a torque motor would be the supply- and take-up reel motors in a tape drive. In this application, driven from a low voltage, the characteristics of these motors allow a relatively-constant light tension to be applied to the tape whether or not the capstan is feeding tape past the tape heads.

Driven from a higher voltage, (and so delivering a higher torque), the torque motors can also achieve fast-forward and rewind operation without requiring any additional mechanics such as gears or clutches. In the computer world, torque motors are used with force feedback steering wheels.

Slip Ring

The slip ring or wound rotor motor is an induction machine where the rotor comprises a set of coils that are terminated in slip rings to which external impedances can be connected. The stator is the same as is used with a standard squirrel cage motor. By changing the impedance connected to the rotor circuit, the speed/current and speed/torque curves can be altered.

The slip ring motor is used primarily to start a high inertia load or a load that requires a very high starting torque across the full speed range. By correctly selecting the resistors used in the secondary resistance or slip ring starter, the motor is able to produce maximum torque at a relatively low current from zero speed to full speed. A secondary use of the slip ring motor is to provide a means of speed control.

Because the torque curve of the motor is effectively modified by the resistance connected to the rotor circuit, the speed of the motor can be altered. Increasing the value of resistance on the rotor circuit will move the speed of maximum torque down.

If the resistance connected to the rotor is increased beyond the point where the maximum torque occurs at zero speed, the torque will be further reduced. When used with a load that has a torque curve that increases with speed, the motor will operate at the speed where the torque developed by the motor is equal to the load torque.

Reducing the load will cause the motor to speed up, and increasing the load will cause the motor to slow down until the load and motor torque are equal. Operated in this manner, the slip losses are dissipated in the secondary resistors and can be very significant. The speed regulation is also very poor.

Stepper Motors

Closely related in design to three-phase AC synchronous motors are stepper motors, where an internal rotor containing permanent magnets or a large iron core with salient poles is controlled by a set of external magnets that are switched electronically.

A stepper motor may also be thought of as a cross between a DC electric motor and a solenoid. As each coil is energized in turn, the rotor aligns itself with the magnetic field produced by the energized field winding.

Unlike a synchronous motor, in its application, the motor may not rotate continuously; instead, it "steps" from one position to the next as field windings are energized and de-energized in sequence. Depending on the sequence, the rotor may turn forwards or backwards.

Simple stepper motor drivers entirely energize or entirely de-energize the field windings, leading the rotor to "cog" to a limited number of positions; more sophisticated drivers can proportionally control the power to the field windings, allowing the rotors to position between the cog points and thereby rotate extremely smoothly.

Computer controlled stepper motors are one of the most versatile forms of positioning systems, particularly when part of a digital servo-controlled system.

Stepper motors can be rotated to a specific angle with ease, and hence stepper motors are used in pre-gigabyte era computer disk drives, where the precision they offered was adequate for the correct positioning of the read/write head of a hard disk drive. As drive density increased, the precision limitations of stepper motors made them obsolete for hard drives, thus newer hard disk drives use read/write head control systems based on voice coils. Stepper motors were upscaled to be used in electric vehicles under the term SRM (switched reluctance machine).

Reviewing A-C Motors

AC Motor History

In 1882, Nikola Tesla discovered the rotating magnetic field, and pioneered the use of a rotary field of force to operate machines. He exploited the principle to design a unique two-phase induction motor in 1883. In 1885, Galileo Ferraris independently researched the concept. In 1888, Ferraris published his research in a paper to the Royal Academy of Sciences in Turin. Tesla had suggested that the commutators from a machine could be removed and the device could operate on a rotary field of force. Professor Poeschel, his teacher, stated that would be akin to building a perpetual motion machine.

Michail Osipovich Dolivo-Dobrovolsky later developed a three-phase "cage-rotor" in 1890. This type of motor is now used for the vast majority of commercial applications.

An AC motor has two parts: a stationary stator having coils supplied with alternating current to produce a rotating magnetic field, and a rotor attached to the output shaft that is given a torque by the rotating field.

AC Motor with Sliding Rotor

A conical-rotor brake motor incorporates the brake as an integral part of the conical sliding rotor. When the motor is at rest, a spring acts on the sliding rotor and forces the brake ring against the brake cap in the motor, holding the rotor stationary. When the motor is energized, its magnetic field generates both an axial and a radial component. The axial component overcomes the spring force, releasing the brake; while the radial component causes the rotor to turn. There is no additional brake control required.

Synchronous Electric Motor

A synchronous electric motor is an AC motor distinguished by a rotor spinning with coils passing magnets at the same rate as the alternating current and resulting magnetic field which drives it. Another way of saying this is that it has zero slip under usual operating conditions. Contrast this with an induction motor, which must slip to produce torque. One type of synchronous motor is like an induction motor except the rotor is excited by a DC field. Slip rings and brushes are used to conduct current to the rotor. The rotor poles connect to each other and move at the same speed hence the name synchronous motor.

Another type, for low load torque, has flats ground onto a conventional squirrel-cage rotor to create discrete poles. Yet another, such as made by Hammond for its pre-World War II clocks, and in the older Hammond organs, has no rotor windings and discrete poles. It is not self-starting. The clock requires manual starting by a small knob on the back, while the older Hammond organs had an auxiliary starting motor connected by a spring-loaded manually operated switch.

Finally, hysteresis synchronous motors typically are (essentially) two-phase motors with a phase-shifting capacitor for one phase. They start like induction motors, but when slip rate decreases sufficiently, the rotor (a smooth cylinder) becomes temporarily magnetized.

Its distributed poles make it act like a permanent-magnet-rotor synchronous motor. The rotor material, like that of a common nail, will stay magnetized, but can also be demagnetized with little difficulty. Once running, the rotor poles stay in place; they do not drift.

Low-power synchronous timing motors (such as those for traditional electric clocks) may have multi-pole permanent-magnet external cup rotors, and use shading coils to provide starting torque. Telechron clock motors have shaded poles for starting torque, and a two-spoke ring rotor that performs like a discrete two-pole rotor.

Induction Motor

An induction motor is an asynchronous AC motor where power is transferred to the rotor by electromagnetic induction, much like transformer action. An induction motor resembles a rotating transformer, because the stator (stationary part) is essentially the primary side of the transformer and the rotor (rotating part) is the secondary side. Polyphase induction motors are widely used in industry.

Induction motors may be further divided into squirrel-cage motors and wound-rotor motors. Squirrel-cage motors have a heavy winding made up of solid bars, usually aluminum or copper, joined by rings at the ends of the rotor. When one considers only the bars and rings as a whole, they are much like an animal's rotating exercise cage, hence the name.

Currents induced into this winding provide the rotor magnetic field. The shape of the rotor bars determines the speed-torque characteristics. At low speeds, the current induced in the squirrel cage is nearly at line frequency and tends to be in the outer parts of the rotor cage. As the motor accelerates, the slip frequency becomes lower, and more current is in the interior of the winding. By shaping the bars to change the resistance of the winding portions in the interior and outer parts of the cage, effectively a variable resistance is inserted in the rotor circuit. However, the majority of such motors have uniform bars.

In a wound-rotor motor, the rotor winding is made of many turns of insulated wire and is connected to slip rings on the motor shaft. An external resistor or other control devices can be connected in the rotor circuit. Resistors allow control of the motor speed, although significant power is dissipated in the external resistance. A converter can be fed from the rotor circuit and return the slip-frequency power that would otherwise be wasted back into the power system through an inverter or separate motor-generator.

The wound-rotor induction motor is used primarily to start a high inertia load or a load that requires a very high starting torque across the full speed range. By correctly selecting the resistors used in the secondary resistance or slip ring starter, the motor is able to produce maximum torque at a relatively low supply current from zero speed to full speed. This type of motor also offers controllable speed.

Motor speed can be changed because the torque curve of the motor is effectively modified by the amount of resistance connected to the rotor circuit. Increasing the value of resistance will move the speed of maximum torque down. If the resistance connected to the rotor is increased beyond the point where the maximum torque occurs at zero speed, the torque will be further reduced.

When used with a load that has a torque curve that increases with speed, the motor will operate at the speed where the torque developed by the motor is equal to the load torque. Reducing the load will cause the motor to speed up, and increasing the load will cause the motor to slow down until the load and motor torque are equal. Operated in this manner, the slip losses are dissipated in the secondary resistors and can be very significant.

Electric Motor Maintenance Sub-Section

General

Make a habit of checking that the motor is securely bolted to its platform. Mounting bolts can vibrate loose. Check to see that rotating parts aren't rubbing on stationary parts of the motor, causing damage to the motor.

Remember that an electric motor is an air-cooled piece of equipment and needs all the ventilation it can get. Excessive heat is a main cause of reduced motor life.

Motors also like to be dry. Keep motor windings dry by keeping pump packing in good condition. Even if windings are protected from moisture, minerals in the pumped water can attach to the windings and cause early failure. Motors that operate at 3600 rpm experience twice as much wear as motors operating at 1800 rpm. Regular maintenance is especially critical for 3600 rpm motors and pumps.

Maintenance Tasks

At season startup:

- Remove tape on all openings and clean out rodents, insects, or debris.
- Locate the motor drain hole on the base or support for the base, and clean it out so water won't be trapped and held directly under the air intake.
- Change oil in reduced voltage starters, using an oil recommended by the manufacturer. Be sure to clean the oil pan before refilling.
- Use vacuum suction or air pressure to remove dust and debris from moving parts of the motor. (Don't exceed 50 psi of air pressure.)

Periodically:

- Clean grass or debris from air ventilation openings on the motor and from around the motor to allow a full flow of cooling air.
- Check screens on motor ventilation openings. Replace with machine cloth (¼-inch mesh) as necessary.

At end of season shutdown:

- Cover the motor with a breathable water-resistant tarp.

Motor Electrical System

Wide temperature fluctuations during the year can cause electrical connections (especially in aluminum wire) to expand and contract, loosening connectors. Loose electrical connections cause heat buildup and arcing at electrical terminals. The voltage drop across loose connections will cause the motor to operate at less than its rated voltage, increasing internal motor temperature. Increased heat will break down motor winding insulation, resulting in electrical shorts and motor failures. A loose or broken connection can also unbalance the phases of three-phase power and damage the motor windings.

Caution: Before conducting these tasks, be sure power is off at the utility disconnect switch. It may be necessary to have the utility company shut the power off.

Maintenance Tasks

At season startup:

- Inspect insulation of motor windings. If the windings are excessively grease-covered, consult your motor repair shop for direction.
- Check all safety switches according to the manufacturer's directions.

Twice a year:

- Check electrical connections from meter loop to motor for corrosion and clean if necessary.
- Coat the wiring (especially aluminum) and connectors with an antioxidant that meets electrical code requirements.
- Check electrical connections from the meter loop to the motor for tightness.
- Tighten and re-tape if necessary.
- Replace overheated connections or wires with new material. Overheated connections will show heat damage such as burnt insulation on wires.

Motor Bearings

Lubricate the motor according to the manufacturer's instructions. Intervals between lubrication will vary with motor speed, power draw, load, ambient temperatures, exposure to moisture, and seasonal or continuous operation. Electric motors should not be greased daily. Bearings can be ruined by either over- or under-greasing.

Fill a grease gun with electric motor bearing grease and label it so it won't be confused with other types of lubricating grease.

Maintenance Tasks

Change the grease at recommended intervals to remove any accumulated moisture:

- Remove the bottom relief plug and clean hardened grease out of passageway.
- Using a grease gun, fill the housing with approved high temperature electric motor bearing grease (refer to the manufacturer's manual for API number of grease) until old grease is expelled.

Caution: If old grease is not expelled as the new grease is pumped in, stop adding grease and have your motor checked by a qualified repair person. Adding new grease without old grease being removed could blow the seals and push grease into the motor windings, causing the motor to overheat and reducing its service life. Do not over-grease your motor.

- Run motor until all surplus grease is thrown out through the bottom grease port (may require 5 to 10 minutes).
- Shut off the motor and use a screwdriver or similar device to remove a small amount of grease from the grease port to allow for grease expansion during full load operation.
- Replace grease plug.

Control Panel Maintenance**Control Panel Safety Precautions**

Never use the main disconnect to start or stop your motor. It is not intended for this purpose. Using the main disconnect to start and stop the motor will cause excessive wear of the contacts and arcing can occur. Use the start and stop button.

If the overhead lines to your control panel's service are obstructed by tree branches or other items, have the utility company clear the lines.

Have an electrician inspect your panel to ensure that:

- Control circuits are protected with the correct size and type of fuse.
- Lightning arresters are properly installed on the meter and motor side of the buss and breaker. They should also be mounted in a secure box to protect you if they blow up.
- The service panel is properly grounded, independently of the pumping plant.
- Service head grommets are in place and in good condition.

General Maintenance

Have your electrician or pump maintenance person do a Megger check on the control panel, motor, conduits, and other electrical connections. The Megger device applies a small amount of voltage to an electrical component and measures the electrical resistance. A Megger test can also detect potentially harmful moisture in windings.

Any time the main disconnect switch has been left open or off, operate it several times before leaving it closed or on. Copper oxide can form in a few hours and result in poor contact and overheating. Any type of corrosion can cause poor contact, poor grounding, and direct or high-resistance shorts.

Caution: After opening the control panel but before touching the controls inside, use a voltmeter to be sure that the incoming power is disconnected or turned off. If necessary, have your utility disconnect the power. If you have any doubts about the safety of your control panel, WALK AWAY AND CALL A QUALIFIED ELECTRICIAN.

Even a current of 15 milliamps (one milliamp is one one-thousandth of an amp) can cause serious injury or death. Always play it safe!

SCADA Sub-Section



What is SCADA and Who Uses It?

Supervisory control and data acquisition (SCADA) is a system of software and hardware elements that allows industrial organizations to:

- Control industrial processes locally or at remote locations
- Monitor, gather, and process real-time data
- Directly interact with devices such as sensors, valves, pumps, motors, and more through human-machine interface (HMI) software
- Record events into a log file

SCADA systems are crucial for industrial organizations since they help to maintain efficiency, process data for smarter decisions, and communicate system issues to help mitigate downtime.

The basic SCADA architecture begins with programmable logic controllers (PLCs) or remote terminal units (RTUs). PLCs and RTUs are microcomputers that communicate with an array of objects such as factory machines, HMIs, sensors, and end devices, and then route the information from those objects to computers with SCADA software. The SCADA software processes, distributes, and displays the data, helping operators and other employees analyze the data and make important decisions.

For example, the SCADA system quickly notifies an operator that a batch of product is showing a high incidence of errors. The operator pauses the operation and views the SCADA system data via an HMI to determine the cause of the issue. The operator reviews the data and discovers that Machine 4 was malfunctioning. The SCADA system's ability to notify the operator of an issue helps him to resolve it and prevent further loss of product.

SCADA systems are used by industrial organizations and companies in the public and private sectors to control and maintain efficiency, distribute data for smarter decisions, and communicate system issues to help mitigate downtime.

SCADA systems work well in many different types of enterprises because they can range from simple configurations to large, complex installations. SCADA systems are the backbone of many modern industries, including:

- Energy
- Food and beverage
- Manufacturing
- Oil and gas
- Power
- Recycling
- Transportation
- Water and wastewater
- And many more

Virtually anywhere you look in today's world, there is some type of SCADA system running behind the scenes: maintaining the refrigeration systems at the local supermarket, ensuring production and safety at a refinery, achieving quality standards at a waste water treatment plant, or even tracking your energy use at home, to give a few examples.

Effective SCADA systems can result in significant savings of time and money. Numerous case studies have been published highlighting the benefits and savings of using a modern SCADA software solution such as Ignition.

SCADA Simply Explained



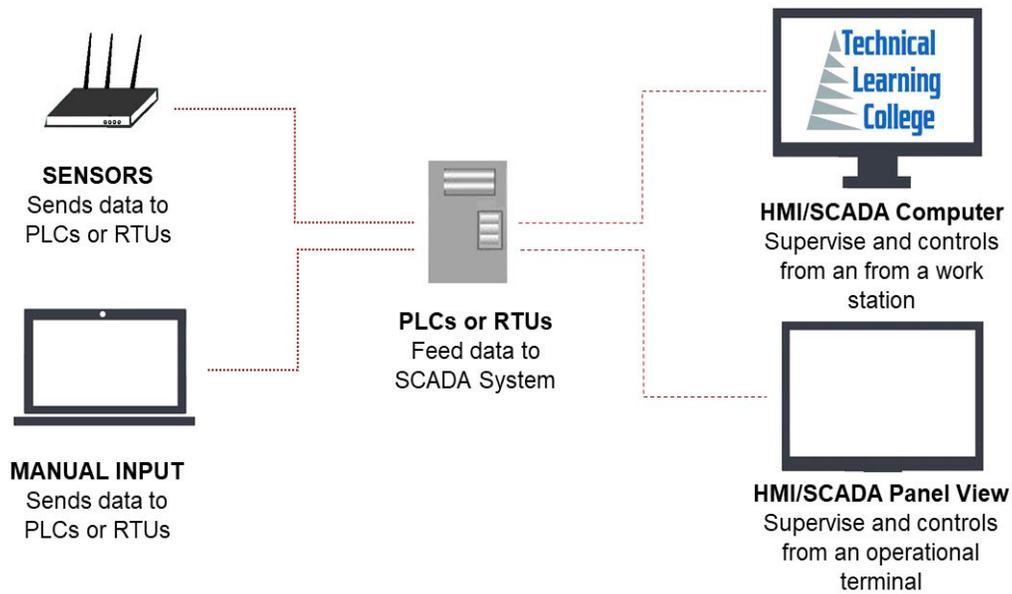
Supervisory control and data acquisition – SCADA refers to ICS (industrial control systems) used to control infrastructure processes (water treatment, wastewater treatment, gas pipelines, wind farms, etc.), facility-based processes (airports, space stations, ships, etc.) or industrial processes (production, manufacturing, refining, power generation, etc.).

Supervisory Control and Data Acquisition (SCADA) is a control system architecture that uses computers, networked data communications and graphical user interfaces for high-level process supervisory management, but uses other peripheral devices such as programmable logic controller (PLC) and discrete PID controllers to interface with the process plant or machinery. The use of SCADA has been also considered for management and operations of project-driven-process in construction.

The following subsystems are usually present in SCADA systems:

- The apparatus used by a human operator; all the processed data are presented to the operator
- A supervisory system that gathers all the required data about the process
- Remote Terminal Units (RTUs) connected to the sensors of the process, which helps to convert the sensor signals to the digital data and send the data to supervisory stream.
- Programmable Logic Controller (PLCs) used as field devices
- Communication infrastructure connects the Remote Terminal Units to supervisory system.

Generally, a SCADA system does not control the processes in real time – it usually refers to the system that coordinates the processes in real time.



BASIC SCADA DIAGRAM

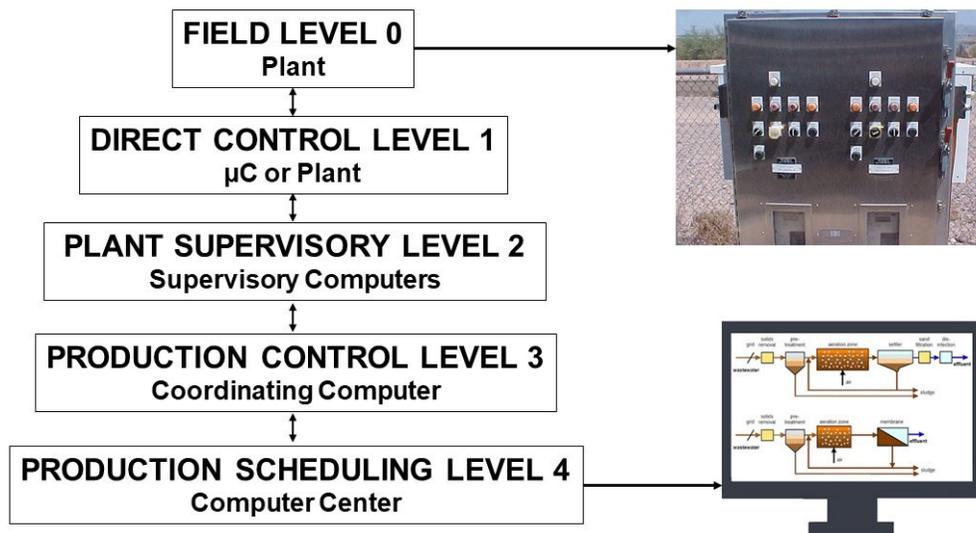
Remote Operation

SCADA is a real time control tool. It is not supposed to be a tool for detailed analysis of past performance but you the operator are able to research past performance to be able to react to current conditions. Thus, some form of trending is included with SCADA. The trending function is as close to analysis as most SCADA software get.

Let us say a water treatment operator wants to examine chemical usage in GAC filters and determine how each filter behaved over the past six weeks. In this case, SCADA is your tool of choice.

Some SCADA let you look at these three filters and compare their performance with some time period in the past.

SCADA Systems Concepts



FUNCTION LEVELS OF CONTROL OPERATION

SCADA refers to the centralized systems that control and monitor the entire sites, or they are the complex systems spread out over large areas. Nearly all the control actions are automatically performed by the remote terminal units (RTUs) or by the programmable logic controllers (PLCs). The restrictions to the host control functions are supervisory level intervention or basic overriding.

For example, the PLC (in an industrial process) controls the flow of cooling water, the SCADA system allows any changes related to the alarm conditions and set points for the flow (such as high temperature, loss of flow, etc.) to be recorded and displayed.

Data acquisition starts at the PLC or RTU level, which includes the equipment status reports, and meter readings. Data is then formatted in such way that the operator of the control room can make the supervisory decisions to override or adjust normal PLC (RTU) controls, by using the HMI.

SCADA systems mostly implement the distributed databases known as tag databases, containing data elements called points or tags. A point is a single output or input value controlled or monitored by the system. Points are either 'soft' or 'hard'.

The actual output or input of a system is represented by a hard point, whereas the soft point is a result of different math and logic operations applied to other points. These points are usually stored as timestamp-value pairs.

Series of the timestamp-value pairs gives history of the particular point. Storing additional metadata with the tags is common (these additional data can include comments on the design time, alarm information, path to the field device or the PLC register).

The key attribute of a SCADA system is its ability to perform a supervisory operation over a variety of other proprietary devices.

The accompanying diagram is a general model which shows functional manufacturing levels using computerized control.

SCADA systems typically use a tag database, which contains data elements called tags or points, which relate to specific instrumentation or actuators within the process system according to such as the Piping and instrumentation diagram.

Data is accumulated against these unique process control equipment tag references.

Referring to the diagram,

Level 0 contains the field devices such as flow and temperature sensors, and final control elements, such as control valves.

Level 1 contains the industrialized input/output (I/O) modules, and their associated distributed electronic processors.

Level 2 contains the supervisory computers, which collate information from processor nodes on the system, and provide the operator control screens.

Level 3 is the production control level, which does not directly control the process, but is concerned with monitoring production and targets.

Level 4 is the production scheduling level.

Level 1 contains the programmable logic controllers (PLCs) or remote terminal units (RTUs).

Level 2 contains the SCADA software and computing platform. The SCADA software exists only at this supervisory level as control actions are performed automatically by RTUs or PLCs. SCADA control functions are usually restricted to basic overriding or supervisory level intervention.

For example, a PLC may control the flow of cooling water through part of an industrial process to a set point level, but the SCADA system software will allow operators to change the set points for the flow.

The SCADA also enables alarm conditions, such as loss of flow or high temperature, to be displayed and recorded. A feedback control loop is directly controlled by the RTU or PLC, but the SCADA software monitors the overall performance of the loop.

Levels 3 and 4 are not strictly process control in the traditional sense, but are where production control and scheduling takes place.

Data acquisition begins at the RTU or PLC level and includes instrumentation readings and equipment status reports that are communicated to level 2 SCADA as required.

Data is then compiled and formatted in such a way that a control room operator using the HMI (Human Machine Interface) can make supervisory decisions to adjust or override normal RTU (PLC) controls. Data may also be fed to a historian, often built on a commodity database management system, to allow trending and other analytical auditing.

Considerations of SCADA System

Typical considerations when putting a SCADA system together are:

- Overall control requirements
- Sequence logic
- Analog loop control
- Ratio and number of analog to digital points
- Speed of control and data acquisition
- Master/operator control stations
- Type of displays required
- Historical archiving requirements
- System consideration
- Reliability/availability
- Speed of communications/update time/system scan rates
- System redundancy
- Expansion capability
- Application software and modeling

Benefits of a SCADA System

Obviously, a SCADA system's initial cost has to be justified.

A few typical reasons for implementing a SCADA system are:

1. Improved operation of the plant or process resulting in savings due to optimization of the system
2. Increased productivity of the personnel
3. Improved safety of the system due to better information and improved control
4. Protection of the plant equipment
5. Safeguarding the environment from a failure of the system
6. Improved energy savings due to optimization of the plant
7. Improved and quicker receipt of data so that clients can be invoiced more quickly and accurately
8. Government regulations for safety and metering of gas (for royalties etc.)

Human Machine Interface Introduction

The HMI, or Human Machine Interface, is an apparatus that gives the processed data to the human operator. A human operator uses HMI to control processes.

The HMI is linked to the SCADA system's databases, to provide the diagnostic data, management information and trending information such as logistic information, detailed schematics for a certain machine or sensor, maintenance procedures and troubleshooting guides.

The information provided by the HMI to the operating personnel is graphical, in the form of mimic diagrams. This means the schematic representation of the plant that is being controlled is available to the operator.

For example, a photograph of the pump that is connected to the pipe shows that this pump is running and it also shows the amount of fluid pumping through the pipe at the particular moment. The pump can then be switched off by the operator.

The software of the HMI shows the decrease in the flow rate of fluid in the pipe in the real time. Mimic diagrams either consist of digital photographs of process equipment with animated symbols, or schematic symbols and line graphics that represent various process elements.

HMI package of the SCADA systems consist of a drawing program used by the system maintenance personnel or operators to change the representation of these points in the interface.

These representations can be as simple as on-screen traffic light that represents the state of the actual traffic light in the area, or complex, like the multi-projector display that represents the position of all the trains on railway or elevators in skyscraper.

SCADA systems are commonly used in alarm systems. The alarm has only two digital status points with values ALARM or NORMAL.

When the requirements of the Alarm are met, the activation will start. For example, when the fuel tank of a car is empty, the alarm is activated and the light signal is on. To alert the SCADA operators and managers, text messages and emails are sent along with alarm activation.

Supervisory Station Introduction

A 'supervisory Station' refers to the software and servers responsible for communication with the field equipment (PLCs, RTUs etc.), and after that, to HMI software running on the workstations in the control room, or somewhere else.

A master station can be composed of only one PC (in small SCADA systems). Master station can have multiple servers, disaster recovery sites and distributed software applications in larger SCADA systems. For increasing the system integrity, multiple servers are occasionally configured in hot standby or dual-redundant formation, providing monitoring and continuous control during server failures.

SCADA Hardware

SCADA system may have the components of the Distributed Control System. Execution of easy logic processes without involving the master computer is possible because 'smart' PLCs or RTUs. IEC61131-3(Ladder Logic) is used, (this is a functional block programming language, commonly used in creating programs running on PLCs and RTUs.) IEC 61131-3 has very few training requirements, unlike procedural languages like FORTRAN and C programming language.

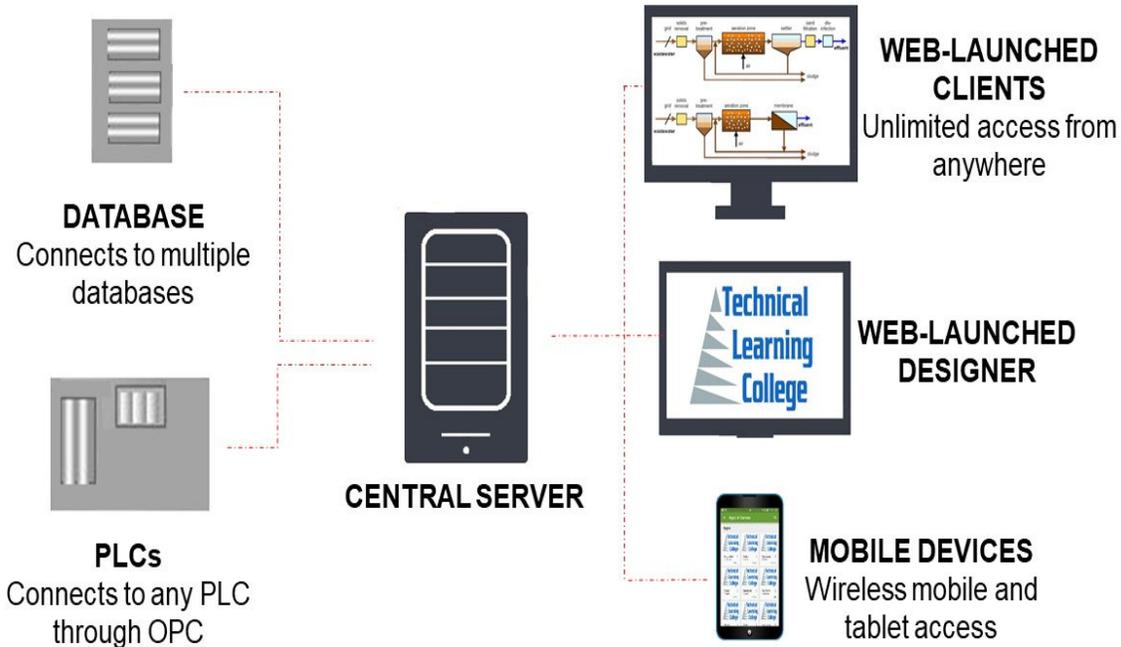
The SCADA system engineers can perform implementation and design of programs being executed on PLC or RTU. The compact controller, Programmable automation controller (PAC), combines the capabilities and features of a PC-based control system with a typical PLC.

'Distributed RTUs', in various electrical substation SCADA applications, use station computers or information processors for communicating with PACs, protective relays, and other I/O devices. Almost all big PLC manufacturers offer integrated HMI/SCADA systems, since 1998. Many of them are using non-proprietary and open communication protocols.

Many skilled third party HMI/SCADA packages have stepped into the market, offering in-built compatibility with several major PLCs, which allows electrical engineers, mechanical engineers or technicians to configure HMIs on their own, without requiring software-developer-written custom-made program.

Remote Terminal Unit (RTU)

The RTU is connected to the physical equipment. Often, the RTU converts all electrical signals coming from the equipment into digital values like the status- open/closed – from a valve or switch, or the measurements like flow, pressure, current or voltage. By converting and sending the electrical signals to the equipment, RTU may control the equipment, like closing or opening a valve or a switch, or setting the speed of the pump.



MODERN SCADA DIAGRAM

SCADA Operational Philosophy

The costs resulting from control system failures are very high. Even lives may be lost. For a few SCADA systems, hardware is ruggedized, to withstand temperature, voltage and vibration extremes, and reliability is increased, in many critical installations, by including communications channels and redundant hardware. A part which is failing can be identified and the functionality taken over automatically through backup hardware. It can be replaced without any interruption of the process.

Communication Methods and Infrastructure

SCADA systems initially used modem connections or combinations of direct and radio serial to meet communication requirements, even though IP and Ethernet over SONET/SDH can also be used at larger sites like power stations and railways. The monitoring function or remote management of the SCADA system is called telemetry.

SCADA protocols have been designed to be extremely compact and to send information to the master station only when the RTU is polled by the master station. Typically, the legacy of SCADA protocols consists of Conitel, Profibus, Modbus RTU and RP-570. These protocols of communication are specifically SCADA-vendor. Standard protocols are IEC 61850, DNP3 and IEC 60870-5-101 or 104. These protocols are recognized and standardized by all big SCADA vendors. Several of these protocols have extensions for operating through the TCP/IP.

The development of many automatic controller devices and RTUs had started before the advent of industry standards for the interoperability.

For better communication between different software and hardware, PLE for Process Control is a widely accepted solution that allows communication between the devices that originally weren't intended to be part of the industrial network.

Alarm Management Introduction

An important part of most SCADA implementations is alarm handling. The system monitors whether certain alarm conditions are satisfied, to determine when an alarm event has occurred. Once an alarm event has been detected, one or more actions are taken (such as the activation of one or more alarm indicators, and perhaps the generation of email or text messages so that management or remote SCADA operators are informed).

In many cases, a SCADA operator may have to acknowledge the alarm event; this may deactivate some alarm indicators, whereas other indicators remain active until the alarm conditions are cleared.

Alarm conditions can be explicit—for example, an alarm point is a digital status point that has either the value NORMAL or ALARM that is calculated by a formula based on the values in other analogue and digital points—or implicit: the SCADA system might automatically monitor whether the value in an analogue point lies outside high and low- limit values associated with that point.

Examples of alarm indicators include a siren, a pop-up box on a screen, or a colored or flashing area on a screen (that might act in a similar way to the "fuel tank empty" light in a car); in each case, the role of the alarm indicator is to draw the operator's attention to the part of the system 'in alarm' so that appropriate action can be taken.

PLC/RTU Programming

"Smart" RTUs, or standard PLCs, are capable of autonomously executing simple logic processes without involving the supervisory computer. They employ standardized control programming languages such as under, IEC 61131-3 (a suite of 5 programming languages including function block, ladder, structured text, sequence function charts and instruction list), is frequently used to create programs which run on these RTUs and PLCs.

Unlike a procedural language such as the C programming language or FORTRAN, IEC 61131-3 has minimal training requirements by virtue of resembling historic physical control arrays. This allows SCADA system engineers to perform both the design and implementation of a program to be executed on an RTU or PLC.

A programmable automation controller (PAC) is a compact controller that combines the features and capabilities of a PC-based control system with that of a typical PLC. PACs are deployed in SCADA systems to provide RTU and PLC functions.

In many electrical substation SCADA applications, "distributed RTUs" use information processors or station computers to communicate with digital protective relays, PACs, and other devices for I/O, and communicate with the SCADA master in lieu of a traditional RTU.

PLC Commercial Integration

Since about 1998, virtually all major PLC manufacturers have offered integrated HMI/SCADA systems, many of them using open and non-proprietary communications protocols.

Numerous specialized third-party HMI/SCADA packages, offering built-in compatibility with most major PLCs, have also entered the market, allowing mechanical engineers, electrical engineers and technicians to configure HMIs themselves, without the need for a custom-made program written by a software programmer.

The Remote Terminal Unit (RTU) connects to physical equipment. Typically, an RTU converts the electrical signals from the equipment to digital values such as the open/closed status from a switch or a valve, or measurements such as pressure, flow, voltage or current. By converting and sending these electrical signals out to equipment the RTU can control equipment, such as opening or closing a switch or a valve, or setting the speed of a pump.

SCADA Architectures

Monolithic: The First Generation

In the first generation, mainframe systems were used for computing. At the time SCADA was developed, networks did not exist. Therefore, the SCADA systems did not have any connectivity to other systems, meaning they were independent systems. Later on, RTU vendors designed the Wide Area Networks that helped in communication with RTU. The usage of communication protocols at that time was proprietary. If the mainframe system failed, there was a back-up mainframe, connected at the bus level.

Distributed: The Second Generation

The information between multiple stations was shared in real time through LAN and the processing was distributed between various multiple stations. The cost and size of the stations were reduced in comparison to the ones used in the first generation. The protocols used for the networks were still proprietary, which caused many security issues for SCADA systems. Due to the proprietary nature of the protocols, very few people actually knew how secure the SCADA installation was.

Networked: The Third Generation

The SCADA system used today belong to this generation. The communication between the system and the master station is done through the WAN protocols like the Internet Protocols (IP). Since the standard protocols used and the networked SCADA systems can be accessed through the internet, the vulnerability of the system is increased. However, the usage of security techniques and standard protocols means that security improvements can be applied in SCADA systems.

The Evolution of SCADA

The first iteration of SCADA started off with mainframe computers. Networks as we know them today were not available and each SCADA system stood on its own. These systems were what would now be referred to as monolithic SCADA systems.

In the 80s and 90s, SCADA continued to evolve thanks to smaller computer systems, Local Area Networking (LAN) technology, and PC-based HMI software. SCADA systems soon were able to be connected to other similar systems. Many of the LAN protocols used in these systems were proprietary, which gave vendors control of how to optimize data transfer. Unfortunately, these systems were incapable of communicating with systems from other vendors. These systems were called distributed SCADA systems.

In the 1990s and early 2000s, building upon the distributed system model, SCADA adopted an incremental change by embracing an open system architecture and communications protocols that were not vendor-specific. This iteration of SCADA, called a networked SCADA system, took advantage of communications technologies such as Ethernet. Networked SCADA systems allowed systems from other vendors to communicate with each other, alleviating the limitations imposed by older SCADA systems, and allowed organizations to connect more devices to the network.

While SCADA systems have undergone substantial evolutionary changes, many industrial organizations continued to struggle with industrial data access from the enterprise level. By the late 1990s to the early 2000s, a technological boom occurred and personal computing and IT technologies accelerated in development.

Structured query language (SQL) databases became the standard for IT databases but were not adopted by SCADA developers. This resulted in a rift between the fields of controls and IT, and SCADA technology became antiquated over time.

Traditional SCADA systems still use proprietary technology to handle data. Whether it is a data historian, a data connector, or other means of data transfer, the solution is messy and incredibly expensive. Modern SCADA systems aim to solve this problem by leveraging the best of controls and IT technology.

Communication Infrastructure and Methods

SCADA systems have traditionally used combinations of radio and direct wired connections, although SONET/SDH is also frequently used for large systems such as railways and power stations. The remote management or monitoring function of a SCADA system is often referred to as telemetry. Some users want SCADA data to travel over their pre-established corporate networks or to share the network with other applications. The legacy of the early low-bandwidth protocols remains, though.

SCADA protocols are designed to be very compact. Many are designed to send information only when the master station polls the RTU. Typical legacy SCADA protocols include Modbus RTU, RP-570, Profibus and Conitel. These communication protocols, with the exception of Modbus (Modbus has been made open by Schneider Electric), are all SCADA-vendor specific but are widely adopted and used. Standard protocols are IEC 60870-5-101 or 104, IEC 61850 and DNP3. These communication protocols are standardized and recognized by all major SCADA vendors. Many of these protocols now contain extensions to operate over TCP/IP. Although the use of conventional networking specifications, such as TCP/IP, blurs the line between traditional and industrial networking, they each fulfill fundamentally differing requirements. Network simulation can be used in conjunction with SCADA simulators to perform various 'what-if' analyses.

With increasing security demands (such as North American Electric Reliability Corporation (NERC) and critical infrastructure protection (CIP) in the US), there is increasing use of satellite-based communication. This has the key advantages that the infrastructure can be self-contained (not using circuits from the public telephone system), can have built-in encryption, and can be engineered to the availability and reliability required by the SCADA system operator. Earlier experiences using consumer-grade VSAT were poor. Modern carrier-class systems provide the quality of service required for SCADA.

RTUs and other automatic controller devices were developed before the advent of industry wide standards for interoperability. The result is that developers and their management created a multitude of control protocols. Among the larger vendors, there was also the incentive to create their own protocol to "lock in" their customer base. A list of automation protocols is compiled here.

OLE for process control (OPC) can connect different hardware and software, allowing communication even between devices originally not intended to be part of an industrial network. Standardization in the field of mySCADA protocols resulted into the vendor independent protocol called OPC UA (Unified Architecture). OPC UA is starting to be widely adopted among multiple SCADA vendors.

SCADA Trends

In the late 1990s instead of using the RS-485, manufacturers used open message structures like Modbus ASCII and Modbus RTU (both developed by Modicon). By 2000, almost all I/O makers offered fully open interfacing like Modbus TCP instead of the IP and Ethernet.

SCADA systems are now in line with the standard networking technologies. The old proprietary standards are being replaced by the TCP/IP and Ethernet protocols. However, due to certain characteristics of frame-based network communication technology, Ethernet networks have been accepted by the majority of markets for HMI SCADA.

The 'Next Generation' protocols using XML web services and other modern web technologies, make themselves more IT supportable. A few examples of these protocols include Wonderware's SuiteLink, GE Fanuc's Proficy, I Gear's Data Transport Utility, Rockwell Automation's FactoryTalk and OPC-UA.

Some vendors have started offering application-specific SCADA systems that are hosted on remote platforms all over the Internet. Hence, there is no need to install systems at the user-end facility. Major concerns are related to the Internet connection reliability, security and latency. The SCADA systems are becoming omnipresent day by day. However, there are still some security issues.

SCADA Security Issues

Security of SCADA-based systems is being questioned, as they are potential targets to cyberterrorism/cyberwarfare attacks.

There is an erroneous belief that SCADA networks are safe enough because they are secured physically. It is also wrongly believed that SCADA networks are safe enough because they are disconnected from the Internet.

SCADA systems also are used for monitoring and controlling physical processes, like distribution of water, traffic lights, electricity transmissions, gas transportation and oil pipelines and other systems used in the modern society. Security is extremely important because destruction of the systems would have very bad consequences.

There are two major threats. The first one is unauthorized access to software, be it human access or intentionally induced changes, virus infections or other problems that can affect the control host machine. The second threat is related to the packet access to network segments that host SCADA devices. In numerous cases, there remains less or no security on actual packet control protocol; therefore, any person sending packets to SCADA device is in position to control it. Often, SCADA users infer that VPN is sufficient protection, and remain oblivious to the fact that physical access to network switches and jacks related to SCADA provides the capacity to bypass the security on control software and control SCADA networks.

SCADA vendors are addressing these risks by developing specialized industrial VPN and firewall solutions for SCADA networks that are based on TCP/IP. In addition, white-listing solutions have been implemented due to their ability to prevent unauthorized application changes.

SCADA systems that tie together decentralized facilities such as power, oil, gas pipelines, water distribution and wastewater collection systems were designed to be open, robust, and easily operated and repaired, but not necessarily secure.

The move from proprietary technologies to more standardized and open solutions together with the increased number of connections between SCADA systems, office networks and the Internet has made them more vulnerable to types of network attacks that are relatively common in computer security. For example, United States Computer Emergency Readiness Team (US-CERT) released a vulnerability advisory warning that unauthenticated users could download sensitive configuration information including password hashes from an Inductive Automation Ignition system utilizing a standard attack type leveraging access to the Tomcat Embedded Web server. Security researcher Jerry Brown submitted a similar advisory regarding a buffer overflow vulnerability in a Wonderware InBatchClient ActiveX control. Both vendors made updates available prior to public vulnerability release. Mitigation recommendations were standard patching practices and requiring VPN access for secure connectivity. Consequently, the security of some SCADA-based systems has come into question as they are seen as potentially vulnerable to cyber-attacks.

In particular, security researchers are concerned about

- the lack of concern about security and authentication in the design, deployment and operation of some existing SCADA networks
- the belief that SCADA systems have the benefit of security through obscurity through the use of specialized protocols and proprietary interfaces
- the belief that SCADA networks are secure because they are physically secured
- the belief that SCADA networks are secure because they are disconnected from the Internet

SCADA systems are used to control and monitor physical processes, examples of which are transmission of electricity, transportation of gas and oil in pipelines, water distribution, traffic lights, and other systems used as the basis of modern society. The security of these SCADA systems is important because compromise or destruction of these systems would impact multiple areas of society far removed from the original compromise. For example, a blackout caused by a compromised electrical SCADA system would cause financial losses to all the customers that received electricity from that source. How security will affect legacy SCADA and new deployments remains to be seen.

There are many threat vectors to a modern SCADA system. One is the threat of unauthorized access to the control software, whether it is human access or changes induced intentionally or accidentally by virus infections and other software threats residing on the control host machine. Another is the threat of packet access to the network segments hosting SCADA devices. In many cases, the control protocol lacks any form of cryptographic security, allowing an attacker to control a SCADA device by sending commands over a network.

In many cases, SCADA users have assumed that having a VPN offered sufficient protection, unaware that security can be trivially bypassed with physical access to SCADA-related network jacks and switches. Industrial control vendors suggest approaching SCADA security like Information Security with a defense in depth strategy that leverages common IT practices

The reliable function of SCADA systems in our modern infrastructure may be crucial to public health and safety. As such, attacks on these systems may directly or indirectly threaten public health and safety. Such an attack has already occurred, carried out on Maroochy Shire Council's sewage control system in Queensland, Australia. Shortly after a contractor installed a SCADA system in January 2000, system components began to function erratically. Pumps did not run when needed and alarms were not reported.

More critically, sewage flooded a nearby park and contaminated an open surface-water drainage ditch and flowed 500 meters to a tidal canal. The SCADA system was directing sewage valves to open when the design protocol should have kept them closed. Initially this was believed to be a system bug.

Monitoring of the system logs revealed the malfunctions were the result of cyber-attacks. Investigators reported 46 separate instances of malicious outside interference before the culprit was identified. The attacks were made by a disgruntled ex-employee of the company that had installed the SCADA system. The ex-employee was hoping to be hired by the utility full-time to maintain the system.

In April 2008, the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack issued a Critical Infrastructures Report which discussed the extreme vulnerability of SCADA systems to an electromagnetic pulse (EMP) event. After testing and analysis, the Commission concluded: "SCADA systems are vulnerable to an EMP event.

The large numbers and widespread reliance on such systems by all of the Nation's critical infrastructures represent a systemic threat to their continued operation following an EMP event. Additionally, the necessity to reboot, repair, or replace large numbers of geographically widely dispersed systems will considerably impede the Nation's recovery from such an assault."

Summary

SCADA System

A SCADA (or supervisory control and data acquisition) system means a system consisting of a number of remote terminal units (or RTUs) collecting field data connected back to a master station via a communications system.

The master station displays the acquired data and allows the operator to perform remote control tasks.

The accurate and timely data (normally real-time) allows for optimization of the operation of the plant and process. A further benefit is more efficient, reliable and most importantly, safer operations. This all results in a lower cost of operation compared to earlier non-automated systems.

There is a fair degree of confusion between the definition of SCADA systems and process control system. SCADA has the connotation of remote or distant operation.

Pump Definitions

Hyperlink to the Glossary and Appendix

<http://www.abctlc.com/downloads/PDF/PumpGlossary.pdf>

Fluid: Any substance that can be pumped such as oil, water, refrigerant, or even air.

Gasket: Flat material that is compressed between two flanges or faces to form a seal.

Gland follower: A bushing used to compress the packing in the stuffing box and to control leakoff.

Gland sealing line: A line that directs sealing fluid to the stuffing box.

Horizontal pumps: Pumps in which the center line of the shaft is horizontal.

Impeller: The part of the pump that increases the speed of the fluid being handled.

Inboard: The end of the pump closest to the motor.

Inter-stage diaphragm: A barrier that separates stages of a multi-stage pump.

Key: A rectangular piece of metal that prevents the impeller from rotating on the shaft.

Keyway: The area on the shaft that accepts the key.

Kinetic energy: Energy associated with motion.

Lantern ring: A metal ring located between rings of packing that distributes gland sealing fluid.

Leak-off: Fluid that leaks from the stuffing box.

Mechanical seal: A mechanical device that seals the pump stuffing box.

Mixed flow pump: A pump that uses both axial-flow and radial-flow components in one impeller.

Multi-stage pumps: Pumps with more than one impeller.

Outboard: The end of the pump farthest from the motor.

Packing: Soft, pliable material that seals the stuffing box.

Positive displacement pumps: Pumps that move fluids by physically displacing the fluid inside the pump.

Radial bearings: Bearings that prevent shaft movement in any direction outward from the center line of the pump.

Radial flow: Flow at 90° to the center line of the shaft.

Retaining nut: A nut that keeps the parts in place.

Rotor: The rotating parts, usually including the impeller, shaft, bearing housings, and all other parts included between the bearing housing and the impeller.

Score: To cause lines, grooves, or scratches.

Shaft: A cylindrical bar that transmits power from the driver to the pump impeller.

Shaft sleeve: A replaceable tubular covering on the shaft.

Shroud: The metal covering over the vanes of an impeller.

Slop drain: The drain from the area that collects leak-off from the stuffing box.

Slurry: A thick, viscous fluid, usually containing small particles.

Stages: Impellers in a multi-stage pump.

Stethoscope: A metal device that can amplify and pinpoint pump sounds.

Strainer: A device that retains solid pieces while letting liquids through.

Stuffing box: The area of the pump where the shaft penetrates the casing.

Suction: The place where fluid enters the pump.

Suction eye: The place where fluid enters the pump impeller.

Throat bushing: A bushing at the bottom of the stuffing box that prevents packing from being pushed out of the stuffing box into the suction eye of the impeller.

Thrust: Force, usually along the center line of the pump.

Thrust bearings: Bearings that prevent shaft movement back and forth in the same direction as the center line of the shaft.

Troubleshooting: Locating a problem.

Vanes: The parts of the impeller that push and increase the speed of the fluid in the pump.

Vertical pumps: Pumps in which the center line of the shaft runs vertically.

Volute: The part of the pump that changes the speed of the fluid into pressure.

Wearing rings: Replaceable rings on the impeller or the casing that wear as the pump operates.

Post Quiz

1. _____ are rapidly replacing conventional packing as the means of controlling leakage on rotary and positive-displacement pumps.
2. Mechanical seals eliminate the problem of excessive _____ leakage, which causes failure of pump and motor bearings and motor windings.
3. Mechanical seals are ideal for pumps that operate in _____. They not only conserve the fluid being pumped, but also improve system operation.
4. Most water service pumps use a carbon material for one of the _____ and ceramic (tungsten carbide) for the other. When the seals wear out, they are simply replaced.
5. You should replace a _____ whenever the seal is removed from the shaft for any reason, or whenever leakage causes undesirable effects on equipment or surrounding spaces.
6. _____ a new seal on the sealing face because body acid and grease or dirt will cause the seal to pit prematurely and leak.
7. Mechanical shaft seals are positioned on the shaft by stub or step sleeves. Mechanical shaft seals must not be positioned by _____.
8. _____ are chamfered (beveled) on outboard ends for easy mechanical seal mounting.
9. Mechanical shaft seals serve to ensure that _____ is supplied to the seal faces under all conditions of operation. They also ensure adequate circulation of the liquid at the seal faces to minimize the deposit of foreign matter on the seal parts.
10. If the packing is allowed to dry out, it will score _____.
11. When operating a centrifugal pump, be sure there is always a slight trickle of water coming out of the _____.
12. How often the _____ in a centrifugal pump should be renewed depends on several factors, such as the type of pump, condition of the shaft sleeve, and hours in use.

13. To ensure the longest possible service from pump packing, make certain the shaft or sleeve is smooth when the packing is removed from_____.

14. Rapid wear of the packing will be caused by _____(or shaft where no sleeve is installed).

15. When replacing packing, be sure the packing fits uniformly around_____.

Answers: 1. Mechanical seals, 2. Stuffing box, 3. Closed systems, 4. Seal faces, 5. Mechanical seal, 6. Do not touch, 7. Setscrews, 8. Shaft sleeves, 9. Liquid pressure, 10. The shaft, 11. Stuffing box or seal, 12. Packing, 13. A gland, 14. Roughness of the shaft sleeve, 15. The stuffing box

Chapter 5 – HYDROGEN SULFIDE SECTION

Section Focus: You will learn the basics of hydrogen sulfide gas. At the end of this section, you the student will be able to understand and describe the dangers of hydrogen sulfide gas. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.

Scope/Background: Hydrogen sulfide (H_2S) is a colorless gas with a strong odor of rotten eggs. Exposure to hydrogen sulfide may cause irritation to the eyes and respiratory system. It can also cause apnea, coma, convulsions; dizziness, headache, weakness, irritability, insomnia; stomach upset, and if liquid: frostbite. Workers may be harmed from exposure to hydrogen sulfide. The level of exposure depends upon the dose, duration, and work being done.



The corrosive effects of Sulfuric acid are created by Hydrogen Sulfide gas.

COMMON HAZARDOUS GASES THAT MAY BE PRESENT IN CONFINED SPACE					
SUBSTANCE *	8-HOUR TIME-WEIGHTED AVERAGE (TWA)	15-MINUTE SHORT-TERM EXPOSURE LIMIT (STEL)	CEILING LIMIT (Never To Be Exceeded)	IMMEDIATELY DANGEROUS TO LIFE AND HEALTH (IDLH)	RECOMMENDED ALARM SETTINGS (Low / High)
AMMONIA	25 ppm	35 ppm	—	300 ppm	13 ppm / 25 ppm
CARBON MONOXIDE	25 ppm	100 ppm	—	1200 ppm	13 ppm / 25 ppm
CHLORINE	0.5 ppm	1 ppm	—	10 ppm	0.25 ppm / 0.5 ppm
HYDROGEN SULFIDE	—	—	10 ppm	100 ppm	5 ppm / 10 ppm
METHANE	1000 ppm	—	—	—	500 ppm / 1000 ppm
NITROGEN DIOXIDE	—	—	1 ppm	20 ppm	0.5 ppm / 1 ppm
SULFUR DIOXIDE	2 ppm	5 ppm	—	100 ppm	1 ppm / 2 ppm
OXYGEN	—	—	—	—	20.5 % of Atmosphere
LOWER EXPLOSIVE LIMIT (LEL)	—	—	—	—	5 % LEL

EXAMPLE OF A CHART OF CONFINED SPACE GASES

Hydrogen Sulfide Gas

This section provides answers to basic questions about hydrogen sulfide gas. It will explain what hydrogen sulfide gas is, where it is found, how it can affect your health, and what you can do to prevent or reduce exposure to it. Hydrogen sulfide gas is also known as “sewer gas” because it is often produced by the decay of waste material. Hydrogen sulfide gas has a strong odor at low levels. At higher levels, your nose can become overwhelmed by the gas and you cannot smell it. At these higher levels, hydrogen sulfide gas can make you sick and even kill you.

Hydrogen Sulfide Gas

If you wait for a warning, it may be too late

Hydrogen sulfide is a powerful and deadly gas which smells like rotten eggs at low concentrations and has a sweet smell at high concentrations. But workers should not rely on the smell as a warning. At high concentrations H₂S may overcome one's sense of smell. The result could be instant death. Long exposure to low concentrations will also deaden the sense of smell.

What it is

H₂S is explosive - it will ignite and explode when subjected to a spark or an ordinary flame - in any concentration from 4% to 44% of the air. It is also soluble in water and oil, so it may flow for a considerable distance from its origin before escaping above ground or in an entirely unexpected place. Because the vapor (gas) is heavier than air, it may travel for a long way until ignited and then flash back towards the source. Hydrogen sulfide is found in large amounts in the wastewater collection system.

H₂S Sources

H₂S is easily found widely in our industry and a good manager will warn operators of its dangers or of their exposure. It is formed by the decomposition of organic materials, so it is found in sewers and cesspools.

Health Effects of H₂S Acute Exposure

Most importantly, H₂S will kill you. The extent of acute poisoning danger depends on the concentration of H₂S in the atmosphere. When you breathe in H₂S, it goes directly through your lungs and into your bloodstream. To protect itself, your body "oxidizes" (breaks down) the H₂S as rapidly as possible into a harmless compound. If you breathe in so much H₂S that your body can't oxidize all of it, the H₂S builds up in the blood and you become poisoned. The nervous centers in your brain which control breathing are paralyzed.

Your lungs stop working and you asphyxiate--just as though someone had come up and put their hands around your neck and strangled you. A worker can be overcome by H₂S and lose consciousness in a few seconds. If he is luckily rescued in time and is given artificial respiration within a few minutes, the worker may recover.

This is acute poisoning. It can occur with no warning at all, since even the sense of smell may be overcome, and it can be fatal within a few seconds. Although acute poisoning is deadly if it is not caught in time, when caught and treated it is reversible; this is why rescue attempts with proper safety equipment are so important. Recent evidence has shown irreversible brain damage from acute high doses.

Chronic Effects

H₂S can also cause a wide range of sub-acute and chronic effects. At very low concentrations of 10-100 ppm, headache, dizziness, nausea and vomiting may develop, together with irritation of the eyes and respiratory tract (the lungs and trachea and bronchi, or air pipes from the nose and mouth to the lungs). The eyes become red, sore, inflamed, and sensitive to light. Respiratory system effects include cough, pain in the nose and throat, and painful breathing.

If exposure at low levels continues, the worker may develop a state of chronic poisoning. In addition to eye and respiratory tract irritation, there will be a slowed pulse rate, fatigue, insomnia, digestive disturbances, and cold sweats. More dangerous, if exposure at the level of 100 ppm (which results in eye and respiratory tract irritation and drowsiness after 15 minutes) lasts for several hours, it may result in death within the next 48 hours. Symptoms of chronic exposures at low levels are conjunctivitis (eye infections), headache, and attack of dizziness, diarrhea, and loss of weight. Chronic hydrogen sulfide intoxication is marked by headaches, eye disorders, chronic bronchitis, and a grey-green line on the gums. Reports of nervous system disorders including paralysis, meningitis, and neurological problems have been reported, but not confirmed. A study of workers and community residents of a California Wastewater Treatment facility forum complained of headaches, nausea, vomiting, depression, personality changes, nosebleeds and breathing difficulties. When compared to a non-exposed group of people, the exposed people showed abnormalities of color discrimination, hand-eye coordination, balance, and mood disturbances. In rats, exposure to hydrogen sulfide has caused teratogenic effects.

How Much is Safe?

The OSHA Permissible Exposure Limit (PEL) for a ceiling concentration is 20 ppm hydrogen sulfide, a level which may not ever be exceeded. The acceptable maximum peak, for 10 minutes only, once during an 8 hour day if there is no other measurable exposure, is 50 ppm.

There is no time-weighted average because H₂S is so fast-acting that no fluctuations above 20 ppm are safe; only one peak per day is allowed. This level is too high and recent recommendations are that it be lowered to 10 ppm. You should remember, however, that H₂S is an invisible gas, floating freely and unpredictably, and a reading even below a 10 ppm Permissible Exposure Limit (PEL) may not guarantee your safety. There are no particular medical exams for exposure to H₂S.



Work Practices and Emergency Procedures

Whenever you enter a confined space such as a tank, make sure that you follow strict work practices, including a permit system. Make sure that the Confined Space Entry Standard 1910.146 is followed, that the air is continually monitored for the presence of H₂S, and that an attendant be stationed outside a confined space. Both of you should wear supplied air and lifelines and rescue equipment must be immediately available.

- **If you work with H₂S make sure that...**
 - Your employer has trained you in the hazards of H₂S.
 - Your employer has appropriate rescue equipment onsite.

Hazard Information Bulletin

Following are excerpts from a Hazard Bulletin issued by OSHA after a fatality due to H₂S exposure.

Fundamentally, employers and employees must be alert to the fact that working with a "closed system" does not always ensure safety. Operations involving the opening of valves or pumps on otherwise closed systems, or working on such equipment that is not isolated or locked out, are particular sources of danger. When a normally closed system is opened, the potential exists for releasing hazardous chemicals into the workers' breathing zones in unknown concentrations.

Respiratory Protection -- Respirators must be provided by the employer when effective engineering controls are not feasible, or while they are being instituted, when such equipment is necessary to protect the health of the worker. The employer must provide respirators that are applicable for the purpose intended. Written procedures must be developed for the safe use of respirators during the performance of operations presenting a potential exposure to hazardous chemicals. Under circumstances where individuals may be exposed to an unknown concentration of hydrogen sulfide or some other hazardous chemical, back-up personnel with appropriate respirators and emergency equipment must be present.



You must be careful around sewer mains and always be careful of Hydrogen Sulfide and Carbon Monoxide gases. Never try to enter a confined space to rescue a downed employee unless you have been trained in rescue procedures and have called 911 first.

Hydrogen Sulfide Highlights

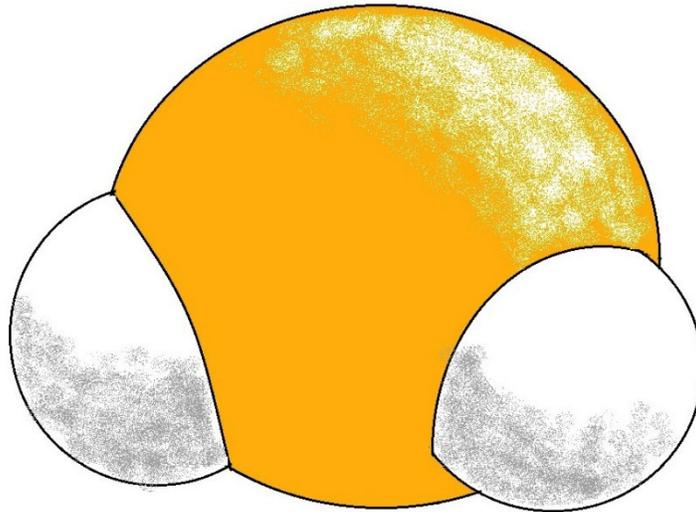
Hydrogen sulfide or H₂S problems are very common in the collection and wastewater system. There are many chemicals used to help or treat this problem. Salts of zinc, lime, hydrogen peroxide, chlorine and magnesium hydroxide are used in the treatment of hydrogen sulfide problems.

Hydrogen sulfide production in collection systems can cause a number of problems, including the following: Corrosion of the pipes and manholes, creation of hazardous atmospheres and foul odors.

The best method of controlling hydrogen sulfide is to eliminate its habitat or growth area by keeping sewers cleaner, this will harbor fewer slime bacteria.

Statements regarding the reduction of hydrogen sulfide: Salts of zinc and iron may precipitate sulfides, lime treatments can also kill bacteria that produces hydrogen sulfide, but this creates a sludge disposal problem. Chlorination is effective at reducing the bacteria which produce hydrogen sulfide.

Hydrogen sulfide conditions occur in the sewer system because of the lack of oxygen.



Hydrogen Sulfide Post-Quiz

1. At very low H₂S concentrations of _____ ppm, headache, dizziness, nausea and vomiting may develop, together with irritation of the eyes and respiratory tract.
2. At very _____ H₂S concentrations, respiratory system effects include cough, pain in the nose and throat, and painful breathing.
3. More dangerous, if exposure at the level of 100 ppm (which results in eye and respiratory tract irritation and drowsiness after 15 minutes) lasts for several hours, it may result in death within the next _____ hours.

How Much is Safe?

4. The OSHA Permissible Exposure Limit (PEL) for a ceiling concentration is _____ ppm hydrogen sulfide, a level which may not ever be exceeded.
5. The acceptable maximum peak, for 10 minutes only, once during an _____ hour day if there is no other measurable exposure, is 50 ppm.
6. There is no time-weighted average because H₂S is so fast-acting that no fluctuations above _____ ppm are safe; only one peak per day is allowed. This level is too high and recent recommendations are that it be lowered to 10 ppm.
7. You should remember, however, that H₂S is an invisible gas, floating freely and unpredictably, and a reading even below a _____ ppm Permissible Exposure Limit (PEL) may not guarantee your safety. There are no particular medical exams for exposure to H₂S.

Work Practices and Emergency Procedures

8. Whenever you enter a confined space such as a tank, make sure that you follow work recommendations, including some type of permit system. True or False
9. Make sure that the Confined Space Entry Standard 1910.146 is followed, that the air is continually monitored for the presence of H₂S, and that an attendant be stationed outside a confined space. Both of you should wear supplied air and lifelines and rescue equipment must be immediately available. True or False

10. Respirators must be provided by the employer when effective engineering controls are not feasible, or while they are being instituted, when such equipment is necessary to protect the health of the worker. True or False

Answers

1. 10-100, 2. Low, 3. 48, 4. 20, 5. 8, 6. 20, 7. 10, 8. False, 9. True, 10. True

Chapter 6- COLLECTION RULES AND REGULATIONS

Section Focus: You will learn the Clean Water Act and the basics of the wastewater collection system. At the end of this section, you the student will be able to describe the basics of the Capacity, Management, Operation and Maintenance program. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.

Scope/Background: Sanitary sewage overflows that reach waters of the U.S. are point source discharges. Like other point source discharges from municipal sanitary sewer systems, sanitary sewage overflows are prohibited unless authorized by a NPDES permit. Moreover, SSOs, including those that do not reach waters of the U.S., may be indicative of improper operation and maintenance of the sewer systems, and may violate NPDES permit conditions.



What are Sanitary Sewer Overflows?

Sanitary Sewer Overflows (SSOs) are discharges of raw sewage from municipal sanitary sewer systems. SSOs can release untreated sewage into basements or out of manholes and onto city streets, playgrounds, and into streams before it can reach a treatment facility. SSOs are often caused by blockages and breaks in the sewer lines.

Why do Sewers Overflow?

SSOs occasionally occur in almost every sewer system, even though systems are intended to collect and contain all the sewage that flows into them. When SSOs happen frequently, it means something is wrong with the system.

Clean Water Act Preface *(Credit USEPA)*

33 U.S.C. s/s 1251 et seq. (1977)

The Clean Water Act is a 1977 amendment to the Federal Water Pollution Control Act of 1972, which set the basic structure for regulating discharges of pollutants to waters of the United States.

The law gave the EPA the authority to set effluent standards on an industry basis (technology-based) and continued the requirements to set water quality standards for all contaminants in surface waters. The CWA makes it unlawful for any person to discharge any pollutant from a point source into navigable waters unless a permit (NPDES) is obtained under the act.

The 1977 amendments focused on toxic pollutants. In 1987, the PCA was reauthorized and again focused on toxic substances, authorized citizen suit provisions, and funded sewage treatment plants (POTW's) under the Construction Grants Program.

The CWA made provides for the delegation by the EPA of many permitting, administrative, and enforcement aspects of the law to state governments. In states with the authority to implement CWA programs, the EPA still retains oversight responsibilities.

In 1972, Congress enacted the first comprehensive national clean water legislation in response to growing public concern for serious and widespread water pollution. The Clean Water Act is the primary federal law that protects our nation's waters, including lakes, rivers, aquifers and coastal areas.

Lake Erie was dying. The Potomac River was clogged with blue-green algae blooms that were a nuisance and a threat to public health. Many of the nation's rivers were little more than open sewers and sewage frequently washed up on shore. Fish kills were a common sight. Wetlands were disappearing at a rapid rate.

Today, the quality of our waters has improved dramatically as a result of a cooperative effort by federal, state, tribal and local governments to implement the pollution control programs established in 1972 by the Clean Water Act.

The Clean Water Act's primary objective is to restore and maintain the integrity of the nation's waters. This objective translates into two fundamental national goals:

- eliminate the discharge of pollutants into the nation's waters, and
- achieve water quality levels that are fishable and swimmable.

The Clean Water Act focuses on improving the quality of the nation's waters. It provides a comprehensive framework of standards, technical tools and financial assistance to address the many causes of pollution and poor water quality. It includes municipal and industrial wastewater discharges, polluted runoff from urban and rural areas, and habitat destruction.



For example, the Clean Water Act requires major industries to meet performance standards to ensure pollution control; charges states and tribes with setting specific water quality criteria appropriate for their waters and developing pollution control programs to meet them; provides

funding to states and communities to help them meet their clean water infrastructure needs; protects valuable wetlands and other aquatic habitats through a permitting process that ensures development and other activities are conducted in an environmentally sound manner. After 25 years, the Act continues to provide a clear path for clean water and a solid foundation for an effective national water program.

In 1972

Only a third of the nation's waters were safe for fishing and swimming. Wetlands losses were estimated at about 460,000 acres annually.

Agricultural runoff resulted in the erosion of 2.25 billion tons of soil and the deposit of large amounts of phosphorus and nitrogen into many waters. Sewage treatment plants served only 85 million people.

Today

Two-thirds of the nation's waters are safe for fishing and swimming.

The rate of annual wetlands losses is estimated at about 70,000-90,000 acres according to recent studies. The amount of soil lost due to agricultural runoff has been cut by one billion tons annually, and phosphorus and nitrogen levels in water sources are down. Modern wastewater treatment facilities serve 173 million people.

The Future

All Americans will enjoy clean water safe for fishing and swimming. We will achieve a net gain of wetlands by preventing additional losses and restoring hundreds of thousands of acres of wetlands. Soil erosion and runoff of phosphorus and nitrogen into watersheds will be minimized, helping to sustain the nation's farming economy and aquatic systems. The nation's waters will be free of effects of sewage discharges.



As a collection system worker or pretreatment inspector, you will need sewer knowledge, mastery of the Clean Water Act and of your wastewater ordinances.

Problems that Can Cause Chronic SSOs Include:

Infiltration and Inflow (I&I): Too much rainfall or snowmelt infiltrating through the ground into leaky sanitary sewers not designed to hold rainfall or to drain property, and excess water inflowing through roof drains connected to sewers, broken pipes, and badly connected sewer service lines.

Undersized Systems: Sewers and pumps are too small to carry sewage from newly-developed subdivisions or commercial areas.

Pipe Failures: blocked, broken or cracked pipes, tree roots grow into the sewer, sections of pipe settle or shift so that pipe joints no longer match, and sediment and other material builds up causing pipes to break or collapse.

Equipment Failures: Pump failures, power failures.

Sewer Service Connections: Discharges occur at sewer service connections to houses and other buildings; some cities estimate that as much as 60% of overflows comes from the service lines.

Deteriorating Sewer System: Improper installation, improper maintenance; widespread problems that can be expensive to fix develop over time, some municipalities have found severe problems necessitating billion-dollar correction programs, often communities have to curtail new development until problems are corrected or system capacity is increased.



Why are SSOs a Problem?

The EPA has found that SSOs caused by poor sewer collection system management pose a substantial health and environmental challenge. The response to this challenge varies considerably from state to state.

Many municipalities have asked for national consistency in the way permits are considered for wastewater discharges, including SSOs, and in enforcement of the law prohibiting unpermitted discharges. In response, the EPA has convened representatives of states, municipalities, health agencies, and environmental advocacy groups to advise the Agency on how to best meet this challenge.

How Big is the SSO Problem?

The total number of SSOs that occur nationwide each year is not known. In some areas, they might not be reported or are underreported to the EPA and state environmental agencies. Two surveys, however, help to define the size of the problem:

- In a 1994 survey of 79 members of the Association of Metropolitan Sewerage Agencies, 65 percent of the respondents reported wet weather SSOs. They reported that between 15 and 35 percent of their sewers were filled above capacity and/or overflowed during wet weather. However, municipal respondents with SSOs had only limited information about them. Only 60 percent had estimated the annual number. Half of those had estimated the amount of sewerage discharged, and 17 percent had determined what pollutants were in their overflows.

- A 1981 survey conducted by the National Urban Institute indicated an average of 827 backups and 143 breaks per 1,000 miles of sewer pipe (about 1,000 miles of sewer pipe are needed to serve 250,000 people.) per year. Breaks occurred most often in the young, growing cities of the South and West.



Downstream of a nonfunctional Combined Sewer Overflow (CSO) Control Facility.

Combined Sewer Overflows

Combined sewer systems are sewers that are designed to collect rainwater runoff, domestic sewage, and industrial wastewater in the same pipe. Most of the time, combined sewer systems transport all of their wastewater to a sewage treatment plant, where it is treated and then discharged to a water body. During periods of heavy rainfall or snowmelt, however, the wastewater volume in a combined sewer system can exceed the capacity of the sewer system or treatment plant. For this reason, combined sewer systems are designed to overflow occasionally and discharge excess wastewater directly to nearby streams, rivers, or other water bodies.

These overflows, called combined sewer overflows (CSOs), contain not only storm water but also untreated human and industrial waste, toxic materials, and debris. They are a major water pollution concern for the approximately 772 cities in the U.S. that have combined sewer systems. CSOs may be thought of as a type of "urban wet weather" discharge. This means that, like sanitary sewer overflows (SSOs) and storm water discharges, they are discharges from a municipality's wastewater conveyance infrastructure that are caused by precipitation events such as rainfall or heavy snowmelt. The EPA's CSO Control Policy, published April 19, 1994, is the national framework for control of CSOs.

The Policy provides guidance on how communities with combined sewer systems can meet Clean Water Act goals in as flexible and cost-effective a manner as possible. EPA's Report to Congress on implementation of the CSO Control Policy assesses the progress made by EPA, states, and municipalities in implementing and enforcing the CSO Control Policy.

Proper function of sanitary sewer systems is vital to protect public health, property, and waterways in the surrounding area. Most utilities have a management, operation, and maintenance (MOM) plan to ensure their system is in working order. However, more than 40,000 sanitary sewage overflows SSOs occur every year, causing huge monetary losses, damage to fish/shellfish beds, polluting groundwater, and decreased tourism. Sanitary sewage overflows (SSOs) release raw sewage from the collection system before it can reach a treatment facility. Sewage may flow out of manholes, into businesses and homes, and eventually ends up in local waterways.

Many factors are involved in SSOs. Many municipalities started constructing sewer systems over 100 years ago. Some of these have not been adequately maintained, improved, or repaired over the last century.

Cities have used a wide variety of building materials, designs, and installation techniques, which aren't durable enough to withstand heavy, continuous use. Problems can be especially bad where an older system is attached to a new system or an older system has fallen into disrepair.

EPA believes that every sanitary sewer system has the capacity to have a sanitary sewer overflows (SSO). This may be due to a number of factors including, but not limited to:

- Blockages
- Structural, mechanical, or electrical failures
- Collapsed or broken sewer pipes
- Insufficient conveyance capacity
- Vandalism

Additionally, high levels of inflow and infiltration (I/I) during wet weather can cause SSOs. Many collection SSOs include untreated discharges from sanitary sewer systems that reach waters of the United States systems that were designed according to industry standards experience wet weather SSOs because levels of I/I may exceed levels originally expected; prevention of I/I has proven more difficult and costly than anticipated; or the capacity of the system has become inadequate due to an increase in service population without corresponding system upgrades (EPA 2004).

The Management, Operation and Maintenance (MOM) Programs Project is a pilot enforcement approach developed by EPA Region 4 to bring municipal sewer systems into full compliance with the Clean Water Act by eliminating sanitary sewer overflows (SSOs) from municipal sewer systems. A SSO is a release of untreated wastewater before the flow reaches a treatment plant. SSOs pose a significant threat to public health and water quality.

Treatment Balance and the Effects of Undesirable Solids

For any wastewater treatment plant to operate properly, the operator has to maintain a skillfully balanced mixture of microorganisms which contact and digest the organics in the wastewater, and bacteria then grows on this media to treat the wastewater. When a plant is properly maintained these bacteria or bugs eat the dissolved organics in the water, thus removing BOD, Ammonia, Nitrates, and Phosphorus.

All of these constituents must be treated and removed from the water. When this is accomplished you achieve a low turbidity and clean decantible water which is then filtered and chlorinated to kill all the remaining bacteria. This incredible process leaves extremely clean and reusable water that can be injected back into the ground, sent to ponds or used for irrigation.

Certain compounds and undesirable solids, like grease and grass clippings, can disturb this delicate balance and necessary process at the wastewater treatment facility. There are compounds and mixtures that should never be introduced into a sanitary sewer system. These destructive compounds include but are not limited to: cleaning solvents, grease (both household and commercial), oils (both household and commercial), pesticides, herbicides, antifreeze and other automotive products.

The solids include but are not limited to: plastics, rubber goods, grass clippings, metal products such as aluminum foil, beer or soda cans, wood products, glass, paper products such as disposable diapers and sanitary napkins. Items such as these disturb or even kill the delicate balance of microorganisms and bacteria that are needed to treat the wastewater. These will also clog the sanitary sewer causing back-ups and sewer overflows. First, we will examine the damage to equipment and we will finish with resolution methods.

Costly Maintenance

These harmful compounds and solids can also cause equipment damage and create costly and unnecessary repairs, as well as frequent and costly maintenance. Repairs include but are not limited to: SBR Motive Pumps--these should last at least 5 years but are failing after only 2 or 3 years because of material that was placed in the sewer system. In a recent 2007 study, the cost of repairing these pumps was around \$30,000.00. The replacement of the influent grinder or, "Muffin Monster" after only 3 years of service was nearly \$7,000.00.

The cost of frequent maintenance consists of, but is not limited to: the extensive amounts of damaging solids that clog lift stations and damage lift station pumps. These costs have almost doubled in today's costs.

To properly clean a lift station may cost around \$3,000 -10,000 for each time that common problems occur like grass clippings from a golf course, overflowing grease from improperly maintained grease traps from a casino, hotel or golf course and improperly maintained grease and oil interceptors.

These costs do not touch the cost of cleaning the sewer mains and manholes. In most cases, no serious damage will occur to the sewer main or manhole, but the chance of overflowing sewage or untreated wastewater getting to the street is greatly increased and does happen in most communities. Most of us know about it and accept it as part of our jobs. But time and rules have changed. We must work harder and be smarter to stop these problems before the damage and overflow occurs.

Municipality Self-Assessment

Under the MOM Programs Project, municipalities are encouraged to undertake a detailed self-assessment of their MOM programs. The municipalities submit this self-assessment along with recommendations for improvements to the MOM programs and/or remedial measures to correct sewer infrastructure problems.

In consideration for undertaking the self-assessment, the municipality is able to establish its own reasonable goals and schedules, which could result to significantly reduced penalties related to SSOs. Where an enforcement action is necessary, the regulator works with the municipality to identify necessary remedial measures and to establish schedules. The Regulator will likely defer any penalty decision until after the completion of the necessary improvements.

Project Initiation

In 1998, Region 4 began the MOM Programs Project by identifying priority watersheds and geographical areas in each of the eight States in the Region. These included areas where SSOs could cause significant public health concerns, such as beaches, shellfish harvesting areas and drinking water supplies. In addition, watersheds already listed as impaired by collection system overflows or bacterial contamination were identified.

Region 4, working with the States, selected a watershed (or geographical area) in each State. All municipal sewer systems in each watershed were identified and invited to participate in the Project and to attend a kickoff meeting held at a location in the watershed.

Those municipalities wanting to participate in the MOM Project undertake the self-assessment using the guidance materials provided and submit the self-assessment to the Region within seven months of the kickoff. Municipalities that don't participate are inspected by the Region and/or State and are subject to traditional enforcement actions, including penalties where appropriate. Improper management and maintenance cause a majority of avoidable SSOs.

Leading Causes of SSOs

Problem/Cause	% of SSOs	Description
Blockages	43%	Blockages may be caused by tree roots or a build-up of sediment and other materials (i.e., grease, grit, debris). Structural defects and a flat slope can also cause excessive deposits of material. Build-ups can cause pipes to break or collapse.
Infiltration and Inflow (I/I)	27%	Infiltration and inflow occurs when rain or snowmelt enters the ground and seeps into leaky sanitation sewers, which were not designed to carry rainfall or drain property. Inflow can also occur when excess waters from roof drains, broken pipes and bad connections at sewer service lines infiltrates the sanitary sewer.
Structural Failures	12%	Line/main breaks are a major result of structural failure. Undersized systems do not have large enough pumps or lines to carry all the sewage generated by the buildings attached to them. This is especially true for new subdivisions or commercial areas. SSOs can occur at sewer service connections to houses or buildings. Some cities estimate that up to 60% of SSOs come from service lines.
Power Failure	11%	Stops pump operation, interrupting sewage flow
Other	7%	Scheduling, vandalism



Above, a cracked sewer main, a SSO waiting to happen.

Purpose of CMOM Programs

CMOM programs incorporate many of the standard operation and maintenance activities that are routinely implemented by the owner or operator with a new set of information management requirements in order to:

- Better manage, operate, and maintain collection systems
- Investigate capacity constrained areas of the collection system
- Proactively prevent SSOs
- Respond to SSO events

The CMOM approach helps the owner or operator provide a high level of service to customers and reduce regulatory noncompliance. CMOM can help utilities optimize use of human and material resources by shifting maintenance activities from “reactive” to “proactive”—often leading to savings through avoided costs due to overtime, reduced emergency construction costs, lower insurance premiums, changes in financial performance goals, and fewer lawsuits.

CMOM programs can also help improve communication relations with the public, other municipal works and regional planning organizations, and regulators. It is important to note that the collection system board members or equivalent entity should ensure that the CMOM program is established as a matter of policy. The program should not be micro-managed, but an understanding of the resources required of the operating staff to implement and maintain the program is necessary. In CMOM planning, the owner or operator selects performance goal targets, and designs CMOM activities to meet the goals.

The CMOM planning framework covers operation and maintenance (O&M) planning, capacity assessment and assurance, capital improvement planning, and financial management planning. Information collection and management practices are used to track how the elements of the CMOM program are meeting performance goals, and whether overall system efficiency is improving. On a periodic basis, utility activities should be reviewed and adjusted to better meet the performance goals. Once the long-term goal of the CMOM program is established, interim goals may be set. For instance, an initial goal may be to develop a geographic information system (GIS) of the system.

Once the GIS is complete, a new goal might be to use the GIS to track emergency calls and use the information to improve maintenance planning. An important component of a successful CMOM program is periodically collecting information on current systems and activities to develop a “snapshot-in-time” analysis. From this analysis, the owner or operator evaluates its performance and plans its CMOM program activities. Maintaining the value of the investment is also important. Collection systems represent major capital investments for communities and are one of the communities’ major capital assets.

Equipment and facilities will deteriorate through normal use and age. Maintaining value of the capital asset is a major goal of the CMOM program. The infrastructure is what produces sales and service. Proper reinvestment in capital facilities maintains the ability to provide service and generate sales at the least cost possible and helps ensure compliance with environmental requirements.

The performance of wastewater collection systems is directly linked to the effectiveness of its CMOM program. Performance characteristics of a system with an inadequate CMOM program include frequent blockages resulting in overflows and backups.

Other major performance indicators include pump station reliability, equipment availability, and avoidance of catastrophic system failures such as a collapsed pipe.

A CMOM program is what an owner or operator should use to manage its assets; in this case, the collection system itself. The CMOM program consists of a set of best management practices that have been developed by the industry and are applied over the entire life cycle of the collection system and treatment plant.

These practices include:

- Designing and constructing for O&M
- Knowing what comprises the system (inventory and physical attributes)
- Knowing where the system is (maps and location)
- Knowing the condition of the system (assessment)
- Planning and scheduling work based on condition and performance
- Repairing, replacing, and rehabilitating system components based on condition and performance
- Managing timely, relevant information to establish and prioritize appropriate CMOM activities

EPA and state NPDES inspectors evaluate collection systems and treatment plants to determine compliance with permit conditions including proper O&M. Among others, these permit conditions are based on regulation in 40 CFR 122.41(e): “The permittee shall at all times properly operate and maintain all facilities and systems of treatment and control (and related appurtenances) which are installed or used by the permittee to achieve compliance with the conditions of this permit.”

When violations occur, the collection system or wastewater treatment plant owner or operator can face fines and requirements to implement programs to compensate residents and restore the environment.

The Elements of a Proper CMOM Program

Utility Specific

The complexity and expense associated with a utility's CMOM or MOM programs is specific to the size and complexity of the Publicly Owned Treatment Works (POTW) and related infrastructure. Factors such as population growth rate and soil/groundwater conditions also dictate the level of investment which should be made.

Purposeful

When MOM programs are present and properly maintained, they support customer service and protect system assets, public health, and water quality.

Goal-Oriented

Proper MOM programs have goals directed toward their individual purposes. Progress toward these goals is measurable, and the goals are attainable.

Uses Performance Measures

Performance measures should be established for each MOM program in conjunction with the program goal. These measures are quantifiable, and used in determining progress to, or beyond, the program goal.

Periodically Evaluated

An evaluation of the progress toward reaching the goals, or a reassessment of the goals, should be made periodically and based upon the quantified performance measures.

Available In Writing

The effectiveness of a MOM program quickly breaks down unless it is available in writing. Personnel turnover and lapses in communication between staff and management can change otherwise proper MOM programs to improper ones. Written MOM programs are useful only if they are made readily available to all personnel and clearly documented.

Implemented by Trained Personnel

Appropriate safety, equipment, technical, and program training is essential for implementing MOM programs properly.

What MOM programs should be audited?

MOM activity at a utility involves its entire wastewater infrastructure. Common utility management activities and operations and maintenance activities associated with sewer systems and pretreatment are listed in the Self-Audit Review Document.

If a utility owns treatment works or a pond system, then activities associated with the management, operation, and maintenance of these facilities should also be included in the audit. A helpful guide for this part is the NPDES Compliance Inspection Manual. Instruction for obtaining this manual is provided in a list of references.

What are the elements of a proper Self-Audit?

Initial Assessment

Begin by performing a general assessment of the utility, and prioritizing the order of programs to be audited. The NPDES Compliance Inspection Manual and Guidance may be useful references in making this assessment.

Develop the Audit Plan

Identify the MOM programs present and/or needed at the utility, establish performance measures, and develop a schedule for auditing the programs.

Conduct the Audit

Evaluate each MOM program against the defined elements of a proper program. This can be accomplished by reviewing the program's records and resources, conducting a field evaluation, and comparing the program understanding of both personnel and management.

Identify Deficiencies

Define any programs needed, or improvements to programs needed, and any infrastructure deficiencies found. Identify any unpermitted discharges that have occurred in the past five years.

Develop Improvement Plan

Define the utility's plan/schedule to remediate the necessary improvements. This plan should include any short-term or long-term program improvements, and any short-term or long-term capital improvements that need addressing.

Prepare the Self-Audit Report

Generate a report of the audit results, including any deficiencies found and the corresponding improvement plan, which is useful for the utility. This report should be capable of serving the utility as a reference when conducting any needed remedial measures, and as a reference to compare current performance with future self-audit results.

Are there federal grants or other compliance assistance resources available to conduct a Self-Audit?

Currently, there are no funds available for the specific purpose of conducting a MOM Programs Self-Audit. However, the Office of Wastewater Management offers a number of financial resources to assist qualified utilities in making improvements to their programs.

Small publicly-owned wastewater treatment plants which discharge less than 5 million gallons per day are also eligible for the Wastewater Treatment Plant Operator On-Site Assistance Training Program. The program provides on-site operator training, financial management, troubleshooting, and other operation and maintenance assistance. A network of operator training personnel, EPA Regional Office Coordinators and States and State Training Centers work in the field with small under-served communities to help solve their operation and maintenance problems. There is no cost incurred by the facility in need of assistance. The only requirement of the program is the willingness to work with a trainer to correct the facility's problems.

What Health Risks do SSOs present?

Because SSOs contain raw sewage they can carry bacteria, viruses, protozoa (parasitic organisms), helminths (intestinal worms), and borroughs (inhaled molds and fungi). The diseases they may cause range in severity from mild gastroenteritis (causing stomach cramps and diarrhea) to life-threatening ailments such as cholera, dysentery, infectious hepatitis, and severe gastroenteritis.

People can be Exposed Through:

- Sewage in drinking water sources.

- Direct contact in areas of high public access such as basements, lawns or streets, or waters used for recreation. At least one study has estimated a direct relationship between gastrointestinal illness contracted while swimming and bacteria levels in the water.
- Shellfish harvested from areas contaminated by raw sewage. One study indicates that an average of nearly 700 cases of illness per year were reported in the 1980s from eating shellfish contaminated by sewage and other sources. The number of unreported cases is estimated to be 20 times that.
- Some cases of disease contracted through inhalation and skin absorption have also been documented.

What other Damage can SSOs do?

SSOs also damage property and the environment. When basements flood, the damaged area must be thoroughly cleaned and disinfected to reduce the risk of disease. Cleanup can be expensive for homeowners and municipalities. Rugs, curtains, flooring, wallboard panels, and upholstered furniture usually must be replaced. A key concern with SSOs that enter oceans, bays, estuaries, rivers, lakes, streams, or brackish waters is their effect on water quality. When bodies of water cannot be used for drinking water, fishing, or recreation, society experiences an economic loss. Tourism and waterfront home values may fall. Fishing and shellfish harvesting may be restricted or halted. SSOs can also close beaches. One 1994 study claims that SSOs closed beaches across the nation that year for a total of more than 300 days.

How can SSOs be Reduced or Eliminated?

Many avoidable SSOs are caused by inadequate or negligent operation or maintenance, inadequate system capacity, and improper system design and construction. These SSOs can be reduced or eliminated by:

- Sewer system cleaning and maintenance
- Reducing infiltration and inflow through system rehabilitation and repairing broken or leaking service lines.
- Enlarging or upgrading sewer, pump station, or sewage treatment plant capacity and/or reliability.
- Construction of wet weather storage and treatment facilities to treat excess flows.

Communities also should address SSOs during sewer system master planning and facilities planning, or while extending the sewer system into previously unsewered areas. A few SSOs may be unavoidable. Unavoidable SSOs include those occurring from unpreventable vandalism, some types of blockages, extreme rainstorms, and acts of nature such as earthquakes or floods.

What Costs are Involved with Reducing or Eliminating SSOs?

Sanitary sewer collection systems are a valuable part of the nation's infrastructure. The EPA estimates that our nation's sewers are worth a total of more than \$1 trillion. The collection system of a single large municipality is an asset worth billions of dollars and that of a smaller city could cost many millions to replace.

Sewer rehabilitation to reduce or eliminate SSOs can be expensive, but the cost must be weighed against the value of the collection system asset and the added costs if this asset is allowed to further deteriorate. Ongoing maintenance and rehabilitation adds value to the original investment by maintaining the system's capacity and extending its life. The costs of rehabilitation and other measures to correct SSOs can vary widely by community size and sewer system type. Those being equal, however, costs will be highest and ratepayers will pay more in communities that have not put together regular preventive maintenance or asset protection programs.

Assistance is available through the Clean Water Act State Revolving Fund for capital projects to control SSOs. State Revolving Funds in each state and Puerto Rico can help arrange low-interest loans. For the name of your State Revolving Fund contact, please call the EPA Office of Water Resource Center, (202) 566-1729.

To reduce sanitary sewer overflows (SSOs), the EPA is proposing to clarify and expand permit regulations that are already in force under the Clean Water Act. This will affect over 19,000 municipal sanitary sewer systems, including 4800 satellite collection systems that will be regulated for the first time. It will allow streamlined CMOM requirements for small communities, and permit them to skip self-audits and annual reports if an SSO hasn't occurred.

More Specifically, CMOM will Require Facilities to:

- Establish general performance standards.
- Have a management program.
- Create an overflow response plan.
- Ensure system evaluations.
- Verify capacity assurance.
- Submit to periodic audits of the CMOM program.
- Notify the public and regulatory agencies of SSOs.

General Performance Standards

A CMOM program will ensure:

- There is enough capacity to handle base and peak flows.
- The use of all reasonable measure to stop SSOs.
- Proper collection, management, operation and maintenance of the system.
- Prompt notification of all parties that may be exposed to an SSO.

Management Programs

Management program documents must include:

- The goals of the CMOM program (may differ depending on the facility.)
- Legal authorities that will help implement CMOM.
- The "chain of command" for implementing CMOM and reporting SSOs.
- Design and performance requirements.
- Measures that will be taken to help implement CMOM.
- Monitoring/performance measures to how effective the CMOM program is.
- Communication plan.

Overflow Response Plan

The overflow response plan should be designed provide a quick response to SSOs. Rapid response to an SSO can mitigate structural damage, pollution of waterways, and the public health risk. The plan must include the following:

- SSO response procedures.
- Immediate notification of health officials.
- Public notification.
- Plan made available to the public.
- Distribution to all appropriate personnel.
- Revision and maintenance of the plan by appropriate personnel.

Collection System Management

Collection system management activities form the backbone for operation and effective maintenance activities. The goals of a management program should include:

- Protection of public health and prevention of unnecessary property damage
- Minimization of infiltration, inflow and exfiltration, and maximum conveyance of wastewater to the wastewater treatment plant
- Provision of prompt response to
- Staffing plans—Number of people and service interruptions
- Efficient use of allocated funds
- Sewer use ordinance
- Identification of and remedy solutions to design, construction, and operational deficiencies
- Performance of all activities in a safe manner to avoid injuries

Without the proper procedures, management and training systems, O&M activities may lack organization and precision, resulting in a potential risk to human health and environmental contamination of surrounding water bodies, lands, dwellings, or groundwater. The following sections discuss the common elements of a robust collection system management program.

Organizational Structure

Well-established organizational structure, which delineates responsibilities and authority for each position, is an important component of a CMOM program for a collection system. This information may take the form of an organizational chart or narrative description of roles and responsibilities, or both. The organizational chart should show the overall personnel structure, including operation and maintenance staff. Additionally, up-to-date job descriptions should be available.

Job descriptions should include the nature of the work performed, the minimum requirements for the position, the necessary special qualifications or certifications, examples of the types work, lists of licenses required for the position, performance measures or promotion potential. Other items to note in regard to the organizational structure are the percent of staff positions currently vacant, on average, the length of time positions remain vacant, and the percent of collection system work that is contracted out.

Reviewer - Point to Note

The reviewer may want to note the turnover rate and current levels of staffing (i.e., how many vacant positions exist and for how long they have been vacant). This may provide some indication of potential understaffing, which can create response problems. Reviewers should evaluate specific qualifications of personnel and determine if the tasks designated to individuals, crews, or teams match the job descriptions and training requirements spelled out in the organizational structure.

From an evaluation standpoint, the reviewer might try to determine what type of work is performed by outside contractors and what specific work is reserved for collection system personnel. If much of the work is contracted, it is appropriate to review the contract and to look at the contractor's capabilities. If the contractor handles emergency response, the reviewer should examine the contract with the owner or operator to determine if the emergency response procedures and requirements are outlined.

The inclusion of job descriptions in the organizational structure ensures that all employees know their specific job responsibilities and have the proper credentials.

Additionally, it is useful in the course of interviews to discuss staff management. The reviewer should note whether staff receive a satisfactory explanation of their job descriptions and responsibilities. In addition, when evaluating the CMOM program, job descriptions will help a reviewer determine who should be interviewed.

Reviewer - Point to Note

A reviewer should look for indications that responsibilities are understood by employees. Such indications may include training programs, meetings between management and staff, or policies and procedures.

When evaluating the organizational structure, the reviewer should look for the following:

- Except in very small systems, operation and maintenance personnel ideally should report to the same supervisor or director. The supervisor or director should have overall responsibility for the collection system. Guide for Evaluating CMOM Programs at Sanitary Sewer Collection Systems

- In some systems, maintenance may be carried out by a citywide maintenance organization, which may also be responsible for such diverse activities as road repair and maintenance of the water distribution system. This can be an effective approach, but only if adequate lines of responsibility and communication are established.

- In general, one supervisor should manage a team of individuals small enough that is safe and effective. However, the individuals on the team may have additional employees reporting to them. This prevents the top supervisors from having to track too many individuals. The employee-supervisor ratio at individual collection systems will vary depending on their need for supervisors. In a utility with well-established organizational structure, staff and management should be able to articulate their job and position responsibilities.

Personnel should be trained to deal with constantly changing situations and requirements, both regulatory and operational. The system's personnel requirements vary in relation to the overall size and complexity of the collection system. In very small systems, these responsibilities may include operation of the treatment plant as well as the collection system.

In many systems, collection system personnel are responsible for the stormwater as well as wastewater collection system. References providing staff guidelines or recommendations are available to help the reviewer determine if staffing is adequate for the collection system being reviewed.

Potential Performance Indicators

Input measures	Per capita costs Number of employee hours
Output measures	Length of pipe maintained Number of service calls completed Percentage of length maintained repaired this year Percentage of length maintained needing repair Length of new sewer constructed Number of new services connected
Outcomes	Number of stoppages per 100 miles of pipe Average service response time Number of complaints
Ecological/Human health/ Resource use	Shellfish bed closures Benthic Organism index Biological diversity index Beach closures Recreational activities Commercial activities

CMOM Audits

CMOM will require regular, comprehensive audits, done by each facility. These audits will help identify non-conformance to CMOM regulations so problems can be addressed quickly. All findings, proposed corrective actions and upcoming improvements should be documented in the audit report.

Communication/Notification

If an SSO occurs, sanitary sewer facilities will be required to immediately notify the NPDES permit authority, appropriate health agencies, state authorities, drinking water suppliers, and, if necessary, the general public in the risk area. This rule will also require an annual report of all overflows, including minor SSOs such as building backups. Facilities must post locations of recurrent SSOs and let the public know that the annual report is available to them. The record keeping provisions mandate that facilities must maintain records for three years about all overflows, complaints, work orders on the system, and implementation measures.

According to the EPA, an effective CMOM program would help NPDES permittees to:

- Develop/revise routine preventive maintenance activities that prevent service interruption and protect capital investments.
- Create an inspection schedule and respond to the inspection results.
- Investigate the causes of SSOs and take corrective measures.
- Respond quickly to SSOs to minimize impacts to human health and the environment.
- Identify and evaluate SSO trends.
- Develop budgets and identify staffing needs.
- Plan for future growth to ensure adequate capacity is available when it's needed.
- Identify hydraulic (capacity) and physical deficiencies and prioritize responses, including capital investments.

- Identify and develop appropriate responses to program deficiencies (e.g., lack of legal authority, inadequate funding, and inadequate preventive maintenance).
- Keep parts and tools inventories updated and equipment in working order.
- Report and investigate safety incidents and take steps to prevent their recurrence.

Implementation

The EPA estimates that implementing this rule will impose an additional \$93.5 to \$126.5 million every year on municipalities (includes planning and permitting costs). A system serving 7,500 people may need to spend an average of \$6,000 every year to comply with the rule.

CMOM regulations will be added to the permit when facilities need to have a permit re-issued. Although a compliance deadline has not been set, the EPA recommends that facilities begin to implement “SSO Standard Conditions” right after the proposed rule is published. Considering the time and costs associated with compliance, this may be good advice.

Continuous Training

Procedures for emergency response plans should be understood and practiced by all personnel in order to ensure safety of the public and the collection system personnel responding. Procedures should be specific to the type of emergency that could occur.

It is important to keep detailed records of all past emergencies in order to constantly improve response training, as well as the method and timing of future responses.

The ability to deal with emergencies depends on the knowledge and skill of the responding crews, in addition to availability of equipment. The crew should be able to rapidly diagnose problems in the field under stress and select the right equipment needed to correct the problem.

If resources are limited, consideration should be given to contracting other departments or private industries to respond to some emergencies, for example, those rare emergencies that would exceed the capacity of staff.

System Evaluation and Capacity Assurance Plan

These two activities work hand-in-hand to detect and address deficiencies and scheduling. These will provide:

- An evaluation of parts of the collection system that have substandard performance.
- Capacity assurance measures to address substandard performance.
- Explanation of prioritization and scheduling.

Performance measures and indicators are important in evaluating collection system performance and implementing capacity management, operation and maintenance programs.

Hydrogen Sulfide Monitoring and Control Sub-Section

The collection system owner or operator should have a program under which they monitor areas of the collection system that may be vulnerable to the adverse effects of hydrogen sulfide. It may be possible to perform visual inspections of these areas. The records should note such items as the condition of metal components, the presence of exposed rebar (metal reinforcement in concrete), copper sulfate coating on copper pipes and electrical components, and loss of concrete from the pipe crown or walls.

Areas Subject to Generation of Hydrogen Sulfide:

- Sewers with low velocity conditions and/or long detention times
- Sewers subject to solids deposition
- Pump stations
- Turbulent areas, such as drop manholes or force main discharge points
- Inverted siphon discharges

The collection system owner or operator should be carrying out routine manhole inspections. The hydrogen sulfide readings generated as a result of these inspections should be added to the records of potential areas of corrosion. A quick check of the pH of the pipe crown or structure enables early indication of potential hydrogen sulfide corrosion. A pH of less than four indicates further investigation is warranted. "Coupons" may be installed in structures or pipelines believed to be potentially subject to corrosion. Coupons are small pieces of steel inserted into the area and measured periodically to determine whether corrosion is occurring.

Reviewer - Point to Note

The reviewer should be aware that a system in which infiltration and inflow (I/I) has successfully been reduced may actually face an increased risk of corrosion. The reviewer should pay particular attention to the hydrogen sulfide monitoring program in these systems. The reduction of flow through the pipes allows room for hydrogen sulfide gases to rise into the airway portion of the sewer pipe and react with the bacteria and moisture on the pipe walls to form sulfuric acid. Sulfuric acid corrodes ferrous metals and concrete. There are several methods to prevent or control hydrogen sulfide corrosion. The first is proper design. Design considerations are beyond the scope of this manual but may be found in the Design Manual: Odor and Corrosion Control in Sanitary Sewerage Systems and Treatment Plants (EPA 1985).

The level of dissolved sulfide in the wastewater may also be reduced by chemical or physical means such as aeration, or the addition of chlorine, hydrogen peroxide, potassium permanganate, iron salts, or sodium hydroxide. Whenever chemical control agents are used, the owner or operator should have procedures for their application and maintain records of the dosages of the various chemicals.

Alternatively, sewer cleaning to remove deposited solids reduces hydrogen sulfide generation. Also, air relief valves may be installed at the high points of the force main system. The valve allows air to exit thus avoiding air space at the crown of the pipe where acid can form. The reviewer should examine the records to see that these valves are receiving periodic maintenance.

Collection systems vary widely in their vulnerability to hydrogen sulfide corrosion. Vitrified clay and plastic pipes are very resistant to hydrogen sulfide corrosion while concrete, steel, and iron pipes are more susceptible. The physical aspects of the collection system are also important.

Sewage in pipes on a decline that moves the wastewater at a higher velocity will have less hydrogen sulfide than sewage in pipes where the wastewater may experience longer detention times. Therefore, some systems may need a more comprehensive corrosion control program while some might limit observations to vulnerable points.

Safety

The reasons for development of a safety program should be obvious for any collection system owner or operator. The purpose of the program is to define the principles under which the work is to be accomplished, to make the employees aware of safe working procedures, and to establish and enforce specific regulations and procedures. The program should be in writing (e.g., procedures, policies, and training courses) and training should be well documented. The purpose of safety training is to stress the importance of safety to employees. Safety training can be accomplished through the use of manuals, meetings, posters, and a safety suggestion program.

One of the most common reasons for injury and fatalities in wastewater collection systems is the failure of victims to recognize hazards. Safety training cuts across all job descriptions and should emphasize the need to recognize and address hazardous situations.

Safety programs should be in place for the following areas:

- Confined spaces
- Chemical handling
- Trenching and excavations
- Safety Data Sheets (SDS)
- Biological hazards in wastewater
- Traffic control and work site safety
- Lockout/Tagout
- Electrical and mechanical safety
- Pneumatic or hydraulic systems safety

The collection system owner or operator should have written procedures that address all of the above issues and are made available to employees. In addition to training, safety programs should incorporate procedures to enforce the program.

For example, this could include periodic tests or “pop” quizzes to monitor performance and/or compliance and follow-up on safety related incidents. The owner or operator should maintain all of the safety equipment necessary for system staff to perform their daily activities and undertake any emergency repairs.

This equipment should include, at minimum:

- Atmospheric gas testing equipment
- Respirators and/or self-contained breathing apparatus
- Full body harness
- Tripods or non-entry rescue equipment
- Hard hats
- Safety glasses
- Rubber boots
- Rubber and/or disposable gloves
- Antibacterial soap
- First aid kit
- Protective clothing

- Confined space ventilation equipment
- Traffic and/or public access control equipment
- Hazardous gas meter

Reviewer - Point to Note

The reviewer should, in the course of interviewing personnel, determine their familiarity with health and safety procedures according to their job description. Each field crew vehicle should have adequate health and safety supplies. If the reviewer has access to the municipal vehicle storage area, he or she might choose to check actual vehicle stocks, not just supplies in storage.

Confined Space Safety

Collection system operators typically assist with manhole cover removal and other physical activities. The inspector should refrain from entering confined spaces. A confined space is defined by the Occupational Safety and Health Administration (OSHA) as a space that:

- (1) is large enough and so configured that an employee can bodily enter and perform assigned work; and
- (2) has limited or restricted means for entry or exit; and
- (3) is not designed for continuous employee occupancy

[29 CFR 1910.146(b)].

A “permit-required confined space (permit space)” is a confined space that has one or more of the following characteristics:

- (1) contains or has a potential to contain a hazardous atmosphere;
- (2) contains a material that has the potential for engulfing an entrant;
- (3) has an internal configuration such that an entrant could be trapped or asphyxiated by inwardly converging walls or by a floor which slopes downward and tapers to a smaller cross-section; or
- (4) contains any other recognized serious safety or health hazard [29 CFR 1910.146(b)].

Though OSHA has promulgated standards for confined spaces, those standards do not apply directly to municipalities, except in those states that have approved plans and have asserted jurisdiction under Section 18 of the OSHA Act.

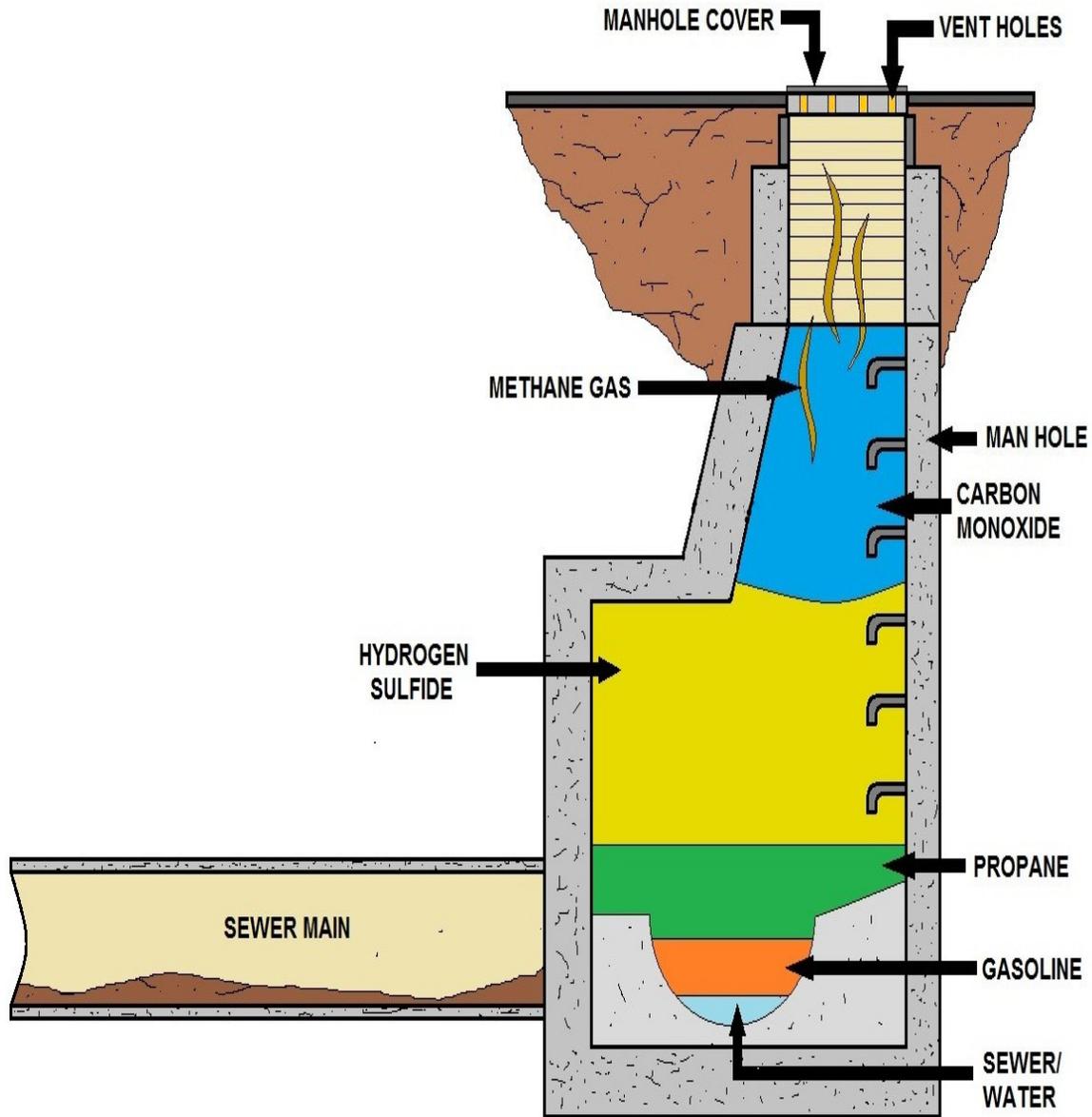
Contract operators and private facilities do have to comply with the OSHA requirements and the inspector may find that some municipalities elect to do so voluntarily. In sewer collection systems, the two most common confined spaces are the underground pumping station and manholes.

The underground pumping station is typically entered through a relatively narrow metal or concrete shaft via a fixed ladder. Inspectors conducting the field evaluation component of the CMOM audit should be able to identify and avoid permit-required confined spaces.

Although most confined spaces are unmarked, confined spaces that may have signage posted near their entry containing the following language:

DANGER–PERMIT REQUIRED–CONFINED SPACE AUTHORIZED PERSONNEL ONLY

If confined space entry is absolutely necessary, inspectors should consult with the collection system owner or operator first, have appropriate training on confined space entry, and use the proper hazard detection and personal safety equipment.



**POSSIBLE HAZARDOUS ATMOSPHERES PRESENT IN A CONFINED SPACE
(EXAMPLE IS OF A SEWER MAIN)**

CMOM Summary

Sewers deteriorate over time and develop cracks, breaks and blockages if not properly maintained. Aging, out-of-sight, out-of-mind sewer systems can be neglected and thus not be inspected or maintained on a regular basis. A CMOM Program is an effective, holistic management tool that owners of collection systems (primarily municipalities) create to operate and manage a collection system to significantly reduce, if not eliminate, sanitary sewer overflows and basement backups. It assures sewage collection system owners proactively operate and maintain this significant and valuable community infrastructure through planned ongoing maintenance and prioritizing rehabilitation and replacement projects.

For EPA and state inspectors or other reviewers, conducting an evaluation of collection system CMOM programs shares many similarities with other types of compliance reviews. Overall, the reviewer would examine records, interview staff and conduct field investigations, generally in that order although tailored, if necessary, to meet site-specific needs.

Prior to performing the onsite interviews and evaluations, preliminary information may be requested that will provide an overall understanding of the organization to allow for a more focused approach for the review. This information also provides a basis for more detailed data gathering during on site activities. The information typically requested prior to the review should include a schematic map of the collection system (could be as-built drawings) and any written operations or maintenance procedures. Depending on the volume of information, the collection system owner or operator may need ample lead time to gather and copy these documents.

Alternatively, the reviewer may offer to examine the documents and bring them back when doing the on-site review so that extra copies are not necessary. No matter which method is used, the importance of up-front preparation cannot be overemphasized. With the exception of pump stations and manholes, much of the collection system is not visible. Therefore, the more complete the reviewer's understanding of the system is prior to the review, the more successful the assessment will be. The reviewer would then proceed with the on-site activities.

Guidance for conducting compliance reviews is provided in the NPDES Compliance Inspection Manual (EPA 2004). The manual provides the general procedures for performing compliance reviews and is a valuable source of information on such topics as entry, legal authority, and responsibilities of the reviewer. Although CMOM evaluations are not specifically addressed in the manual, the general review procedures can be applied to CMOM reviews. Another good reference for general review information is the Multi-Media Investigations Manual, NEIC (EPA 1992). Some issues with entry are specific to CMOM reviews.

Some facilities may be on private property and the reviewer may need property owner consent for entry.

Documents to Review On-site Include:

- Organization chart(s)
- Staffing plans

- Job descriptions
- Sewer use ordinance
- Overall map of system showing facilities such as pump stations, treatment plants, major gravity sewers, and force mains
- O&M budget with cost centers for wastewater collection
- Performance measures for inspections, cleaning, repair, and rehabilitation
- Recent annual report, if available
- Routine reports regarding system O&M activities
- Collection system master plan
- Capital improvement projects (CIP) plan
- Flow records or monitoring
- Safety manual
- Emergency response plan
- Management policies and procedures
- Detailed maps/schematics of the collection system and pump stations
- Work order management system
- O&M manuals
- Materials management program
- Vehicle management and maintenance records
- Procurement process
- Training plan for employees
- Employee work schedules
- Public complaint log
- Rate ordinance or resolution
- Financial report (“notes” section)
- As built plans
- Discharge monitoring reports (DMRs)

Field reviews are typically conducted after interviews. The following is a list of typical field sites the team should visit:

- Mechanical and electrical maintenance shop(s)
- Fleet maintenance facilities (vehicles and other rolling stock)
- Materials management facilities (warehouse, outside storage yards)
- Field maintenance equipment storage locations (i.e., crew trucks, mechanical and hydraulic cleaning equipment, construction and repair equipment, and television inspection equipment)
- Safety equipment storage locations
- Pump stations
- Dispatch and supervisory control and data acquisition (SCADA) systems
- Crew and training facilities
- Chemical application equipment and chemical storage areas (use of chemicals for root and grease control, hydrogen sulfide control [odors, corrosion])
- Site of SSOs, if applicable
- A small, but representative, selection of manholes

Pretreatment Preface (*Credit USEPA*)

The industrial boom in the United States during the 1950s and 60s brought with it a level of pollution never before seen in this country. Scenes of dying fish, burning rivers, and thick black smog engulfing major metropolitan areas were images and stories repeated regularly on the evening news. In December of 1970, the President of the United States created the U.S. Environmental Protection Agency (EPA) through an executive order in response to these critical environmental problems.

In 1972, Congress passed the Clean Water Act (CWA) to restore and maintain the integrity of the nation's waters. Although prior legislation had been enacted to address water pollution, those previous efforts were developed with other goals in mind. For example, the 1899 Rivers and Harbors Act protected navigational interests while the 1948 Water Pollution Control Act and the 1956 Federal Water Pollution Control Act merely provided limited funding for State and local governments to address water pollution concerns on their own.

The CWA required the elimination of the discharge of pollutants into the nation's waters and the achievement of fishable and swimmable water quality levels. The EPA's National Pollutant Discharge Elimination System (NPDES) Permitting Program represents one of the key components established to accomplish this feat.

The NPDES program requires that all point source discharges to waters of the U.S. (i.e., "*direct discharges*") must be permitted. To address "*indirect discharges*" from industries to Publicly Owned Treatment Works (POTWs), the EPA, through CWA authorities, established the National Pretreatment Program as a component of the NPDES Permitting Program. The National Pretreatment Program requires industrial and commercial dischargers to treat or control pollutants in their wastewater prior to discharge to POTWs.

In 1986, more than one-third of all toxic pollutants entered the nation's waters from publicly owned treatment works (POTWs) through industrial discharges to public sewers. Certain industrial discharges, such as slug loads, can interfere with the operation of POTWs, leading to the discharge of untreated or inadequately treated wastewater into rivers, lakes, etc. Some pollutants are not compatible with biological wastewater treatment at POTWs and may pass through the treatment plant untreated.

This "pass through" of pollutants impacts the surrounding environment, occasionally causing fish kills or other detrimental alterations of the receiving waters. Even when POTWs have the capability to remove toxic pollutants from wastewater, these toxins can end up in the POTW's sewage sludge, which in many places is land applied to food crops, parks, or golf courses as fertilizer or soil conditioner.

The National Pretreatment Program is unique in that the General Pretreatment Regulations require all large POTWs (i.e., those designed to treat flows of more than 5 million gallons per day) and smaller POTWs with significant industrial discharges to establish local pretreatment programs.

These local programs must enforce all national pretreatment standards and requirements in addition to any more stringent local requirements necessary to protect site-specific conditions at the POTW.

More than 1,500 POTWs have developed and are implementing local pretreatment programs designed to control discharges from approximately 30,000 significant industrial users. Since 1983, the Pretreatment Program has made great strides in reducing the discharge of toxic pollutants to sewer systems and to waters of the U.S. In the eyes of many, the Pretreatment Program, implemented as a partnership between the EPA, States, and POTWs, is a notable success story in reducing impacts to human health and the environment. These strides can be attributed to the efforts of many Federal, State, local, and industrial representatives who have been involved with developing and implementing the various aspects of the Pretreatment Program.

The EPA has supported the Pretreatment Program through development of numerous guidance manuals. The EPA has released more than 30 manuals that provide guidance to the EPA, States, POTWs, and industry on various pretreatment program requirements and policy determinations. Through the EPA's guidance, the Pretreatment Program has maintained national consistency in interpretation of the regulations. Nevertheless, turnover in pretreatment program staff has diluted historical knowledge, leaving new staff and other interested parties unaware of existing materials.

- (1) provide a reference for anyone interested in understanding the basics of pretreatment program requirements, *and*
- (2) provide a roadmap to additional and more detailed guidance materials for those trying to implement specific elements of the Pretreatment Program.

While the Pretreatment Program has demonstrated significant reductions in pollutants discharged to POTWs, Congress' goals of zero discharge of toxic pollutants and fishable/swimmable water quality have not been realized. The EPA is currently working to establish more cost-effective and common sense approaches to environmental protection (e.g., using watershed, streamlining, and reinvention concepts), creating new responsibilities for all those involved in the National Pretreatment Program. Many current challenges remain, while many new ones likely lie ahead.

This course is intended to provide an understanding of the basic concepts that drive the Program, the current status of the Program and program guidance, and an insight into what the future holds for all those involved with implementing the Pretreatment Program.



Two lab techs examine various samples, including QA/QC and Trip Blanks to ensure both sample integrity and lab equipment/sample equipment quality.

National Pollutant Discharge Elimination System (NPDES) Permit Program Sub-Section



A Pretreatment Inspector sampling an SIU Interceptor.
A great job promotion for any Collection System's Operator.

National Pollutant Discharge Elimination System (NPDES) Permit Program

The Clean Water Act requires that all point source wastewater dischargers obtain and comply with an NPDES permit. NPDES permits regulate the discharges from publicly owned wastewater treatment facilities, other wastewater treatment facilities, industrial facilities, concentrated animal feeding operations, aquaculture, and other “point source” dischargers.

The NPDES program also regulates wet weather discharges such as stormwater discharges from industrial activities (e.g. factory stormwater runoff) and municipal stormwater discharges including urban storm-water runoff, combined sewer overflows, and storm sewer overflows.

NPDES permits are developed to ensure that such discharges to receiving waters are protective of human health and the environment. They establish specific discharge limits, monitoring, and reporting requirements and may also require that dischargers undertake measures to reduce or eliminate pollution to receiving waters.

Violations of permit conditions are enforceable under the Clean Water Act. The EPA uses a variety of techniques to monitor permittee compliance status, including on-site inspections and review of data submitted by permittees. NPDES permits are issued for a term of five years (or less).

State NPDES Programs

The Clean Water Act provides that states may be authorized to operate their own NPDES programs, provided such programs meet minimum federal requirements. As of February 1998, 42 states and the United States Virgin Islands have authorized NPDES programs. Indian nations can also be authorized to operate an NPDES program. More than 200,000 sources are regulated by NPDES permits nationwide. *NPDES Watershed Permitting a NPDES Watershed Strategy* has been developed to ensure that the NPDES Program protects watersheds as effectively as possible. Chief among the NPDES program's responsibilities is the effective implementation of EPA's *wet-weather strategies*, including stormwater management and the control of combined sewer and sanitary sewer overflows.

Stormwater Management

Stormwater discharges from many sources are largely uncontrolled. For this reason, the mandate of the *Stormwater Program* is particularly challenging. Amendments to the Clean Water Act established a two-phased approach to address stormwater discharges. Phase 1, currently being implemented, requires permits for separate storm water systems serving large and medium-sized communities (those with over 100,000 inhabitants), and for stormwater discharges associated with industrial and construction activity involving at least five acres. To address the large number of industrial dischargers of stormwater—for populations over 100,000—EPA has developed a strategy with a tiered framework to control administrative burden while emphasizing reduction in risk to human health and ecosystems. Phase 2 will address remaining stormwater discharges. This new regulatory approach would require permits for municipalities in urban areas with populations under 100,000, and smaller construction sites.

Combined Sewer Overflows (CSOS)

A combined sewer overflow is a discharge from a sewer system that is designed to carry sanitary wastewater and stormwater in the same pipe to a sewage treatment plant. In periods of rainfall or snowmelt, a combined sewer system can discharge excess wastewater directly to rivers, lakes, and estuaries, causing health and environmental hazards because treatment plants cannot handle the extra flow.

Coal Mining

Abandoned coal mines cause many of the greatest impairments to water quality throughout the Appalachian region of the United States. The EPA, the Office of Surface Mining (OSM), the Interstate Mining Compact Commission (IMCC) and concerned states have combined their efforts to develop a proposed comprehensive watershed restoration program to help improve water quality in the areas where abandoned mines are located. These efforts are designed to clean up rivers and streams polluted by coal mine drainage, as well as continuing to work with all affected stakeholders. The program includes, among other things, efforts to provide incentives for remaining abandoned sites, use of best management practices (BMPs) to achieve limitations on various chemicals, and an increased focus on a cumulative watershed approach that relies upon total maximum daily loads (TMDLs) to achieve compliance with water quality standards (WQS).

Whole Effluent Toxicity (WET)

WET is the total toxic effect of an effluent measured by a biological toxicity test. A WET test captures the effect of all toxicants on exposed test organisms without requiring the identification of specific toxicants. WET replicates to the greatest extent possible the actual environmental exposure of aquatic life to effluent toxicants. WET tests use the same essential procedures as those used to generate water quality criteria.

WET is used in NPDES permits in two fundamental ways:

- to regulate the toxicity of a discharge
- to generate data on the toxicity of a discharge

NPDES permit limits for WET typically are expressed either as a concentration of effluent in clean water that must not result in an unacceptable WET test endpoint (such as lethality of more than half of the test organisms) or a number of toxic units (such as 3 TU) which corresponds to an effluent concentration.

WET Limits

WET limits are typically calculated to ensure that state water quality criteria for toxicity (numeric or narrative) are attained and maintained. Alternatively, WET monitoring requirements instead of WET limits are often included in NPDES to generate toxicity data for use in making future decisions about whether WET needs to be controlled at a particular discharge point.

Pretreatment

The National Pretreatment Program is a cooperative effort of federal, state, and local regulatory environmental agencies established to protect water quality. The program is designed to reduce the level of pollutants discharged by industry and other non-domestic wastewater sources into municipal sewer systems, and thereby, reduce the amount of pollutants released into the environment through wastewater.

The objective of the program is to protect the Publicly Owned Treatment Works (POTW) from pollutants that may interfere with plant operation, prevent untreated pollutants from being introduced into the POTW, and to improve opportunities for the POTW to reuse wastewater and biosolids that are generated.

The General Pretreatment Regulations require POTWS that meet certain requirements to develop local pretreatment programs to control industrial discharges into their municipal sewer systems. These programs must be approved by either EPA or the state acting as the pretreatment Approval Authority. More than 1,500 POTWs have developed Approved Pretreatment Programs. EPA has also developed national categorical pretreatment standards that apply numeric pollutant limits to industrial users in specific industrial categories. The General Pretreatment Regulations include reporting and other requirements necessary to implement these categorical standards.

Types of Regulated Pollutants

CONVENTIONAL POLLUTANTS are contained in the sanitary wastes of households, businesses, and industries. These pollutants include human wastes, ground-up food from sink disposals, and laundry and bath waters. Conventional pollutants include:

PATHOGENS are organisms which cause disease in humans.

TOXIC POLLUTANTS are a group of more than 100 pollutants that have been found to be harmful to animal or plant life by certain pathways of exposure. They are primarily grouped into organics (including pesticides, solvents, polychlorinated biphenyls (PCBS), and dioxins) and metals (including lead, silver, mercury, copper, chromium, zinc, nickel, and cadmium).

NONCONVENTIONAL POLLUTANTS are any additional substances that are not conventional or toxic that may require regulation. These include nutrients such as nitrogen and phosphorus.

The term "pretreatment" refers to the requirement that non-domestic sources discharging wastewater to POTWs control their discharges, and meet limits established by the EPA, and/or your state or the local municipality (Control Authority) on the amount of pollutants allowed to be discharged. The control of the pollutants may necessitate treatment prior to discharge to the POTW (therefore the term "pretreatment").

Limits may often be met by the non-domestic source through pollution prevention techniques (product substitution, recycle and reuse of materials, more efficient production practices, improved environmental management systems, etc.), pretreatment of wastewater, or implementation of best management practices.

The National Pretreatment Program is a cooperative effort of federal, state, and local regulatory environmental agencies established to protect water quality. The program is designed to reduce the level of pollutants discharged by industry and other non-domestic wastewater sources into municipal sewer systems, and thereby, reduce the amount of pollutants released into the environment from these sources.

The national pretreatment program was established by Congress under authority of the Federal Water Pollution Control Act of 1972 (Pub. L. 92-500) as amended by the Clean Water Act of 1977 (Pub. L. 95-217). Implementation requirements of the pretreatment portions of these laws were first codified into 40 Code of Federal Regulations (CFR) Part 403 in 1978.

Objectives of the pretreatment program:

1. Protect publicly owned treatment works (POTW) from pollutants that may cause interference with sewage treatment plant operations.
2. Prevent introducing pollutants into a POTW that could cause pass through of untreated pollutants to receiving waters.
3. Manage pollutant discharges into a POTW to improve opportunities for reuse of POTW wastewater and residuals (sewage sludge).
4. Prevent introducing pollutants into a POTW that could cause worker health or safety concerns, or that could pose a potential endangerment to the public or to the environment.

Publicly Owned Treatment Works (POTWS)

Publicly owned treatment works (POTWs) collect wastewater from homes, commercial buildings, and industrial facilities and transport it via a series of pipes, known as a collection system, to the treatment plant. Here, the POTW removes harmful organisms and other contaminants from the sewage so it can be discharged safely into the receiving stream. Generally, POTWs are designed to treat domestic sewage only.

However, POTWs also receive wastewater from industrial (non-domestic) users. The General Pretreatment Regulations establish responsibilities of Federal, State, and local government, industry and the public to implement Pretreatment Standards to control pollutants from the industrial users which may pass through or interfere with POTW treatment processes or which may contaminate sewage sludge.

Generally, POTWs are designed to treat domestic sewage only. Simply defined, the typical POTW treatment process consists of primary and secondary treatment, along with some form of solids handling. Primary treatment is designed to remove large solids (e.g., rags and debris) and smaller inorganic grit. Typical primary treatment operations include screening and settling. Secondary treatment removes organic contaminants using microorganisms to consume biodegradable organics.



Odor control facility at a modern wastewater treatment plant--the photo on the right is of an enclosed “*headworks*” to help lower odor complaints.

Activated sludge, trickling filters, and rotating biological contactors are examples of common secondary treatment operations. Depending on effluent discharge requirements, POTWs may perform other “*advanced treatment*” operations such as nitrification (to convert ammonia and nitrite to the less toxic nitrate), denitrification (to convert nitrate to molecular nitrogen).

Conventional Pollutants *Figure 1*

- Biochemical Oxygen Demand (BOD)
- Total Suspended Solids (TSS)
- Fecal Coliform
- pH
- Oil and Grease (O&G)



A small wastewater treatment operator's lab.

Physical-Chemical Treatment

Physical-chemical treatment (to remove dissolved metals and organics), and disinfection (to kill any remaining pathogens). After treatment is complete, effluent is discharged to the receiving stream, typically a creek, river, lake, estuary or ocean. Some POTWs may apply treated effluent directly to golf courses, parkland, or croplands.

Both primary and secondary treatment processes generate waste solids, known as sewage sludge or biosolids. Sludges from the treatment process may be used productively (i.e., as fertilizer or soil conditioner), disposed of in a landfill or incinerated in a dedicated sewage sludge incinerator with the ash also disposed of in a landfill.

As described above, POTWs are designed to treat typical household wastes and biodegradable commercial and biodegradable industrial wastes. The Clean Water Act (CWA) and the EPA define the contaminants from these sources as conventional pollutants.

Conventional pollutants are identified in Figure 1 above and include those specific pollutants that are expected to be present in domestic discharges to POTWs.

Commercial and industrial facilities may, however, discharge toxic pollutants that the treatment plant is neither designed for nor able to remove.

Discharge to POTW (*Credit to USEPA*)

As noted above, POTWs are not designed to treat toxics in industrial waste. As such, these discharges, from both industrial and commercial sources, can cause serious problems. The undesirable outcome of these discharges can be prevented using treatment techniques or management practices to reduce or eliminate the discharge of these contaminants. The act of treating wastewater prior to discharge to a POTW is commonly referred to as “pretreatment.”

The National Pretreatment Program, published in Title 40 Code of Federal Regulations (CFR) Part 403, provides the regulatory basis to require non-domestic dischargers to comply with pretreatment standards (effluent limitations) to ensure that the goals of the CWA are attained.

As noted in 40CFR §403.2, the objectives of the National Pretreatment Program are to:

- a. Prevent the introduction of pollutants into POTWs which will interfere with the operation of a POTW, including interference with its use or disposal of municipal sludge;
- b. Prevent the introduction of pollutants into POTWs which will pass through the treatment works or otherwise be incompatible with such works; and
- c. Improve opportunities to recycle and reclaim municipal and industrial wastewaters and sludges.

The two key terms used in the EPA’s objectives for the National Pretreatment Program, “*interference*” and “*pass through*,” are defined below.

Definitions

Interference - a discharge which, alone or in conjunction with a discharge or discharges from other sources, both inhibits or disrupts the POTW, its treatment processes or operations, or its sludge processes, use or disposal, and- therefore is a cause of a violation of any NPDES permit requirement or of the prevention of sewage sludge use or disposal in compliance with any applicable requirements.

Pass Through - a discharge which exits the POTW into waters of the U.S. in quantities or concentrations which, alone or in conjunction with a discharge or discharges from other sources, is a cause of a violation of any NPDES permit requirement.

As outlined in the EPA’s objectives, toxic pollutants may pass through the treatment plant into the receiving stream, posing serious threats to aquatic life, to human recreation, and to consumption of fish and shellfish from these waters.

Pass through can make waters unswimmable or unfishable in direct contrast to the goals of the CWA. Or, these discharges can interfere with the biological activity of the treatment plant causing sewage to pass through the treatment plant untreated or inadequately treated.

Problems Associated With Toxic Discharges *Figure 3*

Air pollution can occur from volatilization of toxic chemicals in the POTW collection system or treatment plant, or through incineration of sewage sludge.

Corrosion of collection system and treatment plant from acidic discharges or discharges containing elevated levels of sulfate (forming toxic and corrosive hydrogen sulfide).

Groundwater pollution can occur from leaks in the collection system or pollutants from contaminated sewage sludge.

National Pretreatment Program's Objectives

The national pretreatment program requires nondomestic dischargers to comply with pretreatment standards to ensure the goals of the Clean Water Act (CWA) are attained.

The objectives of the program are to:

- prevent the introduction of pollutants into a POTW that will interfere with its operation, including interference. A discharge that, alone or in conjunction with a discharge or discharges from other sources, both (1) inhibits or disrupts the POTW, its treatment processes or operations, or its sludge processes, use, or disposal; and (2) therefore is a cause of a violation of any requirement of the POTW's NPDES permit (including an increase in the magnitude or duration of a violation) or of the prevention of sewage sludge use or disposal in compliance with ... [applicable] statutory provisions and regulations or permits issued thereunder (or more stringent state or local regulations). [paraphrased from 40 CFR 403.3(k)] with its use or disposal of municipal sludge,
- prevent the introduction of pollutants into a POTW that will pass through the treatment works or otherwise be incompatible with it, and
- improve opportunities to recycle and reclaim municipal and industrial wastewaters and sludges.

Pretreatment Summary

Pollutants in industrial wastewater may compromise municipal treatment plant processes or contaminate waters of the state. To protect municipal treatment plants and the environment, the Pretreatment Program requires industrial dischargers to use treatment techniques and management practices to reduce or eliminate the discharge of harmful pollutants to sanitary sewers. The Pretreatment Program is a core part of the Clean Water Act's National Pollutant Discharge Elimination System (NPDES).

The National Pretreatment Program's primary goal is to protect Publicly Owned Treatment Works (POTWs) and the environment from adverse impacts that might occur when pollutants are discharged into a sewage system.

The Specific Pretreatment Program Goals are as Follows:

- Prevent the introduction of pollutants into the POTW that will pass through the treatment works or are otherwise incompatible with treatment
- Prevent the introduction of pollutants that could interfere with POTW operations, including interference with the POTW's chosen sewage sludge use and disposal practices, as well as pollutants that could threaten worker health and safety
- Improve opportunities to recycle and reclaim municipal and industrial wastewaters and sludges

Discharges to a POTW have the potential to cause the POTW to violate its National Pollutant Discharge Elimination System (NPDES) permit if the treatment system is not able to adequately remove the pollutant contained in the discharge or the pollutant otherwise damages or disrupts operations of the POTW. Industrial discharges to POTWs have historically been a significant source of pollutants in our nation's waters. Certain industrial discharges can interfere with the operation of POTWs, leading to the discharge of untreated or inadequately treated wastewater into rivers, lakes, and such.

Some pollutants are not compatible with biological wastewater treatment at POTWs and may pass through the treatment plant untreated. This pass through of pollutants affects the surrounding environment, occasionally causing fish kills or other detrimental alterations of the receiving waters. Even when POTWs have the capability to remove toxic pollutants from wastewater, the toxics can end up in the POTW's sewage sludge, which in many places is land applied to food crops, parks, or golf courses as fertilizer or soil conditioner.

The Clean Water Act (CWA or the Act) addresses this problem by requiring the U.S. Environmental Protection Agency (EPA) to promulgate federal standards for the pretreatment of wastewater discharged to a POTW [33 U.S.C. § 1317(b)(3)]. Section 307(d) of the Act prohibits discharge in violation of any pretreatment standard [33 U.S.C. § 1317(d)]. The CWA prohibits the introduction of pollutants into a POTW that might pass through or interfere with the POTW and its operations.

Discharge of a pollutant is a term specifically defined in the CWA to mean the discharge of a pollutant to navigable waters, and such discharges are generally prohibited except in compliance with the Act and a permit under section 402 of the Act. While this document uses the word discharge in its commonly understood meaning when referring to the introduction of pollutants into a POTW, such a discharge is not a CWA discharge of pollutants to navigable waters.

To address indirect discharges from industries to POTWs, EPA has established the National Pretreatment Program as a component of the NPDES Permitting Program. The National Pretreatment Program requires industrial and commercial dischargers to treat or control pollutants in their wastewater before discharge to POTWs. EPA has chosen to promulgate pretreatment standards at the same time it promulgates effluent limitations guidelines for industry categories of direct dischargers under sections 301(b) and 304(b) of the Act [33 U.S.C. § 1311(b) and 1314(b)].

These pretreatment regulations are applicable to industrial indirect dischargers—those discharging to POTWs—and are known as categorical pretreatment standards.

EPA has also developed other nationally applicable pretreatment standards (national pretreatment standards) under section 307(b) in its General Pretreatment Regulations for Existing and New Sources of Pollution (Pretreatment Regulations) at 40 CFR Part 403. Such pretreatment standards are applicable to any user of a POTW, defined as a source of an indirect discharge [40 CFR 403.3(i)].

These national pretreatment standards include (1) a general prohibition and (2) specific prohibitions. The general prohibition prohibits any user of a POTW from introducing a pollutant into the POTW that will cause pass through or interference. EPA's regulations define both pass through and interference. Pass through is defined as a discharge that exits the POTW into waters of the United States in quantities or concentrations that, alone or in conjunction with a discharge or discharges from other sources, is a cause of a violation of any requirement of the POTW's NPDES permit.

Interference includes a discharge that, alone or in conjunction with a discharge from other sources will, among other things, prevent sewage sludge use in compliance with described regulatory provisions including section 405 of the Act [40 CFR 403.3(k)(2)]. In addition, under the Pretreatment Regulations, certain POTWs must develop and enforce local limits to implement the general and specific prohibitions of section 403.5(a)(1) and (b). Local limits that are developed by a POTW in accordance with the regulations are pretreatment standards for purposes of section 307(d) of the CWA [40 CFR 403.5(d)]. See also 40 CFR 403.3(l) ("The term National Pretreatment Standard, Pretreatment Standard, or Standard ... includes any prohibitive discharge limits established pursuant to § 403.5.").

Finally, states and POTWs always have the option of establishing more stringent requirements if such requirements are authorized and necessary, pursuant to their state or local law. Generally, this document describes only the National Pretreatment Program requirements established pursuant to the CWA and implementing regulations. Where state or local requirements are implemented in the same control mechanism, the control mechanism should clearly identify the applicable local or state regulation or enabling legislation. Therefore, each the pretreatment program can be a mixture of federal, state, and local standards and requirements.

National Pretreatment Program's Purpose

It is a cooperative effort of federal, state, and local environmental regulatory agencies established to protect water quality. The EPA authorizes the NPDES permit program to state, tribal, and territorial governments to perform permitting, administrative, and enforcement tasks for discharges to surface waters (NPDES program), EPA and authorized NPDES state pretreatment programs approve local municipalities to perform permitting, administrative, and enforcement tasks for discharges into the municipalities' publicly owned treatment works (POTWs). The national pretreatment program is a component of the NPDES program.

Post Quiz

Purpose of CMOM Programs

1. The CMOM approach helps the owner or operator provide a high level of service to customers and reduce _____.
2. Once the GIS is complete, a new goal might be to use the GIS to track emergency calls and use the information to improve _____.
3. In CMOM planning, the owner or operator selects _____ targets, and designs CMOM activities to meet the goals.
4. Information collection and management practices are used to track how the elements of the CMOM program are meeting _____, and whether overall system efficiency is improving.
5. An important component of a _____ is periodically collecting information on current systems and activities to develop a “snapshot-in-time” analysis. From this analysis, the owner or operator evaluates its performance and plans its CMOM program activities.
6. Performance characteristics of a system with an inadequate CMOM program include frequent blockages resulting in _____.
7. Other major performance indicators include pump station reliability, equipment availability, and avoidance of _____ such as a collapsed pipe.

The Elements of a Proper CMOM Program

Purposeful

8. _____ when present and properly maintained, they support customer service and protect system assets, public health, and water quality.

Goal-Oriented

9. _____ have goals directed toward their individual purposes. Progress toward these goals is measurable, and the goals are attainable.

Uses Performance Measures

10. Performance measures should be established for each of this _____ in conjunction with the program goal.

Periodically Evaluated

11. An evaluation of the progress toward reaching the goals, or _____, should be made periodically and based upon the quantified performance measures.

Available In Writing

12. The effectiveness of a MOM program quickly breaks down unless it is available in writing. Personnel turnover and lapses in communication between staff and management can change otherwise proper MOM programs to improper ones.

A. True B. False

Implemented by Trained Personnel

13. Appropriate safety, equipment, technical, and program training is essential for implementing?

What MOM programs should be audited?

14. _____ at a utility involves its entire wastewater infrastructure. Common utility management activities and operations and maintenance activities associated with sewer systems and pretreatment are listed in the Self-Audit Review Document?

15. If a utility owns treatment works or a pond system, then activities associated with the management, operation, and maintenance of these facilities should be included in the audit.

A. True B. False

Identify Deficiencies

16. Identify any permitted discharges that have occurred in the past seven years.

A. True B. False

Develop Improvement Plan

17. Define the utility's plan/schedule to remediate the?

Prepare the Self-Audit Report

18. _____ including any deficiencies found and the corresponding improvement plan, which is useful for the utility?

Answers

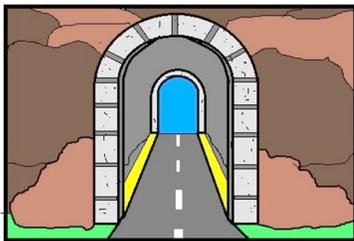
1. Regulatory noncompliance, 2. Maintenance planning, 3. Performance goal, 4. Performance goals, 5. Successful CMOM program, 6. Overflows and backups, 7. Catastrophic system failures, 8. MOM programs, 9. Proper MOM programs, 10. MOM program, 11. A reassessment of the goals, 12. True, 13. MOM program(s), 14. MOM activity, 15. True, 16. False, 17. Necessary improvements, 18. Audit results

Chapter 7- CONFINED SPACE SECTION

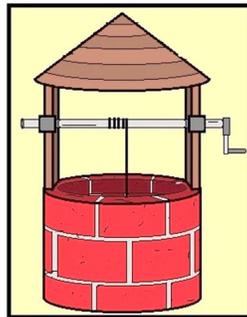
Section Focus: You will learn the basics of proper confined space entry. At the end of this section, you the student will be able to understand and describe confined space and permit required confined spaces. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.

Scope/Background: The Confined Space Entry Program is provided to protect authorized employees that will enter confined spaces and may be exposed to hazardous atmospheres, engulfment in materials, conditions which may trap or asphyxiate due to converging or sloping walls, or contains any other safety or health hazards.

Reference: OSHA-Permit-Required Confined Spaces (29 CFR 1910.146).



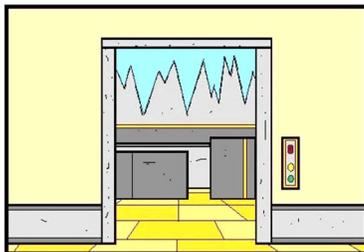
TUNNELS



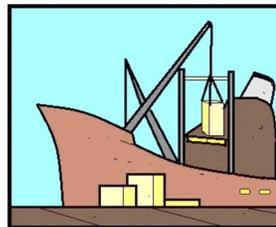
WELLS



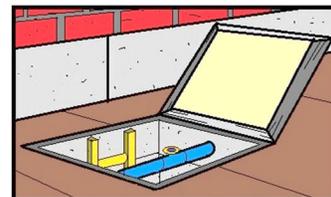
MANHOLES



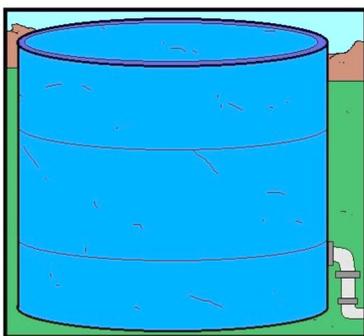
COLD STORAGE



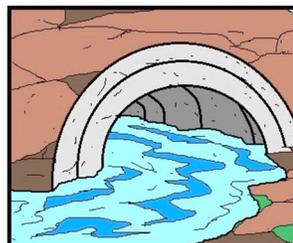
SHIP HOLDS



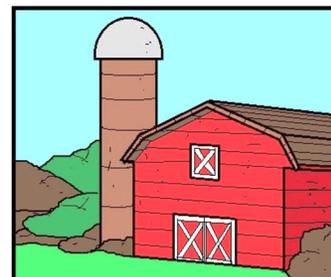
SUB-CELLARS



STORAGE TANKS



CULVERTS



SILOS

EXAMPLES OF CONFINED SPACES



Scenario. A fixed ladder drops deep inside a permit required or type II confined space. One man goes inside and passes out from hazardous fumes. A second man goes in and dies within seconds trying to help his buddy.

A third man goes in to save the others and dies on the spot. Only the first man survives, that is if you can say that being brain dead is surviving. Never try to rescue your buddies unless you are trained and have proper equipment. Never! Call 911 first. This scenario actually happened inside a sewer system. ***Don't be the next victim.***

Confined Spaces are

- large enough to allow entry of any body part, and
- limited or restricted entry or exit, and
- not designed for continuous employee occupancy

Permit Required Confined Spaces are confined spaces that have any of the following

- potential hazardous atmosphere
- material inside that may engulf or trap you
- internal design that could trap or asphyxiate you
- any other serious safety or health hazard

Entry Permits are required before you enter any "Permit Required Confined Space"

Hazards include

- Fire & Explosion
- Engulfment
- Asphyxiation
- Entrapment
- Slips & Falls
- Electric Shock
- Noise & Vibration
- Chemical Exposure
- Toxic Atmospheres
- Thermal / Chemical Burns

Engineering Controls

- Ventilation
- Locked Access
- Lighting

Administrative Controls

- Controlled Access
- Hazard Assessments
- Entry Permits & Procedures
- Signs & Lockout Tagout
- Training

Smart Safety Rules

Know what you are getting into.

Know how to get out in an emergency.

Know the hazards & how they are controlled.

Only authorized & trained personnel may enter a Confined Space or act as an attendant.

No smoking in Confined Space or near entrance or exit area.

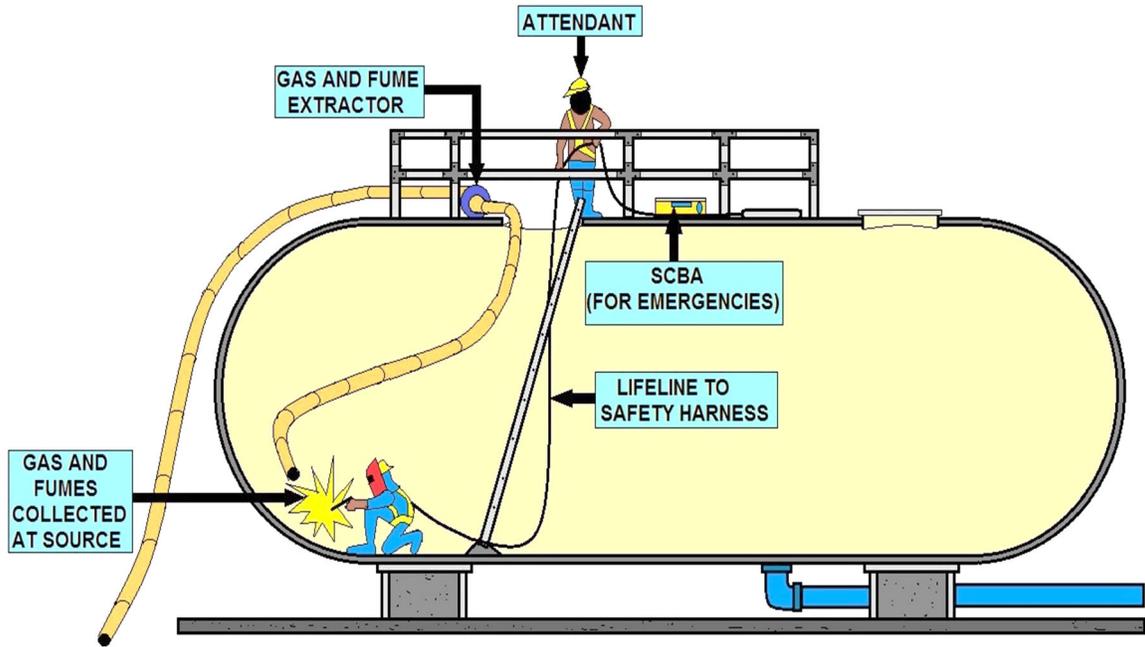
Attendant must be present at all times.

Constant visual or voice communication must be maintained between the attendant and entrants.

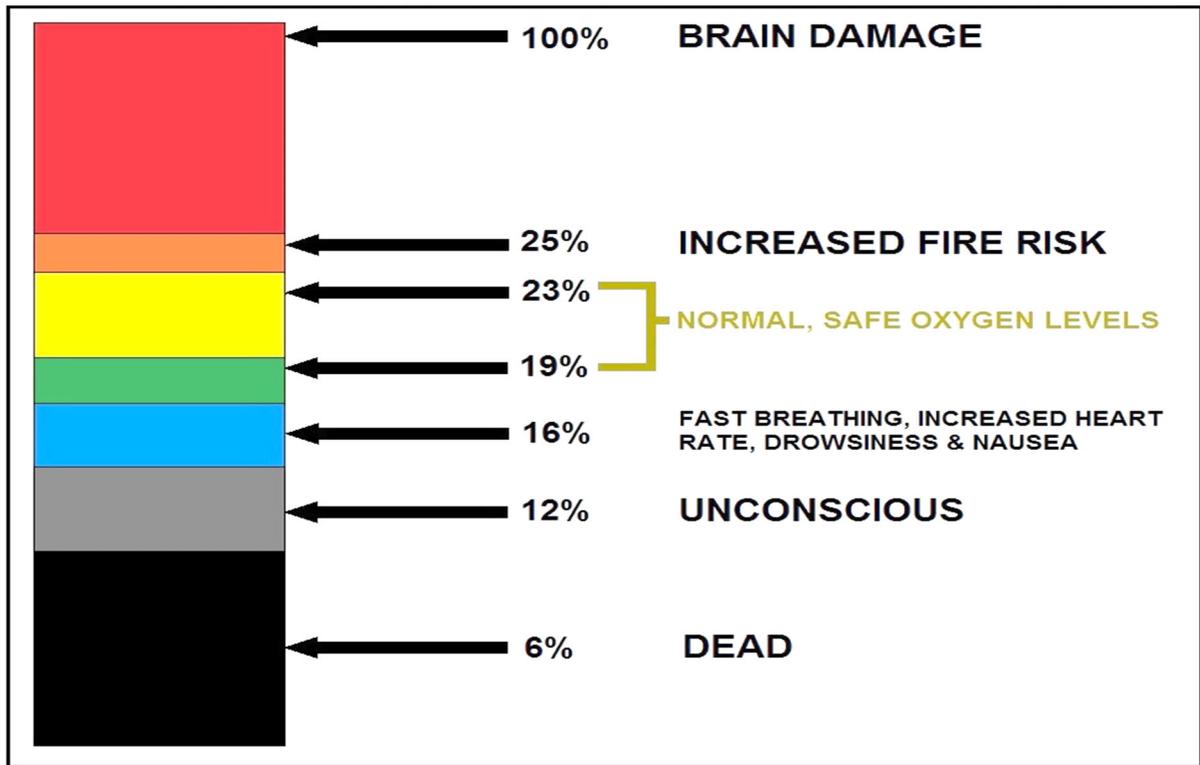
No bottom or side entry will be made, or work conducted below the level any hanging material or material which could cause engulfment.

Air and oxygen monitoring is required before entering a Permit-Required Confined Space.

Ventilation & oxygen monitoring is required when welding is performed.



CONFINED SPACE DIAGRAM



RESULTS OF OXYGEN LEVELS IN CONFINED SPACES

Confined Space Terms

"Acceptable entry conditions" means the conditions that must exist in a permit space to allow entry and to ensure that employees involved with a permit-required confined space entry can safely enter into and work within the space.

"Attendant" means an individual stationed outside one or more permit spaces who monitors the authorized entrants and who performs all attendant's duties assigned in the employer's permit space program.

"Authorized entrant" means an employee who is authorized by the employer to enter a permit space.

"Blanking or blinding" means the absolute closure of a pipe, line, or duct by the fastening of a solid plate (such as a spectacle blind or a skillet blind) that completely covers the bore and that is capable of withstanding the maximum pressure of the pipe, line, or duct with no leakage beyond the plate.

"Confined space" means a space that:

(1) Is large enough and so configured that an employee can bodily enter and perform assigned work; and

(2) Has limited or restricted means for entry or exit (for example, tanks, vessels, silos, storage bins, hoppers, vaults, and pits are spaces that may have limited means of entry.); and

(3) Is not designed for continuous employee occupancy.

"Double block and bleed" means the closure of a line, duct, or pipe by closing and locking or tagging two in-line valves and by opening and locking or tagging a drain or vent valve in the line between the two closed valves.

"Emergency" means any occurrence (including any failure of hazard control or monitoring equipment) or event internal or external to the permit space that could endanger entrants.

"Engulfment" means the surrounding and effective capture of a person by a liquid or finely divided (flowable) solid substance that can be aspirated to cause death by filling or plugging the respiratory system or that can exert enough force on the body to cause death by strangulation, constriction, or crushing.

"Entry" means the action by which a person passes through an opening into a permit-required confined space. Entry includes ensuing work activities in that space and is considered to have occurred as soon as any part of the entrant's body breaks the plane of an opening into the space.

"Entry permit (permit)" means the written or printed document that is provided by the employer to allow and control entry into a permit space and that contains the information specified in paragraph (f) of this section.

"Entry supervisor" means the person (such as the employer, foreman, or crew chief) responsible for determining if acceptable entry conditions are present at a permit space where entry is planned, for authorizing entry and overseeing entry operations, and for terminating entry as required by this section.

NOTE: An entry supervisor also may serve as an attendant or as an authorized entrant, as long as that person is trained and equipped as required by this section for each role he or she fills. Also, the duties of entry supervisor may be passed from one individual to another during the course of an entry operation.

"Hazardous atmosphere" means an atmosphere that may expose employees to the risk of death, incapacitation, impairment of ability to self-rescue (that is, escape unaided from a permit space), injury, or acute illness from one or more of the following causes:

- (1) Flammable gas, vapor, or mist in excess of 10 percent of its lower flammable limit (LFL);
- (2) Airborne combustible dust at a concentration that meets or exceeds its LFL;

NOTE: This concentration may be approximated as a condition in which the dust obscures vision at a distance of 5 feet (1.52 m) or less.

- (3) Atmospheric oxygen concentration below 19.5 percent or above 23.5 percent;
- (4) Atmospheric concentration of any substance for which a dose or a permissible exposure limit is published in Subpart G, Occupational Health and Environmental Control, or in Subpart Z, Toxic and Hazardous Substances, of this Part and which could result in employee exposure in excess of its dose or permissible exposure limit;

NOTE: An atmospheric concentration of any substance that is not capable of causing death, incapacitation, impairment of ability to self-rescue, injury, or acute illness due to its health effects is not covered by this provision.

- (5) Any other atmospheric condition that is immediately dangerous to life or health.

NOTE: For air contaminants for which OSHA has not determined a dose or permissible exposure limit, other sources of information, such as Material Safety Data Sheets that comply with the Hazard Communication Standard, section 1910.1200 of this Part, published information, and internal documents can provide guidance in establishing acceptable atmospheric conditions.

"Hot work permit" means the employer's written authorization to perform operations (for example, riveting, welding, cutting, burning, and heating) capable of providing a source of ignition.

"Immediately dangerous to life or health (IDLH)" means any condition that poses an immediate or delayed threat to life or that would cause irreversible adverse health effects or that would interfere with an individual's ability to escape unaided from a permit space.

NOTE: Some materials -- hydrogen fluoride gas and cadmium vapor, for example -- may produce immediate transient effects that, even if severe, may pass without medical attention, but are followed by sudden, possibly fatal collapse 12-72 hours after exposure. The victim "feels normal" from recovery from transient effects until collapse. Such materials in hazardous quantities are considered to be "immediately" dangerous to life or health.

"Inerting" means the displacement of the atmosphere in a permit space by a noncombustible gas (such as nitrogen) to such an extent that the resulting atmosphere is noncombustible.

NOTE: This procedure produces an IDLH oxygen-deficient atmosphere.

"Isolation" means the process by which a permit space is removed from service and completely protected against the release of energy and material into the space by such means as: blanking or blinding; misaligning or removing sections of lines, pipes, or ducts; a double block and bleed system; lockout or tagout of all sources of energy; or blocking or disconnecting all mechanical linkages.

"Line breaking" means the intentional opening of a pipe, line, or duct that is or has been carrying flammable, corrosive, or toxic material, an inert gas, or any fluid at a volume, pressure, or temperature capable of causing injury.

"Non-permit confined space" means a confined space that does not contain or, with respect to atmospheric hazards, have the potential to contain any hazard capable of causing death or serious physical harm.

"Oxygen deficient atmosphere" means an atmosphere containing less than 19.5 percent oxygen by volume.

"Oxygen enriched atmosphere" means an atmosphere containing more than 23.5 percent oxygen by volume.

"Permit-required confined space (permit space)" means a confined space that has one or more of the following characteristics:

- (1) Contains or has a potential to contain a hazardous atmosphere;
- (2) Contains a material that has the potential for engulfing an entrant;
- (3) Has an internal configuration such that an entrant could be trapped or asphyxiated by inwardly converging walls or by a floor which slopes downward and tapers to a smaller cross-section; or
- (4) Contains any other recognized serious safety or health hazard.

"Permit-required confined space program (permit space program)" means the employer's overall program for controlling, and, where appropriate, for protecting employees from, permit space hazards and for regulating employee entry into permit spaces.

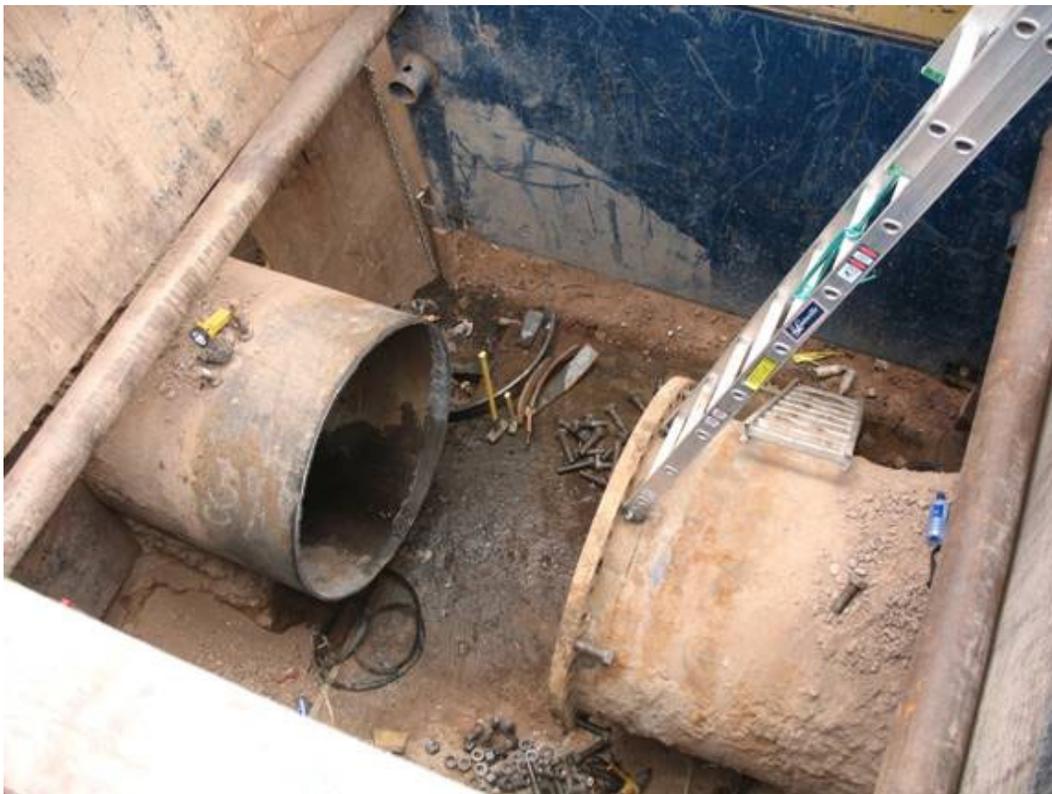
"Permit system" means the employer's written procedure for preparing and issuing permits for entry and for returning the permit space to service following termination of entry.

"Prohibited condition" means any condition in a permit space that is not allowed by the permit during the period when entry is authorized.

"Rescue service" means the personnel designated to rescue employees from permit spaces.

"Retrieval system" means the equipment (including a retrieval line, chest or full-body harness, wristlets, if appropriate, and a lifting device or anchor) used for non-entry rescue of persons from permit spaces.

"Testing" means the process by which the hazards that may confront entrants of a permit space are identified and evaluated. Testing includes specifying the tests that are to be performed in the permit space.



Would you consider this a confined space? How about a permit required?
Think about the various chemicals that we use inside confined spaces.

New Confined Space Construction Standard

On May 4, 2015, OSHA issued a new standard for construction work in confined spaces, which became effective August 3, 2015. Confined spaces can present physical and atmospheric hazards that can be avoided if they are recognized and addressed prior to entering these spaces to perform work. The new standard, Subpart AA of 29 CFR 1926 will help prevent construction workers from being hurt or killed by eliminating and isolating hazards in confined spaces at construction sites similar to the way workers in other industries are already protected.

The new standard, Subpart AA of 29 CFR 1926, will help prevent construction workers from being hurt or killed by eliminating and isolating hazards in confined spaces at construction sites similar to the way workers in other industries are already protected.

Training requirements

Employers must provide training to each employee whose work is regulated by this standard, at no cost to the employee, and ensure that employees possess the understanding, knowledge and skills necessary to safely perform the duties assigned under this standard. Training must result in an understanding of the hazards in the permit space and the methods used to isolate, control or in other ways protect employees from these hazards. For employees not authorized to perform entry rescues, it must convey the dangers of attempting such rescues.

Affected employees must be trained:

- In both a language and vocabulary that the employee can understand;
- Before the employee is first assigned duties under this standard;
- Before there is a change in assigned duties;
- Whenever there is a change in permit space entry operations that presents a hazard about which an employee has not previously been trained; and
- Whenever there is any evidence of a deviation from the permit space entry procedures required by paragraph §1926.1204(c) of this standard or there are inadequacies in the employee's knowledge or use of these procedures.

The training must establish employee proficiency in the duties required by this standard and must introduce new or revised procedures, as necessary, for compliance.

The employer must maintain training records to show required training has taken place. Training records must contain each employee's name, the name of the trainers, and the dates of training. Documentation must be available for inspection by employees and their authorized representatives, for the period of time the worker is employed by that employer.

Common questions

To assist employers in complying with the new standard, here are some frequently asked questions and answers outline by on its website at www.osha.gov:

How do I know whether to follow the general industry or construction confined space rule?

If you are doing construction work – such as building a new structure or upgrading an old one – then you must follow the construction confined space rule.

Why did OSHA believe that the former standard needed to be changed?

Previously the only requirement for confined spaces in construction was training. OSHA concluded this was inadequate as injuries and fatalities continued to occur.

How does the new final rule differ from the rules that previously applied to construction work performed in confined spaces?

The rule requires employers to determine what kinds of spaces their workers are in, what hazards could be there, how those hazards should be made safe, what training workers should receive, and how to rescue those workers if anything goes wrong.

Where can I find the final rule for Confined Spaces in Construction?

Information on the new confined spaces standard can be found on the Confined Spaces page at www.osha.gov/confinedspaces/index.html.

How can I contact OSHA if I have questions about the final rule?

For compliance assistance regarding application of the final rule contact: Directorate of Construction, Room N3468, OSHA, U.S. Department of Labor, 200 Constitution Avenue NW, Washington, DC 20210; telephone (202)-693-2020 or fax (202)-693-1689.

Who is affected by Subpart AA?

All construction employers whose workers may be exposed to confined space hazards.

Do I need to do anything if there are permit spaces at the worksite, but my employees will not need to enter the permit space?

Yes, you must take effective steps to prevent your employees from entering the space.

What standard should I follow if my workers are doing construction AND general industry work in confined spaces?

An employer whose workers are engaged in both construction and general industry work in confined spaces will meet OSHA requirements if that employer meets the requirements of 29 CFR 1926 Subpart AA - Confined Spaces in Construction.

Confined Space Entry Program - Introduction

Purpose

The Confined Space Entry Program is provided to protect authorized employees that will enter confined spaces and may be exposed to hazardous atmospheres, engulfment in materials, conditions which may trap or asphyxiate due to converging or sloping walls, or contains any other safety or health hazards.

Reference: OSHA-Permit-Required Confined Spaces (**29 CFR 1910.146**).

Scope

You are required to recognize the dangers and hazards associated with confined spaces, and this program is designed to assist you in the safety of and compliance with the OSHA standards associated with such.

Most communities will utilize the Fire Department for all rescues and additional assistance dealing with confined spaces, understanding that most Fire Department operations utilize additional in house SOG's/SOP's pertaining to such operations.

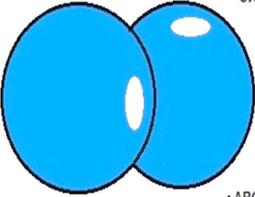
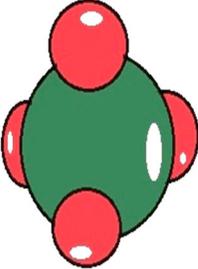
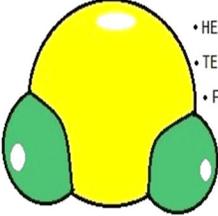
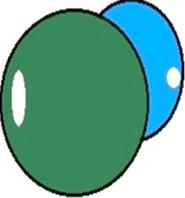
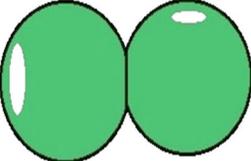
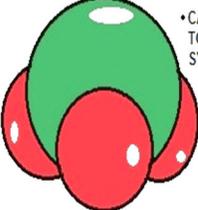
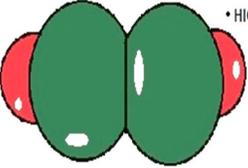
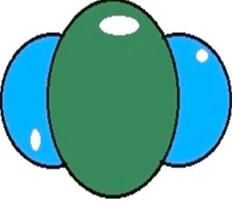
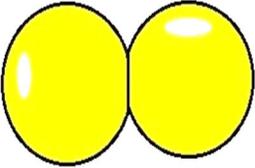
Definitions

Confined space:

- ✓ Is large enough or so configured that an employee can bodily enter and perform work.
- ✓ Has limited or restricted means for entry or exit (i.e. tanks, vessels, silos, storage bins, hoppers, vaults, and pits are spaces that may have limited means of entry).
- ✓ Is not designed for continuous employee occupancy.
- ✓ Permit required confined space (permit space), is a confined space that has one or more of the following characteristics:
 1. Contains or has a potential to contain a hazardous atmosphere.
 2. Contains a material that has the potential for engulfing an entrant.
 3. Has an internal configuration such that an entrant could be trapped or asphyxiated by inwardly covering walls or by a floor which slopes downward and tapers to a smaller cross-section.
 4. Contains any other recognized serious safety or health hazard.



**Each Permit-Required Confined Space will be marked "*Confined Space - Entry Permit Required*".
*Most of this text is credited to OSHA.***

OXYGEN O_2	METHANE CH_4	HYDROGEN SULFIDE H_2S
 <ul style="list-style-type: none"> • BELOW 19.5% IS OXYGEN DEPLETED • ABOVE 23.5% IS OXYGEN ENRICHED 	 <ul style="list-style-type: none"> • AN ASPHIXIANT <p>OXYGEN LEVELS SHOULD BE KEPT ABOVE 19.5%</p>	 <ul style="list-style-type: none"> • VERY HAZARDOUS • HEAVIER THAN AIR • TENDS TO POOL • FLAMMABLE <p>LEL OF 4%</p>
CARBON MONOXIDE CO	NITROGEN N_2	AMMONIA NH_3
 <ul style="list-style-type: none"> • AN ASPHIXIANT <p>PERMISSABLE EXPOSURE LIMIT (PEL) IS 50ppm OVER AN 8-HOUR TWA</p>	 <ul style="list-style-type: none"> • AN ASPHIXIANT <p>USED AS AN INERTING AGENT REPLACING OXYGEN IN THE AIR</p>	 <ul style="list-style-type: none"> • CAUSES DAMAGE TO RESPIRATORY SYSTEM, EYES, SKIN <p>50ppm PEL 8-HOUR TWA</p>
ACETYLENE C_2H_2	CARBON DIOXIDE CO_2	CHLORINE Cl_2
 <ul style="list-style-type: none"> • LIGHTER THAN AIR • HIGHLY FLAMMABLE • USED FOR WELDING <p>LEL OF 2.5%</p>	 <ul style="list-style-type: none"> • AN ASPHIXIANT <p>PEL IS 5000ppm OVER 8-HOUR TWA</p>	

COMMON GASES THAT CAN BE FOUND IN CONFINED SPACE

Confined Space Hazards

Fatalities and injuries constantly occur among construction workers who, during the course of their jobs, are required to enter confined spaces. In some circumstances, these workers are exposed to multiple hazards, any of which may cause bodily injury, illness, or death.

Newspaper and magazine articles abound with stories of workers injured and killed from a variety of atmospheric factors and physical agents. Throughout the construction jobsite, contractors and workers encounter both inherent and induced hazards within confined workspaces.

Inherent Hazards

Inherent hazards, such as electrical, thermal, chemical, mechanical, etc., are associated with specific types of equipment and the interactions among them.

Examples include high voltage (shock or corona discharge and the resulting burns), radiation generated by equipment, defective design, omission of protective features (no provision for grounding non-current-carrying conductive parts), high or low temperatures, high noise levels, and high-pressure vessels and lines (rupturing with resultant release of fragments, fluids, gases, etc.).

Inherent hazards usually cannot be eliminated without degrading the system or equipment, or without making them inoperative. Therefore, emphasis must be placed on hazard control methods.

Induced Hazards

Induced hazards arise, and are induced from, a multitude of incorrect decisions and actions that occur during the actual construction process. Some examples are: omission of protective features, physical arrangements that may cause unintentional worker contact with electrical energy sources, oxygen-deficient atmospheres created at the bottom of pits or shafts, lack of safety factors in structural strength, and flammable atmospheres.

Typical Examples of Confined Workspaces

Following are typical examples of confined workspaces in construction which contain both inherent and induced hazards.

Vaults

A variety of vaults are found on the construction jobsite. On various occasions, workers must enter these vaults to perform a number of functions.

The restricted nature of vaults and their frequently below-grade location can create an assortment of safety and health problems.

Oxygen-Deficient Atmosphere

One of the major problems confronting construction workers while working in vaults is the ever-present possibility of an oxygen-deficient atmosphere.



Explosive or Toxic Gases, Vapors, or Fumes

While working in an electrical vault, workers may be exposed to the build-up of explosive gases such as those used for heating (propane). Welding and soldering produce toxic fumes which are confined in the limited atmosphere.

Electrical Shock

Electrical shock is often encountered from power tools, line cords, etc. In many instances, such electrical shock results from the fact that the contractor has not provided an approved grounding system or the protection afforded by ground-fault circuit interrupters or low-voltage systems.

Purging

In some instances, purging agents such as nitrogen and argon may enter the vault from areas adjacent to it. These agents may displace the oxygen in the vault to the extent that it will asphyxiate workers almost immediately.

Materials Falling In and On

A hazard normally considered a problem associated with confined spaces is material or equipment which may fall into the vault or onto workers as they enter and leave the vault.

Vibration could cause the materials on top of the vault to roll off and strike workers. If the manhole covers were removed, or if they were not installed in the first place, materials could fall into the vault, causing injury to the workers inside.

Condenser Pits

A common confined space found in the construction of nuclear power plants is the condenser pit. Because of their large size, they are often overlooked as potentially hazardous confined spaces.

These below-grade areas create large containment areas for the accumulation of toxic fumes, gases, and so forth, or for the creation of oxygen-deficient atmospheres when purging with argon, Freon, and other inert gases.

Other hazards will be created by workers above dropping equipment, tools, and materials into the pit.

Manholes

Throughout the construction site, manholes are commonplace. As means of entry into and exit from vaults, tanks, pits, and so forth, manholes perform a necessary function. However, these confined spaces may present serious hazards which could cause injuries and fatalities.

A variety of hazards are associated with manholes. To begin with, the manhole could be a dangerous trap into which the worker could fall. Often covers are removed and not replaced, or else they are not provided in the first place.

Pipe Assemblies

One of the most frequently unrecognized types of confined spaces encountered throughout the construction site is the pipe assembly. Piping of sixteen to thirty-six inches in diameter is commonly used for a variety of purposes.

For any number of reasons, workers will enter the pipe. Once inside, they are faced with potential oxygen-deficient atmospheres, often caused by purging with argon or another inert gas. Welding fumes generated by the worker in the pipe, or by other workers operating outside the pipe at either end, subject the worker to toxic atmospheres.

The generally restricted dimensions of the pipe provide little room for the workers to move about and gain any degree of comfort while performing their tasks. Once inside the pipe, communication is extremely difficult. In situations where the pipe bends, communication and extrication become even more difficult. Electrical shock is another problem to which the worker is exposed.

Ungrounded tools and equipment or inadequate line cords are some of the causes. As well, heat within the pipe run may cause the worker to suffer heat prostration.

Ventilation Ducts

Ventilation ducts, like pipe runs, are very common at the construction site. These sheet metal enclosures create a complex network which moves heated and cooled air and exhaust fumes to desired locations in the plant.

Ventilation ducts may require that workers enter them to cut out access holes, install essential parts of the duct, etc. Depending on where these ducts are located, oxygen deficiency could exist. They usually possess many bends, which create difficult entry and exit and which also make it difficult for workers inside the duct to communicate with those outside it. Electrical shock hazards and heat stress are other problems associated with work inside ventilation ducts.

Tanks

Tanks are another type of confined workspace commonly found in construction. They are used for a variety of purposes, including the storage of water, chemicals, etc.

Tanks require entry for cleaning and repairs. Ventilation is always a problem. Oxygen-deficient atmospheres, along with toxic and explosive atmospheres created by the substances stored in the tanks, present hazards to workers. Heat, another problem in tanks, may cause heat prostration, particularly on a hot day.

Since electrical line cords are often taken into the tank, the hazard of electrical shock is always present. The nature of the tank's structure often dictates that workers must climb ladders to reach high places on the walls of the tank.

Sumps

Sumps are commonplace. They are used as collection places for water and other liquids. Workers entering sumps may encounter an oxygen-deficient atmosphere.

Also, because of the wet nature of the sump, electrical shock hazards are present when power tools are used inside. Sumps are often poorly illuminated. Inadequate lighting may create an accident situation.

Containment Cavities

These large below-grade areas are characterized by little or no air movement. Ventilation is always a problem. In addition, the possibility of oxygen deficiency exists. As well, welding and other gases may easily collect in these areas, creating toxic atmospheres. As these structures near completion, more confined spaces will exist as rooms are built off the existing structure.

Electrical Transformers

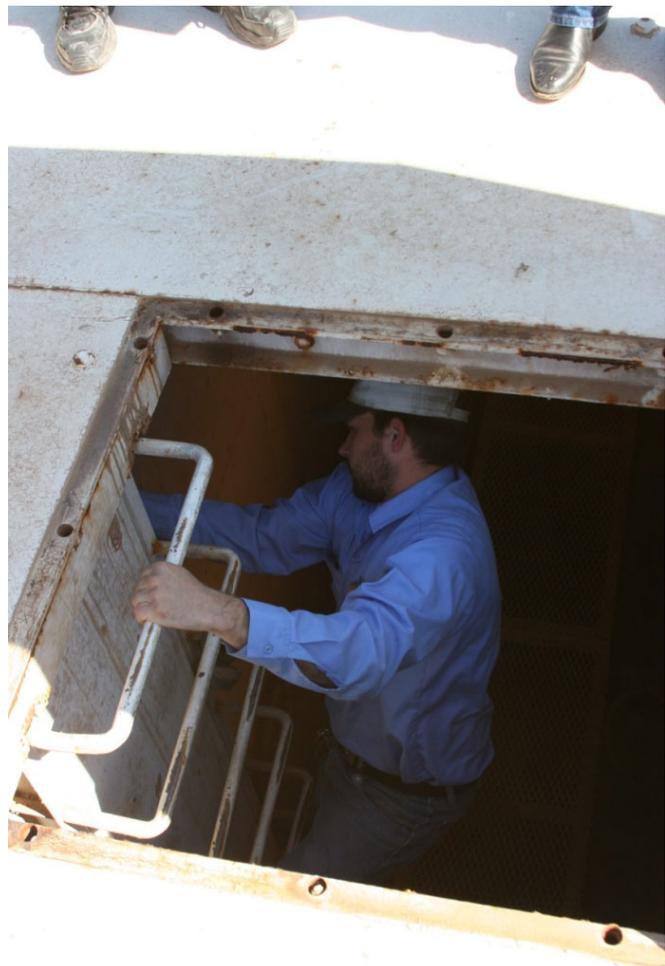
Electrical transformers are located on the jobsite. They often contain a nitrogen purge or dry air. Before they are opened, they must be well vented by having air pumped in. Workers, particularly electricians and power plant operators, will enter these transformers through hatches on top for various work-related reasons. Testing for oxygen deficiency and for toxic atmospheres is mandatory.

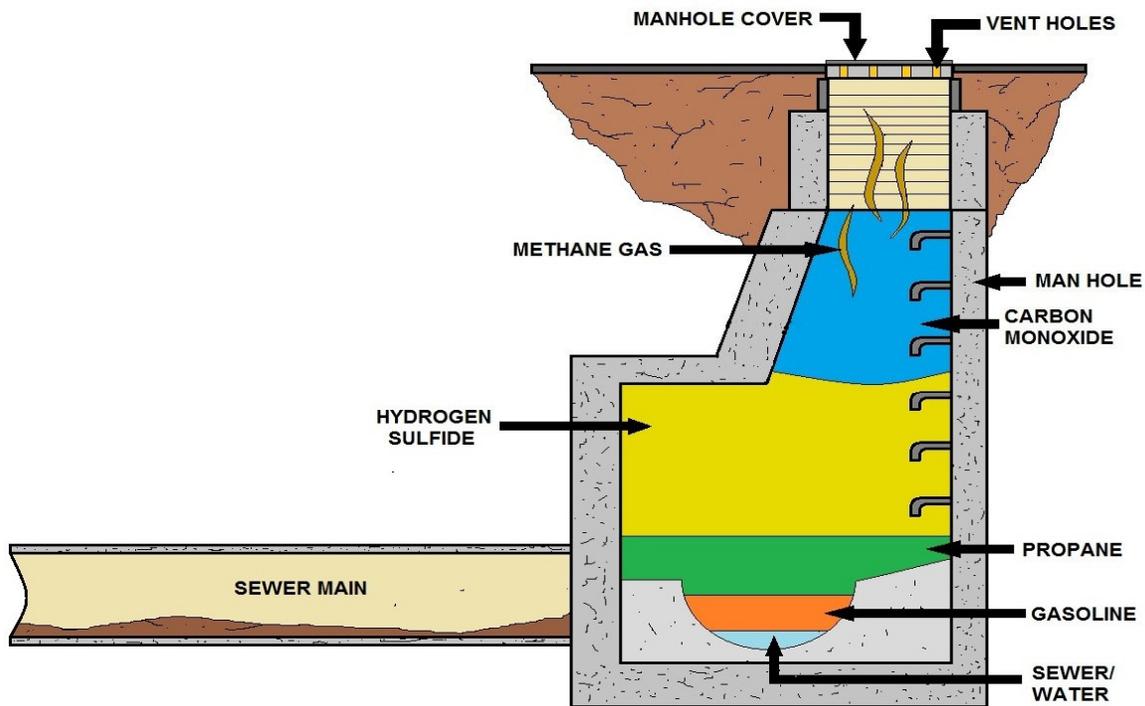
Heat Sinks

These larger pit areas hold cooling water in the event that there is a problem with the pumps located at the water supply to the plant--normally a river or lake--which would prevent cooling water from reaching the reactor core.

When in the pits, workers are exposed to welding fumes and electrical hazards, particularly because water accumulates in the bottom of the sink.

Generally, it is difficult to communicate with workers in the heat sink, because the rebar in the walls of the structure deaden radio signals.





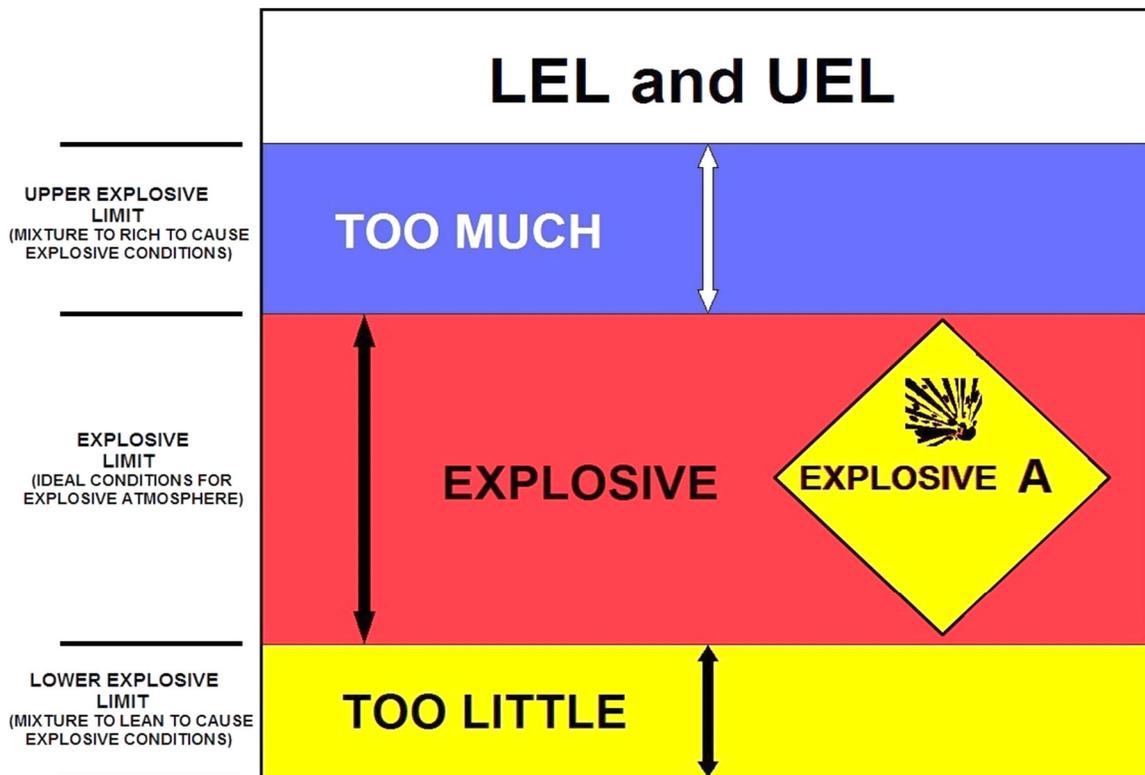
**POSSIBLE HAZARDOUS ATMOSPHERES PRESENT IN A CONFINED SPACE
(EXAMPLE IS OF A SEWER MAIN)**

COMMON HAZARDOUS GASES THAT MAY BE PRESENT IN CONFINED SPACE					
SUBSTANCE *	8-HOUR TIME-WEIGHTED AVERAGE (TWA)	15-MINUTE SHORT-TERM EXPOSURE LIMIT (STEL)	CEILING LIMIT (Never To Be Exceeded)	IMMEDIATELY DANGEROUS TO LIFE AND HEALTH (IDLH)	RECOMMENDED ALARM SETTINGS (Low / High)
AMMONIA	25 ppm	35 ppm	—	300 ppm	13 ppm / 25 ppm
CARBON MONOXIDE	25 ppm	100 ppm	—	1200 ppm	13 ppm / 25 ppm
CHLORINE	0.5 ppm	1 ppm	—	10 ppm	0.25 ppm / 0.5 ppm
HYDROGEN SULFIDE	—	—	10 ppm	100 ppm	5 ppm / 10 ppm
METHANE	1000 ppm	—	—	—	500 ppm / 1000 ppm
NITROGEN DIOXIDE	—	—	1 ppm	20 ppm	0.5 ppm / 1 ppm
SULFUR DIOXIDE	2 ppm	5 ppm	—	100 ppm	1 ppm / 2 ppm
OXYGEN	—	—	—	—	20.5 % of Atmosphere
LOWER EXPLOSIVE LIMIT (LEL)	—	—	—	—	5 % LEL

EXAMPLE OF A CHART OF CONFINED SPACE GASES



EXAMPLE OF A CONFINED SPACE ENTRY DANGER SIGN



UNDERSTANDING UPPER (UEL) & LOWER (LEL) EXPLOSIVE LIMITS

Unusual Conditions

Confined Space within a Confined Space

By the very nature of construction, situations are created which illustrate one of the most hazardous confined spaces of all--a confined space within a confined space.

This situation appears as tanks within pits, pipe assemblies or vessels within pits, etc. In this situation, not only do the potential hazards associated with the outer confined space require testing, monitoring, and control, but those of the inner space also require similar procedures.

Often, only the outer space is evaluated. When workers enter the inner space, they are faced with potentially hazardous conditions.

A good example of a confined space within a confined space is a vessel with a nitrogen purge inside a filtering water access pit. Workers entering the pit and/or the vessel should do so only after both spaces have been evaluated and proper control measures established.

Hazards in One Space Entering another Space

During an examination of confined spaces in construction, one often encounters situations which are not always easy to evaluate or control. For instance, a room or area which classifies as a confined space may be relatively safe for work.

However, access passages from other areas outside or adjacent to the room could, at some point, allow the transfer of hazardous agents into the "**safe**" one. One such instance would be a pipe coming through a wall into a containment room.

Welding fumes and other toxic materials generated in one room may easily travel through the pipe into another area, causing it to change from a safe to an unsafe workplace.

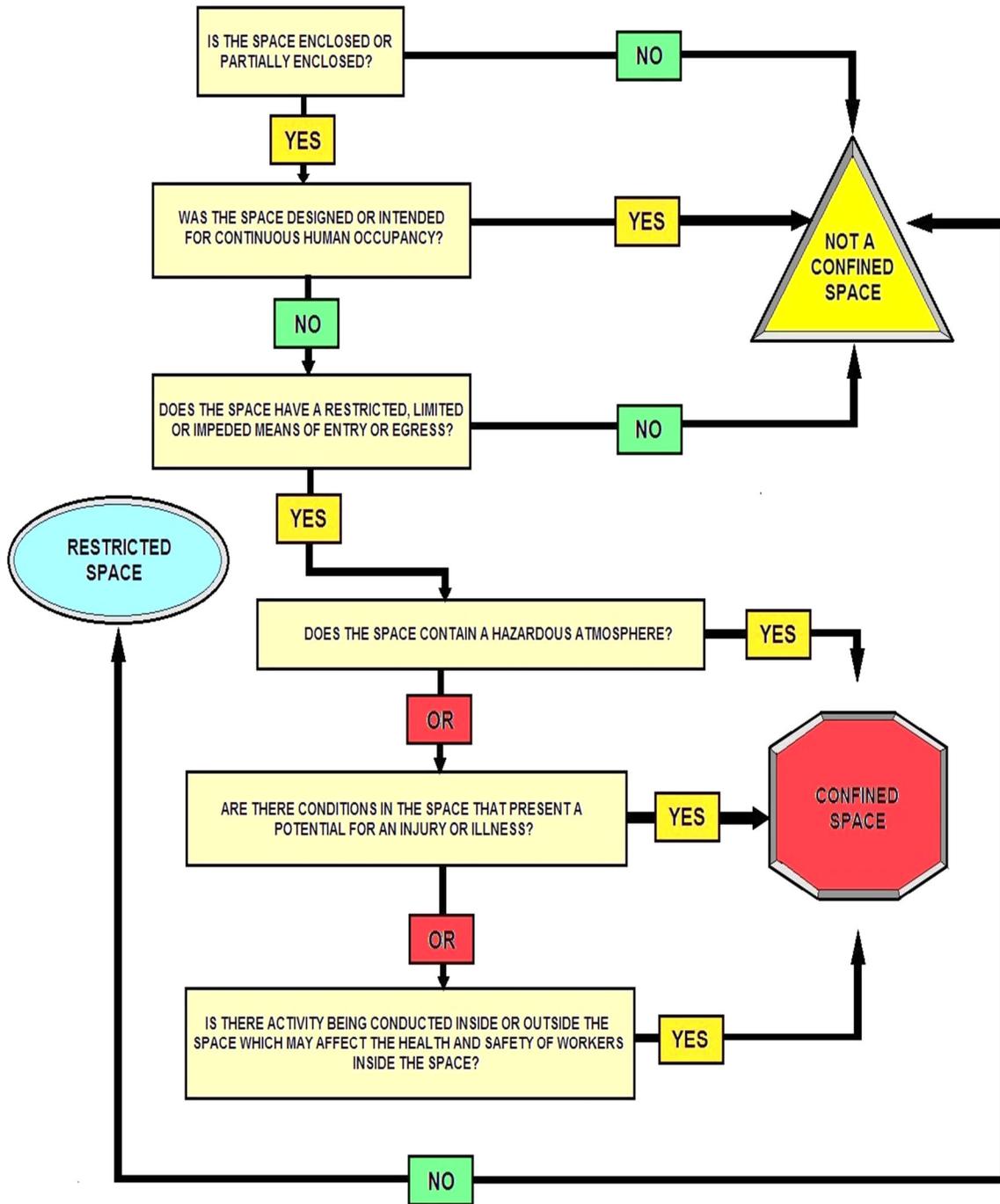
A serious problem with a situation such as this is that workers working in the "**safe**" area are not aware of the hazards leaking into their area. Thus, they are not prepared to take action to avoid or control it.



Session Conclusion

In this discussion, we have defined inherent and induced hazards in confined spaces. We have examined typical confined spaces on construction sites and we have described representative hazards within these confined spaces.

Most of this text is credited to OSHA.



HOW TO DETERMINE CONFINED SPACES

Permitted Confined Space Entry Program

Definition of Confined Spaces Requiring an Entry Permit

Confined space:

- ✓ Is large enough or so configured that an employee can bodily enter and perform work.
- ✓ Has limited or restricted means for entry or exit (i.e. tanks, vessels, silos, storage bins, hoppers, vaults, and pits are spaces that may have limited means of entry).
- ✓ Is not designed for continuous employee occupancy.

Purpose

The Permit Required Space (**PRCS**) Program is provided to protect authorized employees that will enter confined spaces and may be exposed to hazardous atmospheres, engulfment in materials, conditions which may trap or asphyxiate due to converging or sloping walls, or contains any other safety or health hazards.

Many workplaces contain confined spaces not designed for human occupancy which due to their configuration hinder employee activities including entry, work and exit. Asphyxiation is the leading cause of death in confined spaces.

Subpart P applies to all open excavations in the earth's surface.

- ✓ All trenches are excavations.
- ✓ All excavations are not trenches.

Permit Required Confined Space Entry General Rules

During all confined space entries, the following safety rules must be strictly enforced:

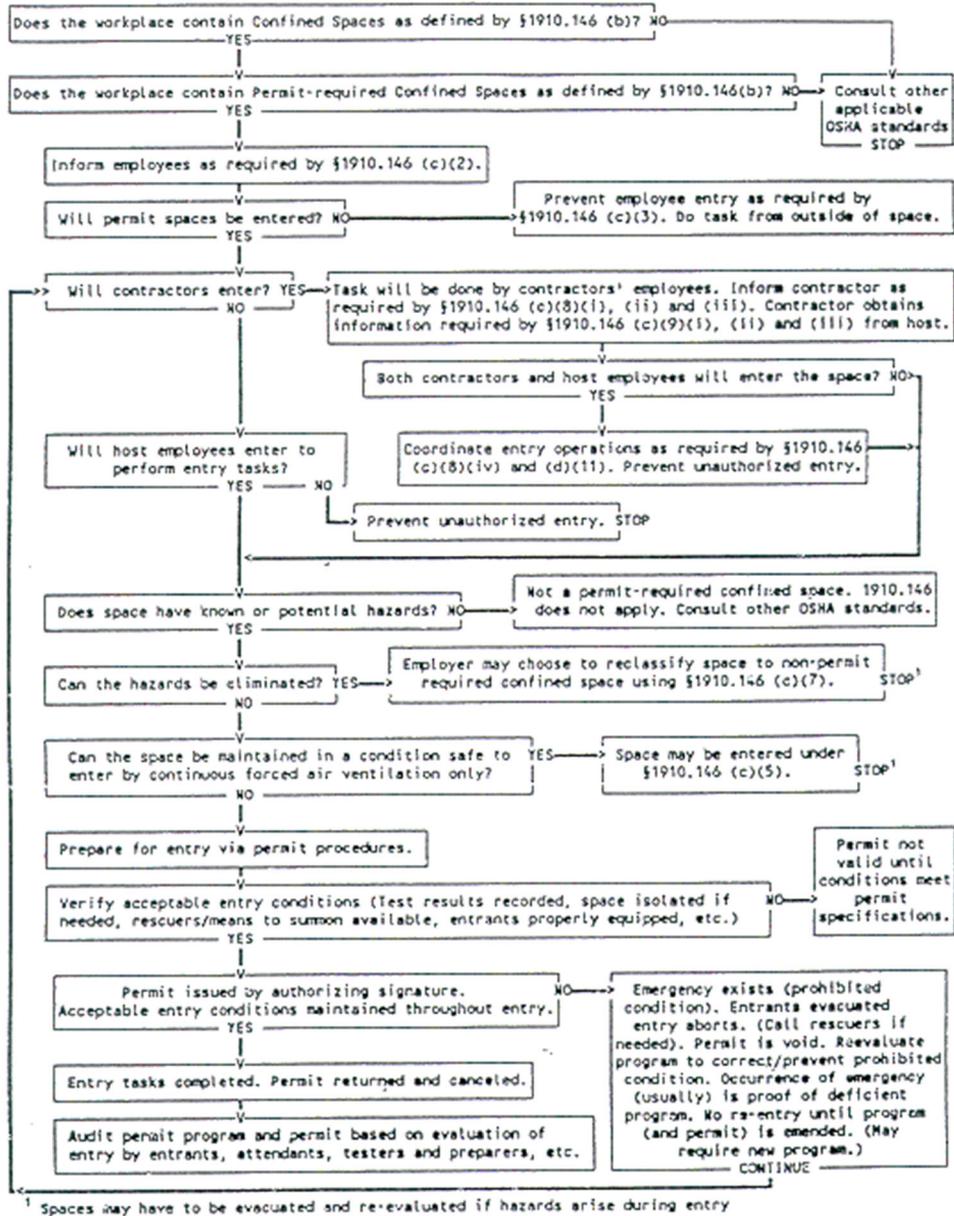
1. Only authorized and trained employees may enter a confined space or act as safety watchmen/attendants.
2. No smoking is permitted in a confined space or near entrance/exit area.
3. During confined space entries, a watchmen or attendant must be present at all times.
4. Constant visual or voice communication will be maintained between the safety watchmen and employees entering a confined space.
5. No bottom or side entry will be made or work conducted below the level any hanging material or material which could cause engulfment.
6. Air and oxygen monitoring is required before entering any permit-required confined space. Oxygen levels in a confined space must be between 19.5 and 23.5 percent. Levels above or below will require the use of an SCBA or other approved air supplied respirator. Additional ventilation and oxygen level monitoring is required when welding is performed. The monitoring will check oxygen levels, explosive gas levels and carbon monoxide levels. Entry will not be permitted if explosive gas is detected above one-half the Lower Explosive Limit (LEL).
7. To prevent injuries to others, all openings to confined spaces will be protected by a barricade when covers are removed.

Appendix A to §1910.146

Permit-Required Confined Space Decision Flow Chart

Note: Appendices A through F serve to provide information and non-mandatory guidelines to assist employers and employees in complying with the appropriate requirements of this section.

APPENDIX A TO §1910.146—PERMIT-REQUIRED CONFINED SPACE DECISION FLOW CHART



[58 FR 4549, Jan. 14, 1993; 58 FR 34846, June 29, 1993; 63 FR 66039, Dec. 1, 1998]

Confined Space Entry Permit *Example*

Date & Time Issued		Date & time Expires	
Space I.D.		Supervisor	
Equipment Affected		Task	
Standby Team			
Pre-Entry Atmospheric Checks	Time (am - pm)		
	Oxygen		
	Explosive (% LEL)		
	Toxic (PPM)		
	Testers Signature		
Pre-entry Fluid System Isolation		Yes	No
Pumps /lines blinded, blocked, disconnected			
Ventilation Source Established			
Mechanical Forced Air			
Natural Ventilation			
Post Ventilation Pre-Entry Atmospheric Checks			
Time			
Oxygen (%)			
Explosive (% LEL)			
Toxic (PPM)			
Tester Signature			
Communication Procedures Established per specific Confined Space SOP			
Rescue Procedures established per specific Confined Space SOP			

Training Verification - for the following persons & space to be entered				YES	NO	
All persons entering Confined Space						
All persons acting as Supervisor for the Entry						
All persons assigned backup positions						
All persons assigned to monitor access and interior activities						
All persons assigned to emergency rescue team						
Equipment on Scene	YES	NO	NA	YES	NO	NA
Gas Monitor						
Safety Harness						
Fall Arrest Gear						
SCBAs						

Protective Clothing				Elect Gear Properly Rated			
Periodic Atmospheric Checks							
Time (am - pm)							
Oxygen							
Explosive (% LEL)							
Toxic (PPM)							
Testers Signature							

A review of the work authorized by this permit and the information contained on this Entry Permit. Written instructions and safety procedures have been received and are understood. Entry cannot be approved if any squares are marked in the "No" column. This permit is not valid unless all appropriate items are completed.

Permit Prepared By: (Supervisor) _____

Approved By: (Unit Supervisor) _____

**This permit to be kept at job site.
Return job site copy to Safety Office following job completion.**

Copies: Safety Office, Unit Supervisor, Job site

Confined Space Duties & Responsibilities

Examples of Assignments

Employees

- Follow program requirements.
- Report any previously un-identified hazards associated with confined spaces.
- Do not enter any confined spaces that have not been evaluated for safety concerns.

Management

- Provide annual Confined Space training to all employees that may need confined space training.
- Ensure confined space assessments have been conducted.
- Annually review this program and all Entry Permits.

Rescue or Training Department

- Ensure proper training for entry & rescue teams.
- Provide proper equipment for entry & rescue teams.
- Ensure all permit required confined spaces are posted.
- Evaluate rescue teams and service to ensure they are adequately trained and prepared.
- Ensure rescue team at access during entry into spaces with Immediately Dangerous to Life or Health (IDLH) atmospheres.
- Provide annual confined space awareness training to all employees that may need confined space awareness training.

Entry Supervisor

Entry supervisors are responsible for the overall permit space entry and must coordinate all entry procedures, tests, permits, equipment and other relevant activities.

The following entry supervisor duties are required:

Know the hazards that may be faced during entry, including information on the mode, signs or symptoms, and consequences of the exposure.

- Verify by checking that the appropriate entries have been made on the permit, all tests specified by the permit have been conducted, and that all procedures and equipment specified by the permit are in place before endorsing the permit and allowing entry to begin.
- Terminate the entry and cancel the permit when the entry is complete or there is a need for terminating the permit.
- Verify that rescue services are available and that the means for summoning them are operable.



- Remove unauthorized persons who enter or attempt to enter the space during entry operations.

Determine whenever responsibility for a permit space entry operation is transferred and at intervals dictated by the hazards and operations performed within the space that entry operations remain consistent with the permit terms and that acceptable entry conditions are maintained.

Entry Attendants

At least one attendant is required outside the permit space into which entry is authorized for the duration of the entry operation.

Responsibilities include:

- To know the hazards that may be faced during entry, including information on the mode, signs or symptoms, and consequences of the exposure.
- To be aware of possible behavioral effects of hazard exposure on entrants.
- To continuously maintain an accurate count of entrants in the permit space and ensures a means to accurately identify authorized entrants.
- To remain outside the permit space during entry operations until relieved by another attendant (once properly relieved, they may participate in other permit space activities, including rescue if they are properly trained and equipped).
- To communicate with entrants as necessary to monitor entrant status and alert entrants of the need to evacuate.
- To monitor activities inside and outside the space to determine if it is safe for entrants to remain in the space; orders the entrants to immediately evacuate if: the attendant detects a prohibited condition, detects entrant behavioral effects of hazard exposure, detects a situation outside the space that could endanger the entrants; or if the attendant cannot effectively and safely perform all the attendant duties.
- To summon rescue and other emergency services as soon as the attendant determines the entrants need assistance to escape the permit space hazards.
- To perform non-entry rescues as specified by that rescue procedure and entry supervisor and not to perform duties that might interfere with the attendants' primary duty to monitor and protect the entrants.

Most of this text is credited to OSHA.



Is Entry Necessary?

Can the task be accomplished from the outside? For example, measures that eliminate the need for employees to enter confined spaces should be carefully evaluated and implemented if at all possible before considering human entry into confined spaces to perform non-emergency tasks.



CONFINED SPACE ENTER BY PERMIT ONLY

PREPARE FOR ENTRY

- IDENTIFY HAZARDS OF PERMIT SPACE.
- DE-ENERGIZE AND LOCKOUT ALL ENERGY SOURCES
- DRAIN, CLEAN AND VENTILATE CONFINED SPACE
- ISOLATE CONFINED SPACE - DISCONNECT ALL FILL AND DRAIN LINES.

TEST ATMOSPHERE

- OXYGEN SHOULD BE BETWEEN 19.5% and 23.5%
- FLAMMABLE GASES / VAPORS LESS THAN 10% of EFL
- ALL SUBSTANCES BELOW ESTABLISHED PEL

PREPARE PERSONAL PROTECTIVE DEVICES

- RESPIRATOR, PROTECTIVE CLOTHING, LIFELINE AND SAFETY HARNESS

**ATTENDANT AND RESCUE EQUIPMENT IN PLACE
REVIEW COMMUNICATION PROCEDURES
OBTAIN AUTHORIZED CONFINED SPACE PERMIT**

CONFINED SPACE ENTRY CHECKLIST EXAMPLE

Entering a Confined Space Procedures



This space requires an emergency retrieval system, continuous air monitoring, and safety watch or two-way communication for safe entry.



Donning the personal protective equipment (PPE) necessary for confined space entry.

The full-body harness provides fully adjustable leg and shoulder straps for worker comfort and proper fit. Stamped steel sliding back D-ring and sub-pelvic strap provide optimum force distribution.



Example of a "**D-Ring**" and fall protection harness used when entering a confined space. The D-Ring provides a compatible anchor point for connecting devices such as lanyards or retractable lifelines. The shock absorbing lanyard provides a deceleration distance during a fall to reduce fall arrest forces for extra protection against injury.



Tripod-retrieval assembly in use for an entry into one of the many confined spaces.



Checking the cable tension and inertial locking mechanism of the retrieval assembly.

Correct use of this device prevents free-falls greater than 2 feet.



The entrant descends into the space as the attendant critiques the operation.



Dramatic rescue simulation using the tripod-retrieval system.



The entrant is now safely out of the space and is ready to return to his many other projects after this simulated exercise.

Duties of the Person Authorizing or in Charge of the Entry

The person who authorizes or is in charge of the permit entry confined space must comply with the following:

1. Make certain that all pre-entry requirements as outlined on the permit have been completed before any worker is allowed to enter the confined space.
2. Make certain that any required pre-entry conditions are present.
3. If an in-plant/facility rescue team is to be used in the event of an emergency, make sure they would be available. If your Employer does not maintain an in-plant rescue team, dial 911 on any telephone for the Rescue Squad.
4. Make sure that any communication equipment which would be used to summon either the in-plant rescue team or other emergency assistance is operating correctly.
5. Terminate the entry upon becoming aware of a condition or set of conditions whose hazard potential exceeds the limits authorized by the entry permit.

If the person who would otherwise issue an entry permit is in charge of the entry and present during the entire entry, then a written permit is not required if that person uses a checklist as provided in the section on "**Permits**".

This person may also serve as the attendant at the site.

Special Considerations During A Permit Required Entry

Certain work being performed in a permit entry confined space could cause the atmosphere in the space to change.

Examples of this are welding, drilling, or sludge removal. In these situations, air monitoring of the confined space should be conducted on a continuous basis throughout the time of the entry.

If the workers leave the confined space for any significant period of time, such as for a lunch or other break, the atmosphere of the confined space must be retested before the workers reenter the confined space.

Unauthorized Persons

Take the following actions when unauthorized persons approach or enter a permit space while entry is under way:

1. Warn the unauthorized persons that they must stay away from the permit space,
2. Advise unauthorized persons that they must exit immediately if they have entered the space, and
3. Inform the authorized entrants and the entry supervisor if unauthorized persons have entered the permit space.

Entrants

All entrants must be authorized by the entry supervisor to enter permit spaces, have received the required training, have used the proper equipment, and observed the entry procedures and permit requirements.

The following entrant duties are required:

Know the hazards that may be faced during entry, including information on the mode, signs or symptoms, and consequences of the exposure;

Properly use the equipment required for safe entry;
Communicate with the attendant as necessary to enable the attendant to monitor the status of the entrants and to enable the attendant to alert the entrants of the need to evacuate the space if necessary;

Alert the attendant whenever; the entrant recognizes any warning signs or symptoms of exposure to a dangerous situation, or any prohibited condition is detected; and Exit the permit space as quickly as possible whenever the attendant or entry supervisor gives an order to evacuate the permit space, the entrant recognizes any warning signs or symptoms of exposure to a dangerous situation, the entrant detects a prohibited condition, or an evacuation alarm is activated.



Hazards

- ✓ Explosive / Flammable Atmospheres
- ✓ Toxic Atmospheres
- ✓ Engulfment
- ✓ Asphyxiation
- ✓ Entrapment
- ✓ Slips & falls
- ✓ Chemical Exposure
- ✓ Electric Shock
- ✓ Thermal / Chemical Burns
- ✓ Noise & Vibration

Hazard Control

Engineering Controls

- Locked entry points
- Temporary ventilation
- Temporary Lighting

Administrative Controls

- Signs
- Employee training
- Entry procedures
- Atmospheric Monitoring
- Rescue procedures
- Use of prescribed Personal Protective Equipment

Entry Standard Operating Procedures

This program outlines:

- Hazards
- Hazard Control & Abatement
- Acceptable Entry Conditions
- Means of Entry
- Entry Equipment Required
- Emergency Procedures



FRONT



**CONFINED SPACE
ENTRY PERMIT**

DATE & TIME OF ISSUE

EQUIPMENT I.D.

EQUIPMENT LOCATION

EXPIRATION

WORK TO BE DONE _____

CONFINED SPACE APPROVAL

QUALIFIED PERSON _____

OTHER QUALIFIED PERSON _____

EMPLOYEE(S) TO ENTER _____

SUPERVISOR _____

CHECKLIST ON OTHER SIDE MUST BE COMPLETED BEFORE APPROVAL

BACK



CHECKLIST

SPECIAL REQUIREMENTS	YES	NO
LOCKOUT - DE-ENERGIZER		
LINES BROKEN - CAPPED OR BLANKED		
PURGE - FLUSH AND VENT		
VENTILATION		
SECURE AREA		
BREATHING APPARATUS (SCBA)		
RESUCITATOR - INHALATOR		
ESCAPE HARNESS		
TRIPOD EMERGENCY ESCAPE UNIT		
LIFELINES		
FIRE EXTINGUISHERS		
LIGHTING		
PROTECTIVE CLOTHING (PPE)		

	P.E.L.	YES	NO
% OF OXYGEN	19.5% - 23.5%		
% OF L.E.L.	ANY % OVER 10		
CARBON MONOXIDE	35ppm		
HYDROGEN SULFIDE	10ppm		

EXAMPLE OF A CONFINED SPACE ENTRY TAG

Permit Required Confined Space Entry General Rules

During all confined space entries, the following safety rules must be strictly enforced:

1. Only authorized and trained employees may enter a confined space or act as safety watchman/attendant.
2. No smoking is permitted in a confined space or near entrance/exit area.
3. During confined space entries, a watchman must be present at all times.
4. Constant visual or voice communication will be maintained between the safety watchman/attendant and employees entering a confined space.
5. No bottom or side entry will be made or work conducted below the level of any hanging material or material which could cause engulfment.
6. Air and oxygen monitoring is required before entering any permit-required confined space. Oxygen levels in a confined space must be between 19.5 and 23.5 percent. Levels above or below will require the use of an SCBA or other approved air supplied respirator.

Additional ventilation and oxygen level monitoring is required when welding is performed.

The monitoring will check oxygen levels, explosive gas levels and carbon monoxide levels. Entry will not be permitted if explosive gas is detected above one-half the Lower Explosive Limit (**LEL**), or 10% of a specific gas explosive limit.

7. To prevent injuries to others, all openings to confined spaces will be protected by a barricade when covers are removed.

Confined Space Entry Procedures

Each employee who enters or is involved in the entry must:

1. Understand the procedures for confined space entry
2. Know the Hazards of the specific space
3. Review the specific procedures for each entry
4. Understand how to use entry and rescue equipment

Confined Space Entry Permits

- ✓ Confined Space Entry Permits must be completed before any employee enters a permit-required confined space. The permit must be completed and signed by an authorized member of management before entry.
- ✓ Permits will expire before the completion of the shift or if any pre-entry conditions change.
- ✓ Permits will be maintained on file for 12 months.

Contractor Entry

All work by non-company employees that involves the entry into confined spaces will follow the procedures of this program. The information of this program and specific hazards of the confined spaces to be entered will be provided to contractor management prior to commencing entry or work.



Important Rescue Service Questions

What is the availability of the rescue service?

Is it unavailable at certain times of the day or in certain situations?

What is the likelihood that key personnel of the rescue service might be unavailable at times?

If the rescue service becomes unavailable while an entry is underway, does it have the capability of notifying the employer so that the employer can instruct the attendant to abort the entry immediately?

Confined Space Training Sub-Section

Training for Confined Space Entry includes:

1. Duties of entry supervisor, entrant and attendants
2. Confined space entry permits
3. Hazards of confined spaces
4. Use of air monitoring equipment
5. First aid and CPR training
6. Emergency action & rescue procedures
7. Confined space entry & rescue equipment
8. Rescue training, including entry and removal from representative spaces

Confined Space Training and Education

OSHA's General Industry Regulation, §1910.146 Permit-required confined spaces, contains requirements for practices and procedures to protect employees in general industry from the hazards of entry into permit-required confined spaces. This regulation does not apply to construction.

On May 4, 2015, OSHA issued a new standard for construction work in confined spaces, which became effective August 3, 2015. Confined spaces can present physical and atmospheric hazards that can be avoided if they are recognized and addressed prior to entering these spaces to perform work. The new standard, Subpart AA of 29 CFR 1926 will help prevent construction workers from being hurt or killed by eliminating and isolating hazards in confined spaces at construction sites similar to the way workers in other industries are already protected. These requirements are shown below.

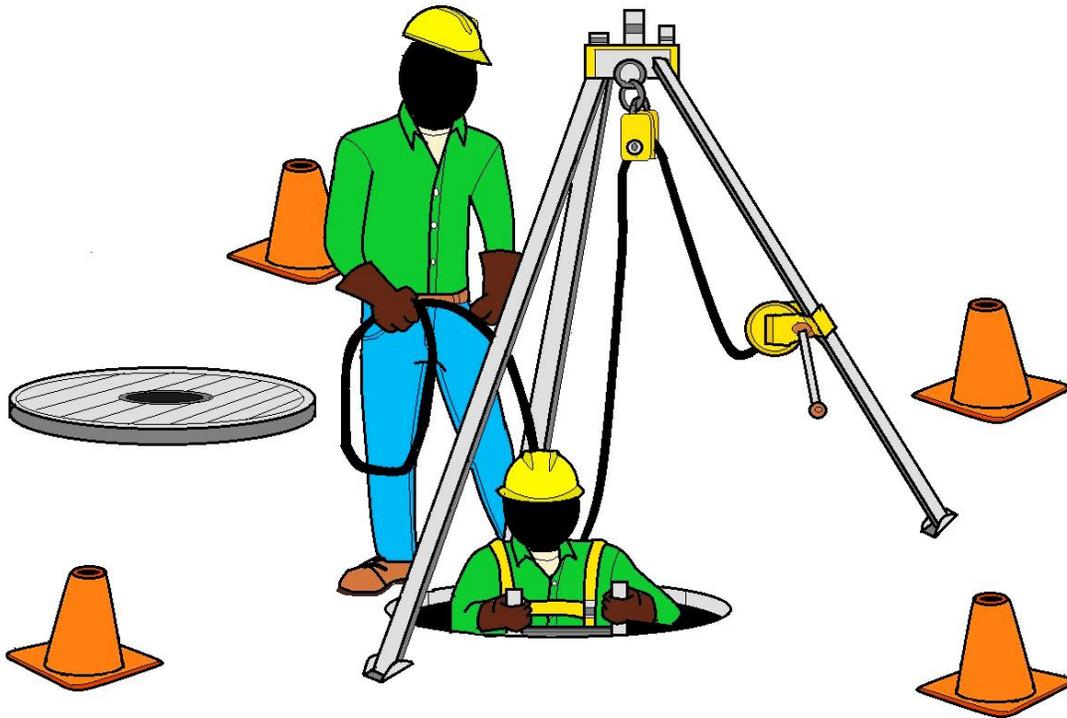
§1926.21 Safety Training and Education. (Partial)

(b)(6)(i) All employees required to enter into confined or enclosed spaces shall be instructed as to the nature of the hazards involved, the necessary precautions to be taken, and in the use of protective and emergency equipment required. The employer shall comply with any specific regulations that apply to work in dangerous or potentially dangerous areas.

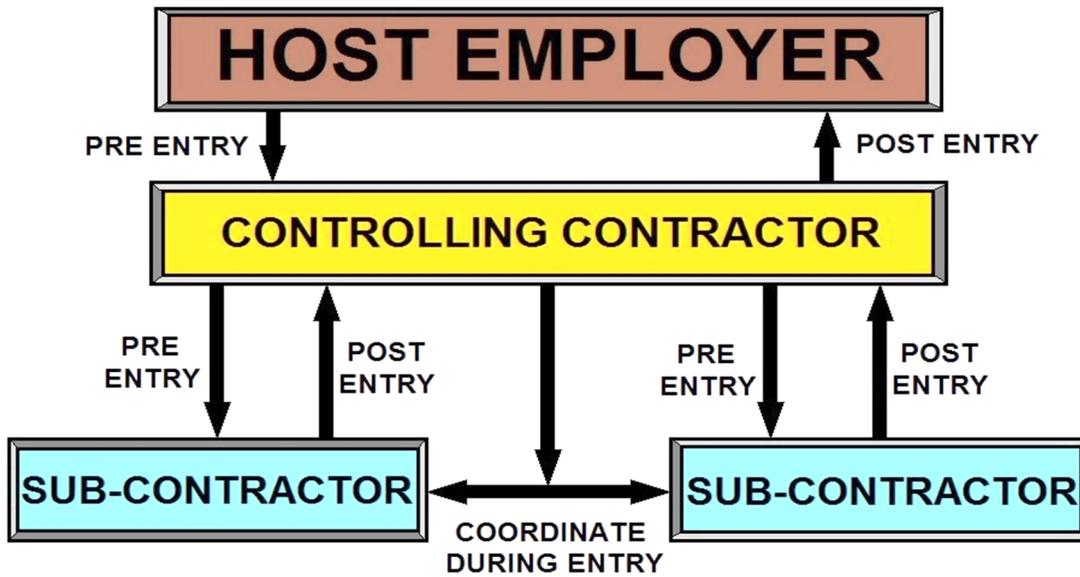
(ii) For purposes of paragraph (b)(6)(i) of this section, "**confined or enclosed space**" means any space having a limited means of egress, which is subject to the accumulation of toxic or flammable contaminants or has an oxygen deficient atmosphere. Confined or enclosed spaces include, but are not limited to, storage tanks, process vessels, bins, boilers, ventilation or exhaust ducts, sewers, underground utility vaults, tunnels pipelines, and open top spaces more than 4 feet in depth such as pits, tubs, vaults, and vessels.

OSHA's Construction Regulations also contain requirements dealing with confined space hazards in underground construction (Subpart S), underground electric transmission and distribution work (§1926.956), excavations (Subpart P), and welding and cutting (Subpart J).

Further guidance may be obtained from American National Standard ANSI Z117.1-1989, Safety Requirements for Confined Spaces. This standard provides minimum safety requirements to be followed while entering, exiting and working in confined spaces at normal atmospheric pressure. This standard does not pertain to underground mining, tunneling, caisson work or other similar tasks that have established national consensus standards.



ENTERING A CONFINED SPACE



COORDINATING CONFINED SPACE ENTRY ON JOBSITES

Your Employer is Responsible for Certain Training Requirements

These are as follows:

1. **GENERAL:** As an employer, your employer must ensure that all workers who must enter a permit entry confined space in the course of their work are informed of appropriate procedures and controls for entry into such spaces. These workers must be made aware of the fact that an unauthorized entry could be fatal, and that their senses are unable to detect and evaluate the severity of atmospheric hazards.

2. **TRAINING FOR AUTHORIZED ENTRANTS:** Your employer must ensure that all authorized entrants know the emergency action plan and have received training covering the following subjects prior to entering any permit entry confined space:

a. **Hazard Recognition:** Each worker must understand the nature of the hazard before entering and the need to perform appropriate testing to determine if it is safe to enter.

b. **Use of Personal Protective Equipment:** Each employee must be taught the proper use of all personal protective equipment required for entry or rescue, and the proper use of protective barriers and shields.

c. **Self-Rescue:** Each worker must be trained to get out of the confined space as rapidly as possible without help whenever an order to evacuate is given by the attendant, whenever an automatic evacuation alarm is activated, or whenever workers recognize the warning signs of exposure to substances that could be found in the confined space.

They must also be made aware of the toxic effects or symptoms of exposure to hazardous materials he could encounter in the confined space. This includes anything that could be absorbed through the skin or which could be carried through the skin by any solvents that are used. They must be trained to relay an alarm to the attendant and to attempt self-rescue immediately upon becoming aware of these effects.

d. **Special Work Practices or Procedures:** Each worker must be trained in any modifications of normal work practices that are necessary for permit entry confined space work.

3. **TRAINING FOR PERSONS AUTHORIZING OR IN CHARGE OF ENTRY:** In addition to other requirements already covered, the person authorizing or in charge of entry shall be trained to recognize the effects of exposure to hazards that could be in the confined space. They must also carry out all duties that the permit assigns to them.

4. TRAINING FOR ATTENDANT Any worker functioning as an attendant at a permit entry confined space must be trained in the company's emergency action plan, the duties of the attendant, and in;

a. Proper use of the communications equipment furnished for communicating with authorized workers entering the confined space or for summoning emergency or rescue services.

b. Authorized procedures for summoning rescue or other emergency services.

c. Recognition of the unusual actions of a worker which could indicate that they could be experiencing a toxic reaction to contaminants that could be present in the space.

d. Any training for rescuers, if the attendant will function as a rescuer also.

e. Any training for workers who enter the confined space, if the permit specifies that the duty of the attendant will rotate among the workers authorized to enter the confined space.



Rescue practice training. This photo is showing a sand bag being utilized as a dummy.

CONFINED SPACE AUTHORIZED ENTRANT'S LOG EXAMPLE

CONFINED SPACE:

DATE:

TIME:

ENTRANT'S NAME (PRINT)	TIME IN	TIME OUT

ENTRY Attendant:

ENTRY Supervisor Review:

CONFINED SPACE PROCEDURE CHECKLIST

Space _____ Date Last Modified _____

Place check mark in all applicable areas

Hazards	Personal Protective Equipment	
Explosive / Combustion Hazard	Air supplied Respirator	
Exposed Electrical Circuits	Air Purifying Respirator	
Unguarded Machine Parts	Welding Protection	
Atmospheric Hazard	Gloves	
Potential Atmospheric Hazard	Hard Hat	
Thermal Hazard	Ventilation Requirements	
Chemical Hazard	Continuous ___cu.ft/min Note: See <i>Ventilation Guidelines for Confined Spaces</i> for typical ventilation configurations and formulas.	
Fall Hazard		
Engulfment hazard	Note: Additional ventilation may be required for hot work, grinding or other operations that would produce airborne fumes, mist or dust. Entry Supervisor must assess additional ventilation requirements base on tasks to be performed in the space	
Converging Walls		
Floors slope-small cross-section		
Slip Hazard		
Entry Path		
Side entry	Vent Exhaust Point:	
Bottom entry	Vent Supply Point:	
Door	Space Volume	
Top open entry	Initial Purge Time= $\frac{7.5 \times \text{(space volume)}}{\text{Effective Blower Capacity}}$	
Top manhole entry	20 Air Changes per Hour (ACH) for duration of entry	
Hinged hatch	Minimum initial Purge Time= 20 Minutes	
Entry & Rescue Equipment		
Life Line	Adequate Blower Capacity (ABC) = _____ ABC = $\frac{\text{Space Volume} \times 20 \text{ ACH}}{60 \text{ minutes}}$	
Acceptable Entry Conditions		
Floor level opening barrier	Confined Space Entry permit posted	
Body Harness	Oxygen 19.5 - 23.5%	
Tripod	Lower Explosive Level %	
Man Winch	Toxic fumes/vapors Less than PEL	
Fall Arrest Unit	No engulfing material in space	
Emerg Retrieval Line	No hazardous chemicals or material	
Atmospheric Monitor	Drained - Flushed	
Blower /Saddle / Trunks	Rescue Team Available on Site	
Drop Light	Ventilation Established & Maintained	
Communication Gear	LOTO Electrical components in space	
Ladder	LOTO Mechanical Components in space	
Hand held radios	LOTO All pipes to and from space	
Portable Lighting		

Other Hazards

Flammable Atmospheres

A flammable atmosphere generally arises from enriched oxygen atmospheres, vaporization of flammable liquids, byproducts of work, chemical reactions, concentrations of combustible dusts, and desorption of chemical from inner surfaces of the confined space.

An atmosphere becomes flammable when the ratio of oxygen to combustible material in the air is neither too rich nor too lean for combustion to occur. Combustible gases or vapors will accumulate when there is inadequate ventilation in areas such as a confined space.

Flammable gases such as acetylene, butane, propane, hydrogen, methane, natural or manufactured gases or vapors from liquid hydrocarbons can be trapped in confined spaces, and since many gases are heavier than air, they will seek lower levels as in pits, sewers, and various types of storage tanks and vessels. In a closed top tank, it should also be noted that lighter than air gases may rise and develop a flammable concentration if trapped above the opening.

The byproducts of work procedures can generate flammable or explosive conditions within a confined space. Specific kinds of work such as spray painting can result in the release of explosive gases or vapors. Welding in a confined space is a major cause of explosions in areas that contain combustible gas.

Chemical reactions forming flammable atmospheres occur when surfaces are initially exposed to the atmosphere, or when chemicals combine to form flammable gases. This condition arises when dilute sulfuric acid reacts with iron to form hydrogen or when calcium carbide makes contact with water to form acetylene.

Other examples of spontaneous chemical reactions that may produce explosions from small amounts of unstable compounds are acetylene-metal compounds, peroxides, and nitrates. In a dry state, these compounds have the potential to explode upon percussion or exposure to increased temperature.

Another class of chemical reactions that form flammable atmospheres arise from deposits of pyrophoric substances (carbon, ferrous oxide, ferrous sulfate, iron, etc.) that can be found in tanks used by the chemical and petroleum industry. These tanks containing flammable deposits will spontaneously ignite upon exposure to air.

Combustible dust concentrations are usually found during the process of loading, unloading, and conveying grain products, nitrated fertilizers, finely ground chemical products, and any other combustible material.

High charges of static electricity, which rapidly accumulate during periods of relatively low humidity (below 50%) can cause certain substances to accumulate electrostatic charges of sufficient energy to produce sparks and ignite a flammable atmosphere.

These sparks may also cause explosions when the right air or oxygen to dust or gas mixture is present.

Toxic Atmospheres

The substances to be regarded as toxic in a confined space can cover the entire spectrum of gases, vapors, and finely-divided airborne dust in industry. The sources of toxic atmospheres encountered may arise from the following:

1. The manufacturing process (for example, in producing polyvinyl chloride, hydrogen chloride is used as well as vinyl chloride monomer, which is carcinogenic).
2. The product stored [removing decomposed organic material from a tank can liberate toxic substances, such as hydrogen sulfide (H_2S)].
3. The operation performed in the confined space (for example, welding or brazing with metals capable of producing toxic fumes).

During loading, unloading, formulation, and production, mechanical and/or human error may also produce toxic gases which are not part of the planned operation.

Carbon monoxide (CO) is a hazardous gas that may build up in a confined space. This odorless, colorless gas that has approximately the same density as air is formed from incomplete combustion of organic materials such as wood, coal, gas, oil, and gasoline; it can be formed from microbial decomposition of organic matter in sewers, silos, and fermentation tanks.

CO is an insidious toxic gas because of its poor warning properties. Early stages of CO intoxication are nausea and headache. CO may be fatal at as little as 1000 ppm or 10% in air, and is considered dangerous at 200 ppm or 2%, because it forms Carboxyhemoglobin in the blood which prevents the distribution of oxygen in the body.

CO is a relatively abundant colorless, odorless gas. Therefore, any untested atmosphere must be suspect. It must also be noted that a safe reading on a combustible gas indicator does not ensure that CO is not present. CO must be tested for specifically.

The formation of CO may result from chemical reactions or work activities, therefore fatalities due to CO poisoning are not confined to any particular industry. There have been fatal accidents in sewage treatment plants due to decomposition products and lack of ventilation in confined spaces.

In another area, the paint industry, varnish is manufactured by introducing the various ingredients into a kettle, and heating them in an inert atmosphere, usually town gas, which is a mixture of carbon dioxide and nitrogen.

In welding operations, oxides of nitrogen and ozone are gases of major toxicological importance, and incomplete oxidation may occur and carbon monoxide can form as a byproduct.

Another poor work practice, which has led to fatalities, is the recirculation of diesel exhaust emissions. Increased CO levels can be prevented by strict control of the ventilation and the use of catalytic converters.

Procedures for Atmospheric Testing. - 1910.146 App B

OSHA Requirement

Sub-Part Title: General Environmental Controls

Atmospheric testing is required for two distinct purposes:

evaluation of the hazards of the permit space and verification that acceptable entry conditions for entry into that space exist.

(1) Evaluation testing. The atmosphere of a confined space should be analyzed using equipment of sufficient sensitivity and specificity to identify and evaluate any hazardous atmospheres that may exist or arise, so that appropriate permit entry procedures can be developed and acceptable entry conditions stipulated for that space.

Evaluation and interpretation of these data, and development of the entry procedure, should be done by, or reviewed by, a technically qualified professional (e.g., OSHA consultation service, or certified industrial hygienist, registered safety engineer, certified safety professional, certified marine chemist, etc.) based on evaluation of all serious hazards.

(2) Verification testing. The atmosphere of a permit space which may contain a hazardous atmosphere should be tested for residues of all contaminants identified by evaluation testing using permit specified equipment to determine that residual concentrations at the time of testing and entry are within the range of acceptable entry conditions.

Results of testing (i.e., actual concentration, etc.) should be recorded on the permit in the space provided adjacent to the stipulated acceptable entry condition.

(3) Duration of testing. Measurement of values for each atmospheric parameter should be made for at least the minimum response time of the test instrument specified by the manufacturer.

(4) Testing stratified atmospheres. When monitoring for entries involving a descent into atmospheres that may be stratified, the atmospheric envelope should be tested a distance of approximately 4 feet (1.22 m) in the direction of travel and to each side. If a sampling probe is used, the entrant's rate of progress should be slowed to accommodate the sampling speed and detector response.

(5) Order of testing. A test for oxygen is performed first because most combustible gas meters are oxygen dependent and will not provide reliable readings in an oxygen deficient atmosphere.

Combustible gases are tested for next because the threat of fire or explosion is both more immediate and more life threatening, in most cases, than exposure to toxic gases and vapors. If tests for toxic gases and vapors are necessary, they are performed last.



This is a ten-minute escape air pack or emergency air supply. The plastic bag will go over your head during an emergency and provide enough air to get out of the hole. There are smaller versions of this system.

Confined Space Program *Multi-gas Meter Instructions*

Functional Buttons:



On/Off	Press black button and hold until display tells you to RELEASE. Turn on in a clean-air environment.
Mode	Press "mode" button at display prompt.
E Button	Press (E) button at display prompt.
Alarm Mode	Red lights flash and unit beeps. Beeps are more frequent at higher contaminant levels, or lower oxygen level.



Forced air ventilation with a disposable air shaft.

Typical Display of the TMX412

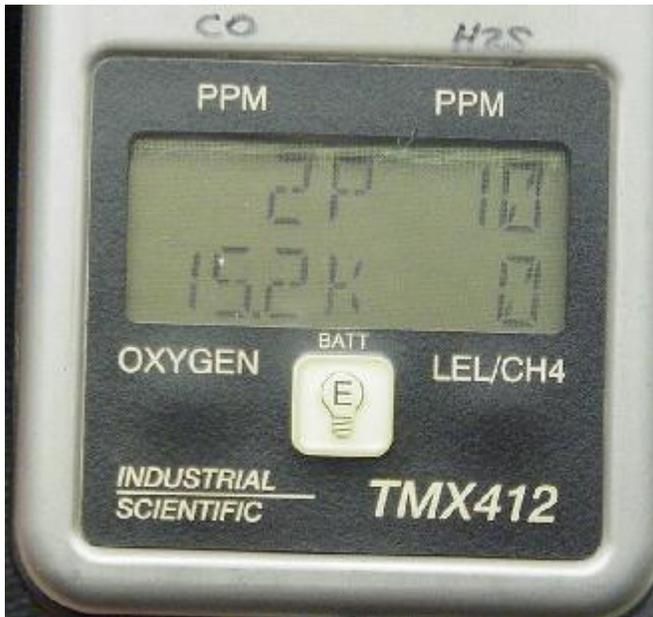


Location of gases on display.



Example of a clean air display. Carbon monoxide (**CO**) and hydrogen sulfide (**H₂S**) are in ppm; oxygen (**O₂**) and lower explosive limit (**LEL**) readings are percentage values. The battery-life indicator is just right of the oxygen display (i.e., 20.9); each line represents about one hour of service remaining.

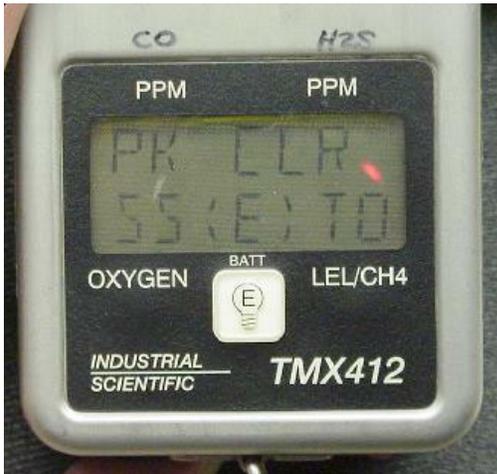
Peak Display Function



Example Display for Peak Mode: The display reads 2 ppm peak value for CO and 10 ppm peak value for H₂S (top line); 15.2 % for oxygen and 0 % for LEL (bottom line).

- Use the PEAK function to display highest recorded readings for CO, H₂S, and LEL, and the lowest reading for O₂.
- Readings are not erased when you turn the unit off. You must use the PEAK CLEAR function to erase the memory.
- Make sure you check the peak readings have been cleared before you start your monitoring session.
- Press mode button until display reads "P" (top line), and "K" (bottom line) (see photo).

Peak Clear Function



- Use the **PEAK CLEAR** function to clear peak readings from the internal memory. Readings are not erased when you turn the unit off. You must use the **PEAK CLEAR** function to erase the memory.

- Press mode button until display reads "**PK CLR PRESS (E) TO RESET**". After you press the (E) button, press mode button again until peak reading appears. Unit should now read 0,0 (top line), and 21, 0 (bottom line) assuming this was performed in a clean-air environment.

Zero Function and Calibration Function:

- Zero and Calibration Functions are performed by Attendant or as specified by the Supervisor or manufacturer.
- Special equipment and experience is necessary to properly perform these functions.

Documentation and Training:

- Make sure you are familiar with all of our confined space entry equipment, including the multi-gas monitor, before use.
- Make sure to document your air monitoring data (e.g., peak values and other relevant data) on the Confined Space Air Monitoring Data Form.



You need continued atmospheric monitoring during the entry in any confined space. Most entrants will carry two gas monitors for increased safety.

Atmospheric Testing Policy *Example*

Before entry, it is necessary to test the atmosphere in the confined space for oxygen levels, flammability, and/or any contaminants that have a potential to be present in that confined space. This testing must be done by a qualified person using equipment which has been approved for use in such areas.

The testing equipment itself should be checked to make sure it is working properly before using it. Follow the manufacturer's recommended procedures.

Testing of the confined spaces should be conducted throughout the entire portion of the space that workers will occupy during the entry. This testing shall be done without the use of ventilation systems.

Where the entry is vertical into the confined space, it is recommended that remote probes be used to measure the atmosphere at various levels. This is necessary because some gases and vapors are lighter or heavier than air and can accumulate at different levels in the confined space. Test outside the confined space to make sure the surrounding air is not contaminated.

Atmospheric conditions are considered unacceptable if oxygen levels are less than 19.5% or greater than 23.5%. Regulations define the following unacceptable levels of other hazards monitored:

1. A flammable gas, vapor or mist greater than 10% of its lower flammable limit (**LFL**). LFL means the minimum concentration of the flammable material which will ignite if an ignition source is present.
2. An airborne combustible dust at a concentration that obscures vision at a distance of five feet or less.
3. An atmospheric concentration of a substance greater than the allowed limit in the Material Safety Data Sheet for that substance.

If test results conclude that the atmospheric condition of the confined space is unacceptable, entry is prohibited until such conditions are brought into acceptable limits. This may be done by purging, cleaning and/or ventilating the space.

Purging refers to the method by which gases, vapors, or other airborne impurities are displaced from a confined space.

The confined space may also be made non-flammable, non-explosive or otherwise chemically non-reactive by displacing or diluting the original atmosphere with steam or gas that is non-reactive with respect to that space, a process referred to as "***inerting***".



Fire, Explosion, and Reactivity Hazards

Some chemicals present physical hazards such as the potential for fire, explosion, and reactivity. The SDS formerly called the MSDS explains these physical hazards.

Flammable chemicals—catch fire easily. The SDS will tell if it's flammable.

Flash point—the minimum temperature at which a liquid gives off enough vapors to burn. The lower the flash point, the more flammable the substance.

Flammable limits—the range of concentration of a substance in the air within which a substance can readily catch fire. Concentrations below or above the limits are less likely to ignite or burn.

Irritant (Corrosive) Atmospheres

Irritant or corrosive atmospheres can be divided into primary and secondary groups. The primary irritants exert no systemic toxic effects (effects on the entire body).

Examples of primary irritants are chlorine, ozone, hydrochloric acid, hydrofluoric acid, sulfuric acid, nitrogen dioxide, ammonia, and sulfur dioxide. A secondary irritant is one that may produce systemic toxic effects in addition to surface irritation. Examples of secondary irritants include benzene, carbon tetrachloride, ethyl chloride, trichloroethane, trichloroethylene, and chloropropene.

Irritant gases vary widely among all areas of industrial activity. They can be found in plastics plants, chemical plants, the petroleum industry, tanneries, refrigeration industries, paint manufacturing, and mining operations.

Prolonged exposure at irritant or corrosive concentrations in a confined space may produce little or no evidence of irritation. This may result in a general weakening of the defense reflexes from changes in sensitivity. The danger in this situation is that the worker is usually not aware of any increase in his/her exposure to toxic substances.

Asphyxiating Atmospheres

The normal atmosphere is composed approximately of 20.9% oxygen and 78.1% nitrogen, and 1% argon with small amounts of various other gases. Reduction of oxygen in a confined space may be the result of either consumption or displacement.

The consumption of oxygen takes place during combustion of flammable substances, as in welding, heating, cutting, and brazing. A more subtle consumption of oxygen occurs during bacterial action, as in the fermentation process.

Oxygen may also be consumed during chemical reactions as in the formation of rust on the exposed surface of the confined space (iron oxide). The number of people working in a confined space and the amount of their physical activity will also influence the oxygen consumption rate.

A second factor in oxygen deficiency is displacement by another gas. Examples of gases that are used to displace air, and therefore reduce the oxygen level are helium, argon, and nitrogen.

Carbon dioxide may also be used to displace air and can occur naturally in sewers, storage bins, wells, tunnels, wine vats, and grain elevators.

Aside from the natural development of these gases, or their use in the chemical process, certain gases are also used as inerting agents to displace flammable substances and retard pyrophoric reactions.

Gases such as nitrogen, argon, helium, and carbon dioxide, are frequently referred to as non-toxic inert gases but have claimed many lives. The use of nitrogen to inert a confined space has claimed more lives than carbon dioxide.

The total displacement of oxygen by nitrogen will cause immediate collapse and death.

Carbon Dioxide

Carbon dioxide and argon, with specific gravities greater than air, may lie in a tank or manhole for hours or days after opening. Since these gases are colorless and odorless, they pose an immediate hazard to health unless appropriate oxygen measurements and ventilation are adequately carried out.

Oxygen Deprivation

Oxygen deprivation is one form of asphyxiation. While it is desirable to maintain the atmospheric oxygen level at 21% by volume, the body can tolerate deviation from this ideal. When the oxygen level falls to 17%, the first sign of hypoxia is deterioration to night vision, which is not noticeable until a normal oxygen concentration is restored.

Physiologic effects are increased breathing volume and accelerated heartbeat.

Between 14-16% physiologic effects are increased breathing volume, accelerated heartbeat, very poor muscular coordination, rapid fatigue, and intermittent respiration.

Between 6-10% the effects are nausea, vomiting, inability to perform, and unconsciousness. Less than 6%, the effects are spasmodic breathing, convulsive movements, and death in minutes.

Mechanical Hazards

If activation of electrical or mechanical equipment would cause injury, each piece of equipment should be manually isolated to prevent inadvertent activation before workers enter or while they work in a confined space. The interplay of hazards associated with a confined space, such as the potential of flammable vapors or gases being present, and the build-up of static charge due to mechanical cleaning, such as abrasive blasting, all influence the precautions which must be taken.

To prevent vapor leaks, flashbacks, and other hazards, workers should completely isolate the space. To completely isolate a confined space, the closing of valves is not sufficient.

All pipes must be physically disconnected or isolation blanks bolted in place. Other special precautions must be taken in cases where flammable liquids or vapors may re-contaminate the confined space.

The pipes blanked or disconnected should be inspected and tested for leakage to check the effectiveness of the procedure. Other areas of concern are steam valves, pressure lines, and chemical transfer pipes. A less apparent hazard is the space referred to as a void, such as double walled vessels, which must be given special consideration in blanking off and inerting.

Thermal Effects

Four factors influence the interchange of heat between people and their environment. They are: (1) air temperature, (2) air velocity, (3) moisture contained in the air, and (4) radiant heat. Because of the nature and design of most confined spaces, moisture content and radiant heat are difficult to control.

As the body temperature rises progressively, workers will continue to function until the body temperature reaches approximately 102°F.

When this body temperature is exceeded, the workers are less efficient, and are prone to heat exhaustion, heat cramps, or heat stroke. In a cold environment, certain physiologic mechanisms come into play, which tend to limit heat loss and increase heat production.

The most severe strain in cold conditions is chilling of the extremities so that activity is restricted. Special precautions must be taken in cold environments to prevent frostbite, trench foot, and general hypothermia.



Proper signage is essential.

Abbreviations:

PEL - permissible exposure limit: Average concentration that must not be exceeded during 8-hour work shift of a 40-hour workweek.

STEL - Short-term exposure limit: 15-minute exposure limit that must not be exceeded during the workday.

REL - Recommended exposure limit: Average concentration limit recommended for up to a 10-hour workday during a 40-hour workweek.

IDLH - Immediately dangerous to life or health: Maximum concentration from which person could escape (in event of respiratory failure) without permanent or escape-impairing effects within 30 minutes.



SCBA Storage Box

Required Confined Space Equipment Policy *Example*

Air Testing Equipment

All air-testing equipment should be calibrated in accordance with the manufacturer's instruction.

Oxygen Meters and Monitors

The oxygen content of the air in a confined space is the first and most important constituent to measure before entry is made. The acceptable range of oxygen is between 19.5 and 23.5 percent. This content is measured before flammability is tested because rich mixtures of flammable gases or vapors give erroneous measurement results.

For example, a mixture of 90 percent methane and 10 percent air will test nonflammable because there is not enough oxygen to support the combustion process in the flammability meters. This mixture will not support life and will soon become explosive if ventilation is provided to the space. Before entry, spaces must be ventilated until both oxygen content and flammability are acceptable.

Flammability Meters

Flammability meters are used to measure the amount of flammable vapors or gases in the atmosphere as a percent of the LEL/LFL. The oxygen content must be near 21 percent for results to be meaningful.

Toxic Air Contamination Testers

Tests for toxic contaminants must be specific for the target toxin. The instrument manufacturer should be consulted for interferences. Therefore, it is important to know the history of the confined space so proper tests can be performed. Part of hazard assessment is to identify all possible contaminants that could be in the confined space.

Protective Devices

Fall-Protection Equipment

Fall-protection equipment for confined spaces should be the chest-waist harness type to minimize injuries from uncontrolled movements when it arrests a worker's fall. This type of harness also permits easier retrieval from a confined space than a waist belt. Adjustable lanyards should be used to limit free fall to two feet before arrest.

Respirators

An industrial hygienist should select respirators on the basis of his or her evaluation of possible confined-space hazards. NIOSH-approved respirators should be identified in the approved procedure required by the confined-space entry permit. It is important to note that air-purifying respirators cannot be used in an oxygen deficient atmosphere.

Lockout/Tagout Devices

Lockout/tagout devices permit employees to work safely on de-energized equipment without fear that the devices will be accidentally removed. Lock and tag devices are required to withstand a 50-pound pull without failure.

Devices used to block or restrain stored mechanical energy devices must be engineered for safety.

Safety Barriers

Safety barriers separate workers from hazards that cannot reasonably be eliminated by other engineering controls.

Required barriers will be identified in the approved confined-space entry procedure.

Ground Fault Circuit Interrupters

Ground fault circuit interrupter must be used for all portable electrical tools and equipment in confined spaces because most workers will be in contact with grounded surroundings.

Emergency Response Equipment

Fire Extinguishers

"Hot work" inside a confined space requires that an approved fire extinguisher and a person trained in its use be stationed in the confined space or in a suitable vantage point where he or she could effectively suppress any fire that might result from the work.

First Aid Equipment

Blankets, first-aid kit, Stokes stretchers, and any other equipment that may be needed for first-response treatment must be available just outside the confined space. Medical and safety professionals should select equipment on the basis of their evaluations of the potential hazards in the confined space.

Retrieval Equipment

A tripod or another suitable anchorage, hoisting device, harnesses, wristlets, ropes, and any other equipment that may be needed to make a rescue must be identified in the confined-space safety entry procedures.



It is important that this equipment be available for immediate use. Harnesses and retrieval ropes must be worn by entrants unless they would increase hazards to the entrants or impede their rescue.

Summary

A Confined Space Entry Program Should Include the Following:

- Written confined space entry procedures
- Evaluation to determine whether entry is necessary
- Issuance of a confined space entry permit
- Evaluation of the confined space by a qualified person
- Testing and monitoring the air quality in the confined space to ensure:
 - Oxygen level is at least 19.5%
 - Flammable range is less than 10% of the LFL (lower flammable limit)
- Training of workers and supervisors in the selection and use of:
 - *safe entry procedures*
 - *respiratory protection*
 - *lifelines and retrieval systems*
 - *protective clothing*
- Training of employees in safe work procedures in and around confined spaces
- Training of employees in confined space rescue procedures
- Conducting safety meetings to discuss confined space safety
- Availability and use of proper ventilation equipment
- Monitoring the air quality while workers are in the confined space.

Recommendation #2: Employers should identify the types of confined spaces within their jurisdiction and develop and implement confined space entry and rescue programs.

Discussion: Employers may be required to enter confined spaces to perform either non-emergency tasks or emergency rescue.

Therefore, employers should identify the types of confined spaces within their jurisdiction and develop and implement confined space entry and rescue programs that include written emergency rescue guidelines and procedures for entering confined spaces. A confined space program, as outlined in NIOSH Publications 80-106 and 87-113, should be implemented. At a minimum, the following should be addressed:

1. Is entry necessary? Can the task be accomplished from the outside? For example, measures that eliminate the need for employees to enter confined spaces should be carefully evaluated and implemented if at all possible before considering human entry into confined spaces to perform non-emergency tasks.
2. If entry is to be made, has the air quality in the confined space been tested for safety based on the following:
 - oxygen supply at least 19.5%
 - flammable range for all explosive gases less than 10% of the lower flammable limit
 - absence of toxic air contaminants?
3. Is ventilation equipment available and/or used?
4. Is appropriate rescue equipment available?

5. Are supervisors being continuously trained in the selection and use of appropriate rescue equipment such as:

- SCBA's
- lifelines
- human hoist systems offering mechanical advantage
- protective clothing
- ventilation systems

6. Are employees being properly trained in confined space entry procedures?

7. Are confined space safe work practices discussed in safety meetings?

8. Are employees trained in confined space rescue procedures?

9. Is the air quality monitored when the ventilation equipment is operating?

The American National Standards Institute (ANSI) Standard Z117.1-1989 (Safety Requirements for Confined Spaces), 3.2 and 3.2.1 state, "*Hazards shall be identified for each confined space. The hazard identification process shall include, ... the past and current uses of the confined space which may adversely affect the atmosphere of the confined space; ... The hazard identification process should consider items such as ... the operation of gasoline engine powered equipment in or around the confined space.*"



D-Ring on the rear of the harness is necessary for the entrant to be retrieved from the confined space.

Confined Space Post Quiz

Confined space:

1. A confined space is large enough or so configured that an employee can _____.
2. A confined space is not designed for _____.
3. A permit required confined space (permit space) contains a material that has _____.

Confined Space Hazards

4. Fatalities and injuries constantly occur among construction workers who are required to enter _____.
5. _____ are associated with specific types of equipment and the interactions among them. These hazards can be electrical, thermal, chemical, mechanical, etc.

Typical Examples of Confined Workspaces

6. Confined workspaces in construction contain _____.
7. Workers must enter _____ found on the construction jobsite to perform a number of functions.
8. The ever-present possibility of _____ is one of the major problems confronting construction workers while working in vaults.
9. According to the text, a _____ normally considered a problem associated with confined spaces is material or equipment which may fall into the vault.
10. Manholes are necessary to provide a means of entry into and exit from vaults, tanks, and pits, but these confined spaces may present _____ which could cause injuries and fatalities.
11. The pipe assembly is one of the _____ encountered throughout the construction site,

12. Once inside a pipe assembly, workers are faced with _____, often caused by purging with argon or another inert gas.

13. _____ is another problem to which the worker is exposed when inside a pipe assembly.

14. The worker may suffer _____ caused by heat within the pipe run.

15. Tanks are _____ that are used for a variety of purposes, including the storage of water and chemicals.

16. According to the text, oxygen-deficient atmospheres, along with toxic and explosive atmospheres created by the substances stored in the tanks, present hazards to workers.

A. True B. False

17. Heat in tanks may cause _____, particularly on a hot day.

18. Entry supervisors must coordinate all entry procedures, tests, _____, equipment, and other activities related to the permit space entry.

19. Before endorsing the permit and allowing entry to begin, the _____ must check that all appropriate entries have been made on the permit, all tests specified by the permit have been conducted, and that all procedures and equipment specified by the permit are in place.

20. A responsibility of the entry attendant is to know the hazards that may be faced during entry, including information on the mode, signs or symptoms, and consequences of the exposure.

A. True B. False

Confined Space Chapter Answers

1. Bodily enter and perform work, 2. Continuous employee occupancy, 3. The potential for engulfing an entrant, 4. Confined spaces, 5. Inherent hazards, 6. Both inherent and induced hazards, 7. A variety of vaults, 8. An oxygen-deficient atmosphere, 9. Hazard, 10. Serious hazards, 11. Most frequently unrecognized types of confined spaces, 12. Potential oxygen-deficient atmospheres, 13. Electrical shock, 14. Heat prostration, 15. Another type of confined workspace, 16. True, 17. Heat prostration, 18. Permits, 19. Entry supervisor, 20. True

CHAPTER 8 – EXCAVATION AND TRENCHING SECTION

Section Focus: You will learn the basics of proper excavation and trenching safety. At the end of this section, you the student will be able to understand and describe commonly found trench safety procedures and devices. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.

Scope/Background: The OSHA SUBPART P - 29 CFR 1926.650-652 requires the employer to set up an excavation safety program to protect employees from cave-in and other excavation dangers.



OSHA SUBPART P - 29 CFR 1926.650-652 COMPETENT PERSON TRAINING

PREFACE

Anyone who has done excavation work will tell you that once the first bucket of dirt is out of the ground, you never know what surprises await. Tales of unmarked utilities, unexpected rock and other nightmares are common. The greatest variable, however, is the type of excavation or trenching will be done and how to protect yourself for a cave-in.

The OSHA excavation standard was revised because excavating is the most dangerous of all construction operations. More workers are killed or seriously injured in and around excavations than in any other construction work. The second reason that OSHA revised the existing standard was to clarify the requirements. The revised standard makes the standard easier to understand. The new standard uses performance criteria where ever possible. This added flexibility provides employers with options when classifying soil and when selecting methods to protect the employee from cave-ins.

Although the standard has been clarified and employers have options when meeting some of the requirements, employers must realize that the employee must be protected at all times.

Some employers have a mindset of not needing this training until they are caught by OSHA, which is equivalent to buying car insurance only after a car collision.

Excavation decisions will have to be made right from the planning stages through completion of the work. Some sections of the standard require that documentation be kept. In some situations professional engineers will be required to plan or design the excavation and/or method of protecting the worker (such as when an excavation exceeds 20 feet in depth).

The purpose of this session is to provide you with information about the OSHA excavation standard. This program is not designed or intended to provide participants with all the information, rules, regulations and methods that they may need to know to perform all excavation work safety.

Every plan involving excavation must be studied carefully to determine the specific hazards for each job.



Supporting utilities is mandatory.

Excavation Facts

Every year in the United States:

- ✓ 100 to 500 people are killed in an excavation cave-in.
- ✓ 1000 to 5000 employees are seriously injured.

The average worker that is killed by a cave-in is a 20 to 30 year old male who has had little or no training at all. Most deaths occur in trenches 5 feet to 15 feet in depth.

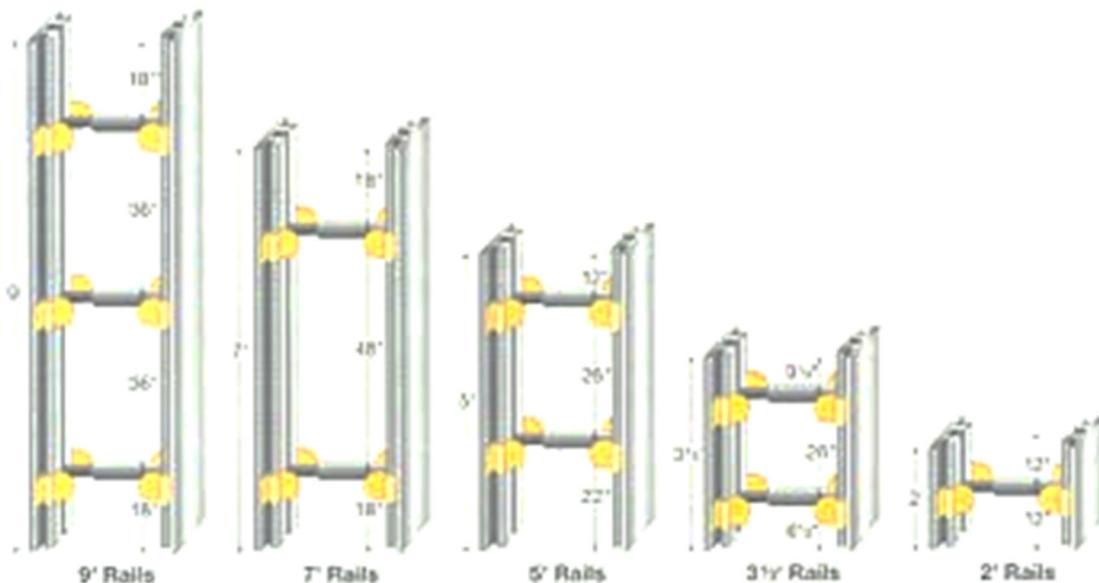
Cave-ins cause deaths and injuries by:

- ✓ Suffocation
- ✓ Crushing
- ✓ Loss of circulation
- ✓ Falling objects

One cubic foot (12" x 12" x 12") can weigh between 90 and 140 pounds. Therefore, one cubic yard (3' x 3' x 3') weighs as much as a backhoe (approximately 3000 pounds).

Subpart P applies to all open excavations in the earth's surface.

- ✓ All trenches are excavations.
- ✓ All excavations are not trenches.





Notice that employees are wearing hard hats but no ladders are present. Spoil piles are too close to the hole. Forgot the ladder.

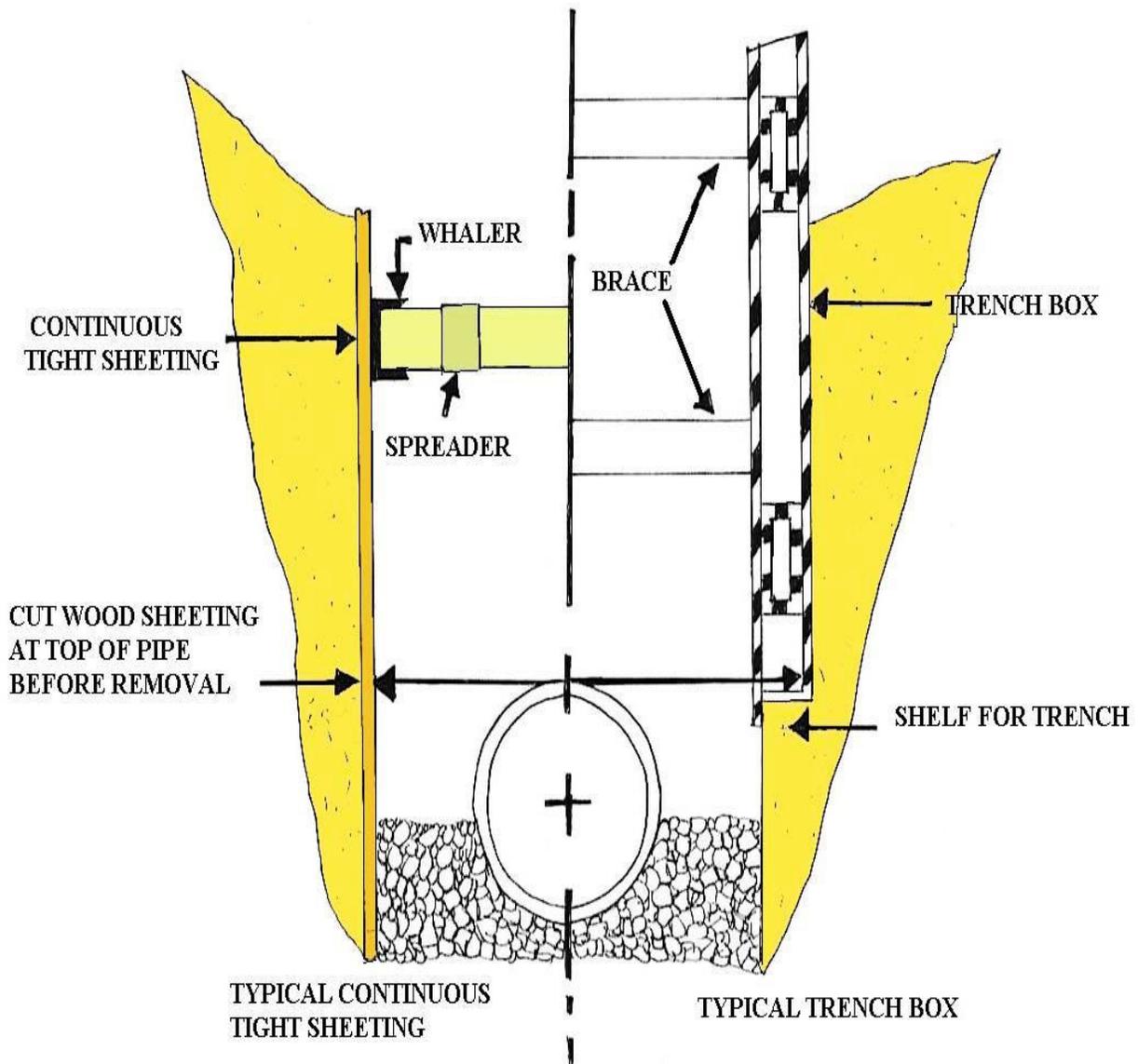


Notice the ladder it should be three rungs out and tied but not staked.

Competent Person

Competent person means one who is capable of identifying existing hazards in the surroundings or working conditions which are unsanitary, hazardous, or dangerous to employees and has authorization to take prompt corrective measures to eliminate them.

In order to be a "**Competent Person**" for the purpose of this standard, one must have specific training in and be knowledgeable about soils analysis, the use of protective systems and the requirements of 29 CFR Part 1926.650-652 Subpart P.



Competent Person Duties

- Performs daily inspections of the protective equipment, trench conditions, safety equipment and adjacent areas.
- Inspections shall be made prior to the start of work and as needed throughout the shift.
- Inspections shall be made after every rainstorm or other hazard occurrence.
- Knowledge of emergency contact methods, telephone or radio dispatch.
- Removes employees and all other personnel from hazardous conditions and makes all changes necessary to ensure their safety.
- Insures all employees have proper protective equipment, hard-hats, reflective vests, steel-toed boots, harnesses, eye protection, hearing protection and drinking water.
- Categorize soil conditions and conduct visual and manual tests.
- Determine the appropriate protection system to be used.
- Maintain on-site records of inspections and protective systems used.
- Maintain on-site Hazard Communication program, Material Safety Data Sheets and a Risk Management Plan, if necessary.
- Maintain current First Aid and CPR certifications. Maintain current Confined Space certification training.

Scope of Work

1. During excavation work a competent person shall be on the job site at all times when personnel are working within or around the excavation. This is necessary in order to monitor soil conditions, equipment and protection systems employed.
2. The estimated locations of utility installations, such as sewer, telephone, fuel, electric, water lines, or any other underground installation that reasonably may be expected to be encountered during excavation work, shall be determined prior to opening an excavation.
3. Adequate precautions shall be taken to protect employees working in excavations, against the hazards posed by water accumulation.
4. Employees shall be protected from excavated or other materials or equipment that could pose a hazard by falling or rolling into excavations. Protection shall be provided by placing and keeping such material or equipment at least two (2') feet from the edge of excavations.
5. A stairway, ladder, or ramp shall be used as a means of access or egress in trench excavations that are four (4') feet or more in depth. The ladder(s), stairway(s), or ramp shall be spaced so that no employee in the trench excavation is more than twenty five (25') feet from a means of egress. When ladder(s) are employed, the top of the ladder shall extend a minimum of three (3') feet above the ground and shall be properly secured.
6. When excavations are exposed to vehicular traffic, each employee shall wear a warning vest made with reflective material or highly visibility material. All personnel within the construction area shall wear a hard-hat at all times.
7. Employees shall not be permitted underneath loads handled by lifting or digging equipment. Employees shall be required to stand away from any vehicle being loaded or unloaded to avoid being struck by any spillage or falling materials.
8. In excavations where oxygen deficiency or gaseous conditions exist, or could be reasonably expected to exist, air in the excavation shall be tested.
9. Where oxygen deficiency (atmospheres containing less than 19.5 percent oxygen) exists, the area must be continuously ventilated until the oxygen levels are above 19.5 percent.
10. Where a gaseous condition exists, the area shall be ventilated until the flammable gas concentration is below 20 percent of the lower flammable limit.

11. Whenever oxygen deficiency or gaseous conditions exist or could reasonably exist, the area shall be monitored continuously to assure that employees are protected.
12. Where the stability of adjoining buildings, walls or other structures are endangered by excavation operations, support systems such as shoring, bracing, or underpinning shall be provided to ensure the stability of such structures for the protection of employees.
13. Sidewalks, pavement and appurtenant structures shall not be undermined unless a support system such as shoring is provided to protect employees from the possible collapse of such structures.



Always wait for the buried utilities to be marked before excavation begins. Believe it or not, this crew dug 9 feet deep before the Locator showed up and marked fiber optics in the same trench. Notice that the employees do not have hard hats, ladders, or any protective systems. Several major OSHA violations.

Personnel Protective Systems

Employees in excavations shall be protected from cave-ins by an adequate protective system, which shall be inspected by a competent person.

The use of protective systems is required for all excavations, in excess of five (5') feet, except when excavation is within stable rock.

Trench excavation less than five (5') feet in depth may not require the use of protective systems, unless there is evidence of a potential cave-in. The competent person shall determine the need for the use of protective systems when such conditions exist.

When sloping, benching or protective systems are required, refer to requirements in CFR 1926.652 (OSHA Construction Standards).

Whenever support systems, shield systems, or other protective systems are being used, a copy of the manufacturer's specifications, recommendations, and limitations sheet shall be in written form and maintained at the job site.



This poor soul is probably going to be a short timer here on earth. He is sitting on the sewer main in a bell shaped hole under a steel plate which cars are driving over. No protection at all. There was a ladder in the trench but was about 50 feet away. He wouldn't make it out of a cave-in unless he had wings.

Excavation Protection Systems

The three basic protective systems for excavations and trenches are sloping and benching systems, shoring, and shields. The protective systems shall have the capacity to resist without failure all loads that are intended or could reasonably be expected to be applied to or transmitted to the system. Every employee in an excavation shall be protected from cave-ins by an adequate protective system.

Exceptions to Using Protective System:

- Excavations are made entirely in stable rock.
- Excavations are less than 5 feet deep and declared safe by a competent person.

Sloping and Benching Systems

There are four options for sloping:

- Slope to the angle required by the standard for Type C, which is the most unstable soil type.
- The table provided in Appendix B of the standard may be used to determine the maximum allowable angle (after determining the soil type).
- Tabulated data prepared by a registered professional engineer can be utilized.
- A registered professional engineer can design a sloping plan for a specific job.

Sloping and benching systems for excavations five (5) to twenty (20) feet in depth must be constructed under the instruction of a designated competent person. Sloping and benching systems for excavations greater than twenty (20) feet must be designed and stamped by a registered professional engineer. Sloping and benching specifications can be found in Appendix B of the OSHA Standard (Subpart P).

Shoring Systems

Shoring is another protective system or support system. Shoring utilizes a framework of vertical members (uprights), horizontal members (whales), and cross braces to support the sides of the excavation to prevent a cave-in. Metal hydraulic, mechanical or timber shoring are common examples.



This is my favorite photograph of all. Here are two men in a 30 foot deep trench without any protection or ladders. They are lucky to have a rope. Please do not work in this dangerous environment.

The different examples of shoring are found in the OSHA Standard under these appendices:

APPENDIX C - Timber Shoring for Trenches

APPENDIX D - Aluminum Hydraulic Shoring for Trenches

APPENDIX E - Alternatives to Timber Shoring

Shield Systems (Trench Boxes)

Shielding is the third method of providing a safe workplace. Unlike sloping and shoring, shielding does not prevent a cave-in. Shields are designed to withstand the soil forces caused by a cave-in and protect the employees inside the structure. Most shields consist of two flat, parallel metal walls that are held apart by metal cross braces.

Shielding design and construction is not covered in the OSHA Standards. Shields must be certified in design by a registered professional engineer and must have either a registration plate on the shield or registration papers from the manufacturer on file at the jobsite office. **ANY REPAIRS OR MODIFICATIONS MUST BE APPROVED BY THE MANUFACTURER.**

Safety Precautions for Shield Systems

- Shields must not have any lateral movement when installed.
- Employees will be protected from cave-ins when entering and exiting the shield (examples - ladder within the shield or a properly sloped ramp at the end).
- Employees are not allowed in the shield during installation, removal, or during any vertical movement.
- Shields can be 2 ft. above the bottom of an excavation if they are designed to resist loads at the full depth and if there are no indications of caving under or behind the shield.
- The shield must extend at least 18 inches above the point where proper sloping begins (the height of the shield must be greater than the depth of the excavation).
- The open end of the shield must be protected from the exposed excavation wall. The wall must be sloped, shored, or shielded. Engineer designed end plates can be mounted on the ends of the shield to prevent cave-ins.



Personal Protective Equipment

It is **OSHA** policy for you to wear a hard hat, safety glasses, and work boots on the jobsite. Because of the hazards involved with excavations, other personal protective equipment may be necessary, depending on the potential hazards present (examples-goggles, gloves, and respiratory equipment).

Excavation & Trenching Guidelines

This section outlines procedures and guidelines for the protection of employees working in and around excavations and trenches. This section requires compliance with OSHA Standards described in Subpart P (**CFR 1926.650**) for the construction industry.

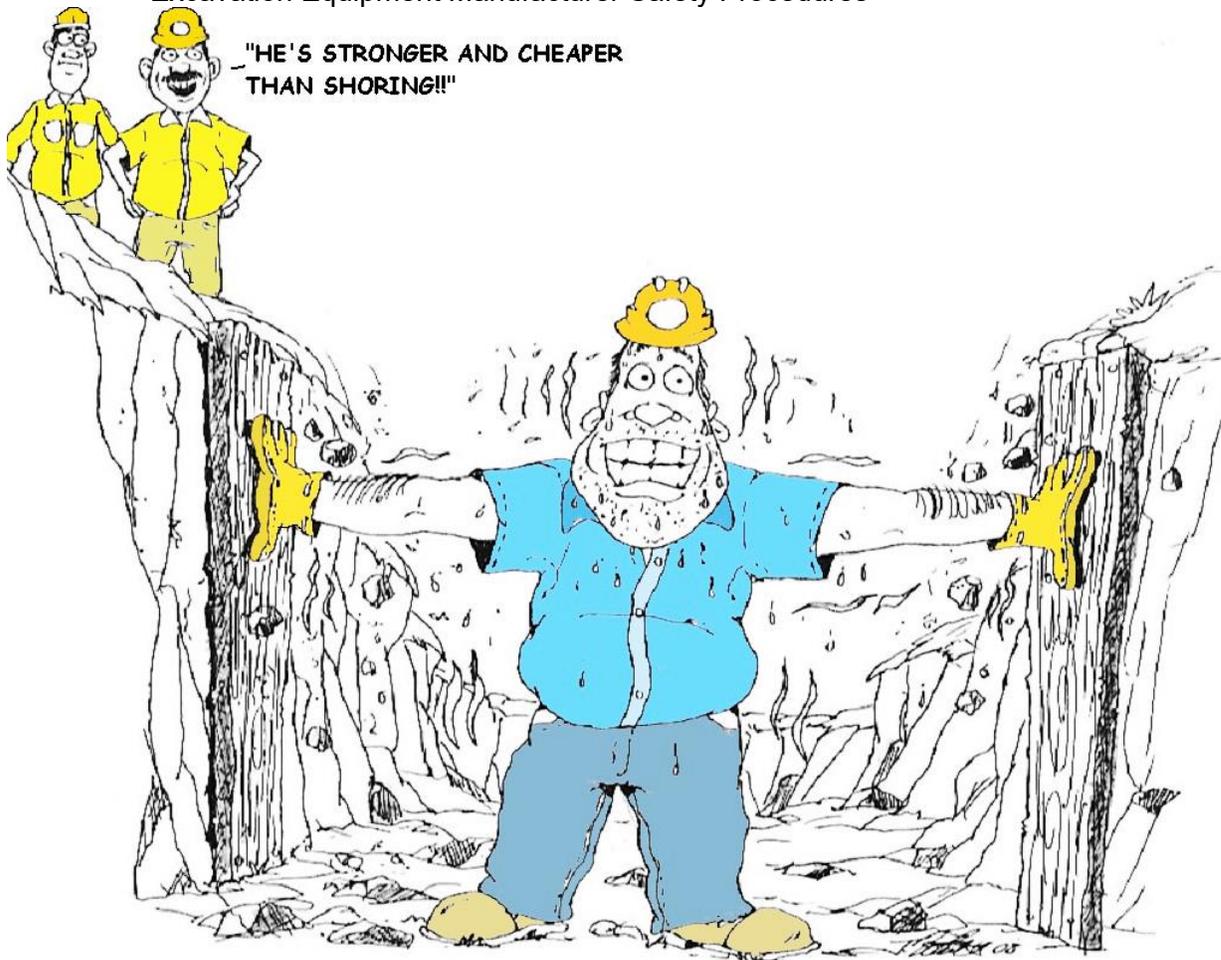
Safety compliance is mandatory to ensure employee protection when working in or around excavations.

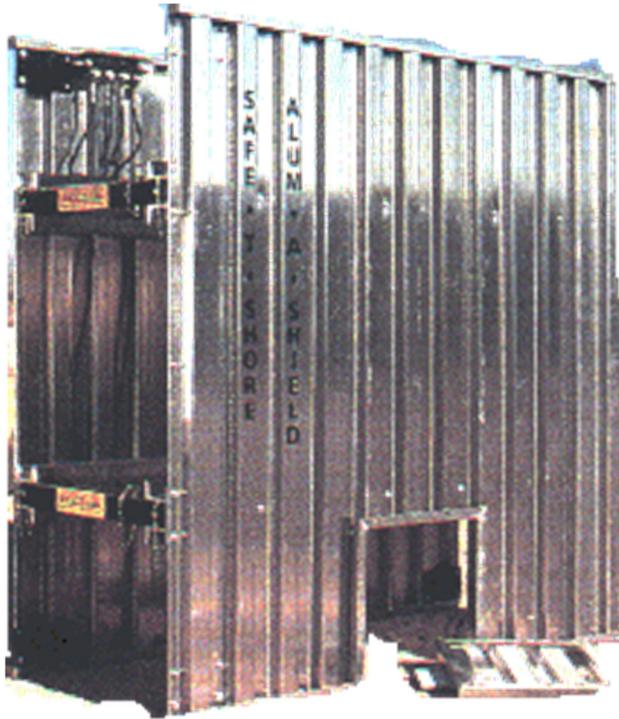
The competent person(s) must be trained in accordance with the OSHA Excavation Standard, and all other programs that may apply (examples Hazard Communication, Confined Space, and Respiratory Protection), and must demonstrate a thorough understanding and knowledge of the programs and the hazards associated.

All other employees working in and around the excavation must be trained in the recognition of hazards associated with trenching and excavating.

REFERENCES

- 29 CFR 1926.650, Subpart P - Excavations
- Excavation Equipment Manufacturer Safety Procedures





Trench Shields and Boxes



Hazards

One of the reasons OSHA requires a competent person on-site during excavation & trenching are the numerous potential hazardous that may be encountered or created.

Hazards include:

- Electrocution
- Gas Explosion
- Entrapment
- Struck by equipment
- Suffocation

Hazard Controls

Before any work is performed and before any employees enter the excavation, a number of items must be checked and insured:

- Before any excavation, underground installations must be determined. This can be accomplished by either contacting the local utility companies or the local "**one-call**" center for the area. All underground utility locations must be documented on the proper forms. All overhead hazards (**surface encumbrances**) that create a hazard to employees must be removed or supported to eliminate the hazard.
- If the excavation is to be over 20 feet deep, it must be designed by a registered professional engineer who is registered in the state where the work will be performed.
- Adequate protective systems will be utilized to protect employees. This can be accomplished through sloping, shoring, or shielding.
- The worksite must be analyzed in order to design adequate protection systems and prevent cave-ins. There must also be an excavation safety plan developed to protect employees.
- Workers must be supplied with, and wear, any personal protective equipment deemed necessary to assure their protection.
- All spoil piles will be stored a minimum of **two (2) feet** from the sides of the excavation. The spoil pile must not block the safe means of egress.
- If a trench or excavation is 4 feet or deeper, stairways, ramps, or ladders will be used as a safe means of access and egress. For trenches, the employee must not have to travel any more than 25 feet of lateral travel to reach the stairway, ramp, or ladder.
- No employee will work in an excavation where water is accumulating unless adequate measures are used to protect the employees.
- A competent person will inspect all excavations and trenches daily, prior to employee exposure or entry, and after any rainfall, soil change, or any other time needed during the shift. The competent person must take prompt measures to eliminate any and all hazards.
- Excavations and trenches 4 feet or deeper that have the potential for toxic substances or hazardous atmospheres will be tested at least daily. If the atmosphere is inadequate, protective systems will be utilized.
- If work is in or around traffic, employees must be supplied with and wear orange reflective vests. Signs and barricades must be utilized to ensure the safety of employees, vehicular traffic, and pedestrians.



Excavation Safety Plan

An excavation safety plan is required in written form. This plan is to be developed to the level necessary to insure complete compliance with the OSHA Excavation Safety Standard and state and local safety standards.

Excavation Safety Plan Factors:

- Utilization of the local one-call system.
- Determination of locations of all underground utilities.
- Consideration of confined space atmosphere potential.
- Proper soil protection systems and personal protective equipment and clothing.
- Determination of soil composition and classification.
- Determination of surface and subsurface water.
- Depth of excavation and length of time it will remain open.
- Proper adherence to all OSHA Standards, this excavation and trenching safety program, and any other coinciding safety programs.

1. **Warning system for mobile equipment, methods to help prevent vehicles and equipment from falling in the trench can be accomplished by providing:**

- A. Barricades.
- B. Hand or mechanical signals.
- C. Stop logs.
- D. Grade away from the excavation.

All equipment with an obstructed rear view is required to have a back-up alarm or an observer when backing {1926.601 (b) (4).}

2. **Hazardous atmospheres, you must limit all exposures to hazardous atmospheres.**

- A. Oxygen deficient is anything less than 19.5% oxygen. Symptoms will include dizziness, increased heart rate or may experience a buzzing in the ears.
- B. Normal is 21% oxygen.
- C. Oxygen enriched atmospheres increase flammability of combustible materials.
- D. Carbon monoxide causes oxygen starvation and can be fatal at a concentration of 1% for one minute. This is equal to 10,000 PPM. The Threshold Limit Value (TLV) is only 50 PPM.
- E. If there is a possibility that a hazardous atmosphere exists or could be reasonably expected to exist, test the atmosphere before the employee enters an excavation. Some areas of concern include; digging near gas lines, sewers, landfills and near areas of high traffic.
- F. Provide respirators or ventilation when needed. All personnel must be fit tested before wearing a respirator and all personnel must be training how to use ventilation.

The use of any respirator by employees will require a written respirator program form the employer {1926.103}.

- A. Ventilate trench if flammable gas exceeds 20% of the lower flammable limit.
- B. Test the atmosphere often--this will ensure that the trench remains safe.
- C. Perform regular maintenance on gas meters. Calibrate and change out filters regularly.

D. Never enter a hazardous atmosphere to rescue an employee unless you have been trained in rescue techniques and have proper rescue equipment. More than half the deaths occur while attempting a rescue.

3. Emergency rescue equipment must be available when a hazardous atmosphere exists or could be reasonably expected to exist.

- A. Respirator must be suitable for the exposure. An air supplied or self-contained breathing apparatus is preferable
- B. Harness and lifeline is required when an employee enters bellbottom piers and other deep confined spaces. The lifeline must be attended at all times.

**Employees entering confined spaces must be trained. {1926.21 (b) (6) I}
Specific requirements for welding in confined spaces {1926.352 (g) and 1926.653 (b)}.**

4. Protection from hazards associated with water accumulation is necessary to prevent cave-ins.

- A. Methods for controlling accumulated water vary with each situation.
- B. Employees are not permitted to work in trenches where water accumulation exists.
- C. Special support system or shield systems may be used to protect employees from cave-ins.
- D. Water removal equipment may be used and must be monitored by a competent person to prevent water accumulation.
- E. Safety harness and lifeline may be used to protect employees.
- F. Surface water must be diverted and controlled.
- G. Trench must be inspected after rain.

5. Stability of adjacent structures to protect employees from cave-ins.

- A. Support systems such as shoring, bracing, or underpinning must be used to support structures that may be unstable due to excavation operations.
- B. Excavation below the base or footing of a foundation or wall is not permitted unless:
 - i. **Support system is provided to ensure the stability of the structure.**
 - ii. **The excavation is in stable rock.**
 - iii. **A Registered Professional Engineer approves the operation.**
- C. Support systems must be provided for sidewalks, pavements and other structures that may be affected by the excavation operations.

6. Protection of employees from loose rock or soil.

- A. Employees must be protected from being struck by materials falling or rolling from the edge and the face of the trench.
- B. Spoils and equipment must be set back at least 2 feet from the edge of the trench and/or a retaining device must be installed.

7. Fall protection is required for walkways and bridges over trenches. Other fall protection may also be required.

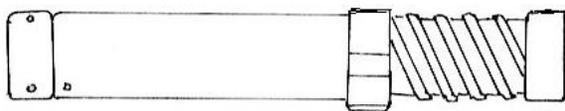
8. Remotely located excavations shall be backfilled, covered, or barricaded (for example wells, pits, shafts, etc.)

Inspections must be made:

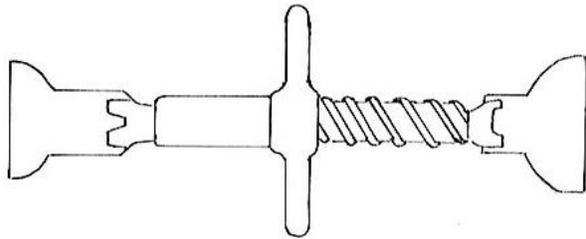
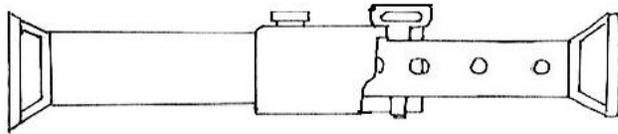
- A. Daily prior to starting work
- B. As needed throughout the shift by a competent person.
- C. After every rainstorm.
- D. After other hazard increasing occurrence (snowstorm, windstorm, thaw, earthquake, etc.).
- E. Inspect the trench for indications of possible cave-ins (fissures, tension cracks, sloughing, undercutting, water seepage, bulging at the bottom).
- F. Inspect adjacent areas (spoil piles, structures).
- G. To protective systems and their components (uprights, wales sheeting, shields hydraulics) before and after use.
- H. Check for indications of a hazardous or potentially hazardous atmosphere.
- I. Test the atmosphere if a hazard could reasonably be expected to exist.



Major OSHA Violation. Do not operate equipment in unprotected trenches. This guy is trying hard to get to Heaven before his time is up.



PNEUMATIC / HYDRAULIC JACKS

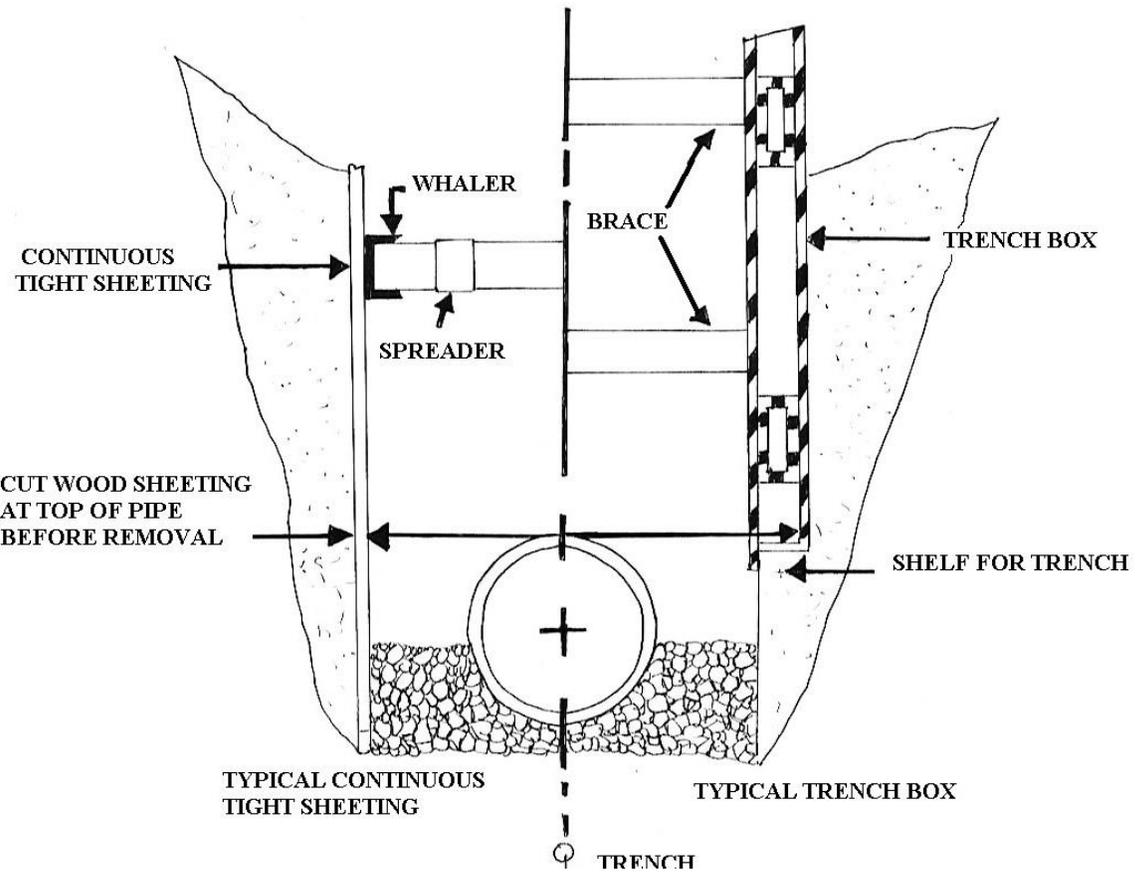
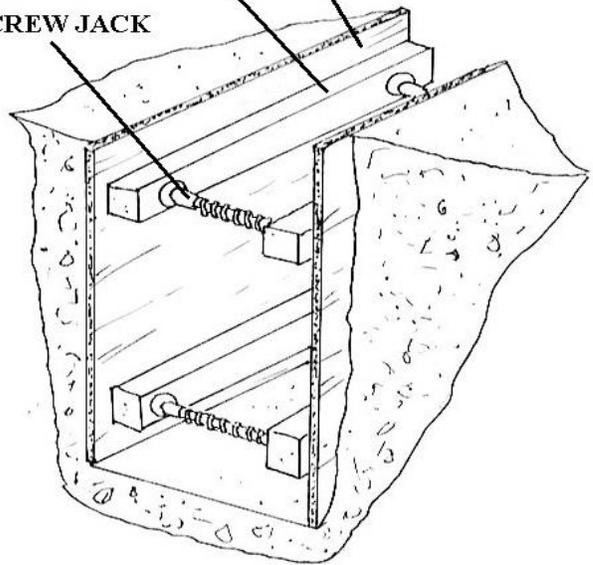


SCREW JACK

UPRIGHT SHEETING

WALE

SCREW JACK



Soil Classification and Identification

The OSHA Standards define soil classifications within the Simplified Soil Classification Systems, which consist of four categories: Stable rock, Type A, Type B, and Type C. Stability is greatest in stable rock and decreases through Type A and B to Type C, which is the least stable. Appendix A of the standard provides soil mechanics terms and types of field tests used to determine soil classifications. Stable rock is defined as natural solid mineral matter that can be excavated with vertical sides and remain intact while exposed.

Type A soil is defined as:

- Cohesive soils with an unconfined compressive strength of 1.5 tons per square foot (**TSF**) or greater.
- Cemented soils like caliche and hardpan are considered Type A.

Soil is NOT Type A if:

- It is fissured.
- The soil is subject to vibration from heavy traffic, pile driving or similar effects.
- The soil has been previously disturbed.
- The material is subject to other factors that would require it to be classified as a less stable material.
- The exclusions for Type A most generally eliminate it from most construction situations.

Type B soil is defined as:

- Cohesive soil with an unconfined compressive strength greater than .5 TSF, but less than 1.5 TSF.
- Granular cohesion-less soil including angular gravel, silt, silt loam, and sandy loam.
- The soil has been previously disturbed except that soil classified as Type C soil.
- Soil that meets the unconfined compressive strength requirements of Type A soil, but is fissured or subject to vibration.
- Dry rock that is unstable.

Type C soil is defined as:

- Cohesive soil with an unconfined compressive strength of .5 TSF or less.
- Granular soils including gravel, sand and loamy sand.
- Submerged soil or soil from which water is freely seeping.
- Submerged rock that is not stable.



Soil Test & Identification

The competent person will classify the soil type in accordance with the definitions in Appendix A based on at least one visual and one manual analysis. These tests should be run on freshly excavated samples from the excavation and are designed to determine stability based on a number of criteria: the cohesiveness, the presence of fissures, the presence and amount of water, the unconfined compressive strength, and the duration of exposure, undermining, and the presence of layering, prior excavation and vibration.

The cohesion tests are based on methods to determine the presence of clay. Clay, silt, and sand are size classifications, with clay being the smallest sized particles, silt intermediate and sand the largest.

Clay minerals exhibit good cohesion and plasticity (can be molded). Sand exhibits no elasticity and virtually no cohesion unless surface wetting is present. The degree of cohesiveness and plasticity depend on the amounts of all three types and water.

When examining the soil, three questions must be asked: Is the sample granular or cohesive? Is it fissured or non-fissured? What is the unconfined compressive strength measured in TSF?

The competent person will perform several tests of the excavation to obtain consistent, supporting data along its depth and length. The soil is subject to change several times within the scope of an excavation and the moisture content will vary with weather and job conditions. The competent person must also determine the level of protection based on what conditions exist at the time of the test, and allow for changing conditions.



Ribbon Soil Test

Sloping

MAXIMUM ALLOWABLE SLOPES

SOIL TYPE	SLOPE (H:V)	ANGLE(°)
Stable Rock	Vertical	90°
Type A	3/4 : 1	53°
Type B	1 : 1	45°
Type C	1/2 : 1	34°

MAXIMUM ALLOWABLE SLOPE means the steepest incline of an excavation face that is acceptable for the most favorable site conditions as protection against cave-ins and is expressed as the ratio of horizontal distance to vertical rise (H:V).

The tables and configurations within Appendix B may be used to a maximum depth of twenty (20') feet deep. Jobs more than twenty (20') feet in depth require the design of a sloping plan by a registered professional engineer (RPE). If configurations are used for depths less than 20 feet other than those found in Appendix B, they must also be designed by a registered professional engineer.

Shielding

The third method of providing a safe workplace in excavations is shielding. Shielding is different from shoring and sloping in that it does not prevent cave-ins. Instead, it protects the workers in the event of a cave-in. Its function is therefore somewhat similar to that of a bomb shelter.

Shields are simply devices that, when placed in an excavation, have sufficient structural strength to support the force of a cave-in should one occur.

Shields take a number of different shapes and sizes. Most shields consist of two flat, parallel metal walls which are held apart by metal cross braces which are placed at the ends of the "Box" to allow for the installation of pipe within its interior dimensions.



These boxes are used to greatest effect in what is known as "cut and cover" operations where a contractor excavates just enough trench to install the shield, then sets a joint of pipe, then excavates further, then pulls the shield forward to install another joint while the first is being backfilled.

This method is extremely cost effective in that it is fast, safe, requires minimum excavation and minimum open trench. It has become the preferred method of laying pipe in most instances.

While original shields were quite large, smaller shields have gained in popularity with public works maintenance crews and contractors working in shallow excavations because of their ease of use. Recently, round shields, made of corrugated metal have appeared. The sizes, shapes and possibilities for the applications of shields are endless. If they are to be used, however, several points must be borne in mind.

1. Shield construction is not covered by the standard. Users must rely on manufacturers' requirements. For this reason, it is critical that you know your supplier. Reputable manufacturers supply boxes designed by registered professional engineers, and the standard requires that they are certified for their applications. Do not make the mistake of having the neighborhood welder fabricate one. A user must know that their shield is appropriate for the situation.
2. Bent cross braces are not braces, they are hinges. Any bent or deformed structural member must be repaired or replaced according to the manufactures' guidelines.
3. The manufacturer must approve any modification to the shields.
4. Shields must be installed so as to prevent lateral movement in the event of a cave-in.
5. Shields may ride two feet above the bottom of an excavation, provided they are calculated to support the full depth of the excavation and there is no caving under or behind the shield.
6. Workers must enter and leave the shield in a protected manner, such as by ladder within the shield or a properly sloped ramp at the end.
7. Workers may not remain in the shield during its installation, removal or during vertical movement.
8. Do not forget about the open end of the shield if it exposes a wall of the excavation. The wall should be sloped, shored or shielded off to prevent a cave-in from the end.
9. If the excavation is deeper than the shield is tall, attached shields of the correct specifications may be used or the excavation may be sloped back to maximum allowable angle from a point 18 inches below the top of the shield.

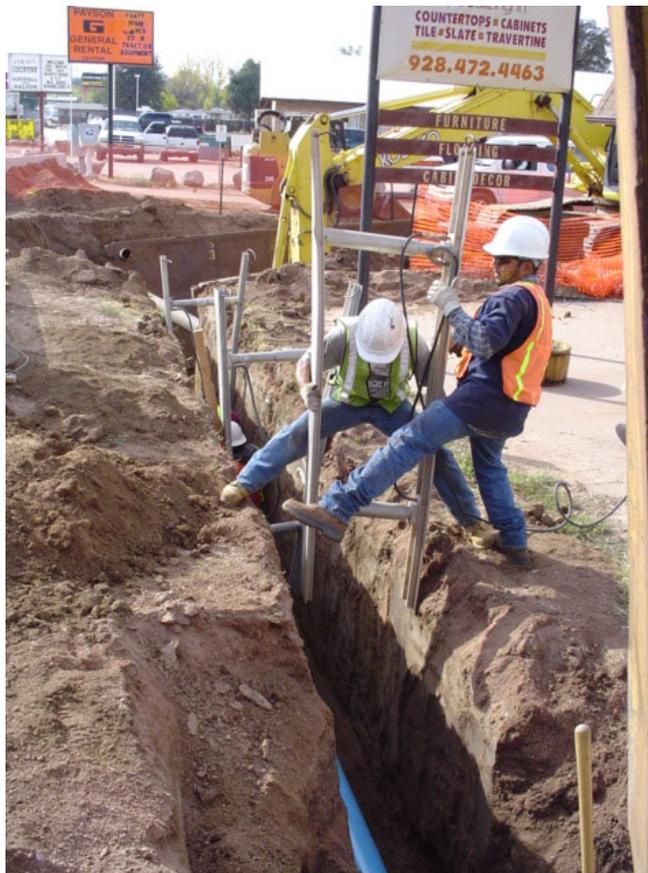


Complete Rule and further instructions are located in TLC's Competent Person Course.

Inspections

Daily inspection of excavations, the adjacent areas and protective systems shall be made by the competent person for evidence of a situation that could result in a cave-in, indications of failure of protective systems, hazardous atmospheres or other hazardous conditions.

- All inspections shall be conducted by the competent person prior to the start of work and as needed throughout the shift.
- Inspections will be made after every rainstorm or any other increasing hazard.
- All documented inspections will be kept on file in the jobsite safety files and forwarded to the Safety Director weekly.
- A copy of the **Daily Excavation Inspection** form is located at the end of this program. The competent person(s) must be trained in accordance with the OSHA Excavation Standard, and all other programs that may apply (examples Hazard Communication, Confined Space, and Respiratory Protection), and must demonstrate a thorough understanding and knowledge of the programs and the hazards associated. All other employees working in and around the excavation must be trained in the recognition of hazards associated with trenching and excavating.





Two unsafe excavation examples: Top, notice the man in a 6 foot deep trench with no ladder or shoring, and the placement of spoil. Bottom photograph, utilities are marked after the excavation has begun, no hard hats, no ladders, no protective system, incorrect spoil placement.



DAILY EXCAVATION CHECKLIST

Client		Date	
Project Name		Approx. Temp.	
Project Location		Approx. Wind Dir.	
Job Number		Safety Rep	
Excavation Depth & Width		Soil Classification	
Protective System Used			
Activities In Excavation			
Competent Person			

Excavation > 4 feet deep? Yes No

NOTE: Trenches over 4 feet in depth are considered excavations. Any items marked **NO** on this form **MUST** be remediated prior to any employees entering the excavation.

YES	NO	N/A	DESCRIPTION
GENERAL			
			Employees protected from cave-ins & loose rock/soil that could roll into the excavation
			Spoils, materials & equipment set back at least 2 feet from the edge of the excavation.
			Engineering designs for sheeting &/or manufacturer's data on trench box capabilities on site
			Adequate signs posted and barricades provided
			Training (toolbox meeting) conducted w/ employees prior to entering excavation
UTILITIES			
			Utility company contacted & given 24 hours' notice &/or utilities already located & marked
			Overhead lines located, noted and reviewed with the operator
			Utility locations reviewed with the operator, & precautions taken to ensure contact does not occur
			Utilities crossing the excavation supported, and protected from falling materials
			Underground installations protected, supported or removed when excavation is open
WET CONDITIONS			
			Precautions taken to protect employees from water accumulation (continuous dewatering)
			Surface water or runoff diverted /controlled to prevent accumulation in the excavation
			Inspection made after every rainstorm or other hazard increasing occurrence

HAZARDOUS ATMOSPHERES			
			Air in the excavation tested for oxygen deficiency, combustibles, other contaminants
			Ventilation used in atmospheres that are oxygen rich/deficient &/or contains hazardous substances
			Ventilation provided to keep LEL below 10 %
			Emergency equipment available where hazardous atmospheres could or do exist
			Safety harness and lifeline used
			Supplied air necessary (if yes, contact safety department)
ENTRY & EXIT			
			Exit (i.e. ladder, sloped wall) no further than 25 feet from ANY employee
			Ladders secured and extend 3 feet above the edge of the trench
			Wood ramps constructed of uniform material thickness, cleated together @ the bottom
			Employees protected from cave-ins when entering or exiting the excavation

Explain how you have secured the site and made it safe to work inside (if possible)



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One-Call Center or Bluestakes

You are required to locate or call for proper buried utility locations before you dig or excavate. You will usually need a 48-hour notice before you excavate. Please check with your local one-call system.



Red spray marks means - Electricity, Yellow marks-Gas, Blue marks-Water



Orange spray marks means - Telephone & Fiber Optics

One Call Program

According to federal safety statistics, damage from unauthorized digging is the major cause of natural gas pipeline failures. To prevent excavation damage to all utilities, including pipelines, all 50 states have instituted "One Call" Programs. The programs provide telephone numbers for excavation contractors to call before excavation begins.

The one-call operator will notify a pipeline company of any planned excavation in the vicinity of its pipeline so that the company can flag the location of the pipeline and assign personnel to be present during excavation, if necessary.

In a related effort, a joint government-industry team has developed a public education program entitled "*Dig Safely*". The team involved representatives from the U.S. Department of Transportation, gas and liquid pipeline companies, distribution companies, excavators, the insurance industry, one-call systems and the telecommunications industry. This campaign provides information to the general public concerning underground utilities and the danger of unknowingly digging into buried lines and cables.

The program has posters, brochures, and other printed materials available for use by interested organizations. For more information, contact www.digsafely.com.



Telephone Cables, difficult to dig around. Not as difficult as electric lines.

One-Call Center, Underground Utilities

One Call Centers were established as a one-call notification system by underground facility owners to assist excavators with statutory requirements to notify underground facility owners prior to excavation. This damage prevention service is provided free of charge to any individual or company planning to excavate. By participating in the program and getting underground facilities located, you can:

- **Comply with Federal Law**
- **Avoid Injuries**
- **Prevent costly damages and interruptions of facility services**
- **Save time and money**
- **Avoid hazards**
- **Eliminate construction delays**

Color Codes for marking underground utility lines.

Red..... Electric Power
Yellow Gas-Oil- Product Lines
Orange..... Communication, Cable television
Blue..... Water systems, slurry pipelines
Green..... Sanitary sewer system
Pink..... Temporary survey markings

Example of a One-Call Center's Rules

Excavations: determining location of underground facilities; providing information; excavator marking; on-site representative; validity period of markings.

- A. A person shall not make or begin any excavation in any public street, alley, right-of-way dedicated to the public use or utility easement or on any express or implied private property utility easement without first determining whether underground facilities will be encountered, and if so where they are located from each and every public utility, municipal corporation or other person having the right to bury such underground facilities within the public street, alley, right-of-way or utility easement and taking measures for control of the facilities in a careful and prudent manner.
- B. Every public utility, municipal corporation or other person having the right to bury underground facilities shall file with the corporation commission the job title, address and telephone number of the person or persons from whom the necessary information may be obtained. Such person or persons shall be readily available during established business hours. The information on file shall also include the name, address and telephone number of each one-call notification center to which the owner of the facility belongs. Upon receipt of inquiry or notice from the excavator, the owner of the facility shall respond as promptly as practical, but in no event later than two days, by marking such facility with stakes, paint or in some customary manner. No person shall begin

excavating before the location and marking are complete or the excavator is notified that marking is unnecessary.

- C. On a timely request by the owner of a facility, the excavator shall mark the boundaries of the location requested to be excavated in accordance with a color code designated by the commission or by applicable custom or standard in the industry. A request under this subsection for excavator marking does not alter any other requirement of this section.
- D. In performing the marking required by subsection B of this section, the owner of an underground facility installed after December 31, 1988 in a public street, alley or right-of-way dedicated to public use, but not including any express or implied private property utility easement, shall locate the facility by referring to installation records of the facility and utilizing one of the following methods:
 - 1. Vertical line or facility markers.
 - 2. Locator strip or locator wire.
 - 3. Signs or permanent markers.
 - 4. Electronic or magnetic location or tracing techniques.
 - 5. Electronic or magnetic sensors or markers.
 - 6. Metal sensors or sensing techniques.
 - 7. Sonar techniques.
 - 8. Underground electrical or radio transmitters.
 - 9. Manual location techniques, including pot-holing.
 - 10. Surface extensions of underground facilities.
 - 11. Any other surface or subsurface location technique at least as accurate as the other marking methods in this subsection not prohibited by the commission or by federal or state law.
- E. For an underground facility other than one installed after December 31, 1988, in a public street, alley or right-of-way dedicated to public use, in performing the marking required by subsection B of this section, the owner may refer to installation or other records relating to the facility to assist in locating the facility and shall locate the facility utilizing one of the methods listed under subsection D of this section.

If an underground facility owner is unable to complete the location and marking within the time period provided by subsection B of this section, the facility owner shall satisfy the requirements of this section by proving prompt notice of these facts to the excavator.

Assigning one or more representatives to be present on the excavation site at all pertinent times as requested by the excavator to provide facility location services until the facilities have been located and marked.

The underground facility owner shall bear all of its costs associated with assigning representatives. If representatives are assigned under this subsection, the excavator is not responsible or liable for damage or repair of the owner's underground facility while acting under the direction of an assigned representative of the owner, unless the damage or need for repair was caused by the excavator's negligence.

Natural Gas Safety

That familiar blue flame that plays such an important role in our lives should, like other sources of energy, be treated with respect. Following a few simple guidelines can help ensure that you can safely enjoy all the benefits natural gas has to offer.

Natural gas is colorless and invisible. When it burns it should appear as a clear, blue flame. Because natural gas has no odor, a special chemical called mercaptan is added to make it easy to detect gas leaks from pipes or appliances. This odor is commonly described as a rotten-egg smell.

Natural gas is clean-burning. When burned completely, it produces only water vapor and carbon dioxide, just as you do when you breathe. Natural gas is such a safe and dependable fuel that it's easy to take for granted. But please, never take safety for granted. As with any source of energy, you should follow certain safety measures when using natural gas.

When it's taken from the ground, natural gas is tasteless, colorless and odorless. To make it easier to detect, a harmless but strong-smelling odorant is added, Ethyl Mercaptan. If you ever smell this "**rotten egg-like**" odor, it may mean there is a gas leak.

WHAT TO DO IF YOU SMELL GAS:

- Do not smoke. Do not use lighters or matches.
- Do not turn on/off any switches or appliances.
- Our personnel are available 24 hours a day to respond to any emergency call.

Carbon Monoxide

Carbon monoxide is produced when burning any fuel incompletely, such as charcoal, gasoline or wood. Carbon monoxide is highly poisonous and it has no odor, taste or color. If natural gas equipment is not maintained, adjusted and operated properly, it could produce carbon monoxide.

Your natural gas appliances should produce a clear, steady blue flame. If your gas appliances exhibit an unusual behavior or produce a yellowish-color flame, that may be a warning sign that your appliance is producing carbon monoxide.

A licensed professional should inspect appliances annually to insure safe operation. An inspection will accomplish the following:

- Make sure the appliance is installed properly and that it is in good working condition.
- Ensure that there is enough fresh air circulating for the fuel to burn properly.
- Check that vents are in good condition and are not blocked with debris.

Other helpful tips:

- The area surrounding your gas appliances should be clear from clutter or trash.
- Carbon monoxide detectors may be helpful in your home or business. But remember, a carbon monoxide detector should never be substituted for using equipment safely - which includes having your heating and cooking equipment inspected once a year by a trained professional.



OSHA's General Industry Regulation, §1910.146 Permit-required confined spaces, contains requirements for practices and procedures to protect employees in general industry from the hazards of entry into permit-required confined spaces. This regulation does not apply to construction.

OSHA's Construction Safety and Health Regulations Part 1926 do not contain a permit-required confined space regulation. Subpart C, §1926.21 Safety training and education specifies training for personnel who are required to enter confined spaces and defines a "*confined or enclosed space*."

Lockout - Tagout Training Sub-Section (LOTO) Lockout and Tagout

Purpose

Control of Hazardous energy is the purpose of the Lockout- Tagout Policy. This policy establishes the requirements for isolation of both kinetic and potential electrical, chemical, thermal, hydraulic and pneumatic and gravitational energy prior to equipment repair, adjustment or removal. The Lockout -Tagout Electrical Safety Policy is part of your overall safety program. If you do not understand this policy, it's your responsibly to ask your supervisor to have this policy explained to you.

Reference: OSHA Standard 29 CFR 1910. 147, the control of hazardous energy.

Definitions

Authorized (Qualified) Employees are the only ones certified to lock and tag-out equipment or machinery. Whether an employee is considered to be qualified will depend upon various circumstances in the workplace. It is likely for an individual to be considered "qualified" with regard to certain equipment in the workplace, but "*unqualified*" as to other equipment.

An employee who is undergoing on-the-job training and in the course of such training, has demonstrated an ability to perform duties safely at his or her level of training and who is under the direct supervision of a qualified person, is considered to be "qualified" for the performance of those duties.

Affected Employees are those employees who operate machinery or equipment upon which lockout or tagging out is required under this program. Training of these individuals will be less stringent in that it will include the purpose and use of the lockout procedures.

Other Employees are identified as those that do not fall into the authorized, affected or qualified employee category. Essentially, it will include all other employees. These employees will be provided instruction in what the program is and not to touch any machine or equipment when they see that it has been locked or tagged out.

Training

Authorized Employees Training Example

All maintenance employees and Department Supervisors will be trained to use the Lock and Tagout Procedures. The training will be conducted by the Supervisor or Safety Coordinator at time of initial hire. Retraining shall be held at least annually. The training will consist of the following:

- Review of General Procedures.
- Review of Specific Procedures for machinery, equipment and processes.
- Location and use of Specific Procedures.
- Procedures when questions arise.



Affected Employee Training

- Only trained and authorized employees will repair, replace or adjust machinery, equipment or processes.
- Affected employees may not remove Locks, locking devices or tags from machinery, equipment or circuits.
- Purpose and use of the lockout procedures.



Other Employee Training

- Only trained and authorized employees will repair, replace or adjust machinery or Equipment.
- Other employees may not remove Locks, locking devices or tags from machinery, equipment or circuits.

Preparation for Lock and Tagout Procedures *Example*

A Lockout - Tagout survey will be conducted to locate and identify all energy sources to verify which switches or valves supply energy to machinery and equipment. Dual or redundant controls will need to be removed.

A Tagout Schedule will be developed for each piece of equipment and machinery. This schedule describes the energy sources, location of disconnects, type of disconnect, special hazards and special safety procedures. The schedule will be reviewed each time to ensure employees properly lock and tag out equipment and machinery.

If a Tagout Schedule does not exist for a particular piece of equipment, machinery and process, one must be developed prior to conducting a Lockout - Tagout. As repairs and/or renovations of existing electrical systems are made, standardized controls will be used. It is your departmental supervisor's responsibility to ensure that a schedule is made.

Routine Maintenance & Machine Adjustments

Lock and Tag out procedures are not required if equipment must be operating for proper adjustment. This rare exception may be used only by trained and authorized employees when specific procedures have been developed to safely avoid hazards with proper training. All consideration shall be made to prevent the need for an employee to break the plane of a normally guarded area of the equipment by use of tools and other devices.

Standard Operating Procedure (SOP): General Lock and Tag out Procedures

Before working on, repairing, adjusting or replacing machinery and equipment, the following procedures will be utilized to place the machinery and equipment in a neutral or zero mechanical state.

Preparation for Shutdown *Example*

Before authorized or affected employees turn off a machine or piece of equipment, the authorized employee will have knowledge of the type and magnitude of the energy, the hazards of the energy to be controlled, and the means to control the energy. Notify all affected employees that the machinery, equipment or process will be out of service.

Machine or Equipment Shutdown.

The machine or equipment will be turned off or shut down using the specific procedures for that specific machine. An orderly shutdown will be utilized to avoid any additional or increased hazards to employees as a result of equipment de-energization.

If the machinery, equipment or process is in operation, follow normal stopping procedures (depress stop button, open toggle switch, etc.). Move switch or panel arms to "Off" or "Open" positions and close all valves or other energy isolating devices so that the energy source(s) is disconnected or isolated from the machinery or equipment.

Machine or Equipment Isolation.

All energy control devices that are needed to control the energy to the machine or equipment will be physically located and operated in such a manner as to isolate the machine or equipment from the energy source.

Lockout or Tagout Device Application.

Lockout or tagout devices will be affixed to energy isolating devices by authorized employees.

Lockout devices will be affixed in a manner that will hold the energy isolating devices from the "safe" or "off" position.

Where tagout devices are used, they will be affixed in such a manner that will clearly state that the operation or the movement of energy isolating devices from the "safe" or "off" positions is prohibited.

The tagout devices will be attached to the same point a lock would be attached. If the tag cannot be affixed at that point, the tag will be located as close as possible to the device in a position that will be immediately obvious to anyone attempting to operate the device.

Lock and tag out all energy devices by use of hasps, chains and valve covers with assigned individual locks.

Stored Energy

Following the application of the lockout or tagout devices to the energy isolating devices, all potential or residual energy will be relieved, disconnected, restrained, and otherwise rendered safe.

Where the re-accumulation of stored energy to a hazardous energy level is possible, verification of isolation will be continued until the maintenance or servicing is complete.

Release stored energy (capacitors, springs, elevated members, rotating fly wheels, and hydraulic/air/gas/steam systems) must be relieved or restrained by grounding, repositioning, blocking and/or bleeding the system.

Verification of Isolation

Prior to starting work on machines or equipment that have been locked or tagged out, the authorized employees will verify that isolation or de-energization of the machine or equipment have been accomplished.

After assuring that no employee will be placed in danger, test all lock and tag outs by following the normal start up procedures (depress start button, etc.).

Caution: After Test, place controls in neutral position.

Extended Lockout - Tagout

Should the shift change before the machinery or equipment can be restored to service, the lock and tag out must remain. If the task is reassigned to the next shift, those employees must lock and tag out before the previous shift may remove their lock and tag.

SOP: Release from LOCKOUT/TAGOUT *Example*

Before lockout or tagout devices are removed and the energy restored to the machine or equipment, the following actions will be taken:

1. The work area will be thoroughly inspected to ensure that nonessential items have been removed and that machine or equipment components are operational.
2. The work area will be checked to ensure that all employees have been safely positioned or removed. Before the lockout or tagout devices are removed, the affected employees will be notified that the lockout or tagout devices are being removed.
3. Each lockout or tagout device will be removed from each energy-isolating device by the employee who applied the device.

SOP: LOTO Procedure for Electrical Plug-Type Equipment *Example*

This procedure covers all Electrical Plug-Type Equipment such as battery chargers, some product pumps, office equipment, powered hand tools, powered bench tools, lathes, fans, etc.

When working on, repairing, or adjusting the above equipment, the following procedures must be utilized to prevent accidental or sudden startup:

1. Unplug electrical equipment from wall socket or in-line socket.
2. Attach "**Do Not Operate**" Tag and Plug Box & Lock on end of power cord.
An exception is granted to not lock & tag the plug if the cord & plug remain in the exclusive control of the Employee working on, adjusting or inspecting the equipment.
3. Test equipment to assure power source has been removed by depressing the "Start" or "On" Switch.
4. Perform required operations.
5. Replace all guards removed.
6. Remove Lock & Plug Box and Tag.
7. Inspect power cord and socket before plugging equipment into power source. Any defects must be repaired before placing the equipment back in service.

NOTE: Occasionally used equipment may be unplugged from power source when not in use.

SOP: LOTO Procedures Involving More Than One Employee

In the preceding SOPs, if more than one employee is assigned to a task requiring a lock and tag out, each must place his/her own lock and tag on the energy isolating device(s).

SOP: Management Removal of Lock and Tag Out

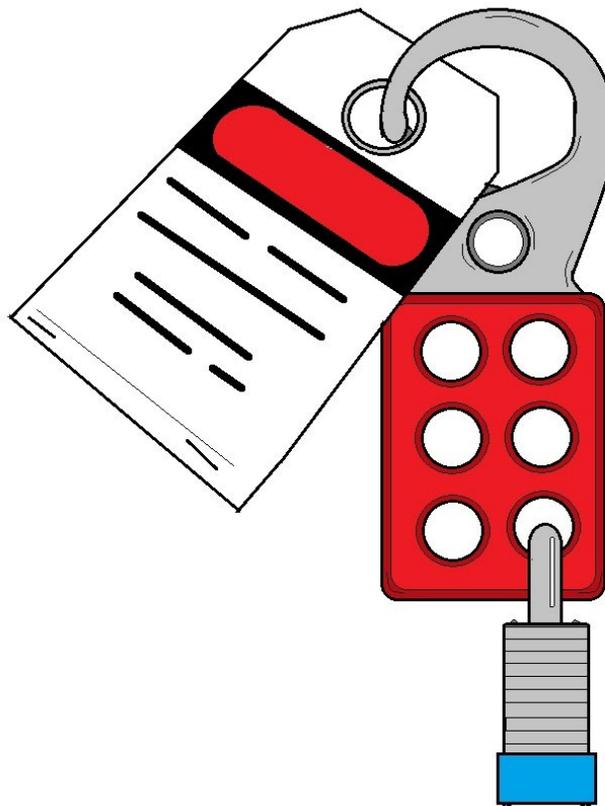
Only the employee that locks and tags out machinery, equipment or processes may remove his/her lock and tag. However, the employee should leave the facility before removing his/her lock and tag, and the supervisor may remove the lock and tag. The supervisor must be assured that all tools have been removed, all guards have been replaced and all employees are free from any hazard before the lock and tag are removed and the machinery, equipment or process are returned to service. Notification of the employee who placed the lock is required prior to lock removal.

Contractors

Contractors working on our property and equipment must use this Lockout-Tagout procedure while servicing or maintaining equipment, machinery or processes.

Lockout - Tag out Safety Equipment

The employer will provide all Lockout-Tagout safety equipment and training to any employee that may need or work with electricity or powered equipment. Your supervisor will be able to provide any assistance or equipment.



**USE LOCK-OUT TAGS, LOCKS AND HASPS TO DENERGIZE EQUIPMENT TO
AVOID ACCIDENTAL START-UP AND PREVENT INJURIES OR DEATH**

Ladder Safety Sub-Section

Purpose

Ladders present unique opportunities for unsafe acts and unsafe conditions. Employees who use ladders must be trained in proper selection, inspection, use and storage. Improper use of ladders has caused a large percentage of accidents in the workplace. Use caution on ladders.

OSHA reference: (29 CFR 1910.25, 1910.26, and 1910.27).

Ladder Hazards

Falls from ladders can result in broken bones and death. Ladder safety is a lifesaving program at our company.

Hazards include:

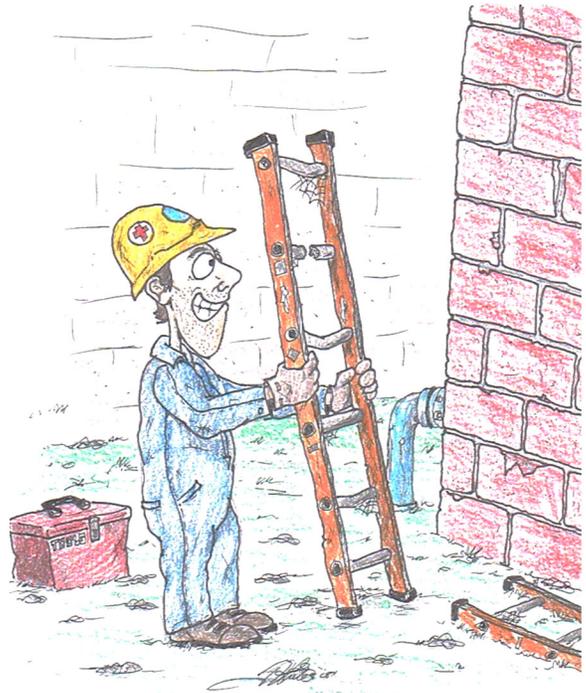
- Ladders with missing or broken parts.
- Using a ladder with too low a weight rating.
- Using a ladder that is too short for the intended purpose.
- Using metal ladders near electrical wires.
- Using ladders as a working platform.
- Objects falling from ladders.

Ladder Inspection

Inspect ladders before each use.

- All rungs and steps are free of oil, grease, dirt, etc.
- All fittings are tight.
- Spreaders or other locking devices are in place.
- Non-skid safety feet are in place.
- No structural defects, all support braces intact.

Do not use broken ladders. Most ladders cannot be repaired to manufacturer specifications. Throw away all broken ladders.



Ladder Storage

Store ladders on sturdy hooks in areas where they cannot be damaged. Store to prevent warping or sagging. Do not hang anything on ladders that are in a stored condition.

Ladder Ratings & Limits

Ladder weight ratings

- I-A 300 pounds (heavy duty)
- I 250 pounds (heavy duty)
- II 225 pounds (medium duty)
- III 200 pounds (light duty).

Limits on ladder length.

- A stepladder should be no more than 20 feet high.
- A one-section ladder should be no more than 30 feet.
- An extension ladder can go to 60 feet, but the sections must overlap.

Ladder Setup

The following procedure must be followed to prevent ladder accidents:

- ✓ Place ladder on a clean, slip-free level surface.
- ✓ Extend the ladder to have about 4 feet above the top support or work area.
- ✓ Anchor the top and bottom of the ladder.
- ✓ Place the ladder base 1/4 the height of the ladder from the wall when using an extension ladder.
- ✓ Never allow more than one person on a ladder.
- ✓ Use carriers and tool belts to carry objects up a ladder.
- ✓ Do not lean out from the ladder in any direction.
- ✓ If you have a fear of heights - don't climb a ladder.
- ✓ Do not allow others to work under a ladder in use.

Ladder Maintenance

- ✓ Keep ladders clean.
- ✓ Never replace broken parts unless provided by the original manufacturer.
- ✓ Do not attempt to repair broken side rails.



We have a ladder in an excavation, but no protective system in place or hard hat.

SAFETY SECTION GLOSSARY

Barricades: Visible warning barriers that keep vehicles and pedestrians from entering a construction site.

Braces: Devices that hold or fasten two or more parts together or in place. Braces are diagonal or horizontal. They may be made of wood or metal.

Bracing System: A system of braces which applies pressure against trench walls to stabilize them. A bracing system is part of a trench shoring system used to prevent trench walls from collapsing.

Benching: A method of cutting back the sides of a trench into horizontal steps to prevent cave-ins.

Bulge: An outward swelling in the soil of a trench; may be a warning sign of trench failure.

Buried Structures: Manholes, junction boxes or catch basins beneath the ground or any other installations that may be encountered during trenching.

Clay: Fine-grained natural soil that is plastic when moist and hard and brittle when dry. Clay is made up of particles smaller than .0002 millimeters.

Clumps: Heavy lumps or thick groupings of soil.

Cohesion: The relative ability to clump together, the force holding two like substances together.

Cohesive: When a soil has grains that hold together and clump well.

Competent Person: One who is capable of identifying existing, and predictable hazards in the surroundings, or working conditions which are unsanitary, hazardous or dangerous to employees. They have the authorization to take prompt corrective measures to eliminate hazards. The Competent Person is trained and knowledgeable about soil analysis and the use of protective systems.

Confined Space: Has limited or restricted means of entry or exit, is large enough for an employee to enter and perform assigned work, and is not designed for continuous occupancy by the employee. These spaces may include, but are not limited to, underground vaults, tanks, storage bins, pits, and diked areas, vessels, and silos.

Diversion Ditches: A ditch cut around the work site to keep water from entering the trench.

Drainage System: Pumps, pipe or channel used to drain off rain or groundwater from inside the trench.

Excavation: Any man-made cut, cavity trench or depression in an earth surface, formed by earth removal.

Fissure: A long narrow opening or crack in the rock or soil. Fissures are often a sign of trench wall failure.

Grain: Particles that once were large rocks, but have been broken down through time and the effects of weathering. The size of the grain of a soil determines the stability and cohesiveness of a soil. The larger the grain is, the more unstable the soil is.

Gravel: A loose mixture of pebbles and rock fragments, which is coarser than sand.

Hardpan: A layer of hard subsoil or clay that does not allow water in. Hardpan is classified as a Type A soil.

Heaving: The swelling of a soil.

Jacks: Jacks are braces or supports within a shoring system. They are placed against beams to resist the pressure of the earth.

Loamy Sand: Soil composed of a mixture of sand, clay and silt, with more sand grains than clay or silt. It is classified as a Type C soil.

Manufacturer's Tabulated Data: Tables and charts approved by a registered professional engineer and used to design and construct a protective system.

Permit Required Confined Space: Meets the definition of a confined space and has one or more of these characteristics: (1) contains or has potential to contain a hazardous atmosphere, (2) contains a material that has the potential for engulfing an entrant, (3) has an internal configuration that might cause an entrant to be trapped or asphyxiated by inwardly converging walls or by a floor that slopes downward and tapers to a smaller cross section, and/or (4) contains any other recognized serious safety or health hazards.

Personal Protective Equipment: Safety goggles and glasses, reflective clothing, work gloves, hard hat, safety shoes, rubber boots, earplugs or protectors, face shield and face mask or respirator.

Registered Professional Engineer: A person who is registered as a professional engineer in the state where the work is to be performed.

Sand: A type C soil with small, loose grains of disintegrated rock.

Sandy Loam: Granular soil with enough silt and clay to make it slightly cohesive

Saturation: The process of a soil being filled to capacity with moisture.

Shear: A phenomenon which happens when a trench wall is subjected to stress. Fissured cracks widen until a portion of the trench wall breaks off and slides into the trench.

Sheeting: Durable sheets of metal or wood, which are held firmly against a trench wall to prevent it from caving-in. Sheeting is a component of a trench shoring system.

Shielding: A device which provides adequate protection from falling or collapsing earth loads. The trench box is a common form of shielding.

Shoring: Main method of stabilizing and supporting a trench wall to prevent cave-ins. It consists of uprights, stingers and braces.

Silt: A soil which contains fine particles and is very smooth.

Silty Clay: A plastic soil that will appear rough or broken when rubbed over the thumb and finger.

Sloping: The process of cutting back the sides of a trench to avoid a cave-in.

Sloughing: When loose soil begins to run in from the lower part of the wall into the excavation. It is the first step to a wall collapse.

Soil Type: A system of classifying soils and rock deposits. Soil must be classified by a qualified person as: Stable rock, Type-A, Type-B, Type-C.

Spall: When a soil begins to crack or flake due to pressure, or from moisture from within the trench.

Spoil Pile/Spoilage: Rock waste, banks and dumps from the excavation.

Supports: Part of a shoring system which helps to bear the weight of braces and other parts of the shoring system.

Trench Box: A prefabricated moveable box usually constructed of metal plates welded to a heavy steel frame. The box is moved along as work progresses. It is able to withstand the forces imposed on it by a cave-in and thereby protects trench workers.

Type-A Soil: The most stable and cohesive type of soil while working at a trench site. Examples are clay, silty clay and hardpan.

Type-B Soil: Type-B soil is next to the most stable soil. Silt, silt loam, sandy loam, medium clay and unstable rock would be good examples of Type-B soils.

Type-C Soil: The least stable type of soil. Examples of Type-C soils are gravel, loamy sand, soft clay, submerged silt and heavy unstable rock.

Unconfined Compressive Strength: Through a variety of tests, a soil's strength is found. The unconfined compressive strength is the soil's measure of bearing capacity and shearing resistance. Measured as the amount of weight per square foot needed to collapse a soil sample.

Uprights: Vertical members of a trench shoring system placed in contact with the earth. These members usually are not placed in direct contact with one another.

Vibration: When a soil or excavation site trembles and shakes rapidly due to forces such as loud noises or heavy equipment or traffic.

Voids: Voids are empty spaces between particles of rocks.

Wales: Wales are parts of a shoring system. They are positioned horizontally and help to brace vertical beams and supports. Wales can be fastened to studs with nails, clips or brackets.

Wall Stability: The relative strength and capacity of walls of a trench.



Provide at least one attendant outside the permit space into which entry is authorized for the duration of entry operations;

NOTE: Attendants may be assigned to monitor more than one permit space provided the duties described in paragraph (i) of this section can be effectively performed for each permit space that is monitored. Likewise, attendants may be stationed at any location outside the permit space to be monitored as long as the duties described in paragraph (i) of this section can be effectively performed for each permit space that is monitored.

Post Quiz

1. A competent person is one who is capable of _____ existing hazards in the surroundings or working conditions which are unsanitary, hazardous, or dangerous to employees; and who has authorization to take prompt corrective measures to eliminate them.
2. In order to be a "Competent Person" for the purpose of this standard, one must have specific training in and be _____ about soils analysis, the use of protective systems and the requirements of 29 CFR Part 1926.650-652 Subpart P.

Competent Person Duties

3. _____ daily inspections of the protective equipment, trench conditions, safety equipment and adjacent areas.
4. _____ shall be made prior to the start of work and as needed throughout the shift.
5. _____ shall be made after every rainstorm or other hazard occurrence.
6. _____ of emergency contact methods, telephone or radio dispatch.
7. _____ the appropriate protection system to be used.
8. _____ on-site records of inspections and protective systems used.
9. _____ current First Aid and CPR certifications. Maintain current confined space certification training.
10. During excavation work, a competent person shall be on the job site at all times when personnel are working within or around the excavation. This is necessary in order to _____ soil conditions, equipment and protection systems employed.
11. The estimated locations of utility installations, such as sewer, telephone, fuel, electric, water lines, or any other underground installation that reasonably may be expected to be encountered during excavation work, shall be _____ prior to opening an excavation.

12. Adequate _____ shall be taken to protect employees working in excavations, against the hazards posed by water accumulation.

13. _____ shall be protected from excavated or other materials, or equipment, that could pose a hazard by falling or rolling into excavations.

14. Protection shall be provided by placing and keeping such material or equipment at least two (2') feet from the edge of _____.

15. A stairway, ladder, or ramp shall be used as a means of _____ in trench excavations that are four (4') feet or more in depth.

16. The ladder(s), stairway(s), or ramp shall be spaced so that no employee in the trench excavation is more than twenty (25') feet from a _____.

17. When ladder(s) are employed, the top of the ladder shall extend a minimum of three (3') feet above the ground and shall be _____.

18. When _____ are exposed to vehicular traffic, each employee shall wear a warning vest made with reflective material or high visibility material.

Excavation Chapter Post Quiz Answers

1. Identifying, 2. Knowledgeable, 3. Performs, 4. Inspection(s) or Inspect, 5. Inspection(s) or Inspect, 6. Knowledge, 7. Determine(s), 8. Maintain(s), 9. Maintain(s), 10. Monitor, 11. Determine(d), 12. Precautions, 13. Employees, 14. Excavation(s), 15. Access or egress, 16. Means of egress, 17. Properly secured, 18. Excavation(s)

Math Conversion Factors

1 PSI = 2.31 Feet of Water
 1 Foot of Water = .433 PSI
 1.13 Feet of Water = 1 Inch of Mercury
 454 Grams = 1 Pound
 2.54 CM = Inch
 1 Gallon of Water = 8.34 Pounds
 1 mg/L = 1 PPM
 17.1 mg/L = 1 Grain/Gallon
 1% = 10,000 mg/L
 694 Gallons per Minute = MGD
 1.55 Cubic Feet per Second = 1 MGD
 60 Seconds = 1 Minute
 1440 Minutes = 1 Day
 .746 kW = 1 Horsepower

LENGTH

12 Inches = 1 Foot
 3 Feet = 1 Yard
 5280 Feet = 1 Mile

AREA

144 Square Inches = 1 Square Foot
 43,560 Square Feet = 1 Acre

VOLUME

1000 Milliliters = 1 Liter
 3.785 Liters = 1 Gallon
 231 Cubic Inches = 1 Gallon
 7.48 Gallons = 1 Cubic Foot of water
 62.38 Pounds = 1 Cubic Foot of water

Dimensions

SQUARE: Area (sq.ft.) = Length X Width
 Volume (cu.ft.) = Length (ft) X Width (ft) X Height (ft)

CIRCLE: Area (sq.ft.) = 3.14 X Radius (ft) X Radius (ft)

CYLINDER: Volume (Cu. ft) = 3.14 X Radius (ft) X Radius (ft) X Depth (ft)

PIPE VOLUME: .785 X Diameter² X Length = ? To obtain gallons multiply by 7.48

SPHERE: $\frac{(3.14) (\text{Diameter})^3}{(6)}$ Circumference = 3.14 X Diameter

General Conversions

Flowrate

Multiply	→	to get
to get	←	Divide
cc/min	1	mL/min
cfm (ft ³ /min)	28.31	L/min
cfm (ft ³ /min)	1.699	m ³ /hr
cfh (ft ³ /hr)	472	mL/min
cfh (ft ³ /hr)	0.125	GPM
GPH	63.1	mL/min
GPH	0.134	cfh
GPM	0.227	m ³ /hr
GPM	3.785	L/min
oz/min	29.57	mL/min

POUNDS PER DAY = Concentration (mg/L) X Flow (MG) X 8.34

A.K.A. Solids Applied Formula = Flow X Dose X 8.34

$$\text{PERCENT EFFICIENCY} = \frac{\text{In} - \text{Out}}{\text{In}} \times 100$$

$$\begin{aligned} \text{TEMPERATURE: } \quad {}^{\circ}\text{F} &= ({}^{\circ}\text{C} \times 9/5) + 32 & 9/5 &= 1.8 \\ {}^{\circ}\text{C} &= ({}^{\circ}\text{F} - 32) \times 5/9 & 5/9 &= .555 \end{aligned}$$

$$\text{CONCENTRATION: } \text{Conc. (A)} \times \text{Volume (A)} = \text{Conc. (B)} \times \text{Volume (B)}$$

$$\text{FLOW RATE (Q): } Q = A \times V \text{ (Quantity = Area X Velocity)}$$

$$\text{FLOW RATE (gpm): } \text{Flow Rate (gpm)} = \frac{2.83 (\text{Diameter, in})^2 (\text{Distance, in})}{\text{Height, in}}$$

$$\% \text{ SLOPE} = \frac{\text{Rise (feet)}}{\text{Run (feet)}} \times 100$$

$$\text{ACTUAL LEAKAGE} = \frac{\text{Leak Rate (GPD)}}{\text{Length (mi.)} \times \text{Diameter (in)}}$$

$$\text{VELOCITY} = \frac{\text{Distance (ft)}}{\text{Time (Sec)}}$$

N = Manning's Coefficient of Roughness

R = Hydraulic Radius (ft.)

S = Slope of Sewer (ft/ft.)

$$\text{HYDRAULIC RADIUS (ft)} = \frac{\text{Cross Sectional Area of Flow (ft)}}{\text{Wetted pipe Perimeter (ft)}}$$

$$\text{WATER HORSEPOWER} = \frac{\text{Flow (gpm)} \times \text{Head (ft)}}{3960}$$

$$\text{BRAKE HORSEPOWER} = \frac{\text{Flow (gpm)} \times \text{Head (ft)}}{3960 \times \text{Pump Efficiency}}$$

$$\text{MOTOR HORSEPOWER} = \frac{\text{Flow (gpm)} \times \text{Head (ft)}}{3960 \times \text{Pump Eff.} \times \text{Motor Eff.}}$$

$$\text{MEAN OR AVERAGE} = \frac{\text{Sum of the Values}}{\text{Number of Values}}$$

$$\text{TOTAL HEAD (ft)} = \text{Suction Lift (ft)} \times \text{Discharge Head (ft)}$$

$$\text{SURFACE LOADING RATE} = \frac{\text{Flow Rate (gpm)}}{\text{Surface Area (sq. ft)}} \text{ (gal/min/sq.ft)}$$

$$\text{MIXTURE STRENGTH (\%)} = \frac{(\text{Volume 1, gal}) (\text{Strength 1, \%}) + (\text{Volume 2, gal}) (\text{Strength 2, \%})}{(\text{Volume 1, gal}) + (\text{Volume 2, gal})}$$

$$\text{INJURY FREQUENCY RATE} = \frac{(\text{Number of Injuries}) \times 1,000,000}{\text{Number of hours worked per year}}$$

$$\text{DETENTION TIME (hrs)} = \frac{\text{Volume of Basin (gals)} \times 24 \text{ hrs}}{\text{Flow (GPD)}}$$

$$\text{SLOPE} = \frac{\text{Rise (ft)}}{\text{Run (ft)}}$$

$$\text{SLOPE (\%)} = \frac{\text{Rise (ft)} \times 100}{\text{Run (ft)}}$$

POPULATION EQUIVALENT (PE):

- 1 PE = .17 Pounds of BOD per Day
- 1 PE = .20 Pounds of Solids per Day
- 1 PE = 100 Gallons per Day

$$\text{LEAKAGE (GPD/inch)} = \frac{\text{Leakage of Water per Day (GPD)}}{\text{Sewer Diameter (inch)}}$$

$$\text{CHLORINE DEMAND (mg/L)} = \text{Chlorine Dose (mg/L)} - \text{Chlorine Residual (mg/L)}$$

MANNING FORMULA

τQ = Allowable time for decrease in pressure from 3.5 PSI to 2.5 PSI

τq = As below

$$\tau Q = (0.022) (d_1^2 L_1) / Q \quad \tau q = \frac{[0.085] [(d_1^2 L_1)]}{q}$$

Q = 2.0 cfm air loss

θ = .0030 cfm air loss per square foot of internal pipe surface

δ = Pipe diameter (inches)

L = Pipe Length (feet)

$$V = \frac{1.486 R^{2/3} S^{1/2}}{v}$$

V = Velocity (ft./sec.)

v = Pipe Roughness

R = Hydraulic Radius (ft)

S = Slope (ft/ft)

$$\text{HYDRAULIC RADIUS (ft)} = \frac{\text{Flow Area (ft.}^2\text{)}}{\text{Wetted Perimeter (ft.)}}$$

$$\text{WIDTH OF TRENCH (ft)} = \text{Base (ft)} + (2 \text{ Sides}) \times \frac{\text{Depth (ft}^2\text{)}}{\text{Slope}}$$

Conversion Factors

1 acre = 43,560 square feet

1 cubic foot = 7.48 gallons

1 foot = 0.305 meters

1 gallon = 3.785 liters

1 gallon = 8.34 pounds

1 grain per gallon = 17.1 mg/L

1 horsepower = 0.746 kilowatts

1 million gallons per day = 694.45 gallons per minute

1 pound = 0.454 kilograms

1 pound per square inch = 2.31 feet of water

1% = 10,000 mg/L

Degrees Celsius = (Degrees Fahrenheit - 32) (5/9)

Degrees Fahrenheit = (Degrees Celsius * 9/5) + 32

64.7 grains = 1 cubic foot

1,000 meters = 1 kilometer

1,000 grams = 1 kilogram

Formula/Conversion Table

$$\text{Acid Feed Rate} = \frac{(\text{Waste Flow}) (\text{Waste Normality})}{\text{Acid Normality}}$$

$$\text{Alkalinity} = \frac{(\text{mL of Titrant}) (\text{Acid Normality}) (50,000)}{\text{mL of Sample}}$$

$$\text{Amperage} = \text{Voltage} \div \text{Ohms}$$

$$\text{Area of Circle} = (0.785)(\text{Diameter}^2) \text{ OR } (\pi)(\text{Radius}^2)$$

$$\text{Area of Rectangle} = (\text{Length})(\text{Width})$$

$$\text{Area of Triangle} = \frac{(\text{Base}) (\text{Height})}{2}$$

$$\text{C Factor Slope} = \text{Energy loss, ft.} \div \text{Distance, ft.}$$

$$\text{C Factor Calculation} = \text{Flow, GPM} \div [193.75 (\text{Diameter, ft.})^{2.63}(\text{Slope})^{0.54}]$$

$$\text{Chemical Feed Pump Setting, \% Stroke} = \frac{(\text{Desired Flow}) (100\%)}{\text{Maximum Flow}}$$

$$\text{Chemical Feed Pump Setting, mL/min} = \frac{(\text{Flow, MGD}) (\text{Dose, mg/L}) (3.785\text{L/gal}) (1,000,000 \text{ gal/MG})}{(\text{Liquid, mg/mL}) (24 \text{ hr. / day}) (60 \text{ min/hr.})}$$

$$\text{Chlorine Demand (mg/L)} = \text{Chlorine dose (mg/L)} - \text{Chlorine residual (mg/L)}$$

$$\text{Circumference of Circle} = (3.141) (\text{Diameter})$$

$$\text{Composite Sample Single Portion} = \frac{(\text{Instantaneous Flow}) (\text{Total Sample Volume})}{(\text{Number of Portions}) (\text{Average Flow})}$$

$$\text{Detention Time} = \frac{\text{Volume}}{\text{Flow}}$$

$$\text{Digested Sludge Remaining, \%} = \frac{(\text{Raw Dry Solids}) (\text{Ash Solids}) (100\%)}{(\text{Digested Dry Solids}) (\text{Digested Ash Solids})}$$

$$\text{Discharge} = \frac{\text{Volume}}{\text{Time}}$$

$$\text{Dosage, lbs/day} = (\text{mg/L})(8.34)(\text{MGD})$$

Dry Polymer (lbs.) = (gal. of solution) (8.34 lbs/gal)(% polymer solution)

Efficiency, % = $\frac{(\text{In} - \text{Out})}{\text{In}} (100\%)$

Feed rate, lbs/day = $\frac{(\text{Dosage, mg/L}) (\text{Capacity, MGD}) (8.34 \text{ lbs/gals})}{(\text{Available fluoride ion}) (\text{Purity})}$

Feed rate, gal/min (Saturator) = $\frac{(\text{Plant capacity, gal/min.}) (\text{Dosage, mg/L})}{18,000 \text{ mg/L}}$

Filter Backwash Rate = $\frac{\text{Flow}}{\text{Filter Area}}$

Filter Yield, lbs/hr./sq. ft = $\frac{(\text{Solids Loading, lbs/day}) (\text{Recovery, \%} / 100\%)}{(\text{Filter operation, hr./day}) (\text{Area, ft}^2)}$

Flow, cu. ft./sec. = (Area, Sq. Ft.)(Velocity, ft./sec.)

Gallons/Capita/Day = $\frac{\text{Gallons / day}}{\text{Population}}$

Hardness = $\frac{(\text{mL of Titrant}) (1,000)}{\text{mL of Sample}}$

Horsepower (brake) = $\frac{(\text{Flow, gpm}) (\text{Head, ft})}{(3,960) (\text{Efficiency})}$

Horsepower (motor) = $\frac{(\text{Flow, gpm}) (\text{Head, ft})}{(3960) (\text{Pump, Eff}) (\text{Motor, Eff})}$

Horsepower (water) = $\frac{(\text{Flow, gpm}) (\text{Head, ft})}{(3960)}$

Hydraulic Loading Rate = $\frac{\text{Flow}}{\text{Area}}$

Leakage (actual) = Leak rate (GPD) ÷ [Length (mi.) x Diameter (in.)]

Mean = Sum of values ÷ total number of values

Mean Cell Residence Time (MCRT) = $\frac{\text{Suspended Solids in Aeration System, lbs}}{\text{SS Wasted, lbs / day} + \text{SS lost, lbs / day}}$

Organic Loading Rate = $\frac{\text{Organic Load, lbs BOD / day}}{\text{Volume}}$

$$\text{Oxygen Uptake} = \frac{\text{Oxygen Usage}}{\text{Time}}$$

$$\text{Pounds per day} = (\text{Flow, MGD}) (\text{Dose, mg/L}) (8.34)$$

$$\text{Population Equivalent} = \frac{(\text{Flow MGD}) (\text{BOD, mg/L}) (8.34 \text{ lbs / gal})}{\text{Lbs BOD / day / person}}$$

$$\text{RAS Suspended Solids, mg/l} = \frac{1,000,000}{\text{SVI}}$$

$$\text{RAS Flow, MGD} = \frac{(\text{Infl. Flow, MGD}) (\text{MLSS, mg/l})}{\text{RAS Susp. Sol., mg/l} - \text{MLSS, mg/l}}$$

$$\text{RAS Flow \%} = \frac{(\text{RAS Flow, MGD}) (100 \%)}{\text{Infl. Flow, MGD}}$$

$$\text{Reduction in Flow, \%} = \frac{(\text{Original Flow} - \text{Reduced Flow}) (100\%)}{\text{Original Flow}}$$

$$\text{Slope} = \frac{\text{Drop or Rise}}{\text{Run or Distance}}$$

$$\text{Sludge Age} = \frac{\text{Mixed Liquor Solids, lbs}}{\text{Primary Effluent Solids, lbs / day}}$$

$$\text{Sludge Index} = \frac{\% \text{ Settleable Solids}}{\% \text{ Suspended Solids}}$$

$$\text{Sludge Volume Index} = \frac{(\text{Settleable Solids, \%}) (10,000)}{\text{MLSS, mg/L}}$$

$$\text{Solids, mg/L} = \frac{(\text{Dry Solids, grams}) (1,000,000)}{\text{mL of Sample}}$$

$$\text{Solids Applied, lbs/day} = (\text{Flow, MGD})(\text{Concentration, mg/L})(8.34 \text{ lbs/gal})$$

$$\text{Solids Concentration} = \frac{\text{Weight}}{\text{Volume}}$$

$$\text{Solids Loading, lbs/day/sq. ft} = \frac{\text{Solids Applied, lbs / day}}{\text{Surface Area, sq. ft}}$$

$$\text{Surface Loading Rate} = \frac{\text{Flow}}{\text{Rate}}$$

$$\text{Total suspended solids (TSS), mg/L} = \frac{\text{(Dry weight, mg)}(1,000 \text{ mL/L})}{\text{(Sample vol., mL)}}$$

$$\text{Velocity} = \frac{\text{Flow}}{\text{Area}} \quad \text{O R} \quad \frac{\text{Distance}}{\text{Time}}$$

$$\text{Volatile Solids, \%} = \frac{\text{(Dry Solids - Ash Solids)} (100\%)}{\text{Dry Solids}}$$

$$\text{Volume of Cone} = (1/3)(0.785)(\text{Diameter}^2)(\text{Height})$$

$$\text{Volume of Cylinder} = (0.785)(\text{Diameter}^2)(\text{Height}) \text{ OR } (\pi)(r^2)(h)$$

$$\text{Volume of Rectangle} = (\text{Length})(\text{Width})(\text{Height})$$

$$\text{Volume of Sphere} = [(\pi)(\text{diameter}^3)] \div 6$$

$$\text{Waste Milliequivalent} = (\text{mL}) (\text{Normality})$$

$$\text{Waste Normality} = \frac{\text{(Titrant Volume)} (\text{Titrant Normality})}{\text{Sample Volume}}$$

$$\text{Weir Overflow Rate} = \frac{\text{Flow}}{\text{Weir Length}}$$

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Aluminum, Copper, And Nonferrous Metals Forming And Metal Powders Pretreatment Standards: A Guidance Manual	December 1989	800-B-89-001	PB91-145441	W119
CERCLA Site Discharges to POTWs Guidance Manual	August 1990	540-G-90-005	PB90-274531	W150
Control Authority Pretreatment Audit Checklist and Instructions	May 1992	-- -- --		
Control of Slug Loadings To POTWs: Guidance Manual	February 1991	21W-4001	-- --	
Environmental Regulations and Technology: The National Pretreatment Program	July 1986	625-10-86-005	PB90-246521	W350
Guidance for Conducting a Pretreatment Compliance Inspection	September 1991	300-R-92-009	PB94-120631	W273
Guidance For Developing Control Authority Enforcement Response Plans	September 1989	--	PB90-185083/AS	--
Guidance for Reporting and Evaluating POTW Noncompliance with Pretreatment Implementation Requirements	September 1987	--	PB95-157764	W304
Guidance Manual For Battery Manufacturing Pretreatment Standards	August 1987	440-1-87-014	PB92-117951	W195
Guidance Manual for Electroplating and Metal Finishing Pretreatment Standard	February 1984	440-1-84-091-G	PB87-192597	W118
Guidance Manual For Implementing Total Toxic Organics (TTO) Pretreatment Standards	September 1985	440-1-85-009-T	PB93-167005	W339
Guidance Manual For Iron And Steel Manufacturing Pretreatment Standards	September 1985	821-B-85-001	PB92-114388	W103
Guidance Manual for Leather Tanning and Finishing Pretreatment Standards	September 1986	800-R-86-001	PB92-232024	W117
Guidance Manual for POTW Pretreatment Program Development	October 1983	--	PB93-186112	W639
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Guidance Manual for Preventing Interference at POTWs	September 1987	833-B-87-201	PB92-117969	W106
Guidance Manual for Pulp, Paper, and Paperboard and Builders' Paper and Board Mills Pretreatment Standards	July 1984	--	PB92-231638	W196
Guidance Manual for the Identification of Hazardous Wastes Delivered to Publicly Owned Treatment Works by Truck, Rail, or Dedicated Pipe	June 1987	--	PB92-149251	W202
Guidance Manual for the Use of Production-Based Pretreatment Standards and the Combined Wastestream Formula	September 1985	833-B-85-201	PB92-232024	U095
Guidance Manual on the Development and Implementation of Local Discharge Limitations Under the Pretreatment Program	December 1987	833-B-87-202	PB92-129188	W107
Guidance on Evaluation, Resolution, and Documentation of Analytical Problems Associated with Compliance Monitoring	June 1993	821-B-93-001	-- --	
Guidance to Protect POTW Workers From Toxic And Reactive Gases And Vapors	June 1992	812-B-92-001	PB92-173236	W115
Guides to Pollution Prevention: Municipal Pretreatment Programs	October 1993	625-R-93-006	-- --	
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