New Mexico

Water Systems Operator

Certification Study Manual

Version IV.2, February 2015

New Mexico Environment Department
Utility Operator Certification Program

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NMED Surface Water Quality Bureau
PO Box 5469
Santa Fe, NM 87502

INTRODUCTION

The "NEW MEXCIO WATER SYSTEMS OPERATOR CERTIFICATION STUDY GUIDE" was developed by Fred Ragsdale of Ragsdale and Associates under contract with NMED Surface Water Quality Bureau. With this edition the title has changed to The "NEW MEXCIO WATER SYSTEMS OPERATOR CERTIFICATION STUDY MANUAL" to reflect the addition of further study material. It should be used as a tool to assist Water Systems operators in New Mexico in preparation for taking the New Mexico Distribution Systems Operator, Small Water Systems Operator, and Water Systems Operator certification exams. In New Mexico Water Certification is divided into the following areas:

- Four classes of Water System Operator certification
- Three classes of Distribution Systems Operator certification
- Two classes of Small Water Systems Operator certification

This manual is not intended to be a complete reference manual for technical information. Its purpose is to guide the reader to study material for each of the major subject areas for each of the classes. There is no implied claim that this study guide covers every possible point on which an operator may be tested. However, it is intended to be comprehensive in its coverage of the essential information for each exam. As new technologies are developed and become available in the State of New Mexico further additions will be made to the Study Manual to assist operators in understanding those advanced water treatment technologies.

The manual is divided into fourteen basic chapters. In the future a chapter fifteen will be added containing information on emerging advanced water treatment technologies. The manaul also contains a useful Appendix: EPA manual "Response Protocol Toolbox: Planning for and Responding to Drinking Water Contamination Threats and Incidents". Each chapter in the study manual has basic and advanced study questions and sample test questions that are intended to help the individual determine the type of information that is covered in an exam. Basic questions will generally cover information in the Small Water Systems exams and the Class 1 and 2 for Water Systems and Distribution Systems exams. Advanced

There is only one correct answer for the Sample Test Questions. No answer sheet is provided. You will have to look them up.

- Distribution Systems exams will include information from Chapters 1-5, 7-10, and 13-14.
- Small Water Systems exam will include information from Chapters 1-5, 7-11, and 13.
- Advanced Small Water Systems exam will also include information from Chapters 6 and 12.
- Water Systems Class 1 exam will include information from Chapters 1-4, 7-11, and 13-14.
- Water System Class 2 exam will include information from Chapters 1-11 and 13-14.
- Water Systems Class 3 and 4 exams will include information from Chapters 1 through 15.

The certification exams use several texts as reference manuals for exam topics. Each chapter of the study manual contains references to specific chapters of these manuals for those who wish to access more information on the topics covered in that particular section.

- Office of Water Programs, California State University, Sacramento, *Water Treatment Plant Operation*. 4th ed., 1999, Volumes 1 & 2.
- Office of Water Programs, California State University, Sacramento, *Small Water Systems O&M*. 4th ed., 2001.
- Office of Water Programs, California State University, Sacramento, *Water Distribution System O&M*. 4th ed., 2000.
- ACR Publications, Inc., Skeet Arasmith, *Introduction to Small Water Systems*, 1993.
- Fletcher Driscoll/US Filter, *Groundwater and Wells*, 2nd Edition, 1986.

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New Mexico Environment Department
Surface Water Quality Bureau
Utility Operator Certification Program

The New Mexico Water Quality Control Commission, through the New Mexico Environment Department (NMED), grants certification for competency to the operators of water and wastewater systems. The Utility Operator Certification Program (UOCP) conducts the testing for certification. Certain requirements must be met before an operator is eligible to take a certification examination.

An operator begins the process by completing a test application from the Utility Operator Certification Program. Applications will only be accepted if they are submitted at least 30 days prior to the exam date. A certification officer will review each application to determine if the operator is eligible to take the requested examination. An application must be submitted every time a test is taken. Examinations are given several times a year at various locations around the state. Fees range from $25.00 - $30.00 depending on the examination. A check or money order for the proper amount must accompany each exam application and paid to Utility Operator Certification Program.

Certificates must be renewed every three years. The renewal date will be the last day of the certificate holder's birth month following the third anniversary of the certificate. The UOCP also handles renewal of certificates. Renewal fees ranges from $20.00 - $30.00 depending on the level of certification to be renewed per certificate.

The Utility Operator Certification Program maintains training credits for certified operators only. Each operator must keep a record of all training credits earned. Anyone who intends to apply for NM certification must include documentation of training credits when the application is submitted. Certified operators that are taking higher level exams may also have to submit training credit documentation to update training record files at the Utility Operator Certification Program.

All correspondence, including applications, should be mailed to:

NMED Surface Water Quality Bureau
Utility Operator Certification Program
PO Box 5469
Santa Fe, NM 87502

Please feel free to call the Utility Operator Certification Program to request information on exam application forms, exam dates and locations, or certification and renewal. The telephone number for the office is 505-827-2804.

Important Facts About Operator Certification

An operator, as defined by NM Water Quality Control Commission Regulations, is "any person employed by the owner as the person responsible for the operation of all or any portion of a water supply system or wastewater facility. Not included in this definition are such persons as directors of public works, city engineers, city managers, or other officials or persons whose duties do not include actual operation or direct supervision of water supply systems or wastewater facilities."

Under the Utility Operator Certification Act, "a certified operator is a person who is certified by the commission as being qualified to supervise or operate one of the classifications of water supply systems or wastewater facilities". Experience is "actual work experience, full or part-time, in the fields of public water supply or public wastewater treatment. Work experience in a related field may be accepted at the discretion of the commission". Any claim of related experience will be reviewed by the Water Quality control Commission (WQCC) or its advisory body, the Utility Operators Certification Advisory Board.

The Utility Operator Certification Advisory Board (UOCAB) is a seven-member board appointed to function with the WQCC to establish qualifications of operators, classify systems, adopt regulations, and advise the administration of the Utility Operators Certification Act. Its members are drawn from certified water systems operators and wastewater facility operators throughout the State of New Mexico.

Experience that includes operation, maintenance, or repair of water treatment and water distribution systems is accepted based on whether it is full or part-time. The NM Utility Operator Certification Advisory Board will review and approve experience in other related fields, such as commercial plumbing or utility construction. Credit for part-time experience will be based on the percentage of time devoted to actual operation or maintenance. Full time water or wastewater laboratory experience may be counted as operator experience at a rate of 25% of actual experience. The credit for this experience will be determined by review of the UOCAB.

Basic Certification Requirements

There are three basic requirements an operator must meet to qualify for New Mexico certification. All certified operators must have at least one year of actual experience in operation or maintenance of a public water system. All levels of certification require high school graduation or GED (see substitutions). All levels of certification require a certain number of training credits in water systems O&M or related fields.

	Experience	Training Credits	Education
Class 1	1 year*	10	HS Grad or GED*
Small Systems	1 year*	10	HS Grad or GED*
Class 2	2 years*	30	HS Grad or GED*
Class 3	4 years*	50	HS Grad or GED*
Class 4	1 year as Class 3	80	HS Grad or GED

*See Substitutions

Substitutions

One year of additional experience may be substituted for the high school graduation or GED requirement for all classes except Class 4. Education may be substituted for experience or training credits in some cases. The education must be in a water or wastewater related field. One year of vocational education can be substituted for up to one year of experience. Associate and Bachelor degrees in a related field may be substituted for up to three years of experience and 50 training credit hours, depending on the amount of actual experience. The criteria for substitution of education for experience are as follows:

- No more than one year (30 semester hours) of successfully completed college education in a non-related field may be
- An Associate degree in a two-year program at an approved school in the water and/or wastewater field, and six months of actual experience in that field (which may be accrued before, during, or after the school program) may be substituted for the requirements of any level up to and including Class 2.
- An Associate degree in a two-year program at an approved school in the water and/or wastewater field and twelve months of actual experience in that field (which may be accrued before, during, or after the school program) may be substituted for the requirements of any level up to and including Class 3.
- Completion of at least three years of actual experience in the water and/or wastewater field, plus high school graduation or equivalent, plus 15 semester hours of successfully completed

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Chapter 1: Water Systems Overview

Water systems today are finding themselves with ever increasing responsibilities in the area of proper treatment and protection of the water supply. The impact on small systems can be substantial. It is more important than ever to make sure the people who run these systems have better understanding of their system's operation.

The basic responsibility of the system is to provide each individual with an adequate supply of safe, potable drinking water. This responsibility extends to all employees; whether on a managerial, supervisory, operational, or clerical level, in some direct or indirect manner. Each employee should be aware of their duties and call to their supervisor's attention any condition that might impair water quality or cause service interruption to any part of the system. These responsibilities can be broken down into three major areas of concern:

1. Providing enough water to meet the total demands of the system.
2. Providing water that is both safe and palatable to the customers.
3. Providing that water to the customer when it is needed.

Meeting Water System Demands

The amount of water used by the entire system is known as the demand placed on that system. This demand may come from several different sources.

Domestic Water Usage

Domestic water usage is any water that is used directly by people in their daily activities. These activities include bathing, drinking, cooking, sanitation and other miscellaneous activities like watering lawns, washing the car and laundry. Two major factors that determine the domestic water demands placed on a system are one, the number of individuals the system serves and secondly the amount of water each person on the system will need per day. On a nationwide basis, the average daily consumption of water (total gallons used divided by the total population) is about 130 gallons per person per day. However, this figure will vary depending on the geographic location involved and the population density of that area. Rural areas tend to have a daily consumption rate lower than the national average, while urban areas may have a higher rate.

Industrial Water Usage

Industrial water usage is water used in manufacturing, processing, and cooling. Industrial demand may require as much water as the entire domestic demand on the system.

Agricultural Water Usage

Agricultural usage of water is considered to be water used in irrigating crops, watering livestock, and in cooling and cleanup of dairies and farm equipment. Agricultural demand will generally represent a larger portion of the total water usage than the industries in rural areas.

Public Water Usage

Public water usage may be defined as any community service that requires potable water. Services may include fire protection, recreation (swimming pools, golf courses, etc.) and street maintenance. In rural communities where these services are limited, public water usage may not be a consideration.

Present conditions and future increases in water production should be considered when designing the system. Operators may not be concerned with the original design of the system but should be aware of the impact of new additions and extensions to the system. This is especially true in areas where present water mains are handling maximum capacities.

Sources of Supply

Finding enough water to satisfy the demand on the system is the certainly a major concern for the water supplier. The legal and financial considerations that arise when trying to procure water rights or finance the capital funding required to construct treatment facilities can limit the options available in many cases.

Systems are faced with essentially two choices when selecting a source of supply. They can drill wells and use ground water or, if a suitable river or lake is present, they may choose to use a surface water supply.

Meeting Water Quality Standards

Prior to 1976, water quality was regulated by individual state standards. In many cases these standards were only recommendations rather than enforceable regulations. The U.S. Congress passed the Safe Drinking Water Act (P.L. 93-523) in 1976. The law sets permissible levels of

record keeping schedules, and public notification are enforced by individual state agencies.

Meeting Water Consumption and Peak Demands

Peak water consumption periods will vary daily according to seasons and geographic locations. The major responsibility of the operator is to make sure the water is available when it is needed.

Seasonal Demands

The amount of water used each day will generally vary according to the time of year. Higher daily demands occur during the hot summer months while the demand will tend to drop off during the winter months. Fluctuations in temperature and rainfall may also dictate a rise or fall in daily water consumption.

Daily Peak Demands

Ninety percent of the daily water usage will occur during a 16-hour period. The peak demand periods occur between the early hours of the morning, (5am to 10am) and the early evening hours, (5pm to 10pm.) Demand will usually increase earlier in rural areas. In urban areas, peak demands will be higher during the week while in rural areas the highest peak demands occur on weekends.

Components of a Water System

Water systems are made up of a number of devices that are used to deliver water to the customer. The major components can be divided into the areas of the source of water, its treatment, and its distribution.

Water Sources and Treatment

The source of water can be from groundwater, surface water, or water purchased from another water system. Usually the source of your water will determine the type of treatment necessary. In most circumstances, groundwater requires little treatment. Groundwater quality problems include: minerals, hardness, and dissolved gasses. Surface water typically requires extensive treatment. Surface water quality issues are: turbidity, taste & odor, and color. Surface water usually requires chemical treatment and filtration.

Distribution and Transmission Water Mains

Main lines transport water from the source or from the treatment facility to the area to be served. These pipes are usually the largest in the system. They also serve as feeder

Services

Services are small lines (usually l" or 3/4") that carry water from the main line to the water user. The service connection includes:

1. Some means of tapping the main line or feeder line.
2. A corporation stop for turning the water off at the main or feeder line.
3. Service pipe or tubing.
4. Some type of meter setter which includes a meter stop.
5. Water meter.
6. A fitting for the water customer's connection.

Pumps

Pumps are used to move raw water from the source into the treatment facility or from the well into the system. They are also used to move treated water from the treatment facility into the system. Pumps are used to create pressure for the system and to fill the water storage facilities.

Storage Tanks

Storage tanks hold a reserve of water for those times when the demand for water is greater than can be supplied by the trunk line or by the pumps. They also provide water for fire protection and for those times when the supply might be interrupted.

Controls

Automatic pump controls sense pressure on the system and turn the pump on when the pressure falls below a desired point or when the water level in the water tower drops below a certain level. When the water level in the tower has been restored or when the system's pressure has been raised to normal, the controls automatically turn the pump off. Pump controls can also turn the pump off, if alarm conditions occur. These types of alarm conditions include; high discharge pressure, motor overload, high motor or bearing temperatures, or low suction pressure.

Isolation Valves

Isolation valves are used throughout the system to stop the flow of water. They are usually gate valves or butterfly valves. The trunk line would have at least one isolation valve per mile of line in small rural systems and in large municipal systems they may need to be located every 300-600 feet. Each branch line should have an isolation valve at the point of connection to the trunk line. The proper location of these valves is important in order to isolate small sections of line for repair. This minimizes the number of customers that are out of water during times when repairs

Control Valves

Control valves are designed to control flows or pressures in the system. There are a number of different applications for the control valves that may be used in the system. They are usually diaphragm operated globe valves that are controlled by hydraulic pilot systems. Here are some of the applications for control valves in a water system:

1. Pressure reducing valves - These valves are used to drop the pressure in a distribution zone in order to avoid damage to the system.
2. Pressure relief valves - These valves are used to "bleed" water from the system when the pressures reach a point that could result in damage to the system.
3. Altitude valves - These valves are used when two or more storage tanks are on the same main line. An altitude valve will isolate the lower tanks and prevent them from overflowing while the other tanks are filling.
4. Pressure sustain/flow limiting valves - These valves are used to limit the amount of flow to a certain portion of the system when it drops the pressure in other sections below a certain point.
5. Pump control valves - These valves are designed to replace check valves on booster pumps. They are closed when the pump starts and open slowly to minimize surges in the system. They also close before the pump stops.

Surge Tanks

Surge tanks act as pressurized shock absorbers in the system. They dissipate the pressure spikes caused by water hammer. Water hammer occurs when waves of high/low pressure occur, usually by opening or closing valves too fast. Water hammer can damage piping.

Fire Hydrants

Fire hydrants allow fire-fighting equipment to draw a large volume of water from the system quickly. They may also be used as sampling sites, flushing stations, and vent points for filling drained lines.

Operator Responsibilities

An operator is the person who is, in whole or part, responsible for the operation of a water system. At times, he/she may be a manager, laboratory technician, mechanic, meter reader, public relations person, troubleshooter, or inspector. Becoming a competent operator requires the development of many skills. To become a competent operator one must have an interest in his/her work, be dependable, be willing to learn, and be willing to assume a water system is "out of sight", it should always be on the mind of the operator. A competent operator provides a large degree of protection for both the tremendous financial investment and the health of the community.

References

Office of Water Programs, California State University, Sacramento, *Water Treatment Plant Operation*, Volume 1, 4th ed., Chapter 1

Office of Water Programs, California State University, Sacramento, *Water Distribution System O&M*, 4th ed., Chapter 1.

Office of Water Programs, California State University, Sacramento, *Small Water System O&M*, 4th ed., Chapter 1

Basic Study Questions

1. What are the three responsibilities of any public water supplier?
2. What are three examples of public water usage?
3. What are the main components of a water system?

Advanced Study Questions

1. Which of the following is not likely to present a water quality issue in a groundwater system?
   A. Hardness
   B. Turbidity
   C. Iron
   D. Bacteria
2. Peak daily consumption may be 2.5 times the daily average.
   A. True
   B. False

Chapter 2: Safe Drinking Water Act

The Federal Safe Drinking Water Act (PL93-523) was enacted in 1974 and went into effect in 1976. The purpose of the Act is to establish national enforceable standards for drinking water quality and to guarantee that water suppliers monitor water to ensure that it meets national standards. This Act established either the maximum concentration of pollutants allowed in, or the minimum treatment required for, water that is delivered to the customers. These substances are known to present adverse health effects to humans. Prior to the passage of PL93-523 standards were set by the individual state regulatory agencies. The limits and enforcement procedures varied from state to state and, in passing the law, Congress has attempted to assure uniformly safe drinking water for the general public. The SDWA was amended in 1986 and again in 1996.

Each state (or tribal government), except Wyoming and the District of Columbia, has primacy regarding the enforcement of the standards. The New Mexico Environment Department is the enforcement agency for New Mexico. All sampling and reporting, except for non-Tribal and Federal systems, is handled through the NMED.

Public Water Systems

The regulations established in PL93-523 apply only to public water systems. A public water system is any system that contains 15 service connections, residential or serves 25 people regularly. These systems are responsible for both complying with these regulations and reporting to the public when any standards are exceeded. Public water systems can include private schools, interstate rest stops, state parks, and even restaurants.

Primary Contaminants

The SDWA identified a number of chemicals and microorganisms that are found in drinking water supplies. Because excessive amounts of some of these substances have been determined or anticipated to cause adverse health effects they are referred to as primary contaminants. These substances can be grouped into four major categories: Inorganic chemicals, organic chemicals, radioactive chemicals, and waterborne bacteria. (See Table 2.1.)

Primary Contaminants

(1) Inorganic Chemicals

(2) Organic Chemicals

(3) Radioactive Chemicals

Maximum Contaminant Levels (MCL)

The maximum amount of any one of these substances that can be allowed in water, according to the regulations, is known as the maximum contaminant level (MCL). The MCLs for these chemicals and compounds are set at levels that are considered to be many times less than the concentrations that are known, or anticipated to cause adverse health effects.

Inorganic Contaminants

These contaminants are mostly heavy metals. They may enter the water supply naturally through ground water formations or from mining runoff and industrial discharges. The MCL for each chemical is listed Table 2.2.

Lead and Copper Rule

A representative sampling survey must be conducted for lead and copper that may be present at the customers' tap. Most of the lead and copper found this way comes from the customers' plumbing. The system will be responsible for treating the water to stabilize the corrosive qualities that cause the leeching of lead and copper from plumbing. Sampling for lead and copper requires taking a "first draw" sample from a customer's tap, after water has been standing in the plumbing for at least 6 hours but no longer than 18 hours. If the 90th percentile results exceed the action levels for either metal, the system must take steps to stabilize the system water through chemical addition of lime or another form of alkalinity.

Nitrates

Nitrates are the only chemical contaminant that represent an immediate health risk. Pregnant mothers and infants under 18 months can develop a condition known as "Blue Baby Syndrome". The presence of nitrates in the bloodstream reduces oxygen uptake that gives the skin a blue tint.

Fluoride

Fluoride is added to water to help prevent tooth decay. The

Inorganic Contaminant	MCL (mg/l)
Antimony	0.006
Arsenic	0.03
Barium	2.0
Beryllium	0.004
Cadmium	0.005
Chromium	0.1
Cyanide	0.2
Mercury	0.002
Nickel	0.1
Selenium	0.05
Thallium	0.002
Copper	1.3* Action level
Lead	0.015* Action level
Nitrates (as N)	10.0
Total Nitrate & Nitrite (as N)	10
Nitrite (as N)	1.0
Fluoride	2.0 Public Notice 4.0 Violation
Turbidity	1 NTU (single occurrence) .3NTU (< 5% of samples)
Asbestos	7,000,000 Fibers/L

Table 2.2 - ***Inorganic Contaminants***

Organic Contaminants

These contaminants include herbicides and insecticides that are primarily used in agriculture applications, organic solvents used in industrial applications, organic by-products of industrial processes, and chemical by-products from chlorination of drinking water. Runoff from agricultural spraying or improper application techniques can be a major source of these contaminants in a surface water supply. Industrial discharges, accidental spills and improper disposal of hazardous wastes can also become sources of contamination.

These compounds are grouped together under the headings of Volatile Organic Compounds or VOC's and Synthetic Organic Compounds or SOC's. There are currently 21 regulated VOC's and 30 SOC's that must be analyzed. Some of the VOC's are listed in Table 2.3.

Radioactive Contaminants

Most radioactive substances occur naturally in ground water and in some surface supplies. Some man-made substances may also enter drinking water supplies from processing facilities, mining areas, and nuclear power plants. (See Table 2.4.)

Turbidity

Turbidity is clay, silt or mud in the water. Although turbidity does not represent a health risk by itself, it can shield harmful bacteria from disinfection processes. Turbidity is measured in Nephelometric Turbidity Units (NTU). The device used to measure NTU's is called a nephelometer or turbidimeter.

Radioactive Contaminant	MCL (pCi/l)
Radium 226 and 228	5
Gross Alpha Activity	15
Gross Beta Activity (man-made)	4 millirem/yr

Table 2.4 - ***Radioactive Contaminants***

Organic Contaminant	MCL (mg/l)
Benzene	0.005
Vinyl Chloride	0.002
Carbon Tetrachloride	0.005

Bacteriological Contaminants

The coliform group of bacteria represents the indicator organisms used in determining bacteriological contamination. Their presence indicates the possibility that some pathogenic (disease causing) organisms may also be present. The MCL is exceeded when 5% of the required

The regulations state that, when repeats are required, a minimum of five (5) samples are now required for the month. This means that any small system that would normally only take one sample per month, will have to take four (4) repeats when they get a positive test result. If any system has to take repeat samples, it must also take a minimum of five (5) samples the following month.

Secondary Contaminants

There are certain substances in water that, although they do not present serious health hazards, can cause temporary physical discomfort and make the water unsuitable for use. Each state may determine which of these standards are included in their regulations. Chlorides can make the water taste salty. This is also known as brackish water. Sulphates can cause minor gastro-intestinal problems. Iron and manganese can result in red or black water problems. The pH of the treated water can also create some digestive problems if it is very high or very low. Recommended levels for secondary contaminants are:

Monitoring and Reporting

The public water systems are responsible for monitoring their water quality and reporting violations of the SDWA standards to the public. The New Mexico Environment Department is currently collecting and submitting samples to the laboratory for all public water supplies. The program is funded through a "Water Conservation Fee" of 3 cents per 1000 gallons paid by each system. However, the systems will still be responsible for the results of testing and any public notification that may be required. Systems must retain copies of chemical analysis records for 10 years and bacteriological tests results for 5 years.

Sampling Schedules

Samples used in testing for chemical and biological contaminants must be collected periodically. Samples for inorganic chemical analysis must be submitted once every year for surface supplies and once every three years for ground water supplies. Sampling for organic compounds is done quarterly for the initial set of samples. Surface water plants must also collect four TTHM samples quarterly during this initial period. After that, samples are collected yearly for surface water and every three years for ground water as long as no VOC's or SOC's are detected. If they are found, the source (well or surface supply) must be sampled every quarter. Radiological samples are taken every four years. Under the new Standardized Monitoring Rule, most chemical contaminants are monitored in a cycle required. Whenever compliance samples are submitted it is important to maintain a "chain of custody" that identifies who handled the sample from the time it was taken until it was tested.

Bacteriological Violations

When a positive BAC-T sample is reported repeat samples are required. If the repeats come back negative there is no violation. If more than 5% of the monthly samples are positive for Total Coliform (TC), including repeats, there is a non-acute violation that requires public notification. This means that any system taking less than 40 samples per month can only have 1 total coliform positive sample per month.

If a monthly routine sample is positive for TC and for fecal or E. Coli; and any repeat is positive for TC, OR if any of the repeats are positive for fecal coliform, or E. Coli, an acute violation has occurr0-ed that requires notification through the electronic media. This sometimes triggers a "Boil Order" advisory.

Public Notification

The water system will be required to notify the public any time maximum contaminant levels are exceeded. These violations of the standards fall into two categories: acute violations and non-acute violations.

A non-acute violation occurs when an MCL is exceeded but the situation does not present an immediate health risk to the public. In this case, notification must be placed on, or with the billing notice within 45 days and must run in the newspaper within 14 days. In addition, all new customers must be sent notice of violations when they connect to the system.

Acute violations are violations that could result in an immediate danger to the public health and therefore require immediate notification through television and radio stations within 72 hours. This is in addition to the newspaper and/or billing notifications. Public notification must continue until the problem is corrected. Notification must also be given to the NMED within 48 hours any time a system fails to comply with the NM Drinking Water Regulations.

Action Plans for Violations

If a water supply exceeds the primary standards the water system must either provide adequate treatment to remove the contaminants or locate a new source of supply that meets these requirements.

circumstances, the system may be granted a variance or exemption. The fact that a variance or exemption has been granted does not mean that the system is no longer required to notify the public of the problem. Notification must continue on a monthly basis until the system meets the standard.

Variances

A variance may be granted to a water system when its supply is found to exceed maximum standards and no technology is available to economically remove these contaminants. Variances may be extended at the discretion of the state regulatory agency if no treatment methods are made available during the period the variance is granted.

Exemptions

When a system is unable to financially provide the necessary treatment to reduce contaminant levels to acceptable limits, an exemption can be granted to the water system. Exemptions are granted by state regulatory agencies only in cases where a serious health hazard is not present.

Other New Regulations

The 1986 amendments to the SDWA included a number of new rules regarding treatment and operations of public water supplies. The major changes are identified below with a brief description of the rule and its implications.

Surface Water Rule

Any system that uses surface water must provide treatment of the supply. The minimum acceptable level of treatment is filtration and disinfection. Infiltration galleries may now be considered surface supplies because they are groundwater that is under the influence of surface water. The concerns about contamination by *Giardia* and *Cryptosporidium* bacteria have created the need for higher free chlorine residuals and longer disinfection contact times.

The "CT" calculation is used to determine the necessary contact time at any given concentration. The formula is C x T = A, where C is the chlorine concentration, T is the contact time in minutes, and A is a temperature-based constant. Removal of *Cryptosporidium* is based on a 3-log reduction of the numbers found in raw water. A 3-log removal or deactivation would mean that 0.1% of the bacteria may survive or 99.9% were removed. A 4- log removal or deactivation would mean that 0.01% of the creation of these by-products causes the system to exceed the MCL for Total TTHMs (0.1 mg/l or 100 ppb), the system will be required to change to a different means of disinfection. Total chlorine residuals are also limited to a maximum of 4.0 mg/l. The Stage 1 & Stage 2 D-DBP rules apply to Community Water Systems and Non-Transient Non-Community Water Systems (as defined in SDQA) that add a disinfectant to the drinking water during any part of the treatment process. The State 1 D-DPB rule also applies to Transient Non-Community water systems that use chlorine dioxide.

References:

Office of Water Programs, California State University, Sacramento, *Water Treatment Plant Operation*, Volume 2, 4rted., 1999, Chapter 22
Safe Drinking Water Act
NMED *Drinking Water Regulations*

Basic Study Questions

1. What is an MCL?
2. Why is turbidity a Primary Contaminant?
3. What is a nephelometer?
4. How much is the "Water Conservation Fee"?
5. How long must bacteriological and chemical sampling results be kept?

Basic Sample Test Questions

1. A public water system is any system that serves a population greater than or equal to:
   A. 25
   B. 50
   C. 100

2. What is the maximum total chlorine residual allowed by the Disinfectant-Disinfection By-Products Rule?
   A. 2 mg/l
   B. 4 mg/l
   C. 6 mg/l
   D. 8 mg/l

3. What type of contaminant is iron?
   A. Primary Inorganic
   B. Primary Organic

4. Which Primary Contaminant is sometimes added to water supplies to prevent tooth decay?
   A. Iron
   B. Arsenic
   C. Fluoride
   D. Mercury

5. The failure of a public water system to comply with the NM Drinking Water Regulations must be reported to NMED within:
   A. 12 Hours
   B. 48 Hours
   C. 4 Days
   D. One week

5. How many bacteriological samples must be taken every month before a system is allowed to have TWO positive samples without violating the drinking water standard?
   A. 10
   B. 20
   C. 40
   D. 60

Advanced Study Questions

1. Which Primary inorganic contaminant poses an immediate health risk?
2. When you get a positive Total Coliform sample result, what is the minimum number of retakes required?
3. What are the action levels for lead and copper?
4. If bacteriological retakes are done this month, what is the minimum numbers of samples that must be turned in next month?
5. If a 3-log removal is required for *Giardia Lamblia*, what percentage of organisms can survive and still meet the requirement?

Advanced Sample Study Questions

1. The MCL for Total Trihalomethanes is:
   A. 0.08 mg/l
   B. 0.1 mg/l
   C. 0.2 mg/l
   D. 2.0 mg/l

2. SDWA sampling results must be reported to:
   A. New Mexico Water Association
   B. American Water Works Association
   C. New Mexico Environment Department

3. Groundwater systems must sample for inorganic chemicals every:
   A. Month
   B. Day
   C. Year
   D. Three years

4. The SDWA Compliance Cycle for the Standardized

WHAT IS WATER?

Water is the most abundant and common material on earth. It covers 70% of the surface of the earth as water and ice.

Life Blood

Water is the life blood of the universe. If we were without water there could be no life. Our bodies are 70% water. Without drinking water for four to seven days our blood becomes thick and contains a high concentration of toxic waste materials. We become delirious and unable to function. Death is not far behind.

Other Planets

As far as we know, earth is the only
planet in the solar system that contains water. Others have ice, but only earth has this miraculous life blood.

Universal Solvent

Water is often called the "universal" solvent. Given enough time it will dissolve almost everything that it comes in contact with. Thus, it is effective in carrying food through our bodies to the individual cells and carrying away the cell waste.

Dissolves Minerals

As water flows through the gravels, fissures and sands in the earth's crust and flows over the top of the ground it picks up minerals, microorganisms[1], dirt and bits of plants. Some of these materials are carried along by the water due to its speed. Others, such as minerals are dissolved in the water.

Gases

Water, like many other fluids, also has the ability to dissolve gases, such as oxygen (02) and carbon dioxide (CO2). The oxygen in the water allows fish and other aquatic life[2] to live in the water. Without oxygen fish, like humans, would die. The gills of the fish allow it to filter this dissolved oxygen directly from the water.

WATER AS A CHEMICAL

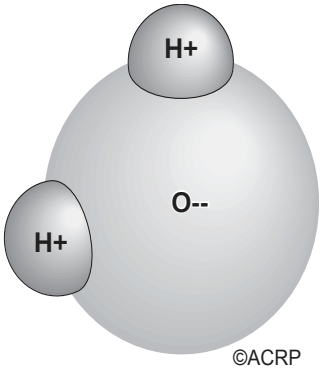
TheWater Molecule

The water molecule[3] is composed of one atom of oxygen and two atoms of hydrogen. This molecule is given the chemical symbol H2O (H2 for two hydrogen atoms and O for one oxygen atom). The chemical symbol is read as "H two O."

Figure 3.1 - ***The World's Water***

Like a Battery

Notice that the two hydrogen atoms are at one end of the molecule. The hydrogen atoms are positively charged. When they attach themselves to the oxygen molecule the whole molecule effectively becomes polarized with negative and positive poles, much like a battery. Because it has both negative and positive charges, it is much easier for it to attract other material. This is one of the reasons it is the "universal" solvent.



States of Water

Water has another unique property; it is the only material that is found on earth in the three basic states at standard temperatures. These states are solid (ice), liquid (water) and gas (water vapor).

Figure 3.2 - ***Water Molecule***

Molecules in Motion

The water molecule, like other molecules, is in constant motion. The rate of this motion is directly related to the temperature of the water. It moves slowest when the water is in the form of ice, and fastest when the water is a vapor.

Density of Water

As the temperature is reduced the rate of movement slows. As this happens the molecules get closer and closer together. At 4°C they are as close together as they are ever going to be. This increases water's density[4] to its maximum. The volume that a set amount of water occupies is at a minimum at this point. Below 4°C the molecules are moving so slow that their electrical charges begin to cause the molecules to line up in a pattern and form crystals.

Expands When it Freezes

At 0°C the crystals are fully formed. This formation allows the molecules to line up in a way so that they occupy a greater space than they did before the temperature reached 0°C. This expansion is what causes water to break a bottle or pipe when it is frozen. Water is one of the few compounds that expands when it freezes. This causes ice to be lighter than the same volume of water and therefore it floats in water.

Water and Heat

The amount of heat it takes to cause the temperature of water to change is used as the basic measurement of heat. In the English system this heat is referred to as a BTU (British Thermal Unit). One BTU is defined as the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit[5]. In the SI (System International - also called the metric system) the unit of heat is the calorie. One calorie is defined as the amount of heat required to raise one gram of water one degree Celsius[6].

Distribution of Water on Earth

The Study of Water

The study of water, its location, use, quantity and occurrence is called hydrology[7]. This next section is a brief discussion of the types of water sources, the distribution of water in those sources and some of the uses of water. This is a small portion of hydrology.

Definition by Sources

The sources of water on the earth are divided into two categories; surface water and groundwater[8].

Surface Water

Surface water is water that is found in the oceans, lakes, streams, springs, and muskeg ponds. Surface water is exposed to the atmosphere[9] and is affected by ambient[10] conditions. This is the source of drinking water for some of our largest communities.

Groundwater

Groundwater is all the water below the earth's surface. However, from a waterworks standpoint we only consider the water between the surface and 2500 feet down. Water below this depth is too hot and expensive to be usable. Groundwater may also include springs. Yes, springs were included in the surface water description. That is because they can be either.

70% of Earth is Water

Seventy percent of the earth's surface is covered with water. The total volume of water on the earth is approximately 305.79 million cubic miles. Of this, 296 million cubic miles are in the oceans, leaving only 9.79 million cubic miles of fresh water.

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[4] Density - The weight per unit volume of a substance.

[5] Fahrenheit - Relating to an English thermometer scale with the boiling point at 212 degrees and the freezing point at 32 degrees.

[6] Celsius - Relating to a thermometer scale used in the metric system on which the freezing point of water is 0 degrees and the

Hydrologic Cycle

The hydrologic cycle[11] is the key to our supply of fresh water. The cycle is made up of four key components.

- The atmosphere
- The lithosphere[12] - the crust of the earth
- The hydrosphere[13] - the water on the earth
- The sun - the energy source used to drive the hydrologic cycle

Available Water Supply

The amount of water available in the atmosphere, lithosphere and hydrosphere remains constant. It was formed during the creation of the earth. There will never be any more or any less than there is today. This water is continually recycled between the lithosphere and the atmosphere by the action of plants and the sun. In order to understand this process lets follow the cycle.

Precipitation

You could start the cycle anywhere because it is continuous and has no beginning or ending. So lets pickup a droplet of precipitation and follow it through the cycle. Precipitation[14] in the form of rain, snow or sleet falls towards the earth.

Fall Toward Earth

As the precipitation falls toward the earth it can pickup contamination in the form of minerals and toxic materials from industrial air pollution and natural pollution such as dust from a volcanic eruption. On its fall toward the earth some of the precipitation evaporates[15].

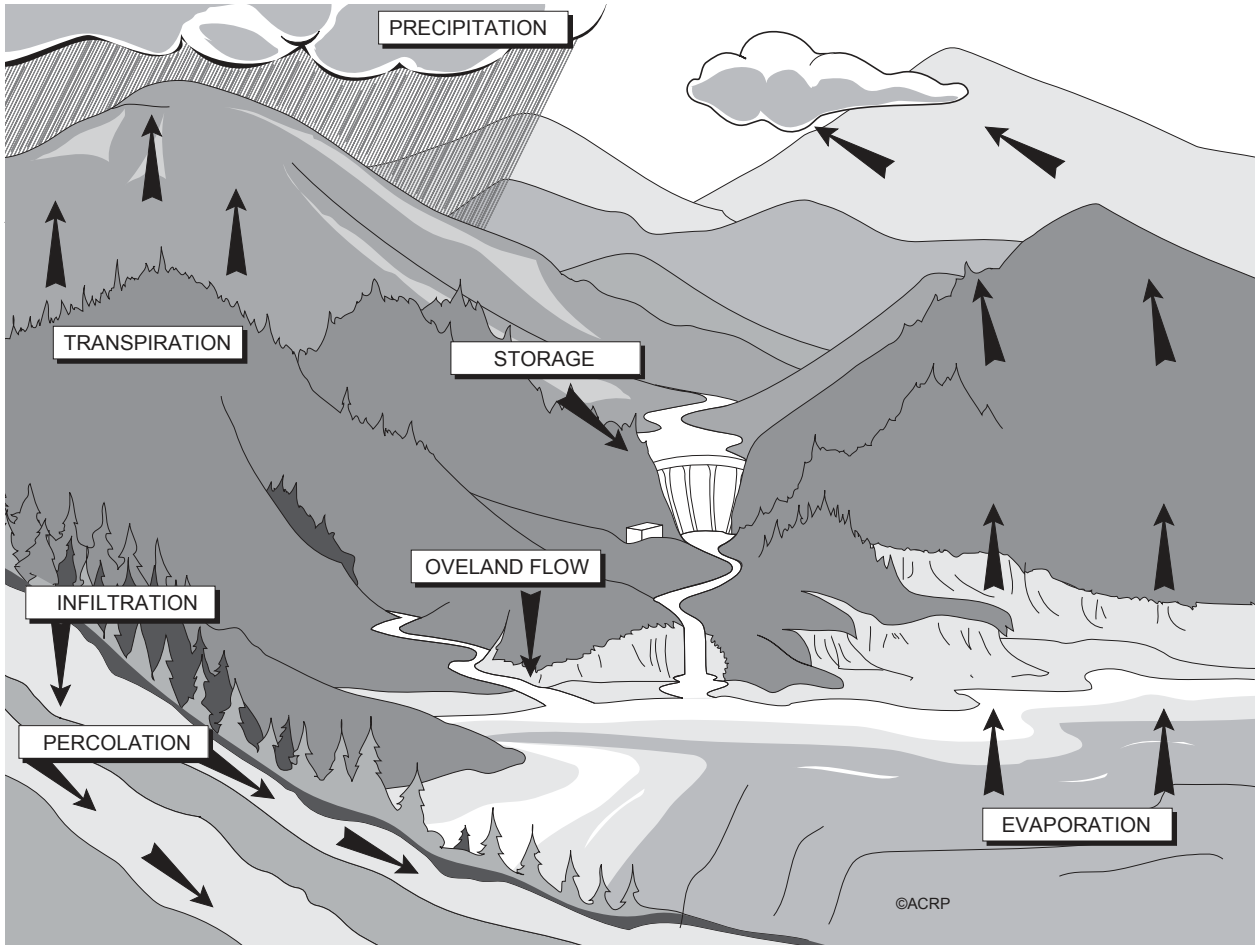

Figure 3.3 - ***The Hydrologic Cycle***

Evaporation

The amount of evaporation is dependent upon several factors. Among them are the humidity[16], air temperature and the amount of wind. There is a significant amount of precipitation that is recycled back to the atmosphere before it ever strikes the ground.

Hits the Forest

Some of the precipitation hits the forest canopy[17], brush and grass. Some of the precipitation evaporates directly from the leaves of the canopy.

Hits the Ground

Some water flows down the outside of the trees onto the ground, and some strikes the ground directly. As water accumulates on the ground it runs downhill. This movement is referred to as overland flow[18].

Flow Along the Surface

As the water moves along the surface it picks up contamination in the form of organic[19] material such as, bits of leaves, microorganisms such as bacteria[20], viruses[21], and protozoa[22], and inorganic[23] matter such as silt, clay, minerals and volcanic ash.

Surface Water

The overland flow accumulates in lakes, streams, muskeg ponds and rivers. Most rivers will eventually run into the ocean. These sources are referred to as surface water. A large quantity of the water that forms surface water will be evaporated back into the atmosphere. In fact in most of the world this is the largest single loss of surface water.

Groundwater

Some of the water that is running along the earth's surface seeps into the soil. This process is called infiltration[24]. As the water infiltrates the soil and moves downward some is taken up by the roots of trees and other plants. The water that is taken in by plants moves upward and is given off into the atmosphere through the leaves of the plants in a process called transpiration[25].

Evaporation & Transpiration

This moisture mixes with the moisture that is evaporated from surface waters and from the plants. This combined process is referred to as evapotranspiration[26].

Groundwater Movement

The water not taken up by plants continues to move downward in a process called percolation[27]. This water continues to move downward until it collects in gravels and sands called aquifers[28]. There the water continues to slowly move towards adjacent lakes, streams and the ocean where it collects with the surface water and is evaporated back into the atmosphere.

Springs

Sometime in the past, changes in the earth's crust left the edge of an aquifer exposed to the surface. Where this happens the groundwater supply exits the hillside or mountain in what is referred to as a spring. From there it runs along the surface and mixes with surface water.

Back to the Atmosphere

As you can see both the groundwater and the surface water eventually mix and are evaporated back into the atmosphere and form water vapor. This vapor is condensed by atmospheric conditions and forms precipitation which falls to the ground and the cycle is continued, providing us with clean fresh water for our water systems.

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[14] Precipitation - The process by which atmospheric moisture is discharged onto the earth's crust. Precipitation takes the form of rain, snow, hail, and sleet.

[15] Evaporate - The process of conversion of liquid water to water vapor.

[16] Humidity - The amount of water vapor in the air.

[17] Forest Canopy - The enclosure mdke by the trees in a forest. The canopy can block all or most of the light from the forest floor.

[18] Overland flow - The movement of water on and just under the earth's crust.

[19] Organic - Chemical substances of animal or vegetable origin, usually containing carbon.

[20] Bacteria - Living organisms, microscopic in size, which consist of a single cell. Most bacteria utilize organic matter for their food and produce waste products as the result of their life processes.

[21] Viruses - A submicroscopic organism which passes through filters capable of removing bacteria.

[22] Protozoa - A small, one-celled animal including, but not limited to, amoebae, ciliates, and flagellates.

Distribution of Water

Total Supply

The total supply of all water in the world is approximately 305.79 million cubic miles. Of this total supply 296 million cubic miles are in the worlds oceans. This leaves 9.79 million cubic miles or 3.2% of all water in the world as fresh water.

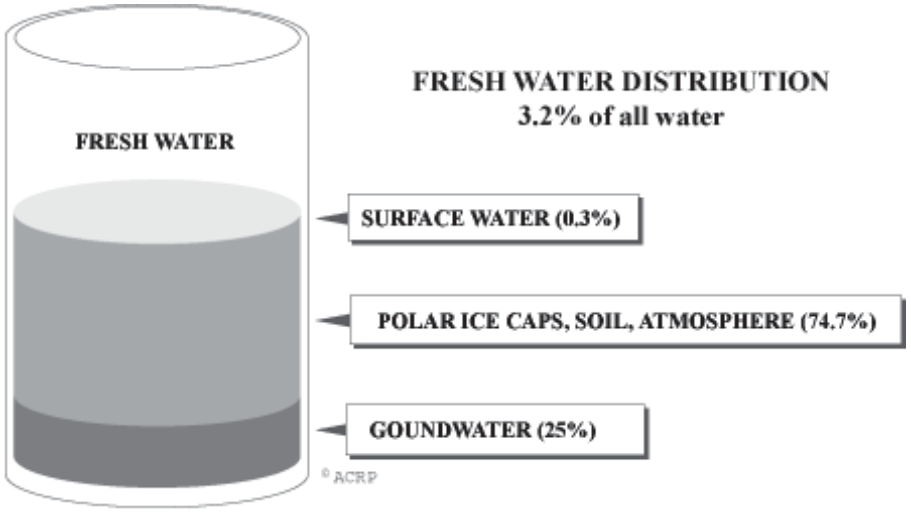


Figure 3.4 - ***Fresh Water***

Distribution of Fresh Water

74.7% of the 9.79 million cubic miles of fresh water is tied up in the polar ice caps, soil moisture and atmosphere. 25% of this fresh water is in the groundwater supply, leaving 0.3% of the fresh water in the lakes and streams.

Usable Fresh Water

The total groundwater supply is estimated at 2.42 million cubic miles. Only 44% of this, or 1.06 million cubic miles, is usable. That is, it is less then 2,500 feet below the surface. The lakes and rivers represent 0.03 million cubic miles of fresh water. This gives a total of 1.09 million cubic miles of usable fresh water.

Division of Fresh Water

Of the usable fresh water, 97% or 1.06 million cubic miles is in the groundwater supply and only 0.3% is in the surface water supply.

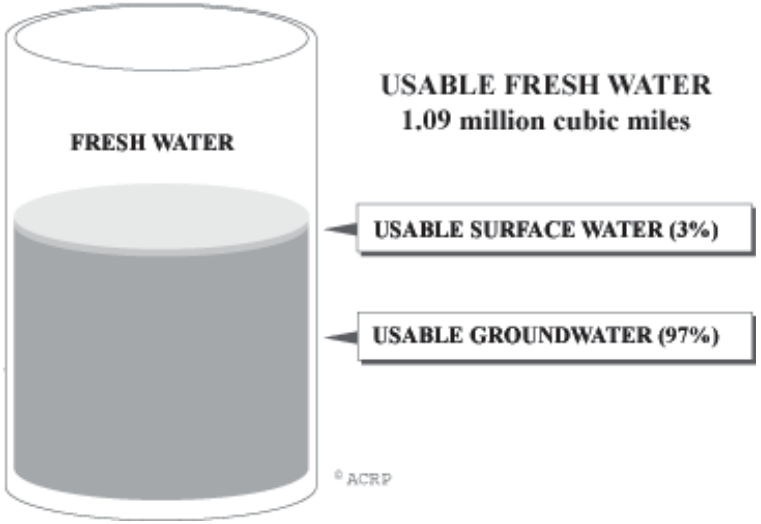


Figure 3.5 - ***Useable Fresh Water***

Table 3.1 - ***Location of the Worlds Fresh Water***

Location by Per Cent of the Worlds Fresh Water

%	Location	Million Cubic Miles
74.60	Polar ice caps	7.33
0.06	Soil moisture	0.00587

Distribution by System

Within the continental United States 77.3% of the public water systems use groundwater and 18% of the systems use surface water. 4.7% of the systems in the US use a combination of surface water and ground water.

Distribution by Population

Within the continental United States 68% of the population is served by surface water suppliers while only 32% of the population relies on groundwater supplies.

Why the Difference?

System Location

There are several reasons for the difference between the number of surface water suppliers and the number of people obtaining their drinking water from surface water suppliers. First, in the continental United States 37 of the 100 largest communities use surface water. This is because the majority of these communities are built next to surface water sources, including ten that are built next to the Great Lakes. In the West, communities such as Los Angeles, San Francisco, Portland and Seattle all utilize surface water.

Water Availability

Second, a large portion of this country is without any surface water source. Finally, there are few ground water supplies which can provide sufficient water for a large community.

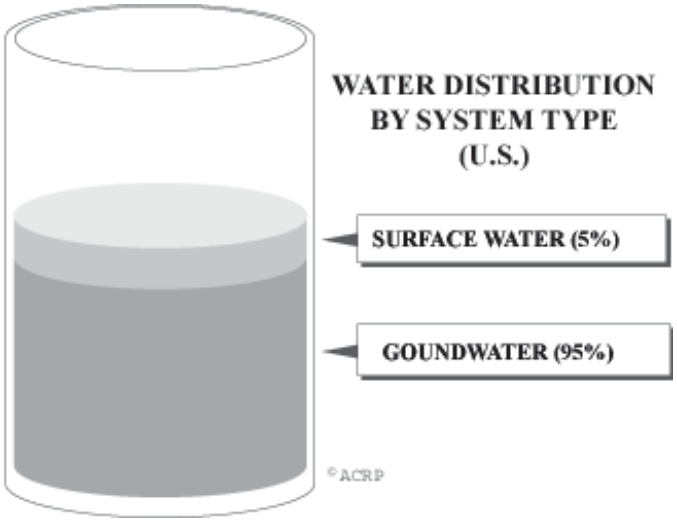


Figure 3.6 - ***Water Distribution by System***

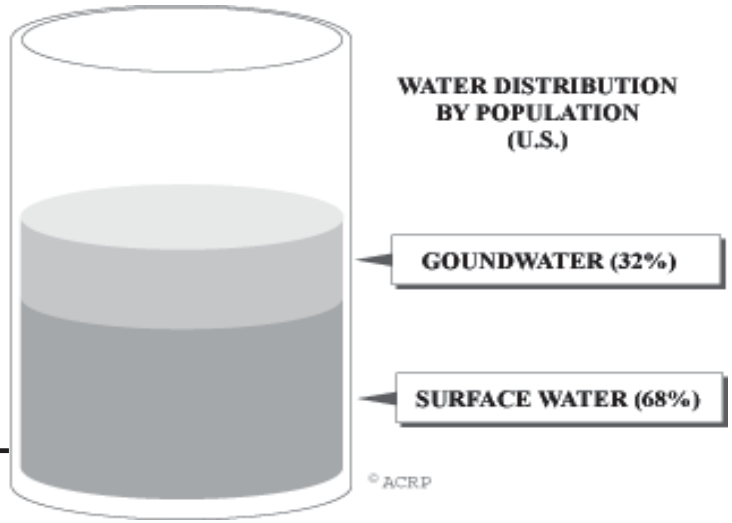


Figure 3.7 - ***Water Distribution by Population (U.S.)***

References

ACR Publications, Inc., Skeet Arasmith, *Introduction to Small Water Systems*, Chapter 1

Basic & Advanced Study Questions

1. Water is called the _____ solvent.

2. What are the two sources of water?

4. Water cycles from the atmosphere to the earth and back to the atmosphere. What is this natural water cycle called?

New Mexico Water Conservation Fee

The NM Water Conservation Fee of 3 cents per 1000 gallons is collected from each public water system in order to fund sample collection and testing for inorganic, organic, and radiological contaminants. The fee also covers bacteriological testing. This means that most water systems are only responsible for collection of monthly bacteriological (microbiological) samples in order to comply with SDWA monitoring schedules.

Waterborne Pathogens

Water systems must strive to keep their drinking water free of pathogens (disease causing bacteria). They can be transported either by water or physical contact. People that have contracted these diseases are called carriers. Without proper medical attention and treatment, individuals can still transmit the disease even though they no longer have any of the symptoms. There are five waterborne pathogens that can be found in all water supplies and two that are only found in surface water supplies. The bacteria that are found only in surface water supplies form cysts and spores that protect them from cold temperatures. Because of this protection, they are much more difficult to kill with disinfectant chemicals.

Waterborne Diseases

All Water Supplies:

- Typhoid
- Paratyphoid (Types A & B)
- Cholera
- Dysentery
- Hepatitis

Surface Water Only:

- Cryptosporidium
- Giardia

All of these diseases are caused by pathogenic bacteria except hepatitis, which is a virus. It is very difficult to identify any one particular pathogen by laboratory testing. To make testing more reliable and economical, the lab tests are designed to identify a large family of bacteria that are related to the disease causing bacteria, rather than identifying each type of pathogen.

Coliform Group of Bacteria

Coliform bacteria are enteric bacteria. This means that they are found in the intestinal tract of warm-blooded animals, including humans. These bacteria, known as E. Coli in humans, do not cause disease but are necessary for the digestion of food. The waterborne pathogens are also enteric bacteria and are part of the coliform family. Therefore, if coliform bacteria are present in the water supply, pathogens may also be present. The coliform bacteria live longer in water and are easier to detect by laboratory testing. This is the reason the coliform group has been chosen as the indicator organism for waterborne pathogens. If coliform bacteria are not present it is assumed there are no pathogens present.

The coliform family has been divided into two groups. Results may come back as total coliform positive or fecal coliform positive. Total coliform positive means that no human coliform are present. Fecal coliform positive indicates the presence of E. Coli, which means there is a greater chance of pathogens being present. The laboratory tests for coliform include the MPN method, the Membrane Filter test, and the Colilert test.

Sampling Schedules and Techniques

It is the responsibility of the system to collect samples for bacteriological ("Bac T") testing. It is very important to make sure samples are collected, tested and reported properly. If a sample becomes contaminated due to poor sampling procedures, or is not sent to the testing facility at the proper time, the system may technically be in violation of SDWA standards. This may result in the system having to notify the public of violations when the water is actually safe.

Sampling Schedules

The federal regulations regarding "Bac T" sampling schedules set the minimum number of samples a water system must submit at one per month. As the size of the system increases so does the minimum number of samples required each month. These sample results, and any necessary re-takes, must be reported to the NMED by the end of each calendar month.

The sampling points should be identified by a sampling plan that samples are taken from all major parts of the system to assure that the entire system is represented. Small systems must have at least two sample sites in the system.

Sampling Techniques

The first consideration in collecting a "Bac T" sample is the sample bottle. These bottles are provided by the New Mexico Environment Department. They are sterilized prior to being sent to the systems. They should be stored in a cool, dry place until they are needed for a sample. Sodium thiosulphate is added to the bottle before it is sterilized. Its presence may be indicated by a trace of white powder in the bottom of the bottle. The purpose of the sodium thiosulphate is to neutralize any chlorine that may kill any bacteria that are in the sample.

Two things to remember when using sample bottles:

1. Never wash out a bottle or even open it until you are ready to take the sample.

2. If a sample bottle has any dirt or junk in it or in the lid, don't use it. It's better to get a new bottle than to take a bad sample.

Once the pre-sterilized bottles are obtained, the next consid-eration is the actual collection of the sample. The procedure for collecting the sample is given below. These instructions should be carefully followed to prevent accidental contamination of the sample.

1. Select a sampling point. Always keep sanitary conditions in mind when selecting a sampling point. Never use a kitchen sink faucet or an outdoor faucet that drips. Any hoses, vacuum breakers or other attachments must also be removed. The rule of thumb is to select a faucet that is used the least.

2. Flush the line. Open the tap and let the water run for several minutes. This will insure that the water being sampled is from the main and not from the customer's plumbing.

3. Collect the sample. Remove the cap, making sure that you do not touch the inside of the cap or the top of the sample bottle. Don't aerate the sample or allow it to splash on the outside of the bottle. Fill the bottle carefully to the shoulder of the bottle. This guarantees that there is at least 100ml of sample in the bottle. Do not fill it all the way. An air bubble is needed to stir the sample before it is tested at the lab. Never set the cap down or leave it off longer than it takes to collect the sample. Mark the bottles for identification. The samples should then be placed under refrigeration until tested.

Table 4.1 - ***BAC-T Sample Form***

1. System name, address, and identification number
2. Location of sampling site
3. Date and time sample was taken
4. Type of water sampled (raw or treated)
5. Chlorine residual
6. Computer ID number
7. Name of operator taking sample

There are times when water systems need to collect Bac-T samples for reasons other than monitoring compliance. New water lines and lines that have been repaired should be tested. Wells that have been disinfected should be tested. These samples must be identified as something other than a compliance sample so they will not count as a violation against the system if they are found to be positive. This is done by checking "Special Sample" on the form and identifying the type of sample in the "Remarks" line.

There are certain requirements regarding the age of a Bac-T sample. New Mexico Drinking Water Regulations state that the sample must be tested within thirty hours after it is taken. If a sample does not arrive at the lab within this time period it will not be tested. To help avoid this, make sure all samples are sent in on time, preferably at the first of the week. Always obtain a receipt from the postmaster as part of the chain of custody.

Retakes and Violations

Anytime a Bac-T sample result comes back positive, indicating the presence of coliform, retake samples must be taken. Three retakes are usually required. One must be taken at the site of the positive sample. The other retakes are upstream and downstream of the site (within five service connections.) These retakes must be taken within 24 hours of receipt of positive results. They must be identified as "Resample" on the sample form. When retakes are needed, a minimum of five samples will be required for the following month.

When retakes come back positive, the system is usually

notification. In either case the NMED must be notified within 24 hours of any positive sample results. The Water system is responsible for any public notification that may be required.

References

Office of Water Programs, California State University, Sacramento, *Water Treatment Plant Operations*, *4th ed. 1999, Volume 2, Chapter 22.*
Safe Drinking Water Act
NMED *Drinking Water Regulations*

Basic Study Questions

1. What is an indicator organism?
2. What is sodium thiosulphate?
3. Why should you flush before sampling?

Basic Sample Test Questions

1. Which of the following is an indicator organism?
   A. Giardia
   B. Cryptosporidium
   C. Hepatitis
   D. E. Coli

2. Which factor is used to determine how many Bac-T samples must be taken?
   A. Number of operators
   B. Type of treatment
   C. Number of people served
   D. Amount of water produced

3. What is the minimum number of Bac-t sample(s) required each month?
   A. 1
   B. 2
   C. 3
   D. 4

Advanced Study Questions

1. How many retakes are required for each positive?
4. How soon must NMED be notified that a bacterial MCL has been exceeded?

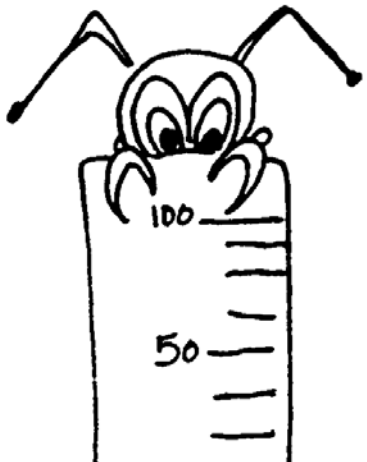
Advanced Sample Test Questions

1. How many samples must be taken before two positive results DO NOT result in an MCL violation?
   A. 10
   B. 20
   C. 40
   D. 80

2. A sample must be tested within how many hours?
   A. 24
   B. 30
   C. 48
   D. 60

3. Anytime the MCL is exceeded and fecal coliform positive results came back from any of the samples…
   A. This is an acute violation
   B. This is a non-acute violation
   C. There is no notification required
   D. Only written notification is required

4. If retakes are required this month, what is the minimum number of samples required next month?
   A. 5
   B. 10
   C. 15
   D. 20



TYPES OF DISINFECTION

The process of killing pathogenic bacteria in the drinking water supply is known as disinfection. Disinfection is the final step in the treatment process and is necessary to provide a "bacteriologically safe" drinking water for the public. Disinfection is now required for all public water supplies. Chlorination is the most common means of killing disease-causing bacteria in water supplies.

While chlorine is used primarily for disinfection in water treatment, it also has other uses in the treatment process. Chlorine can be used to remove iron and manganese, some kinds of tastes and odors, and some dissolved gases, such as Ammonia (NH_3) and Hydrogen sulfide (H_2S). The use of chlorine in these instances usually occurs early in the treatment process. Pre-treatment of raw water by pre-chlorinating used to be a fairly common practice until the mid-1970's. Concerns over disinfection by-products, such as TriHaloMethanes (THM's) and halo acetic acids, have almost eliminated the practice of pre-chlorination in the United States. The removal of taste and odors from raw water is now accomplished using Powdered Activated Carbon (PAC) or oxidizing agents other than chlorine, that do not result in chlorinated by-products. The growing concern regarding the use of chlorine as a disinfectant may eventually mean a change to one of these other oxidizing agents as the primary means of disinfection at sometime in the future.

CHLORINATION

Chlorine is the most widely used disinfectant because it is readily available, easily applied, and cheaper than other oxidizing agents such as potassium permanganate ($KMnO_4$), chlorine dioxide (ClO_2),UV disinfection, or ozone (O_3). Chlorine is applied in one of three forms; chlorine gas, chlorine powder (HTH), or an aqueous solution like chlorine bleach.

CHLORINE GAS

Chlorine gas (Cl_2) is compressed into a liquid for storage. It can be purchased in cylinders containing 150 or 2000 pounds of the liquefied gas. Chlorine gas is cheaper per pound than either of the other forms.

CHLORINE POWDER

disinfectant. Dry chlorine is 2-3 times more expensive, per pound of chlorine, than chlorine gas.

CHLORINE BLEACH

Chlorine bleach is a liquid solution of sodium hypochlorite (NaOCl). Bleach is usually 3 – 12% available chlorine and 88 – 97% water. Bleach is the most expensive form of chlorine and is normally used for disinfecting small wells and water lines. It is sometimes used for supply disinfection in very small water systems.

CHLORINE TREATMENT TERMS

Several terms are used to identify the various stages and reactions that occur when chlorine is used as a disinfectant. The basic unit of measurement for chlorination, or any other chemical treatment is milligrams per liter (mg/l) or parts per million (ppm). These are very small units reflecting concentrations that are essentially one part chemical for every million parts of water. To get some idea of how small a concentration this really is, it should be pointed out that 1% is equal to 10,000 mg/l or ppm.

CHLORINE DOSAGE

The chlorine dosage is the amount of chlorine that is added to the water. The dosage can be determined from the number of pounds of chlorine used and the number of millions of pounds of water treated.

CHLORINE DEMAND

Chlorine is a very reactive oxidizing agent. It will react with a certain substances that may be found in water. This list includes; iron, manganese, hydrogen sulfide, organic compounds and ammonia. When chlorine reacts with these substances, it loses it disinfecting properties. This is referred to as the chlorine demand. For chlorine to be effective as a disinfectant, the dosage must always exceed the demand that is present in the water. The chlorine demand may vary from day to day in a surface water supply. It is usually fairly constant in a ground water supply.

CHLORINE RESIDUAL

The chlorine that remains in the water, after it has finished reacting with those substances that represent the demand, is known as the chlorine residual. The concentration of the residual is determined by subtracting the demand from the dosage.

Dosage	*- Demand*	*=*	*Residual*
		or	
4.0 mg/l	*- 2.5 mg/l*	*=*	*1.5 mg/l Residual*

There are two types of residuals that result from the chlorination of water. They are free chlorine residual and combined chlorine residual.

Free Chlorine Residual

After the demand has been satisfied, any chlorine that is left will react with water to from hydrochloric acid and hyochlorous acid.

$$Cl_2 + H_2O > HCl + HOCl$$

The hypochlorous acid is the disinfecting agent and the presence of the hypochlorous ion ($OC1^-$) is measured to obtain the free chlorine residual.

Combined Chlorine Residual

Chlorine reacts with water to form hypochlorous acid. If ammonia is present, the hypochlorous acid will react with it to form compounds known as chloramines.

$$HOC1 + NH_3 > NH_2Cl + H_2O$$

Chloramines are found in three forms. They may contain from one (NH_2Cl) up to three (NCl_3) atoms of chlorine. The chemistry of the water and concentration of chlorine will dictate which of the chloramines are formed. Chloramines are weak disinfectants. They require longer contact times and higher concentrations to achieve disinfection than free chlorine residual. However, they do not breakdown as quickly as free chlorine and remain in the system longer.

Disinfection Requirements

Two factors must be taken into consideration when disinfecting drinking water. First, enough chlorine must be added to reach a predetermined concentration in the water. Then the bacteria must come in contact with the solution for a certain period of time. This is referred to as achieving the proper residual and contact time. Killing pathogenic bacteria requires a minimum of 0.2-0.4 milligrams per liter (mg/l) of free chlorine residual and a contact time of 20 minutes. The contact time can be reduced if the residual is increased. Viruses, Giardia, and Cryptosporidium are harder to destroy than the other waterborne diseases. Free residuals of 1.5-2.0 mg/l and much longer contact times may be required to destroy these organisms.

down reaction times requiring higher concentrations and longer contact times to achieve proper disinfection. A high pH impedes the formation of the hypochlorous acid and requires a higher dosage to obtain the proper residual.

Breakpoint Chlorination

When chlorine is added to water that contains no ammonia, the residual that is obtained will be free available chlorine. If ammonia is present, and the demand has been satisfied, some of the free chlorine will react with the ammonia to form chloramines or combined chlorine residual. As more chlorine is added, it will breakdown the chloramines that have been formed and the combined residual will begin to drop. A point will be reached where the residual will begin to rise again after all of the chloramines, that can be, are destroyed. There may be some combined residual left in the water at this point. From this point, any additional chlorine dosage will result in the formation of only free chlorine residual. This is known as the "breakpoint". All water systems that chlorinate their water will, in fact, practice breakpoint chlorination. They will add enough chlorine to the water to achieve a free chlorine residual of at least 0.2-0.5 mg/l.

The Breakpoint Curve shown below illustrates the formation and destruction of chloramines before free residuals are achieved. Every system's breakpoint will vary depending on the chemical makeup and chlorine demand of the raw water.

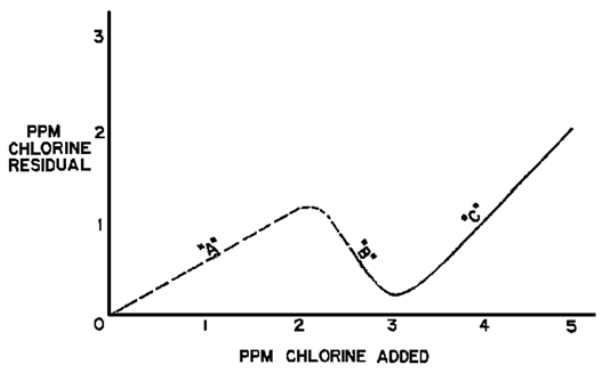


Figure 5.1 - ***Breakpoint Curve***

As chlorine is added to the water, it reacts with the ammonia that is present and a combined residual reading is obtained.

- "B" - When the dosage reaches 3ppm (mg/l), the breakpoint occurs and first free chlorine residual is obtained. Once the breakpoint has been reached, the free residual will increase at the same rate as the dosage.
- "C" - There may still be some combined residual in the water even though the breakpoint has been reached, but it will remain at this minimum level as long as the dosage is greater that 3 ppm (mg/l).

A common complaint received by many operators is that the water has a "chlorine odor." These odors are almost always caused by chloramines in the water rather than a free chlorine residual. Understanding the break point curve may help solve this problem.

The initial reaction to this type of call may be to reduce the chlorine dosage to reduce the odors. This is actually the last thing that you would want to do. First, the problem may be remedied by simply flushing the line in the area of the complaint. The odors are usually a result of stale water sitting in the lines. The free chlorine that was originally present may have broken back down into chloramines. Flushing will remove the stale water and the odor problem, until the water gets stale again. If flushing doesn't correct the problem, look at the breakpoint curve before adjusting the chlorine feed rate.

If the current conditions place us on the left side of the breakpoint there is no free residual present. This can be confirmed with a residual test. That means the water is on the "B" portion of the curve. Decreasing the chlorine dosage will result in moving further to the left on the curve into the "A" portion. Here the chlormine concentration is even higher and the odors may become worse instead of better. If the dosage is increased to the point where free chlorine residuals are present again, the amount of chloramines (and their odors) will be kept to a minimum.

Testing For Chlorine Residuals

There are three methods that are used to test water for chlorine residual. Two of them are field tests. The Ortho-Tolidine-Arsenite (OTA) test was the industry standard until the mid - 1970's. The problem with the OTA test was that iron and nitrites in the water would interfere with the test. In addition, OTA was found to be a carcinogen. It is no longer used for chlorine residual testing today. Instead, the Diethyl-p-Phenylene-Diemine (DPD) test is used for field work. It is similar to OTA test but is not known as the amperometric red. The vial is placed in front of the "color wheel" and the sample is compared to the color wheel and blank. There are two chemical packets for the DPD test. One is used for free chlorine and the other is used for total chlorine residual. Subtracting the free residual from the total residual will give you the combined residual.

General Chlorine Safety

Chlorine is a greenish-yellow gas. It is 2.5 times heavier than air. Chlorine gas is very corrosive. It turns into hydrochloric acid when it comes in contact with moisture (in the water, in the chlorine lines, or in your eyes or lungs). It does not support combustion . It can be harmful if inhaled in small quantities and fatal in larger doses. The following table lists the effects of chlorine gas in various concentrations in the atmosphere. Because of the potential for injury to workers and the general public from chlorine gas accidents, safety must always be the first consideration when handling chlorine.

Table 5.1 - ***Chlorine Symptoms***

SYMPTOM	CONCENTRATION
Noticeable odor	0.2 ppm
Irritation after several hours	1.0 ppm
Irritation of throat after a few minutes	15 ppm
Immediate coughing	30 ppm
Dangerous after 30 minute exposure	50 ppm
Lethal in minutes	1000 ppm

Chorinator Room

The chlorinator room should have a window in the door so that the operator in the room can be seen from the outside. The light and vent switches should also be located outside the room. The room should have ventilation located at floor level since chlorine gas is heavier than air and will settle in the lowest spot in the room.

The room should be kept between 60° F and 120° F. Below 60° F, chlorine gas forms chlorine hydrate, also known as "green ice," when it comes in contact with water. This

rises, the liquid expands and takes up more space in the cylinder. At 157° F the liquid will expand to occupy 100% of the cylinder. If the liquid expands any further the cylinder will rupture, causing a massive chlorine leak.

NEVER enter a chlorine facility without ventilating for several minutes first. The National Fire Code now requires that new gas chlorine facilities be equipped with a scrubber system that will remove chlorine gas that may be present in the ventilation exhaust. These systems must have a backup power supply to keep the scrubber running in the event of a power failure. Check with local Fire authorities before new chlorine facilities are built to make sure they will be in compliance.

Chlorine Storage

The room where chlorine cylinders or HTH drums are stored must be kept dry and well ventilated. Chlorine should always be stored in a room separate from other chemicals. Chlorine cylinders that are empty should be separated from those that are full. When not in use, all cylinders should be chained to the wall.

Chlorine Cylinders

NEVER remove the valve hood from a chlorine cylinder unless it is chained to the scales and ready to be put on the system. All cylinders should be chained to the wall or the scales unless they are being moved. Emergency repair kits are available that can be used to seal leaks in the broken valves or leaking cylinders. Every system that operates a gas chlorine system should have an emergency kit or be able to get access to one on very short notice.

To prevent the cylinder from rupturing when it gets too hot, every gas cylinder will have a "fusible plug" that is designed to melt at 157° F. There is one in the valve assembly of every 150 lb. cylinder and six (three on each end) in the body of very 1-ton cylinder. As one of these fusible plugs melts, it will allow the release of chlorine gas from the cylinder. This still represents a serious problem, but the release will be more gradual than it would if the tank ruptured.

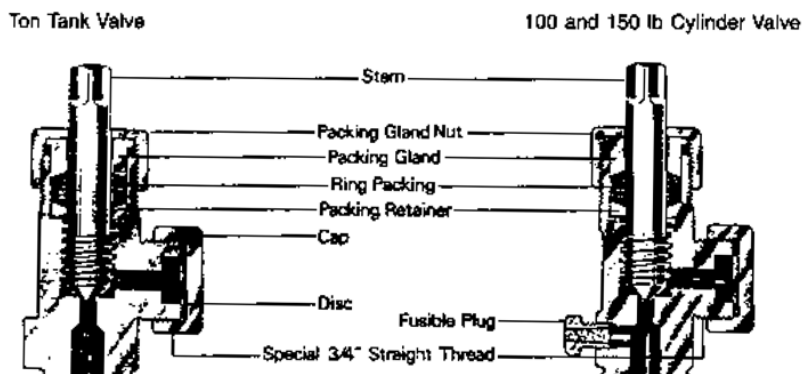
HTH Handling Safety

Powdered chlorine should be stored in a cool dry place separate from other chemicals. HTH must never be allowed to come in contact with petroleum products or organic solvents. If this happens, it will explode violently! This is also true for the other forms of chlorine, but is more likely to occur during the handling of HTH. Care must also be taken to avoid contact with the eyes or bare skin.

Respiratory Protection

Anyone involved in handling chlorine should have access to respiratory protection equipment. Chlorine gas forms hydrochloric acid when it gets in the eyes or lungs. This can result in serious injury or death depending on the concentration and exposure time. The damage caused by exposure to chlorine gas is cumulative. Several incidents involving minor exposure can contribute to serious health problems at sometime in the future.

There are two basic types of respiratory protection. One is the gas mask that uses a filtering device to remove chlorine. These are either a full-face mask or a mouth/nose type respirator. The other type of respirator is the self-contained breathing apparatus (SCBA). The SCBA unit is full-face mask with an air tank to provide the operator with fresh air to breathe when in hazardous atmospheres. Both of these devices may be rendered ineffective if the wearer has facial hair that interferes with the face-to-mask seal.



Gas Masks

The gas mask is designed to allow the operator time to escape the chlorine room when a leak occurs. THESE DEVICES ARE INTENDED FOR ESCAPE PURPOSES ONLY! A GAS CANISTER MASK MUST NEVER BE USED TO ENTER ANY AREA WHERE CHLORINE GAS IS PRESENT! If the release of chlorine drops the oxygen concentration below 12%, it is impossible to survive even if all the chlorine is filtered out. If an operator is wearing a canister mask he must

Self-Contained Breathing Apparatus (SCBA)

The SCBA unit must be used when working in a chlorine gas atmosphere. It has an air tank that allows the wearer to breathe uncontaminated air while attempting to correct a chlorine leak situation. The SCBA tank will hold enough air for approximately 30 minutes, depending on working conditions. When the air pressure drops to a point where there is about five minutes of air remaining in the tank (500 psi), an alarm will ring to signal the operator that it is time to exit the area and change tanks.

Chlorination Equipment

There are two ways to feed chlorine into the water system. Gas chlorination uses liquefied chlorine gas. Hypochlorination uses a positive displacement pump to feed a solution of dissolved HTH or bleach into the system. Many smaller systems will use a hypochlorination system because the equipment cost is lower. The solution of dissolved HTH or bleach is much easier to handle and presents less of a risk compared to a gas system. Gas chlorinating is used where the system requires larger dosages of chlorine than can be delivered by hypochlorination. Though capital costs are higher for gas chlorination, the chemical costs are significantly lower than when HTH or bleach is used.

Gas Chlorination

A gas chlorine system consists of one or more gas cylinders connected to gas chlorinator. The gas chlorinator consists of a pressure regulating valve, a feed rate indicator, a flow regulating device (a V-notch plug or needle valve), and an injector or ejector. The chlorine pressure regulating valve (CPRV) opens when a vacuum is created by the injector and maintains a constant negative pressure inside the chlorinator. The feed rate indicator consists of a ball floating inside a glass tube. The feed rate is indicated on the glass tube and is read in "pounds per day." The feed rate should be read at the widest point of the ball or bead. The feed rate is controlled using the needle valve or V-notch plug. Water flowing past the injector creates a vacuum that draws the gas into the system.

The maximum feed rate for gas drawn from a 150 lb. Cylinder is 40 pounds/day. The maximum gas feed rate for a 1-ton cylinder is 400 pounds/day. If these feed rates are exceeded, the tanks will frost over because heat can't pass through the tanks as fast as it is used to evaporate the chlorine from a liquid to a gas. This can also occur in situations where several tanks are manifolded to the chlorinator. If one of the cylinder valves is partially closed the other tanks may try to feed too much gas and frost over. When this happens, check the tank that isn't frosted for a closed valve or plugged pigtail line. Ton cylinders are sometimes set up to feed liquefied gas. These systems use an evaporator to change the liquid to a gas before it goes to the chlorinator. There is no limit to how much liquid chlorine can be removed from a cylinder since the heat for evaporation is supplied by an outside source. NEVER manifold cylinders together when feeding liquefied chlorine to an evaporator. Expansion tanks equipped

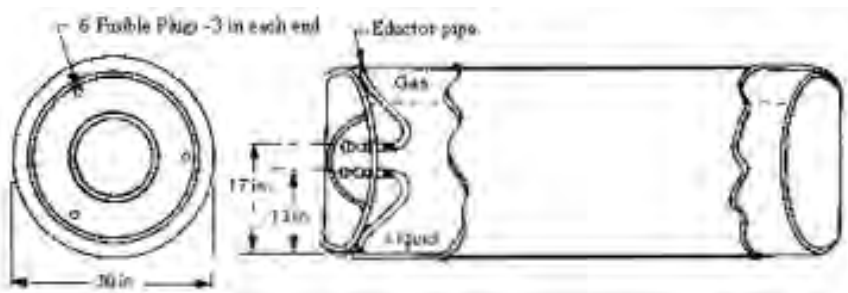
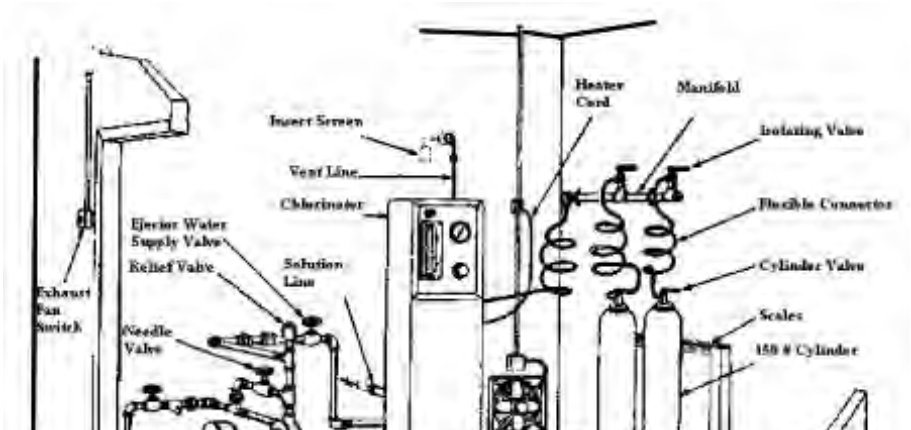


Figure 5.4 - ***Cross Section of a 1-ton Cylinder***



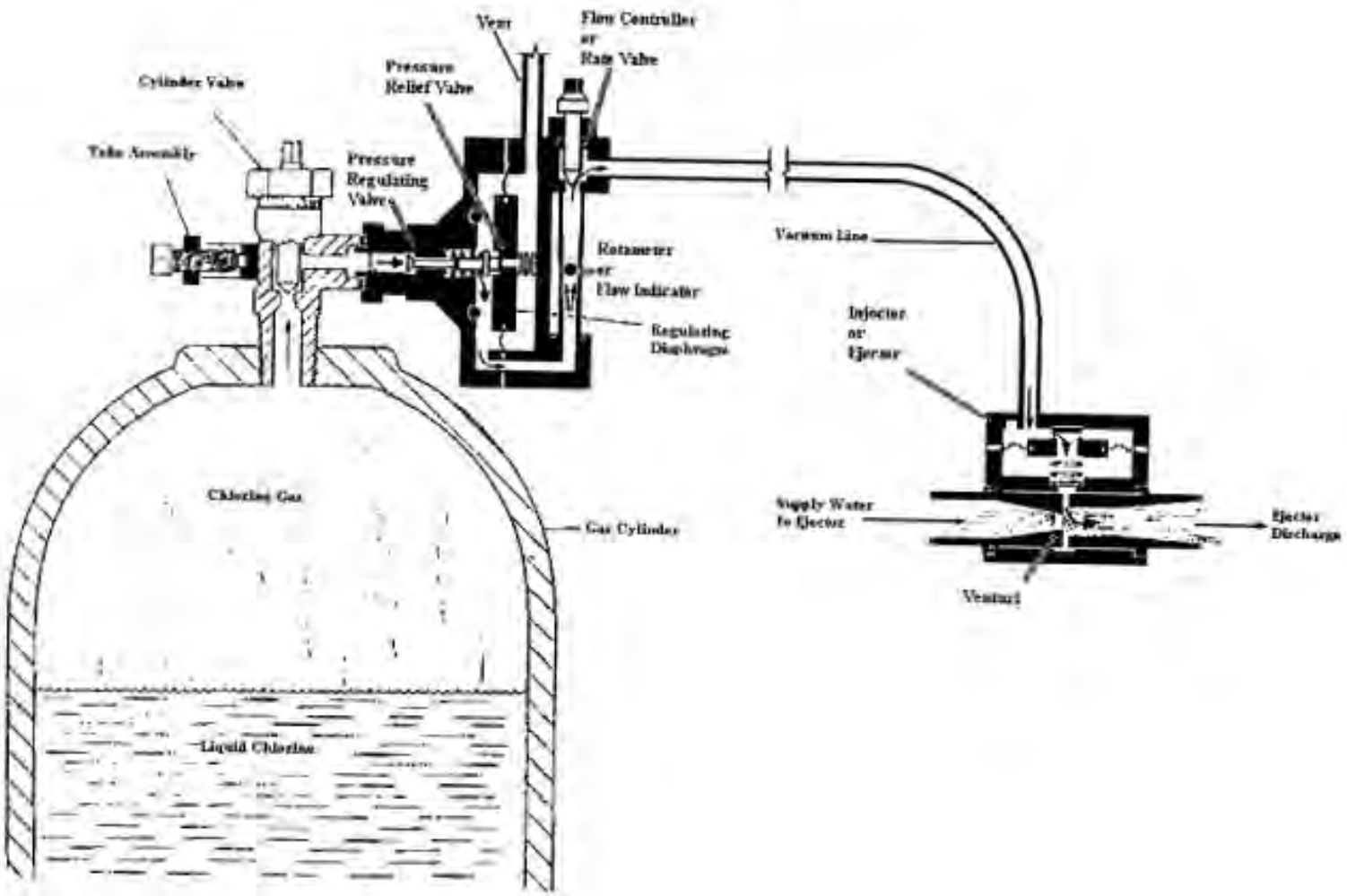


Figure 5.5 - ***150 lb Chlorine Gas Feed Unit***

Hypochlorination Systems

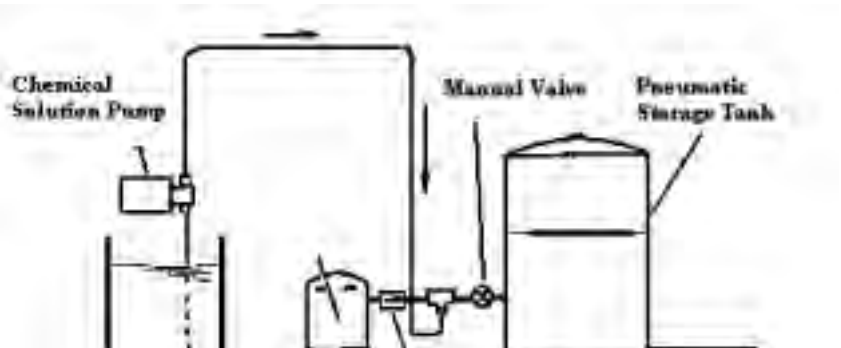
A typical hypochlorination system will consist of:

Table 5.2 - ***Troubleshooting Gas Chlorinators***

Symptom	Probable Cause
Low Feed Rate and Low Vacuum	Clogged Injector/Ejector
Low Feed Rate and High Vacuum	Clogged Gas Feed Line Closed Cylinder Valve Empty Cylinder
Feed Rate Jumps	Clogged Flow Controller/Needle Valve
Feed Rate Won't "Zero"	Dirty Flow Indicator/Rotameter
Chlorine Gas at Vent	Dirty Pressure Regulating Valve
No Vacuum	No Supply Water Vacuum Leak

- A solution tank holding bleach or an HTH solution.
- A chemical feed pump, usually a diaphragm-type pump.
- A tee into the well line as the point of application.

The solution tank should hold at least a one-day supply of chlorine solution. If the solution is bleach, it will have between 5.25% and 12% available chlorine (1/3 to 1 lb./gallon respectively). If HTH is used, add 1.5 pounds of HTH per gallon of water to achieve a 1.0-lb./gallon chlorine solution. Using breakpoint chlorination, adjust the stroke on the pump to achieve the desired dosage. Small systems may need to dilute the solution further, since the low flows may require feed rates too low for most feed pumps. Dilution of 5.25% bleach may be easier than HTH solutions.



The chemical feed pump consists of a diaphragm driven pump chamber, and two check valves. The check valves, that provide the one-way flow through the pump, can get clogged with lime deposits. This occurs because the HTH that is added to the solution tank is 30-35% lime. The strainer on the pump suction line should be located several inches above the bottom of the solution tank to prevent lime and grit from being drawn into the pump and fouling the check valves.

If the check valves get fouled, the pump will not pump any solution. Flushing the line with clean water or a weak acid, like vinegar, may also correct the problem. In severe cases the valves may have to be disassembled and cleaned. Always make sure the pump is primed before putting it back into service. It may also be advantageous to locate the pump so that it has a positive suction head.

Emergency Response Procedures

When chlorine systems are located in areas where a chlorine release might endanger the general public, the water system is responsible for developing an emergency response program.

The following steps should be followed when a leak poses immediate danger to employees or the public:

1. Evacuate, in an upwind direction, to high ground.
2. Once evacuation is complete, notify emergency medical units of casualties and begin administering First Aid to the injured.
3. Notify local fire and police

c. Location of chlorine facility
d. Current wind direction

4. Notify County and State health agencies.

Table 5.3 - ***Components of an Emergency Response Plan***

COMPONENTS OF AN EMERGENCY RESPONSE PLAN

* **Containment and repair of the leak**
* **Notification of other emergency preparedness agencies**
* **Evacuation plans for the general public**
* **Medical evacuation for casualties**

Ultraviolet Light

Background

One of the numerous forms of energy is electromagnetic. Electromagnetic energy travels in wave forms and is found in a wide range of frequencies all the way from radio waves to X-rays and includes visible light. Electromagnetic energy is divided into bands based on frequency. One of these bands is the ultraviolet band. This is a band of light that ranges from 200 to 390 nm (nanometers). Bacteria, when exposed to electromagnetic energy at approximately 260 nm are prevented from multiplying and thus die off. A mercury vapor light will produce an ultraviolet wave at 254 nm and has been found to be very effective in the destruction of bacteria and viruses.

Not Effective With Giardia

Ultraviolet has not been found to be effective in the destruction of *Giardia* cyst because it cannot penetrate the hard wall of the cyst.

Using Ultraviolet Light

Ultraviolet light is not selective. That is, it will kill all bacteria in its path, providing that the water is clean (less than 15 ntu), free of color, the water depth is no more than three inches and an appropriate amount of energy is applied. UV leaves no residual, thus requiring the addition of chlorine or some other disinfectant in order to maintain a residual in the system. Typically, in drinking water systems, UV is more expensive than chlorine.

UV Equipment

A UV device is fairly simple, it is a stainless steel cylinder, housing a mercury vapor light. Water is passed though the cylinder and thus exposed to the light. Slime can build up on the tube and reduce the effectiveness of the device. Many of these devices

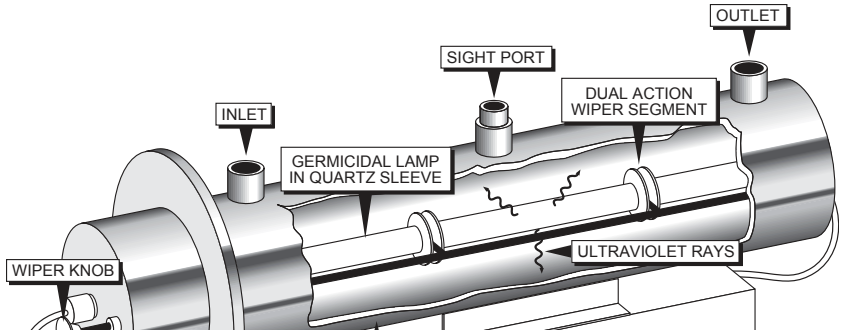
References

Office of Water Programs, California State University, Sacramento, *Water Treatment Plant Operation*, Volume 1, 4th ed., Chapter 7

Office of Water Programs, California State University, Sacramento, *Water Distribution System O&M*, 4th ed., Chapter 6.

Office of Water Programs, California State University, Sacramento, *Small Water System O&M*, 4th ed., Chapter 5

ACR Publications, Inc., Skeet Arasmith, *Introduction to Small Water Systems*, Chapter 4



Basic Study Questions

1. What is meant by disinfection?

2. What are some of the uses for chlorine other than disinfection?

3. What is a free chlorine residual?

4. What are trihalomethanes?

Basic Sample Test Questions

1. Locate chlorine leaks with:
   A. Bleach
   B. Ammonia
   C. Hydrochloric acid
   D. Water

2. Chlorine gas is 2.5 times heavier than air.
   A. True
   B. False

3. Chloramines are:
   A. Formed when chlorine reacts with ammonia.
   B. Weaker disinfectants than free chlorine.
   C. Responsible for most chlorine odor complaints.
   D. All of the above

4. If a single chlorine cylinder freezes, what is wrong?
   A. Valve is too far open
   B. Vacuum is too high
   C. Feed Rate is too high

5. Sodium Hypochlorite is what is found in which type of chlorine?
   A. Bleach
   B. HTH
   C. Gas

Advanced Study Questions

1. What two acids are formed when chlorine reacts with water?

2. Why should chlorine rooms be kept below 120°F?

3. What is the maximum gas feed rate for a 150 lb. cylinder?

Advanced Sample Test Questions

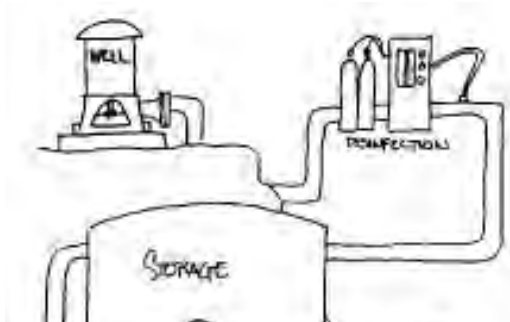
1. Breakpoint chlorination
   A. Results in a free chlorine residual
   B. Occurs when a 0.5 ppm dosage increase raises the free residual by 0.5 ppm
   C. Very seldom causes chlorine odor complaints
   D. All of the above

2. Chloramines
   A. Are a weak disinfectant.
   B. Are formed when chlorine reacts with ammonia.
   C. Are usually responsible for most chlorine odor complaints.
   D. All of the above.

3. If gas is venting from the relief valve on a chlorinator where should you look for the problem?
   A. The injector
   B. The rate of flow control valve
   C. The rotameter
   D. The pressure regulating valve

4. When two ton cylinders are feeding gas and one of them is frosted, what might be the problem?
   A. The feed rate is too high
   B. The line on the frosted tank is clogged
   C. The valve on the unfrosted tank
   D. The injector is clogged

5. There is low vacuum on the system and the flow rate is low when the rate valve is wide open, what is the problem?
   A. The feed rate is too high
   B. The injector is clogged
   C. There is a clogged feed line
   D. The rotameter is clogged



Fluoride has been added to many water systems around the country for the past 40 years. It is used to prevent tooth decay. Fluoride makes the enamel of the teeth harder and more resistant to the bacterial enzymes and acids that can damage the enamel and result in cavities. The problem with fluoride is that it also causes the other bones of the body to become harder and more brittle. This can cause a higher than normal number of broken bones in older individuals that drink water with an excessive amount of fluoride. This is why fluoride is a Primary Inorganic contaminant and is regulated by the Safe Drinking Water Act. The MCL for fluoride is two-tiered. Notification is required at 2 mg/l and a violation occurs when the level exceeds 4 mg/l.

Fluoride can be naturally occurring in a groundwater system. If concentrations exceed the SDWA MCL, the system will have to notify the public every month that the standard has been exceeded . In systems with a high fluoride concentration, people will tend to develop gray or mottled teeth. The optimum range for fluoride concentration is considered to be between 0.8-1.2 mg/l. The range is based on average ambient air temperature. Higher annual average temperatures require lower dosages, since people drink more water when it's hot.

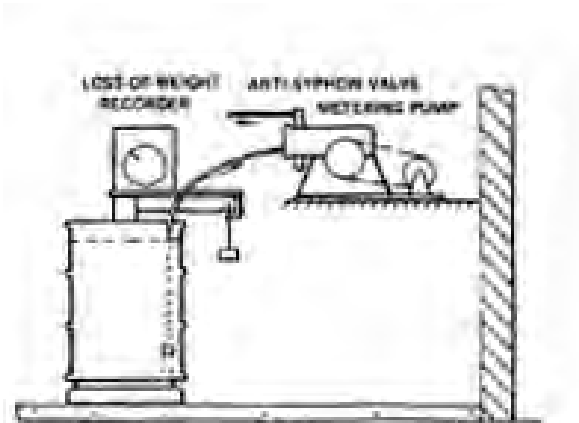
FLUORIDE FEED SYSTEMS

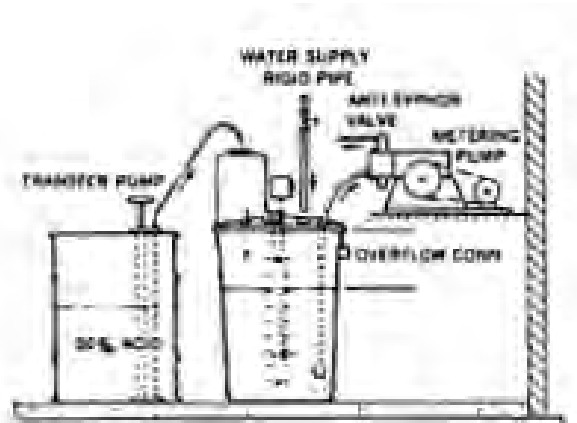
Fluoride is commercially available in several forms. It can be purchased in a dry form as sodium fluoride (NaF) or sodium silicofluoride (Na_2SiF_6). It is also available as a liquid. The liquid form of fluoride is available as hydrofluorosilicic acid (H_2SiF_6) This chemical is also sometimes called fluosilicic acid and hydrofluosilicic acid.

Fluoride is normally fed into the system as a solution, although dry chemical feeders can be used in very large systems. Hydrofluorosilicic acid is more commonly used for liquid feed systems. Positive displacement diaphragm metering pumps, like those used for hypochlorination sites, are used to feed the fluoride into the system. These pumps are subject to the same types of operational problems. These issues are covered in the Mechanical Systems O&M chapter.

SODIUM FLUORIDE SATURATORS

Small systems that use sodium fluoride will probably dissolve it and feed the solution with a metering pump. The equipment used to dissolve the dry chemical is called a saturator. At saturation the fluoride strength will remain constant. Water quality will impact the actual saturation concentration. Hard water can create scaling problems as calcium and magnesium fluorides precipitate out as scale. Water with over 10 mg/l of hardness can create scaling problems. Water softeners must be used upstream, in most cases, to prevent these scale deposits.





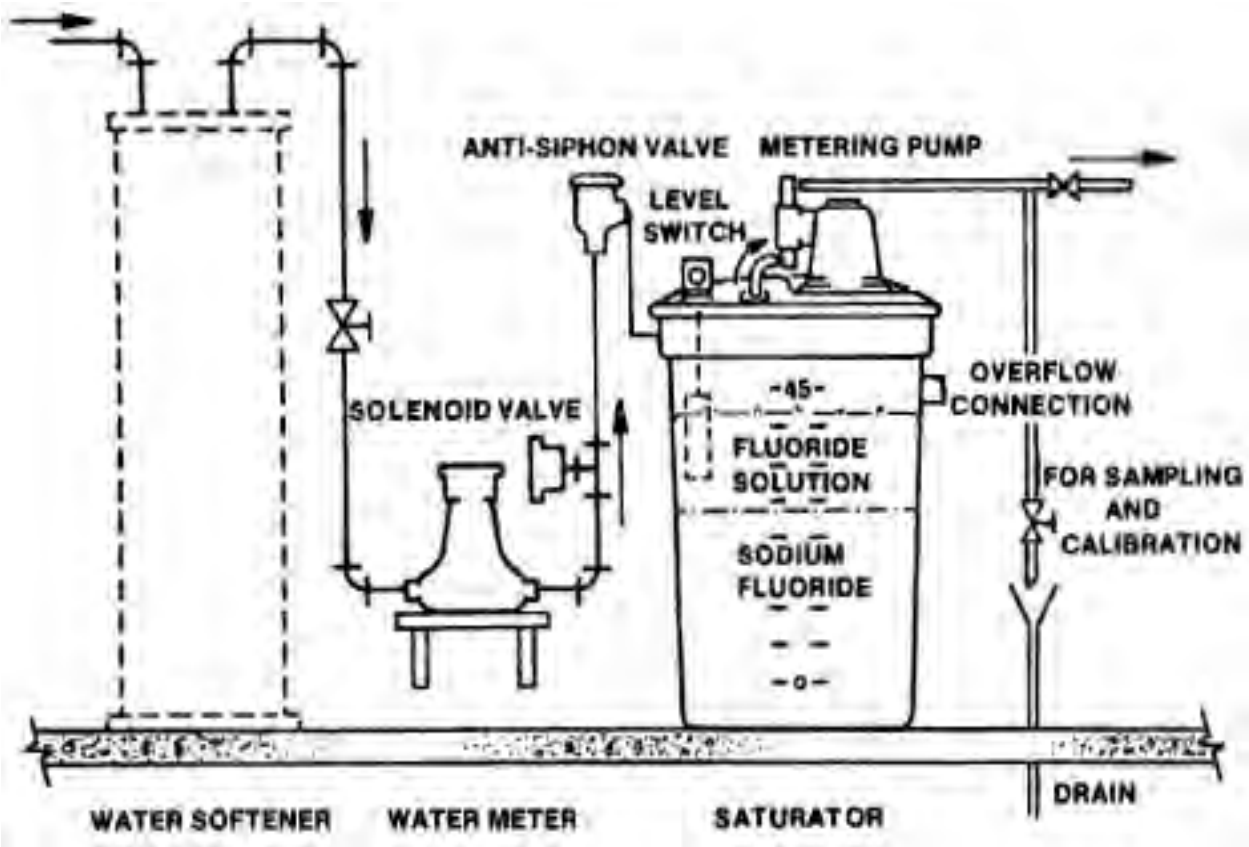


Figure 6.2 - ***Sodium Fluoride Saturator***

Monitoring Fluoride Concentrations

A system that adds fluoride must take care not to overdose and exceed the SDWA MCL. Although a high concentration for a short duration will not cause any immediate health risks to customers, a violation of the SDWA will require public notification. This can lead to a public relations problem that could have been avoided with more careful monitoring. This is particularly important in systems that have naturally occurring fluoride in the raw water. Systems that add fluoride should monitor the concentration in the system on a daily basis.

References

Office of Water Programs, California State University, Sacramento, *Water Treatment Plant Operation*, Volume 2, 4th ed., Chapter 13
NMED, *Drinking Water Regulations*

Basic Study Questions

1. Why is fluoride added to drinking water?
2. Which chemicals can be used as sources of fluoride?

Basic Sample Test Questions

1. What is the optimum concentration of fluoride in water?
   A. 0.2-0.4 mg/l
   B. 0.8-1.2 mg/l
   C. 2.0-4.0 mg/l
   D. 8.0-12.0 mg/l

2. What factor is used to determine the optimum dosage of fluoride?
   A. Air temperature
   B. Water temperature
   C. Fluoride solution temperature.
   D. pH

Advanced Study Questions

1. What type of equipment would be used to feed liquid fluoride?
2. Why is fluoride an Inorganic Primary Contaminant?

Advanced Sample Test Questions

1. Liquid fluoride is delivered as:
   A. Sodium Fluoride
   B. Hydrofluorosilicic acid
   C. Sodium Silicofluoride

2. If a system adds fluoride, fluoride testing should occur:
   A. Daily
   B. Weekly
   C. Yearly
   D. Every three years

PIPED SYSTEM

A piped system can vary from simple to extremely complicated. Most piped systems have the same basic components; pipes, valves, fire hydrants, service connections and reservoirs. Piped systems may also have pumping stations. The following is a description of the various components that could be found in a piped system excluding pumping.

MAIN LINE PIPING MATERIALS

GRAY CAST IRON PIPE (GCIP OR CIP)

Pit Cast & Spin Cast

Gray cast iron pipe used in the waterworks industry is manufactured to meet AWWA[1] standard C-106. This is some of the oldest piping material in use today. Over 200 cities in the US have pipe installed that has been in use for over 100 years. Gray cast iron pipe was first manufactured using a process called pit casting. In this process the molten iron was poured into a mold and allowed to cool. In 1925 a process called spin casting was developed. In this process molten iron is injected into a spinning mold. The result is a pipe of consistent diameter and wall thickness.

DUCTILE CAST IRON PIPE (DCIP OF DIP)

Ductile cast iron is not an alloy. It is formed by injecting magnesium into molten cast iron. The treatment changes the carbon structure of cast iron from a flake to a spherical shape. This alteration results in a material of high strength. It can withstand high impacts, both internally and externally, it has great beam strength (won't break easily), and is much better in resisting corrosion than gray cast iron.

Table 7-1 - ***Pipe Types***

ABBREVIATIONS FOR WATER PIPES

- **Cast Iron Pipe (CIP or GCIP)**
- **Ductile Iron Pipe (DIP or DCIP)**
- **Steel Pipe (ST)**
- **Asbestos-Cement Pipe (AC)**
- **Concrete Cylinder Pipe (CCP)**
- **Reinforced Concrete Pipe (RCP)**
- **Polyvinyl Chloride Pipe (PVC)**
- **High Density Polyethylene Pipe (HDPE)**

Manufacturing Process

Ductile cast iron pipe is commonly manufactured using the spin cast system, in which molten cast iron is injected into a spinning mold. The mold may be either metal or sand lined.

Size

DCIP pipe is available in sizes ranging from 3" to 54" and comes in 18' and 20' lengths. The hydraulic capabilities and corrosion resistance of the pipe are enhanced by lining it with a thin coating of cement mortar. Under these conditions the Hazen and Williams "C" Factor[2] for the pipe is 140.

Joints & Fittings

Ductile cast iron pipe is commonly connected using mechanical joints[3] (M.J.), flanges or the various common rubber ring push-on joints [see Figure - 7.2]. Fittings used are commonly made of gray or ductile cast iron and use M.J. or hub joints [see Figure - 7.3]. Service taps are made by directly tapping the line or using service saddles.

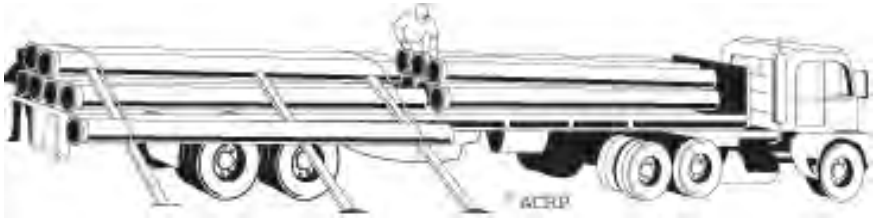


Figure 7.1 - ***DIP on Truck***

[1] AWWA - American Water Works Association - An association of waterworks personnel, equipment manufacturers, suppliers,

Figure 7.2 - ***Rubber Ring Push-on Joint***

Figure 7.3 - ***Mechanical Joint***

ASBESTOS CEMENT (A.C.) PIPE

A.C. pipe is also referred to as Transite™, which is the trade mark of the Johns-Manville Corporation, one of the first U.S. manufacturers of the material. The pipe is made by spraying a solution of portland cement, long fibrous asbestos, silica sand and water onto a spinning anvil. The pipe is then shaped and placed in an autoclave to dry.

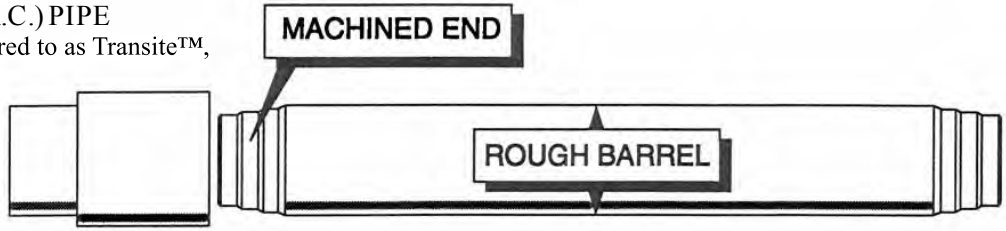


Figure 7.4 - ***Asbestos Cement (A.C.) Pipe***

Size

A.C. pipe is available in sizes from 3" to 36" and comes in a standard length of 13 feet. There are two common dimensions associated with A.C. pipe. The outside dimension of the pipe itself is referred to as the “rough barrel”. The outside dimension where the coupling fits is referred to as the “machined end”. To reduce the amount of field machining required during construction the manufacturers make short sections of pipe that are 3’3" and 6’6" in length. When the short sections are manufactured similar to the regular pipe, they are referred to as MEE (machined each end). However, short sections are also manufactured with machined end dimensions as the outside diameter. This type of section is referred to as MOA (Machined Over All).

Joints

may be made by direct tapping of the line or by using a service saddle.

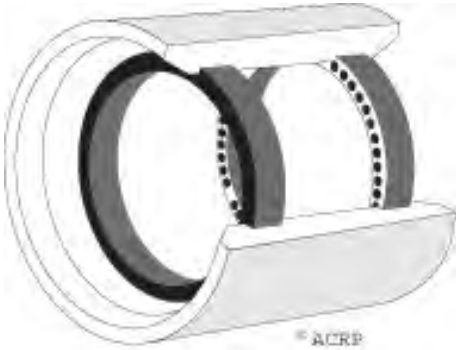


Figure 7.5 - ***AC Coupling***

Steel Pipe

Steel pipe used in the waterworks industry in sizes above 6 inches is manufactured to meet AWWA C-200 standard. Smaller diameter lines used are NSF[4] (National Sanitation Foundation) approved. These materials may be manufactured by anyone using a variety of means. These materials fall into two categories; mill pipe and fabricated pipe.

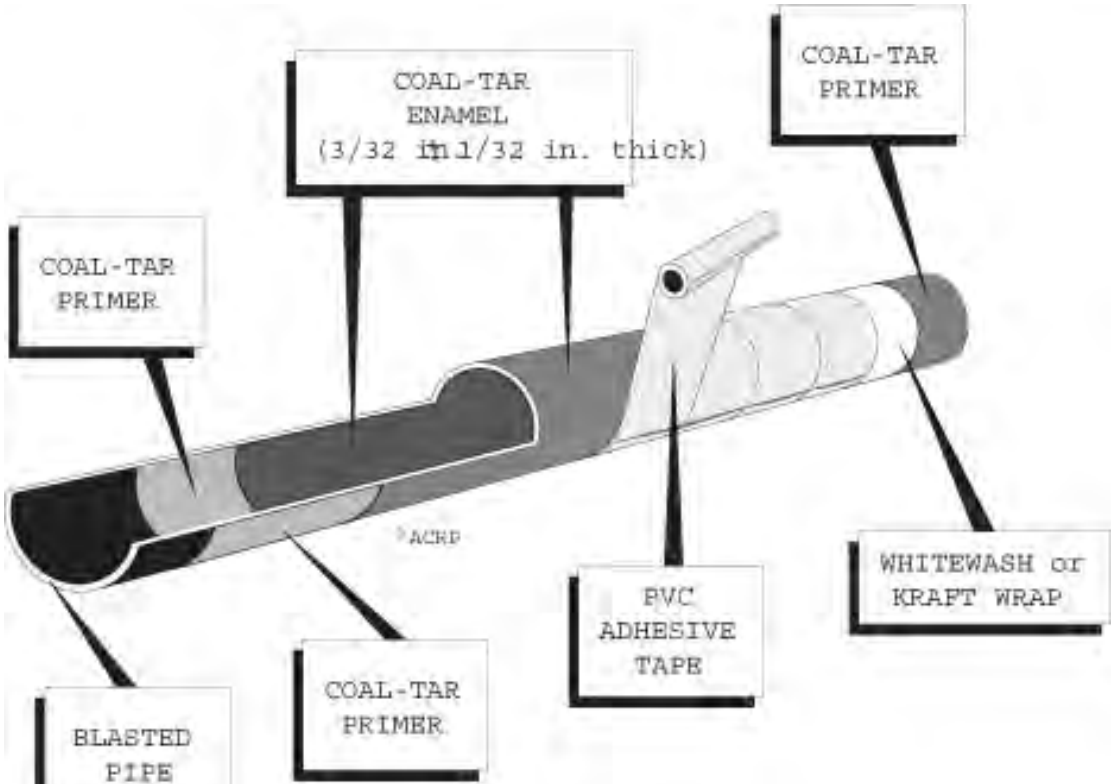
Size - Mill Pipe

Steel mill pipe is available in sizes from 1/8 inch to 36 inches and commonly comes in 21 foot lengths. Two of the most common mill pipes used in the waterworks industry are Standard Weight and Scheduled Pipe. The two common Scheduled Pipes are Schedule 40 and Schedule 80. In sizes from 1/8 inch through 10 inches, standard weight and Schedule 40 pipe are the same OD and wall thickness. From 12 inches through 24 inches, the wall thickness of the standard weight pipe remains constant while the schedule 40 pipe wall thickness increases with an increase in diameter.

Joints

Steel pipe is coupled by a variety of methods; threaded couplings, welded couplings, Dresser™ type couplings, Victaulic™ couplings, flanges and rubber ring push-on joints.

Figure 7.6 - ***Dresser Type Coupling***



PVC - Polyvinyl Chloride Pipe

PVC water pipe is made from unplasticized polyvinyl chloride. The material is heated and shaped by forcing it through a die in a process called extrusion. Although the material was introduced into the U.S. in the late 1940's, it only gained wide acceptance from the larger water systems when a thicker walled material was developed and an AWWA standard was adopted. The standard that governs most of this thick walled PVC pipe is called C-900. This distinguishes it from other PVC water pipe that has a thinner wall.

The material is light weight and easy to install. It is virtually corrosion free and therefore has gained relatively wide acceptance as a major pipeline material.

Figure 7.8 - ***PVC - Integral Bell & Spigot Joint***

Types & Sizes

PVC used for water lines is generally available in sizes of 1/2 inch through 16 inch. There are three common types of PVC utilized; Schedule pipe, Pressure pipe and Class pipe. The primary difference between these various pipe types is wall thickness, outside diameter and burst strength.

Size & Lengths

At the time of printing, scheduled pipe was available in sizes from 1/8 inches through 24 inch, Pressure pipe is available in sizes from 1.5 thru 12 inch and Class pipe is available in sizes from 4 thru 12 inches. All three types are available in standard 20 foot lengths. PVC pipe has a Hazen and Williams "C" fac-tor of 150. PVC pipe is available in various wall thicknesses and outside diameters. This has resulted in considerable confusion about which pipe is which. In the discussion below we offer some clarification.

Joints

PVC Class and Pressure pipe can be connected using either an integral bell and spigot process or a double ended bell. In either case the gasket is a rubber material and the joints are made by lubricating the pipe and pushing it into the coupling or bell.

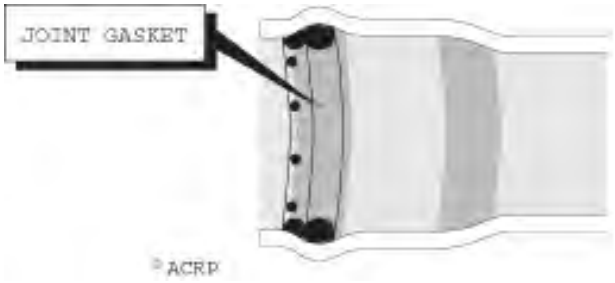


Figure 7.9 - ***PVC Integral Bell Cross-section***

Concrete Pipe

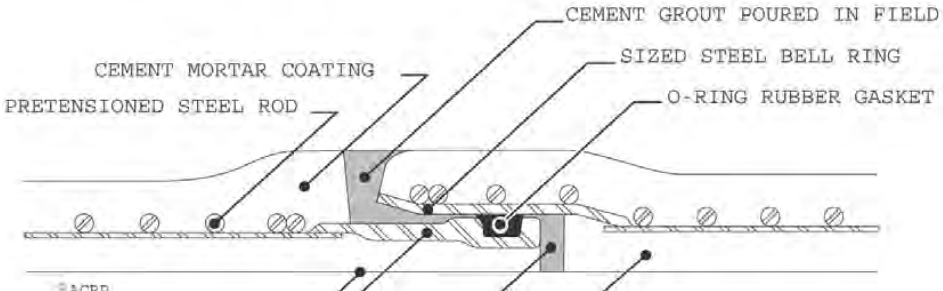
Concrete pipe used in the waterworks industry is manufactured in accordance with AWWA standards C-301 & C-302. This piping material is primarily used for large diameter lines. Several types of concrete pressure pipe are used. However, the most common types of concrete pipe used are manufactured by wrapping a wire around a steel cylinder and using a cement coating to cover the steel cylinder both internally and externally.

Prestressed Concrete Pipe

Concrete cylinder pipe is also available in various prestressed forms. The prestressed pipe is made similar to the pretensioned, except that the wire wrap is much smaller and under much higher tension (up to 170,000 psi). This material is usually used only on large diameter lines. (commonly 36" to 240")

Pretensioned Concrete Cylinder Pipe

One of the most common concrete pressure pipes is referred to as pretensioned concrete cylinder pipe. (A cross section of this pipe is shown below.) This pipe starts from a steel cylinder. The cylinder is wrapped with a steel rod that is under tension. The interior and exterior of the pipe



Sizes of Cylinder Pipe

Pretensioned concrete cylinder pipe is available in sizes from 12" to 42" and in standard sections of 32 and 40 foot lengths.

Joint Types

This pipe is connected by bell and spigot rubber ring push-on joints (see the drawing on the previous page). Once the joint has been connected the exposed steel must be coated with concrete to protect the steel cylinder from corrosion.

HDPE Pipe

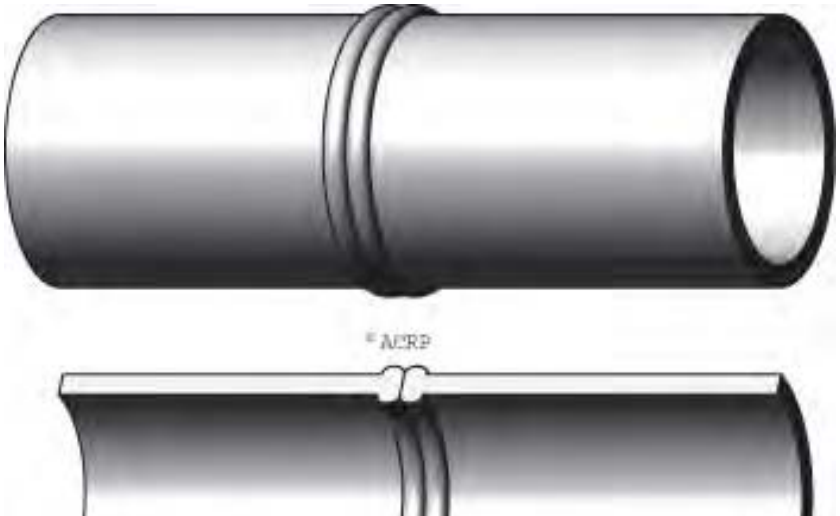
High Density Polyethylene (HDPE) is manufactured using a heat extrusion process and polyethylene resins. The material is used for water services lines and main lines. There are a wide variety of HDPE piping materials manufactured. The primary material used for drinking water is manufactured to meet ASTM standards D1248 and AWWA C-906. The designation used to identify the resin used to produce this piping material is ASTM and the PPI (Plastic Pipe Institute) designation is PE 3408.

Size & Lengths

HDPE, PE 3408 is manufactured in pressure ratings from 65 psi to 220 psi. The most common HDPE used in water systems has a pressure rating of 160 psi. HDPE pipe is available in sizes of 3/4 inches through 16 inch. Sizes of 3/4 inch through 1.5 inch is available in rolls of up to 500 feet, 2 inch is available in 350 foot coils. Larger sizes, 3 inch and up, are available in 20 and 40 foot lengths. All material used for drinking water is manufactured to IPS (Iron Pipe Size) outside dimensions. The wall thickness of the pipe will increase with an increase in pipe diameter. The wall thickness is selected to maintain a ratio of pipe OD divided by wall thickness of 11. This is called the SDR (Standard Dimension Ratio).

Joints

The most common connection for HDPE pipe is a heat fused weld. The pipe is commonly connected using a butt welding process. The welding of HDPE takes special equipment and special training. Small diameter (less and 2 inch) can be connected using compression fittings and stainless steel or brass insert fittings. There are special stainless steel adapters that allow the pipe to be connected using the Victaulic type of coupling. Flanged connections can be made by welding a butt or socket weld flange to the pipe. Repairs can be made to the pipe using typical cast iron couplings, providing a special stainless steel insert is placed in the pipe to prevent collapsing of the pipe.



Bedding & Backfilling the Pipe

Bedding

Examine Figure 7.12 - *Pipe Bedding*, and note the following Right and Wrong ways of bedding:

1. Right – Backfill material completely covers the trench bottom.
2. Right – Couplings are not resting on the trench bottom.
3. Wrong – Backfill material has only been placed under the couplings.
4. Wrong – There is no backfill material and the pipe is not resting on the original trench bottom.
    - Couplings – Never allow couplings to rest on or settle down to original trench bottom.
    - Pipe – Make certain that pipe barrel is given an even bearing for its full length.

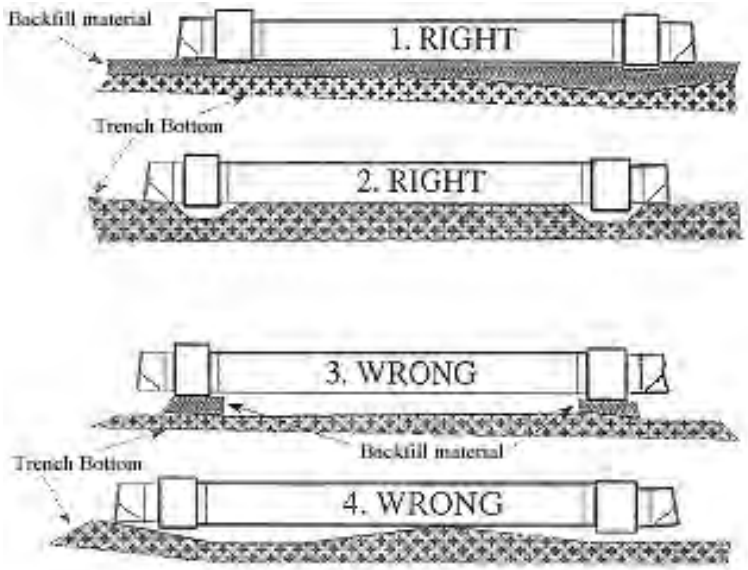


Figure 7.12 - ***Pipe Bedding***

Backfill Considerations

The type of backfill material used is also a very important factor in the protection of all pipes, especially plastic pipe. If rocks or other abrasive material are present in the backfill, a sharp edge may cut into the line and cause a leak to develop. To prevent this kind of damage from happening, a select backfill material, preferably sand, should be used. The backfill should be carefully added and properly tamped to help support trench loads. The backfill material should completely surround the pipe. It should be tamped when the pipe is still half exposed and again when the pipe is covered by about 6 inches of material.

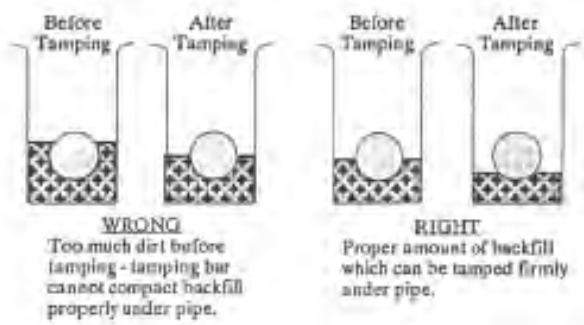


Figure 7.13 - ***Backfilling the Pipe***

An important step in the construction job is the initial backfill over and around the pipe. It is estimated that 90% of underground pipe failures can be traced to lack of proper bedding and initial backfill. The operator should follow these steps:

- Bedding material should be added around the pipe up to over one-half of the diameter and compacted to provide support to the underside of the pipe.
- Next the pipe should be covered to 12 inches above its top side with compacted bedding material or compacted select backfill material. Proper bedding and good side-fill compaction will result in a 150% increase in supporting strength.
- The remaining trench backfill should be select material. Native backfill can be used if it contains no large rocks, lumps of compacted soil or pieces of organic matter such as root, limbs, or grass.
- Backfill should be compacted by mechanical

Plastic pipe should not be used under railroad crossings, highways, or anywhere that vibration and stress loads are a problem. These situations call for iron or steel pipe that can withstand these external pressures. If a plastic line is used, the PVC pipe should be installed in a steel conduit. Even if the reinforced PVC is used, a conduit is worth its cost. In addition to this, a conduit will make it much easier to replace the damaged water main. Keep PVC water lines as far as possible from highway right of ways. All easements to both highways and private property must include access for construction, repair and inspection.

Finally, PVC lines are impossible to locate with a metal detector. This can present problems when repairs must be made. To remedy this situation, a roll of metallic tape can

Pipe Pressure Ratings

Some types of pipe are available in more than one pressure rating. PVC pipe is available in several pressure ratings. Schedule 40 and Schedule 80, the latter being rated at a higher pressure, are the most common types of PVC. The difference in the dimensions of these two is in the pipe wall thickness. They will both have the same OD, but different inside diameters, requiring different sizes of clamps or fittings.

Separation of Water and Sewer Lines

When installing new water lines certain precautions must be taken when crossing or laying parallel to sewage lines. To prevent cross-connections or contamination of the drinking water, the water line should be separated by at least 10 feet horizontally when the lines are side by side. If the water line crossed a sewage line, the water line must be on top and the lines separated by a vertical distance of at least 18 inches. If the sewer line crosses over the water line it must have a 20 foot water tight casing around it with the water line being 10 feet from either end of the casing. It is preferable to cross as close as possible to the middle of the section of water line so the ends of both lines are as far from each other as possible.

Cleaning Water Lines

Some systems find that the build up of scale, tuberculation, or bio-slime can reduce the carrying capacity of the distribution system piping. Pigs can be used to clean the inside of the piping. A pig is a bullet shaped foam swab that can be pushed through a pipe to clean it. The pig must be inserted through a special launch site and is propelled through the pipe by water pressure until it reaches an extraction point. It scours the line and pushes the debris ahead of it.

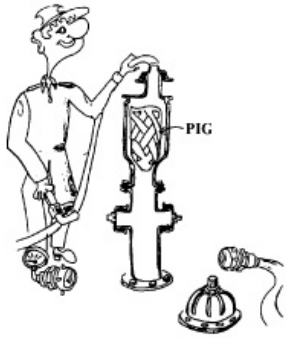


Figure 7.14 -
Launching a Pig

Water Line Repairs

Broken water lines are a major concern of all water operators. They not only create the problem of disruption of service but also represent the loss of revenues from the water that is lost. This can result in excessive amounts of water that is unaccounted when comparing production and billing. This level should not exceed 10% of production. The first concern when a leak is reported, or detected by a rapid drop in the storage level, is to locate the point where the line is broken.

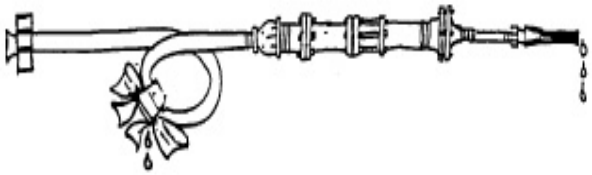
Locating Leaks

Leaks mainly occur at the joints. Often large leaks will be spotted and reported by customers. If not, look for grass and weeds that are greener and larger than others during the growing season. For rural areas, one method of locating losses in excess of 10% is to isolate valves to guide you to the source of the leak. This method works only when the system is as near static conditions as possible. This means working at 2 or 3 A.M. First, shut off the pumps, so water will be flowing only from the storage tank into the distribution system. If you are purchasing water, close the valve near the master meter.

Now that you know from which direction water is flowing, go to the first valve on the main line and slowly begin to close it. When the valve is almost closed, place the bottom of valve wrench on the valve nut and the top against the bone in front of your ear. If water is moving rapidly through the valve, you will hear a “singing” noise. If you hear no such noise, then the leak is a small one or the cause of the water loss is not a leak. If you did hear the “singing”, completely open the valve and go to the next valve on the main line and repeat the procedure. If the noise is again heard, open the valve and continue to the next one.

Continue to go to each valve until you come to one where the noise cannot be heard. That tells you that there is a leak between this valve and the last one. If there are several branch lines between the two valves, partially close each and listen to it. When the right line is located and if it is several miles long, continue to move down the line listening to valves. When the source of the leak is isolated within a certain section, the remaining work can be accomplished during a more reasonable daylight hour. Be certain that all of the valves that were closed are opened and any pumps turned back on.

During the day, close the valves on each end of the section to be isolated. Turn off all of the curb stops on that line except one. At that one residence, connect a pressure gauge and watch it closely for thirty minutes. A slow continuous drop in pressure would indicate a leak. A steady pressure followed by a quick drop would indicate an illegal tap or that someone has turned their water back on. If there is a leak, walk directly over the line in that section and note any damp



locating a leak that has not surfaced is to drive a metal rod into the ground and note if the end of the probe is wet or if water begins to rise in the hole that is created.

Repairing the Leak

Once the leak has been located it is a good public relations practice to inform residents in that area that service may be interrupted while the repair is being made. All businesses in the area should also be notified so that equipment that might be damaged by the loss of water service can be shut down. This may take a little extra time but may also save a lot of unnecessary hard feelings between customers and the water system.

1. Assemble the proper equipment and notify the customers of the interruption. If the work is going to happen at some time in the future, notification should happen at least 24-48 hours in advance.
2. Isolate the break by shutting all gate valves necessary to stop the flow of water. Tag each valve according to OSHA LOTO guidelines. Identify all closed valves on a map.
3. Mark the line using a line locator or probe. A line can also be spotted by siting along two or more valve cans. Line spots should also be called in for other utilities before attempting to excavate the leaks. Contact NMOC (New Mexico One Call), by phone, dial 811. NMOC will coordinate locating and marking all underground services.
4. If the excavation is going to be over 5 feet deep, make sure that the proper shoring equipment is available or that enough of the street has been closed to adequately slope the trench according to OSHA guidelines. The area around the leak should be large enough to work comfortably, usually one foot on either side of the pipe. A sump hole is dug at one end of the trench to allow the water to flow away from the leak and be pumped or dipped out. Any excavation that is over four feet deep must have a ladder for access. The ladder must extend at least 3 feet above the excavation. They must be located so that no workers are more than 25 feet from a ladder. All spoil must be placed at least 2 feet from the side of the trench.
5. The type of repair clamp or coupling is selected once the line has been uncovered. A wrap around repair clamp can be used if the leak is a hole from a blown service or puncture. Lines that developed cracks along couplings are used to reconnect the new section of pipe to the existing line.
6. Backfilling the excavation should be done by hand at first, preferably with sand or gravel. The area underneath and beside the clamp or new section of line should be built up to support the line and 4 to 6 inches of material shoveled in on top of the line. This should be tamped carefully to avoid damaging the clamps and couplings. Once this is completed, the ditch may be filled in with the backhoe and should be tamped in 12-18" lifts.
7. Refill the line by carefully cracking a valve at the low end of the line and opening a hydrant or service to vent air out as it fills. Air relief valves can also be used as vents if they are present on that particular section of pipe. The velocity of the water in the line should be kept below 1 fps and should always be controlled from the fill valve rather than the vent valve. If allowed to fill too quickly, water hammer can occur when the water finally fills the pipe.
8. Reopen all gate valves that were closed and double check to make sure the repair is not leaking. Prior to putting the line back in service, it should be disinfected and have BAC-T samples taken.

Disinfection of Water Lines

Newly laid water lines or lines that have been repaired should be disinfected before they are put into service. This procedure is standard for all water system components including wells and reservoirs. There are four steps that should be taken to insure that the line has been properly disinfected.

1. Flush the line. This will remove any dirt or debris that may be in the line. Flushing it out is easier than burning it up with chlorine. Minimum velocity should be 2.5 fps. Flushing should continue until an amount of water equal to twice the pipe volume has been discharged.
2. Disinfect the line. Enough chlorine should be added to create a 50 mg/l dosage with a 5 mg/l residual after 24 hours. In some instances a higher chorine dosage can be used and the contact time can then be reduced.
3. Flush the line again. This should be done long enough to remove all of the chlorinated water so that “Bac T” samples can be taken.
4. After the line is refilled, take BAC-T samples from the line. If negative results come back, the line is ready to be put into service.

The chlorine should be added at the same point that the water is introduced back into the line. A solution of HTH or, in most small lines, household bleach is normally fed through a corporation stop with a solution pump as the line is slowly filled. Dry HTH should not be put directly into the line or it will be washed to the far end before it dissolves.

mg/l. Take the BAC-T sample and maintain the chlorine residual until the negative test result returns.

Distribution System Valves

Valves are used to control flow in a water system. Most of the valves in a distribution system are installed for isolation of sections of piping for maintenance and repair. Control valves like pressure reducing valves, altitude valves, pressure relief valves, pressure sustaining valves, and pump control valves are designed to control pressures and throttle flows to prevent damage to the system. Air relief valves can vent trapped air from the system. Check valves allow water to flow only in one direction.

General Valve Maintenance

Valves on the water system should be completely closed and then reopened at least once a year. If not, they may become frozen and inoperative when isolation is necessary. An up-to-date map should be kept of all the valves in the system plus an individual record of each valve.

Table 7.2 - ***Valve Maintenance***

General Valve Maintenance Data

- Location of the valve from a reference point
- Type and size of valve
- Make of the valve
- Number of turns to open/shut
- Dates it was operated
- Date it was repacked or repaired
- Condition of the valve

Always check the valve stem for leaks. There is a stuffing box on the valve body where the shaft enters the valve, just like on a centrifugal pump. The difference is that, unlike a pump, the packing gland should be tightened to prevent leakage. The packing seldom wears out, since the valve stem doesn't move often. If it does wear out, the stuffing box can be repacked like a pump. When a valve must be disassembled, the valve seat, the valve face, and the disc should be checked for damage.

Gate Valves

Gate valves are the most common valves in a distribution system. They are used for isolation of equipment and piping. They should never be used to throttle flow. This will cause damage to the valve face. Open gate valves have less friction loss than any other type of valve. Gate valves can have plug type disks or split gates. Split gates are used in higher pressure applications. Gate valves can also have

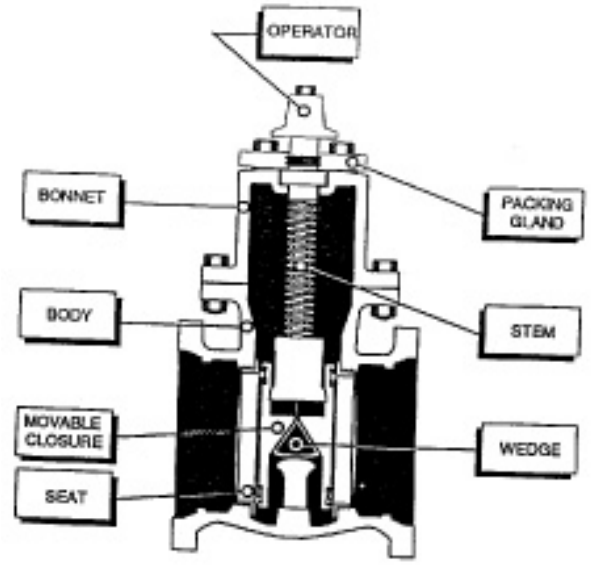


Figure 7.15 - ***Non-Rising Stem Gate Valve***

needed to open or close a gate valve that is not gear reduced is equal to 3 times the diameter plus 1-3 turns to seat properly. So a 6" valve will take 3 x 6 = 18 + 1-2 or about 19-20 turns to close. Larger valves will take 2-3 extra turns.

Large gate valves may have a much smaller bypass valve that is piped in around the large valve. In a distribution system, the water pressure can created tons of force against the valve face. When one side of the valve has been de-pressurized for some reason, the force against the other side can make it impossible to open the valve. The stem will break instead. The bypass valve is much smaller and easier to open (less total force on a smaller surface area.) When the pressure has equalized on both sides of the large valve, all the stem has to do is lift the weight of the gate assembly.

Butterfly Valves

Butterfly valves serve the same purpose as gate valves. These valves usually open and close with ¼ of a turn of the valve disc. Larger valves will have a gear box on the stem and will require a number of turns to open. Butterfly valves are easier to open than gate valves, usually without the need for a

bypass, but have more friction loss when open. They can also be used for throttling flow without damaging the disc. Caution should be used when filling a line through a butterfly valve. When a butterfly valve is 30% open, it can pass 90% of its rated flow. Small butterfly valves will simply have a handle, instead of a threaded stem. The handle is normally aligned with the valve disc. When the handle is in line with the pipe, the valve is open. When it's perpendicular to the pipe it's closed.

Ball or Plug Valves

Ball and plug valves are similar to butterfly valves. They have a ball or cone-shaped plug that has a hole in it, instead of a disc. They open and close with ¼ turn. They are the second most common types of valve on most systems. They are used as corporation stops on service lines, curb stops on meter setters, and isolation petcocks on control valve pilot piping. They are seldom used in sizes above 2 ½".

Check Valves

Check valves are used where flow of water should be in one direction only. The swing check valve should be operated in the horizontal position and the lift check valve is operated in a vertical position. These types of valves are most commonly used on the discharge side of the pumps to prevent backflow and as foot valves on the bottom of suction piping to prevent loss of prime to the pumps.

Air Release Valves

Air release valves are used to allow air that may be trapped in the line to escape. The trapped air can create pressure and pumping problems, milky-water complaints, and pressure spikes that resemble water hammer. They are very useful in systems that are in hilly country. They should be located at the top of hills where the trapped air will collect. They are also used on booster pumps and wells to removed trapped air. Combination air release valves will also let air in when a vacuum occurs. This is done to protect the piping. They can also be used to vent a line that is being drained.

Control Valves

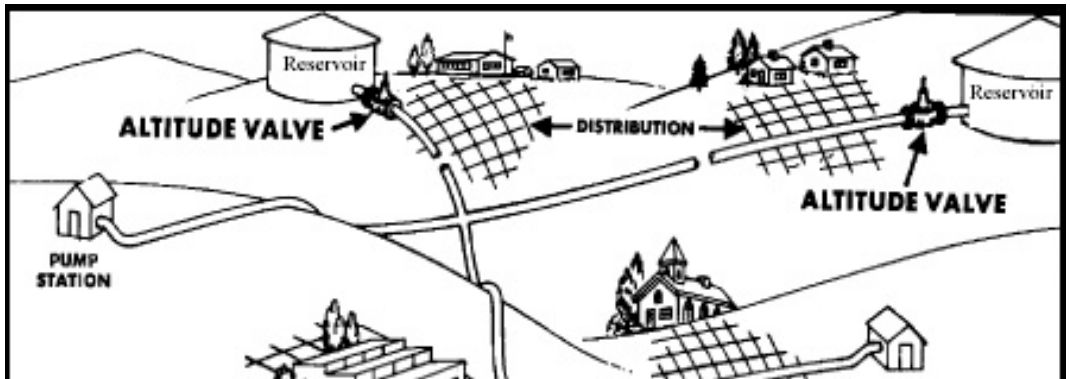
Control valves are usually one of the least understood components of a water system. They are designed to control the flow of water by reacting to changes in the system and automatically opening or closing the valve to compensate. They are globe valves. They share the same basic design as a hose bib valve. The difference is these valves are hydraulically operated, diaphragm actuated, globe valves. The type of pilot or control mechanism that is placed on the valve determines the specific use of a control valve. A control valve can be used as an altitude valve, a pressure reducing valve, a pressure relief valve, a pressure sustaining valve, a pump control valve or a check valve.

Altitude Valves

An altitude valve is a control valve that is designed to close when an elevated storage tank is full. They are needed when there are several storage tanks at different elevations in a system. Altitude valves will be used on the lower tanks to prevent them from overflowing. Each valve will isolate its tank so that the top tank can be filled and not drain out through the lower tanks. This is one of the most common uses of control valves in water systems. The height of the water in the tank can be adjusted by turning the adjustment nut or screw on top of the pilot mechanism. Tighten the nut down to raise the water level and loosen it to lower the level. Adjustments should be made in very small increments and several adjustments may be necessary before the proper level is maintained.

Pressure Reducing Valves

Another common use of a control valve is found in areas where the differences in elevation in the system create unacceptably high water pressures in the lower elevations. With the proper controls, a control valve can reduce and maintain a steady pressure on the downstream side of the valve. The setpoint for the downstream pressure can be increased and decreased by tightening and loosening the pilot control screw. There is a maximum and minimum flow



that a PRV can handle. When the flow drops too low the valve will chatter or start slamming open and closed. This will create severe water hammer problems. To avoid this problem, PRV's are sometimes installed in pairs with a small valve in parallel with the larger valve. The small valve is set at a higher pressure. This will allow it to handle the low flows and keep the large valve shut so it doesn't chatter.

Pressure Relief Valves

Pressure relief valves are used to provide protection against high pressures that may develop in the system. They should be located in any part of the system where pressure is controlled by a pressure reducing valve. They are also used at booster pump stations and on wells that discharge directly to distribution. When the valve senses a high pressure upstream, it will open to pass enough water to drop the pressure back down to setpoint. The water is discharged to a storm sewer or ditch. If the pressure upstream drops, it will close automatically. The setpoint should be about 10-15 psi higher than the normal system pressure at that location.

Pressure Sustaining Valves

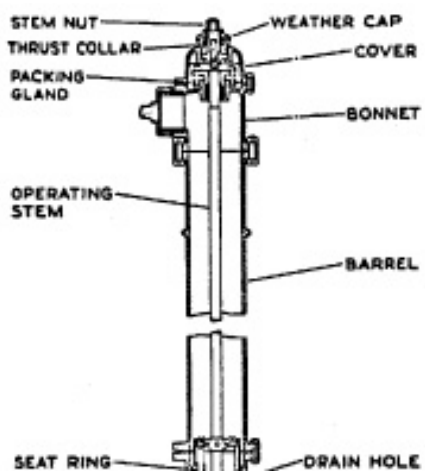
In some systems there are areas of very heavy water demand that can sometimes "rob" the pressure of upstream areas. The control valve will act to maintain the desired upstream pressure during these conditions and throttle the flow of water to the area of heavy demand.

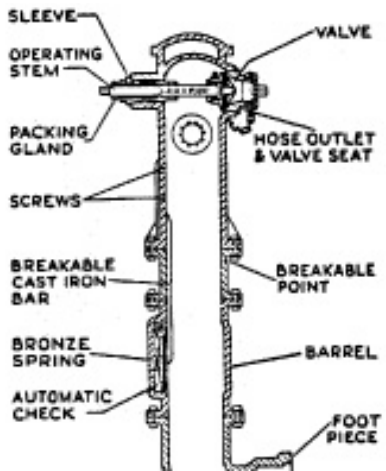
Fire Hydrants

The fire insurance rates for residents on the system will be dependent, in part, on the proper spacing and discharge capabilities of the fire hydrants in the system. Hydrants should not be more than 500-600 feet apart in residential districts. The spacing requirements in industrial and rural districts may vary. They should be located at the end of every dead end line. Hydrants should be operated every 6 months and flow tested annually.

Fire hydrants should never be placed on less than a 6 inch line if it is to be used for fire protection. In addition to provide fire protection, hydrants can also be useful for flushing lines, venting lines as they are filled, and pressure and flow testing. Hydrants on smaller lines (4 inch and down) will not supply enough water to fight a fire but may be used to flush dead end lines. The traffic model of a dry barrel hydrant comes with special breakaway unions on the stem and flanges on the upper barrel that allow it to break cleanly if hit by a vehicle. Hydrants must be installed with the nozzles at least 18 inches above grade. This is the clearance needed to operate a hydrant wrench when removing the nozzle.

Care must be taken to avoid damaging landscaping or creating a safety hazard in traffic when flushing a hydrant. There are two types of fire hydrants used in water systems; wet barrel and dry barrel. A wet barrel hydrant is always pressurized and the main valve is at the top of the hydrant barrel. A dry barrel hydrant has the valve at the bottom of the barrel and a drain hole that drains the barrel when the hydrant is closed. These hydrants are used in areas where freezing occurs in the winter. Never operate a dry barrel hydrant with the main valve cracked to throttle flow. The drain hole will be open and jetting water to undercut the sidewalk and hydrant, anytime the main valve is not completely open.





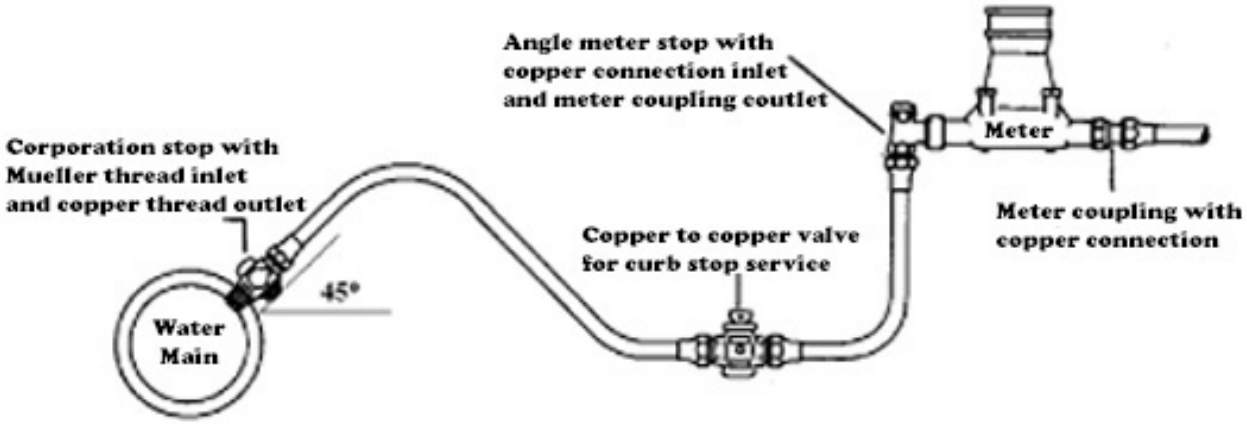


Figure 7.19 - ***Service Line Installation***

Service Lines

Services connect the customer to the main in the street. Services are installed using a tapping machine to drill and connect a corporation stop to the main. The tap is normally done while the main is under pressure. This is called a "wet" tap or "hot" tap. Taps can be made by inserting the corp stop directly into the main or the corp stop can be installed on a saddle that's strapped to the pipe. Taps should be made at a 45% angle from horizontal so that they are less likely to be pulled by a backhoe.

The service line is usually copper, PVC or polyethylene pipe. Galvanized and lead services should be replaced, since the former is prone to corrosion and the latter can cause lead problems if the water is corrosive. The service line should have a bend or goose neck in it at the corp stop. This will allow the service to flex slightly if the trench or piping shifts after backfill. A curb stop should be installed in the easement so that the service can be isolated. Sometimes a meter stop on the yoke is used instead of a cub stop. A service line leak may require killing the main or using a crimping tool to isolate for maintenance when a meter stop is used. Service lines and meters must be laid below the frost line for the area or freezing will become a problem in the winter.

Water Meters

The meter is the primary piece of equipment in a water system that has a direct bearing on income. It is the cash register for the system. Many small systems do not have meters. Billing is based primarily on the size of the service and is a fixed rate. Water meters encourage conservation and distribute the cost of service in proportion to its use. Even though they are critical to maintaining the cash flow for a system, meters tend to be neglected more than any not a good point to impress upon a customer who is sure he or she is being charged for too much water. Instead check the meter readings for the last month. It may be that an error has been made in reading the meter which can be corrected by promising a credit on the next month's bill and re-reading the meter to make sure the books are straight.

If this does not correct the situation, go out to see the customer and take a 5 gallon bucket and a new meter with you. When you get there have the customer turn off all water using appliances in his or her home and then read the meter. Fill the bucket up twice and then re-read the meter. If the meter reads 10 gallons it is indeed accurate. If the reading is less than 10 gallons the meter is worn and should be replaced. At this point the customer may wish he had not called.

If the meter reading is over 10 gallons then there is a substantial leak in the customer's plumbing. This can be confirmed by re-checking the reading as the customer watches and then explain the situation to them. By the time this is done, enough water should have leaked out to make the meter reading change, which identifies the problem as a leak and not the meter.

Meters should be maintained and tested to insure that they are accurate. A meter that has worn out will under register and rob the system of revenues. Meters should be tested every 5-10 years, or anytime a customer has a complaint regarding the meter. Residential meters should have an accuracy of between 98.5 – 101.5% or 100% +/- 1.5%. Larger meters can have a wider accuracy range, but normally not more than +/- 4%.

Positive Displacement Meters

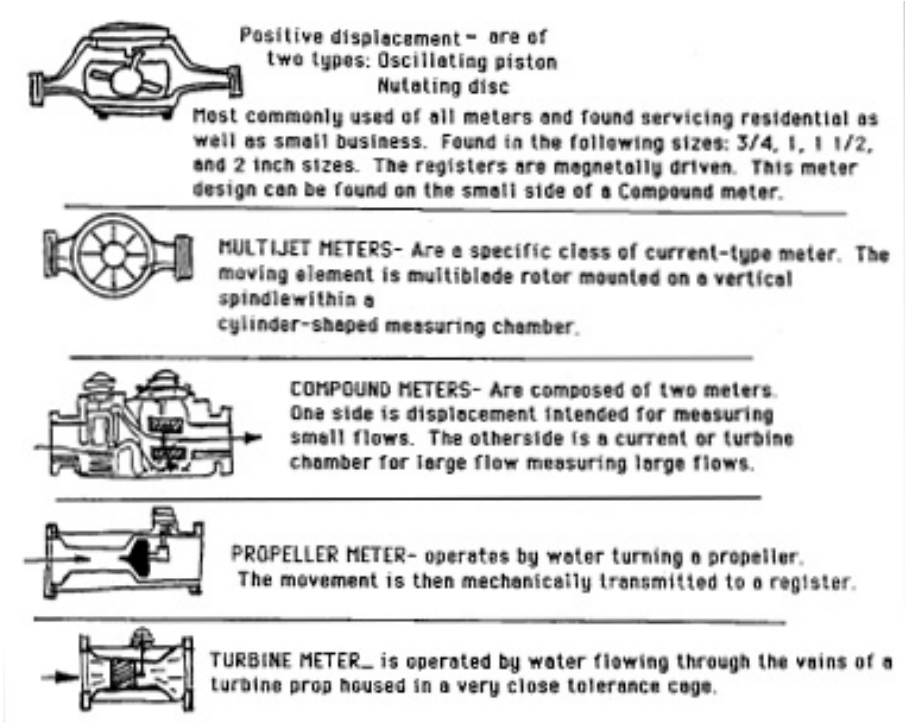


Figure 7.20 - ***Types of Meters***

The positive displacement meter contains a measuring chamber with a fitted disc or piston. Each time the chamber fills and empties a predetermined amount of water is displaced as the disc or piston makes one rotation. The action of the nutating disc or the piston is transferred to the meter head by the use of gears or magnetic drives.

Turbine /Current Meters

This meter is designed so that water flowing through the meter chamber spins a close tolerance turbine or rotor. Propeller meters are used in large low pressure transmission lines. As the velocity of the water increases the speed of the rotor/propeller/turbine increases. The motion is transferred through a shaft to the meter register. In the past turbine meters were used only for high flows and were considered to be inaccurate at low flows. Small rotor-type meters are called multi-jet meters. These meters have been improved over recent years and are now available in sizes 5/8 inch and up. These are very dependable meters and have relatively low loss of head

Venturi Meters

Venturi meters are used to measure high flows such as the intake from rivers or lakes and the discharge from wells. This type of meter usually consists of an upstream reducer, a short throat piece, and a long downstream section to

Reading Meters

A system should get an accurate reading of each meter each month. Most systems have an employee read the meters. Some have the customers reading their own meters. If the customers read their meters, a system representative should check the meters at least twice a year.

Most meters will have a circular register face or a dial face with a totalizer similar to a car odometer. The circular register faces are the more difficult of the two to read. To read this type of meter, start with the scale with the highest number (10,000,000) and then read each of the lower scales until you read the last scale (10.) When the hand is between two numbers record the lower number. If the hand is directly on a number, look at the next scale to see if it is in front of or behind the "0". The

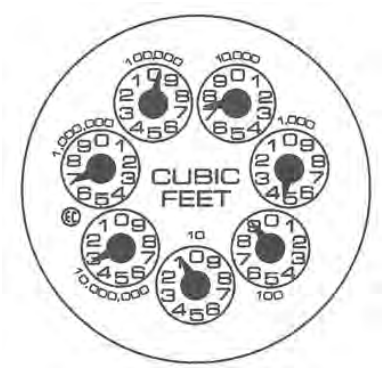


Figure 7.21 - ***Water Meter Dial***

improvement is needed and spare time should be spent looking for the loss. Between 15 20% indicates that the problem is becoming serious and time should be set aside to search for the cause.

Table 7.3 - ***Lost Water***

Reasons for Lost Water
• Non-working or inaccurate meters • Leaks • Illegal taps • Storage tank overflowing

Distribution System Hydraulics

There are a number of issues related to the dynamics of moving water through a distribution system. The pressures in the system are determined by how high water is stacked in the air when conditions are static. But when water begins to move through the system hydraulic factors can affect pressures, flow, and forces exterted against the piping.

Friction Loss

When water flows through a pipe a certain amount of energy must be expended to overcome the friction between the water and the surface of the pipe. The determination of the friction loss in a water line is dependent on four factors:
A certain amount of friction loss results from any flow through any size or type of pipe, and this loss must be overcome, usually by increasing the pumping pressure, in order to maintain a given flow through the pipe. As metal lines get older their inner surfaces get rougher and the "C" Factor increases. Friction losses may be reduced by pigging the lines to remove scale or tuberculation caused by chemical stability problems.

Water Hammer

When water, that is moving through a water line, is suddenly stopped a pressure surge will be created in the line. This occurrence is known as a "water hammer." The faster the water movement is stopped the greater pressure surge, or water hammer, will be. Water hammer can create a pressure surge up to 120 psi greater than the system pressure. Severe water hammer can cause ruptured lines and even lift water hydrants out of the

Table 7.4 - ***Friction Loss***

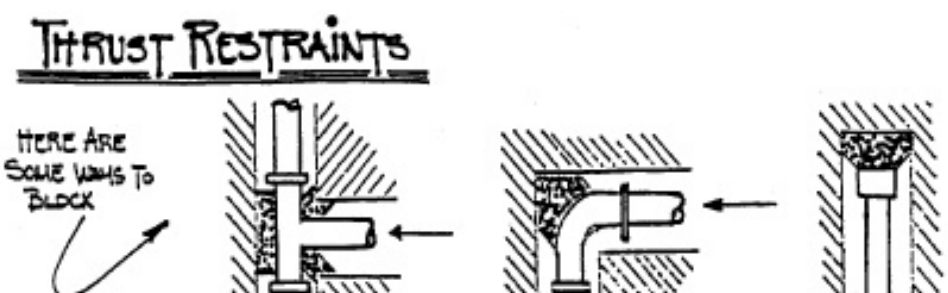
Friction Loss Factors
• Pipe length • Pipe diameter • Flow through the pipe • Coefficient of friction -"C" factor

To minimize the effect of water hammer, all valves and hydrants in the system must be opened and closed slowly. Hydraulically operated check valves known as pump control valves also help to protect the pump and reduce water hammer. All bends and fittings on water mains should be backed by thrust blocks to protect them.

Thrust at Pipe Bends

Wherever a bend, elbow, tee, or dead end exists in a pipeline having flexible joints, a force is exerted which tends to open the joints nearest the fittings. The magnitude of this force varies with the amount of bend, the diameter of pipe, and the pressure inside the pipe. When determining the resultant thrust for a given pipe it is advisable to use the maximum working pressure anticipated in the pipe plus an allowance for surges or water hammer.

Once the resultant thrust has been determined for a particular bend, it becomes necessary to provide a backing block of such size to resist the thrust. The thrust must ultimately be borne by the side of the pipe trench and the surrounding soil. The purpose of the backing block is to spread the thrust over an area sufficiently large that the undisturbed earth can support it. The supporting strength of most solid clay soils should vary between 1,500 and 4,000 pounds per square foot. Sandy soils may not support 1000 pounds per square foot.



Corrosion Control

Corrosion can be a major cause of damage to a distribution system and the test to determine the stability of the water going to the public may be the most important operational tests a system operator can run.

Corrosive Water/Chemical Stability

Water that is corrosive will attack all of the metal components of the distribution system including storage tanks, pipe, valves and meters. It will cause rust and tuberculation in iron pipe and steel storage tanks. Tuberculation can dramatically increase the friction loss and reduce the carrying capacity of a distribution line. Corrosive water can also result in problems from lead and copper that can leach out of the customers plumbing fixtures. Brass is 7-11% lead.

Carbon dioxide (CO_2) dissolved in water will react to form carbonic acid (H_2CO_3) which can cause corrosion. Dissolved oxygen or D.O. in water can also cause corrosion problems, especially if the alkalinity is low. Water can also be corrosive if the proper relationship between the pH and the alkalinity of the water does not exist. The Baylis Curve and the Calcium Carbonate Stability Test (Marble Test) are two of the methods used to determine the chemical stability of water.

Baylis Curve

One method of determining whether the pH and alkalinity are properly adjusted to produce stable, non-corrosive water is with the Baylis Curve. Plotting the pH and alkalinity of the water on this chart will indicate whether the water is corrosive or not. If the point where the pH and alkalinity cross is below the curve (dark gray area), the water is corrosive and will attack metal tanks and pipes in the system. If the point is above the curve, the water is not corrosive but does have excessive amounts of alkalinity present, which will cause the formation of line scale in the lines. This scale formation can restrict the flow of water in the line if allowed to build up over a long period of time and can be as bad for the system as corrosive water. When the point falls within the dotted lines or on the curve itself, the water is stable and will not cause corrosion problems.

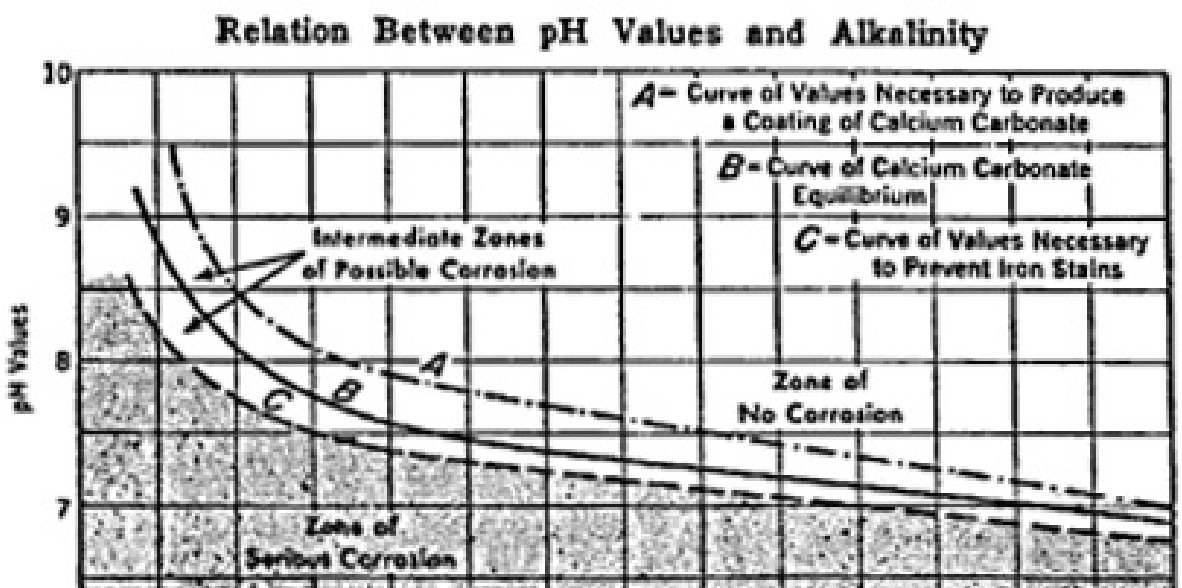
Galvanic Corrosion

Whenever two dissimilar metals come in contact and are submerged in water, an electric current is generated. This type of reaction occurs in most storage batteries. It also occurs in a water system where different kinds of metal components are used, such as meter installations and service connections and couplings.

When these conditions exist, the electric current that is generated will pass from one metal surface to the other. Metal from one side of the connection will be plated onto the other side. This will eventually cause a piping failure as the threads of one side are plated on the other.

Electrolysis

When D.C. electric current enters a metal pipe, it runs down the pipe and, at some point, discharges into the ground. The passage of this current from the pipe into the ground will cause metal in the pipe to be plated into the surrounding soil. This type of corrosion is known as electrolysis.



Any D.C. current machinery or telemetry equipment that is grounded to water lines will cause electrolysis. However, A.C. current, such as household current, can be grounded to water lines without causing electrolysis since alternating current will not plate the metal into the soil. The use of plastic pipe will eliminate electrolysis problems since plastic is a non-conductor.

Corrosive soil

Metal pipe that is laid in highly acid soils may also encounter serious corrosion problems from the outside as well as the inside. If cast iron or ductile iron pipe is to be laid in corrosive soil it should be coated with tar or other protective coating to prevent it from being damaged.

Cross-Connection Control

The plumbing at schools, water treatment plants, wastewater plants and other public and private facilities can be so complicated that the potable water piping can be unintentionally connected to a source of contamination. If this happens, a health risk is created. There are hundreds of incidents each year where contaminated material enters a water system through cross-connections.

In small communities possible sources of contamination are associated with swimming pools and wastewater treatment plants where chemicals such as chlorine, fluoride and boiler additives are used.

A health risk would exist if the drinking water system were connected directly or indirectly to contaminated sources. This could happen when you are mixing a chemical and you place the hose in the mixing tank or connect the drinking water system to the seal water[5] supply on a sewage pump. This direct or indirect connection is called a cross connection[6].

Backflow

The cross-connection can only cause a problem if there is a reversal of flow in the system. This reversal of flow is called backflow. Backflow exists anytime water moves backward through the system.

Backsiphonage

There are two ways that backflow can occur; backsiphonage and backpressure. Backsiphonage occurs when the pressure in the system drops below atmospheric pressure and the water distribution system is connected to a nonpotable source that is open to the atmosphere. This could happen if the distribution system pressure were lowered as a result of a break or heavy use, such as during a fire.

Backpressure

Backpressure exists any time the pressure in the contaminated source exceeds the pressure in the distribution system. Backpressure could happen as a result of a booster pump in a heating system or excessive pressures in a boiler that is improperly connected to the potable water supply.

Failure of the check valve would allow boiler feed chemicals to enter the drinking water system. This could occur if the boiler pressure were greater than the water system pressure or if there was a drop in the water system pressure from a broken line.

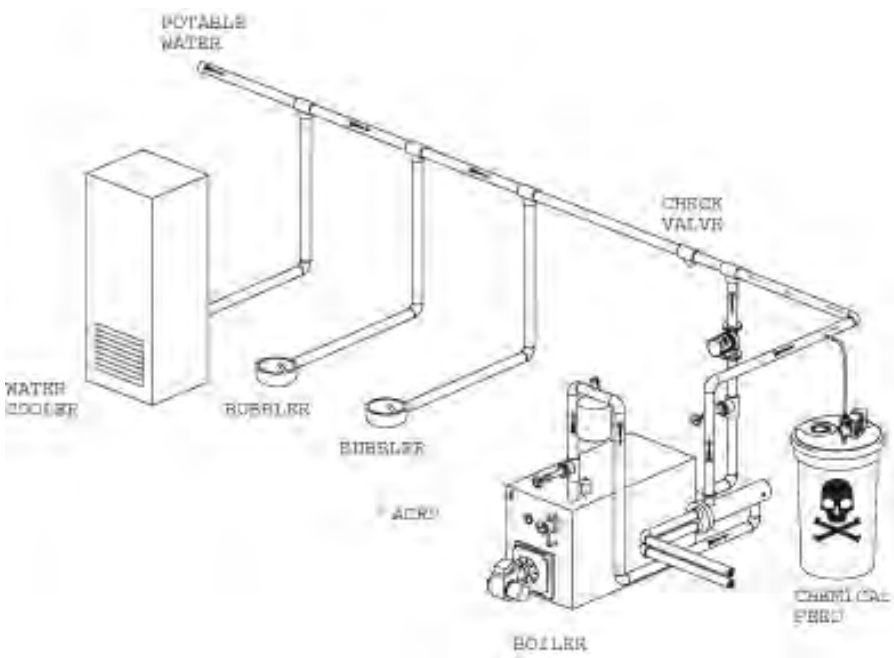


Figure 7.24 - ***Backpressure with boilers***

Prevention

Each state's drinking water regulations indicate that a known cross-connection cannot be allowed to exist. Because inspection of facilities is difficult, time-consuming and not always possible, the waterworks industry has taken a preventive approach to cross-connection control. Under this approach, facilities that have a high potential of cross-connection or handle highly hazardous materials are required to protect the water system. This is accomplished by installing special devices in the facility and on the water service connection where it enters the facility.

Devices

The devices used to prevent backflow from a potential cross-connection are:

- Air gaps
- Atmospheric vacuum breakers
- Pressure vacuum breakers
- Double check[7] valve assemblies
- Reduced pressure backflow prevention device assemblies

Selection of Devices

The device to be used is selected on the basis of the degree of hazard, plumbing arrangement in the facility and the use of additional devices within the facility.

Degree of Hazard

A high hazard facility would include a sewage treatment plant or lift station. A low level of hazard would be a situation where the odor and taste of the water might be affected but there is no health risk.

BACKFLOW PREVENTION DEVICES

Air Gap

The most protective of the devices is the air gap[8]. The air gap is easy to observe and inspect. The air gap is a positive way to protect the water supply from a chemical vat. The requirements are that the air gap between the two water sources be twice the diameter of the outlet of the supply line or a minimum of 1 inch from the rim of the tank. Air gaps can be used on high hazard conditions.

Figure 7.25 - ***Air Gap***

Atmospheric Vacuum Breaker

Atmospheric vacuum breakers are used on low degree hazard conditions such as janitor sinks, lawn sprinkler systems, and supply lines on low concentration chemical vats, such as chlorine and fluoride solutions. Atmospheric vacuum breakers open any time there is a backsiphonage and allow air to be drawn into the line, preventing a backflow of the downstream solution. They will not prevent backflow as a result of backpressure. A downstream valve cannot be installed on an atmospheric vacuum breaker[9].

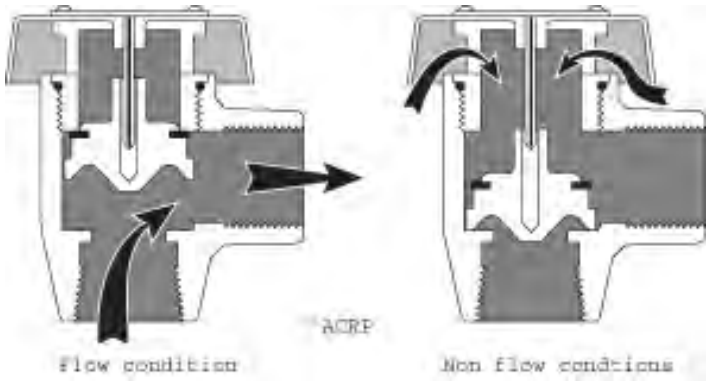


Figure 7.26 - ***Atmospheric vacuum breaker***

Pressure Vacuum Breakers

Pressure vacuum breakers are used for the same functions as an atmospheric vacuum breaker. There are only three differences. The pressure vacuum breaker has an internal spring that helps it open, there are valves to allow the device to be tested, and a valve can be placed in the downstream line.

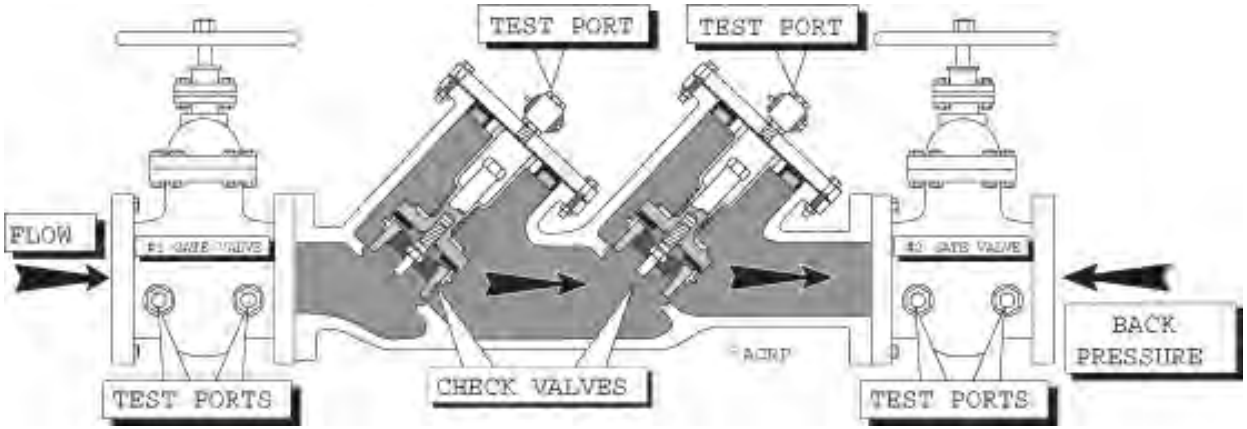


Figure 7.27 - ***Double Check Valve***

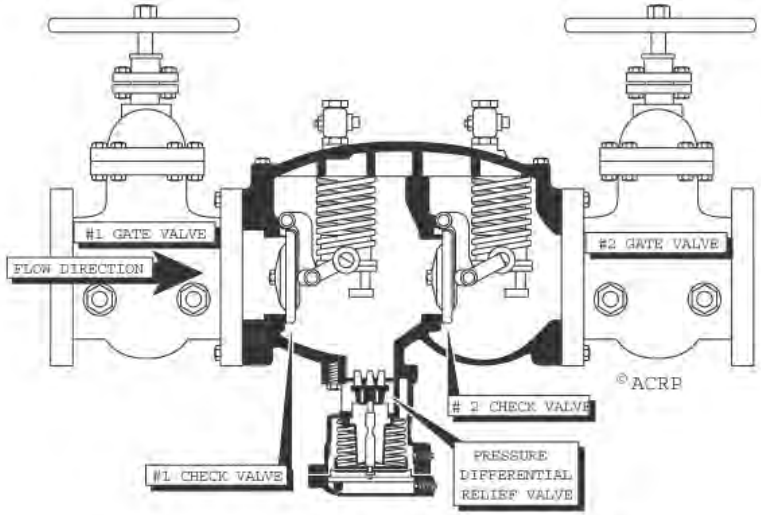


Figure 7.28 - ***RPZ Device***

Double Check Valve Assemblies

A double check valve assembly (DCVA) is composed of two independent internally weighted check valves (springs), isolation valves on each side of the assembly and test ports on the assembly that allow a tester to determine that the check valves are watertight. DCVA will protect against backpressure or backsiphonage on low hazard conditions.

Reduced Pressure Device

High hazard conditions require an air gap or a reduced pressure zone backflow prevention device (RPZ[10]). It is composed of two independent, internally weighted check valves separated by a reduced pressure zone which is valved to the atmosphere. The assembly also has an isolation valve on each end as well as test ports to determine the proper operation of the assembly. The valve is designed so that the valve on the reduced pressure zone will open anytime the pressure in the zone gets to within 2 psi of the supply pressure. In order for backflow to occur through this valve, the two check valves as well as the reduced pressure zone valve would have to fail at the same time.

Selection of Devices

Only approved devices may be installed in a water system. In order for a device to be approved it must undergo extensive testing by a private testing laboratory. Most state regulatory agencies maintain a list of approved devices.

Testing Device

The devices must be tested once each year by a certified backflow prevention device tester. In order to obtain a certification as a backflow prevention device tester you must attend a school and pass a written and practical exam. In order to maintain your certification some states require an annual refresher course, proof that you have tested devices in the past year and a certificate indicating that your test instruments have been tested within the past year.

References

ACR Publications, Inc., Skeet Arasmith, *Introduction to Small Water Systems*, Chapter 5
Office of Water Programs, California State University, Sacramento

Basic Study Questions

1. Which type of pipe is not affected by corrosive water?
2. What is the most common type of residential meter?
3. What type of valve is a corporation stop?
4. What are the two types of fire hydrants?
5. What should be done before you excavate to make a repair?

Basic Sample Test Questions

1. At what percentage does unaccounted-for water become excessive?
   A. 5%
   B. 10%
   C. 20%
   D. 30%

2. A corporation stop will be located:
   A. Where the service is attached to the main
   B. Between the main and the meter
   C. At the meter yoke
   D. On the customer's side of the meter

3. Which type of valve is best suited for throttling flows?
   A. Gate Valve
   B. Butterfly Valve
   C. Check Valve
   D. Air relief Valve

4. When a meter gets worn it will always over register and record water that wasn't used.
   A. True
   B. False
5. Water hammer is caused by:
   A. Opening a valve too slowly
   B. Closing a valve too quickly
   C. Excessive hardness
   D. High pressure on the suction side of a pump

Advanced Study Questions

1. How is a compound meter different from other meters?
2. What is the procedure for disinfecting water lines?
3. Why should you never throttle the flow using the hydrant valve on a dry-barrel hydrant?
4. What are two means of determining the chemical stability of water?
5. What is tuberculation?

Advanced Sample Test Questions

1. The best way to protect the water supply from contamination by cross-connection is:
   A. A double check valve
   B. A vacuum breaker
   C. An air gap
   D. A reduced pressure zone device

2. The positive side of the cathodic protection system is the:
   A. Tank
   B. Cathode
   C. Rectifier
   D. Sacrificial anode

3. A flow meter on a fire line would probably be a:
   A. Venturi meter
   B. Nutating disk meter
   C. Oscillating piston meter
   D. Compound meter

4. When filling a main, the water velocity should never exceed:
   A. 1 ft/sec
   B. 2.5 ft/sec
   C. 10 ft/sec
   D. 20 ft/sec

5. When two storage tanks that serve the same area have different overflow elevations, what type of valve should be included on the lower tank?
   A. Check valve
   B. Altitude valve
   C. Air relief valve
   D. Ball valve

WATER STORAGE

Adequate ground and elevated storage tanks are essential for the proper operation of a water system. These tanks are necessary to provide an ample supply of water during peak demands, dependable fire protection with lower insurance rates, adequate water pressure to outlying areas, and lower pumping costs. Elevated storage tanks are said to "float" on the system. This means that they hold large volumes of water high enough in the air to supply the system with water at usable pressures during peak demands. To maintain a static pressure of 50 psi, water must be stored 115 feet above the customer.

The type and size of a storage tank to be used depends on the desired operating main pressure and the highest daily peak demand. Ground elevations in the area should be surveyed and the storage tanks located at the highest possible elevation to the area served. Ample storage capacity in a water distribution system will mean lower operating costs and fewer pressure problems for the operator.

GROUND STORAGE TANKS

The purpose of ground storage is to hold enough water in reserve to compensate for fluctuation of the water demand in the system. The most common location of ground storage tanks is near the well field or treatment plant. These storage tanks are usually referred to as clear wells. Clear wells are also used to store additional water, which can be pumped into the system for fire fighting purposes.

CONSTRUCTION OF GROUND STORAGE TANKS

Ground storage tanks are constructed of reinforced concrete, pre-stressed concrete, and steel. Reinforced or pre-stressed concrete is the preferred material since it does not deteriorate in contact with water. Concrete requires little maintenance and can help minimize rust scale in corrosive water. Concrete construction is more expensive than when steel is used. Steel is sometimes used when construction budgets are limited. The initial savings may be sufficient to justify the added expense of maintenance on the steel structure.

DESIGN CAPACITIES OF GROUND STORAGE TANKS

A clear well should provide storage equivalent to at least 4 to 6 hours supply at peak daily flow (2.5 times daily average). This amount will usually permit a uniform pumping rate throughout the day. Clear wells should also contain additional storage for filter backwash water. Plants that operate on a part-time basis may require additional clear well capacity to meet these peak flow demands. This storage capacity may range from several thousand gallons in small

LOCATION OF GROUND STORAGE

Some ground storage tanks are built above ground while others may be partially or completely underground. Underground storage should be located above the local ground water table. All tanks should be located so that surface and underground drainage is away from the structure. Tanks should never be located within the 100-year flood plain. Sewer lines within 50 feet of the tank must be watertight cast iron.

PROTECTION OF GROUND STORAGE TANKS

Provisions must be made to insure that sunlight, rain, winds, bugs, and people do not enter the tank. This will prevent possible contamination of the supply from outside sources.

- Vents and overflows should be pointed down to exclude sunlight and rainwater. Sunlight will cause algae to grow, which may result in customer complaints.
- Vents and overflows should have a fine mesh screen cover to prevent the entrance of birds and insects. Some gnats lay eggs in water that hatch into "bloodworms". These are harmless, but their presence in water will always bring customer complaints.
- Manholes should be extended above roof levels. They should be fitted with a watertight cover that should be locked except when working in the tank.

FIRE PROTECTION

In some cases, elevated storage tanks are located near the center of high value districts in order to provide greater protection from fire loss in these areas. Standards set up by the Fire Insurance Commission must be met to receive credit in establishing fire insurance rates. The minimum storage for fire protection, should be 60 gallons per capita per 24 hours, or at least 50,000 gallons per day. This quantity of water plus the amount needed should satisfy daily peak demands must be available in storage.

CATHODIC PROTECTION

When two dissimilar metal rods are connected to a voltage meter and submerged in water that contains dissolved salts, a very small voltage reading (less than 0.0001 volts) will occur. This is the way electric storage batteries work. In an elevated storage tank the impurities in the water and the tank itself can cause a voltage to be generated, with the tank giving up metal as the current flows into the surrounding water and to ground.

Cathodic protection systems can be installed to prevent this corrosion by reversing the flow of the electrical current

set up between the tank and the water. The tank is now the ground and will not become pitted.

The sacrificial anode is usually a piece of iron, magnesium, carbon, or aluminum that is 1-2 inches in diameter and 12 to 18 inches long. The anodes are designed to give up metal to the water instead of the tank. Therefore, they will eventually need replacing. They should be inspected every six months and usually replaced yearly. Installation and maintenance of a cathodic protection system can be hazardous work and should be done by a professional tank and tower company. The success of an installation depends on the proper spacing of the anodes so that all surfaces of the tank receive the flow of current equally. When cathodic systems run at too high a voltage, above 1.2v on a test cell, hydrogen gas can be generated between the tank and any coating material. This can result in blistering and peeling of the coating, which can also cause corrosion.

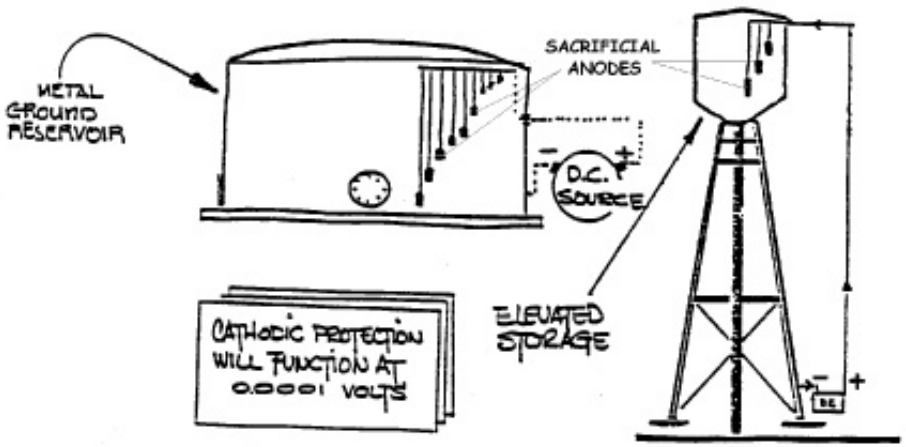


Figure 8.1 - ***Sacrificial Anodes Used for Cathodic Protection***

Level Indicators

Automatic pump controls are operated by signals from the storage tank that indicate that the water is at the lowest or highest desired level. A signal from the low-level indicator will start the pump. The pump will continue to run until the water fills the tank up to the high level. A signal will then go back to the pump to shut it off. There are three main types of liquid level control systems. They are electrode systems, float systems, and pressure sensing systems.

Electrode Systems

The use of electrodes is the most common system used today. Pump controls are activated as the water level rises above or drops below these electrodes. As the water level drops below the low-level electrode, the circuit is opened triggering a control signal to start the pump. As the water level rises to contact the high level electrode, the circuit is closed triggering a control signal to shut off the pumps. The pump will not restart until the water level drops below the low-level electrode again.

Float Systems

Float systems are used primarily in ground storage tanks. As the float rises or falls with the water level, high level or and falls. Circulation of water inside the tank may help minimize ice buildup.

Pressure Sensing Systems

Pressure sensing controls are normally located near the bottom of the storage tank. This type of control is activated by the amount of head pressure in the tank. As the pressure increases, a spring or metal band is expanded tripping a microswitch or a mercury switch that then activates the pump. The on and off levels on these switches are set by applying or decreasing the tension on the spring, or by setting manual control points on a dial for the mercury switch. These switches must be protected from freezing and extreme vibrations for proper operation. Pressure transmitters can also be used to control multiple wells or pumps and the signal can be converted into a tank level reading.

Hydropneumatic Storage

Very small water systems may find that elevated storage tanks are too expensive and, in some types of terrain, very difficult to install. They must resort to other means of supplying pressure to the customer. One way to do this would be to run a pump continuously to pressurize a closed system. This is sometimes referred to as a deadhead condition. Without some special control valving and bypass piping, this could result in the pump running against shutoff head much of the time and cause the pump to overheat. It also limits consumption to the rated flow of the pump.

Hydropneumatic storage tanks are pressurized by a surcharge of air that forms a bubble in the tank. They can be used to pressurize the system and provide storage. The storage capacity keeps the pump from cycling off and on

Types of Pneumatic Tanks

Pneumatic storage tanks are available in several designs. They all look the same from the outside. The difference is how the air pocket inside is controlled. The plain steel tank simply has an air bubble in it. There is nothing to separate the air from the water. The advantage of this tank is that air that may be in the water can be separated in the tank. The disadvantage is that air is being continuously dissolved in the water absorbed, so the bubble will shrink over time. This means that air must be introduced into the tank periodically. Some wells have a special snifter valve on the discharge line that injects a small amount of air into the line as the pump runs. Since this may put too much air in the tank, a relief valve acts as a level control to keep the proper volume of air in the tank.

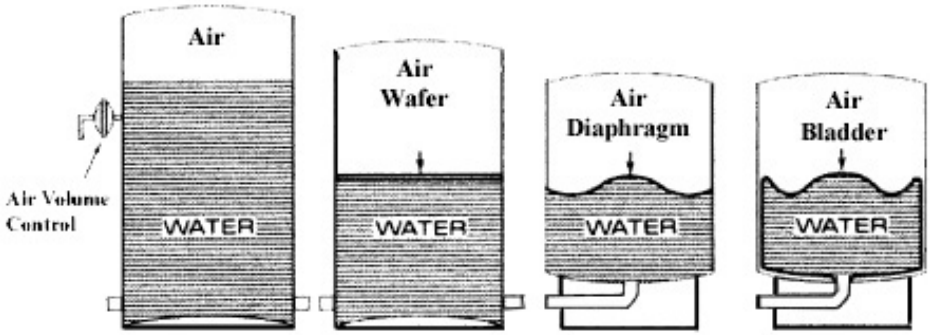
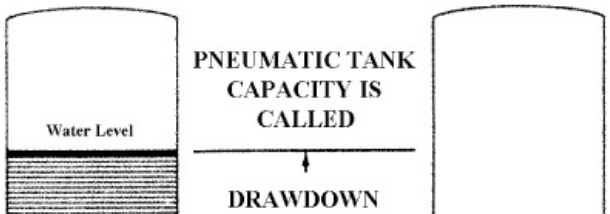


Figure 8.2 - ***Types of Pneumatic Tanks***

The other types of pneumatic tanks have a barrier between the air and water to minimize or eliminate the amount of air lost of absorption. Wafers and diaphragms separate the water from the air, but a bladder design also prevents the water from coming in direct contact with the sides of the tank. This can help prevent corrosion from soft, low alkalinity water. The wafer, diaphragm, and bladder designs require air charging from an external source. Air compressors tied to level switches automatically maintain the proper air volume in large tanks. Smaller tanks should be checked regularly and charged with portable air compressors or air tanks. If the air pocket does disappear, the tank will be full of water and the pump will begins to cycle more often since there will be no drawdown in the tank.

Sizing a Pneumatic System

The capacity of a pneumatic tank is the drawdown. The drawdown is the difference in water levels from the point where the pump cuts in to the point where it cuts out. The general rule for sizing a pneumatic tank is that the drawdown in the tank should equal at least two minutes of the pump's rated flow. For example, if a well produces 30 gallons per minute, the drawdown should be at least 60 gallons. This means that the pump will always run for at least two minutes each time it cycles on and off. This will greatly reduce the impact that cycling has on the pump.



The pump will actually get a start signal from a pressure switch rather than a level indicator. The pressure switch will normally be set to start at 40 psi and stop at 60 psi, although some very small systems may run from 20-40psi. The equipment supplier can calculate what this would means in terms of gallons of drawdown for a new tank. For an existing tank, just isolate the tank at shutoff pressure and see how much water drains out to drop the pressure to the cut in point.

Elevated storage tanks are located in areas that have pressure problems due to small lines or long runs of piping. Pneumatic tanks can also be moved out into the system where pressure problems exist. It will also increase the amount of water in storage for the system. Pneumatically pressurized systems provide no fire protection since there is not enough water available at pressure.

References

Office of Water Programs, California State University, Sacramento, *Water Distribution System O&M*, 4th ed., Chapter 2.
Office ofWater Programs, California State University, Sacramento, *Small Water System O&M*, 4th ed., Chapter 3

Basic Study Questions

1. Where would you find an air gap on a ground storage tank?
2. What does cathodic protection do?
3. What are sacrificial anodes?
4. What is the drawdown in a pneumatic storage tank?

Basic Sample Test Questions

1. All vents and overflows on a storage tank should be screened.
   A. True
   B. False

2. Pneumatic storage tanks must be full of water to work properly.
   A. True
   B. False

Advanced Study Questions

1. Which types of storage tanks are more likely to have corrosion problems?
2. What are three ways to control the water level in a storage tank?
3. Why is ice a problem in the winter?

Advanced Sample Test Questions

1. What type of electrical current is used in cathodic protection?
   A. AC current
   B. DC current
   C. 3-phase current
   D. Synchronous current

2. What is likely to grow in a storage tank that is not covered?
   A. Sulphur bacteria
   B. Algae
   C. Trout

Pumps provide the means for moving water through the system at usable working pressures. The operation and maintenance of these pumps are some of the most important duties for many water utility operators. There are two basic types of pumps used in water and wastewater systems. The most common type of pump is the centrifugal pump. The other type is the positive displacement pump.

All pumps are rated by the flow they produce and the pressure they must work against. Centrifugal pumps are used for high flow and low head pressure applications. Booster pumps or primary service pumps are required to move high volumes of water and usually operated at low head pressures (200-300 feet of head for water and as little as 50 feet of head for wastewater applications). Centrifugal pumps are ideally suited to these types of applications and are much more efficient than positive displacement pumps of comparable size. Positive displacement pumps are used for low flow and high-pressure applications. High pressure water jet systems like those used for well screen or sewer line cleaning use positive displacement pumps since pressure in excess of 2500 feet of head are needed and the flows seldom exceed 100 gpm. Sludge pumps and chemical feed pumps are also likely to be positive displacement pumps. Piston pumps, diaphragm pumps, and progressive cavity screw pumps are the most common types of positive displacement pumps.

Another difference between centrifugal and positive displacement pumps has to do with how they react to changes in discharge pressure. When the pressure that a centrifugal pump has to work against changes, the flow from the pump changes. As the pressure increases, the flow from the pump will decrease, and when the pressure drops the flow will increase. Positive displacement pumps do not react this way. The flow does not change when the discharge pressure changes. This is the main reason that positive displacement pumps are used for chemical feeding and sludge pumping. The operator knows that every time the pump strokes, it is pumping the same amount of fluid. This is important if accurate records are to be kept of chemical dosages and pounds of solids that are moving through the system.

CENTRIFUGAL PUMPS

A centrifugal pump moves water by the use of centrifugal force. Any time an object moves in a circular motion there is a force exerted against the object in the direction opposite the center of the circle. This would be easier to explain if we use an example of a person with a bucket full of water. If the person swings the bucket in a circle fast enough, the water will stay in the bucket even when it is upside down. The force that holds the water in the bucket is called centrifugal force. If a hole is made in the bottom of the bucket, and it is swung in a circular motion, the centrifugal force will push the water out of the bucket through the hole. The same principle applies when water is moved through a centrifugal pump.

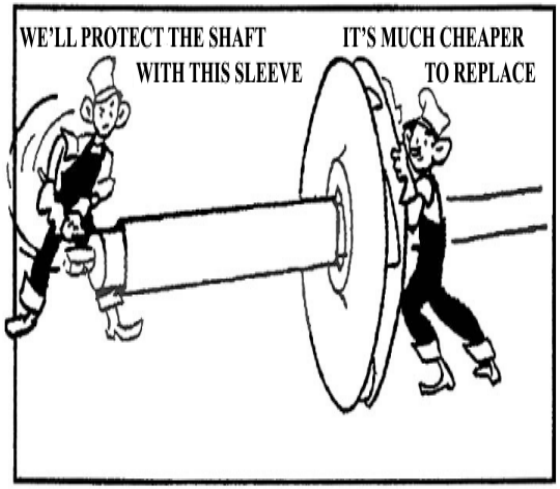


Figure 9.1 - ***Impeller Rotation & Centrifugal Force***

Table 9.1 - ***Pump Characteristics Overview***

TYPE OF PUMP	PRESSURE/FLOW RATING	CHARACTERISTICS
Centrifugal	Low Pressure/High Flow	Flow changes when pressure changes

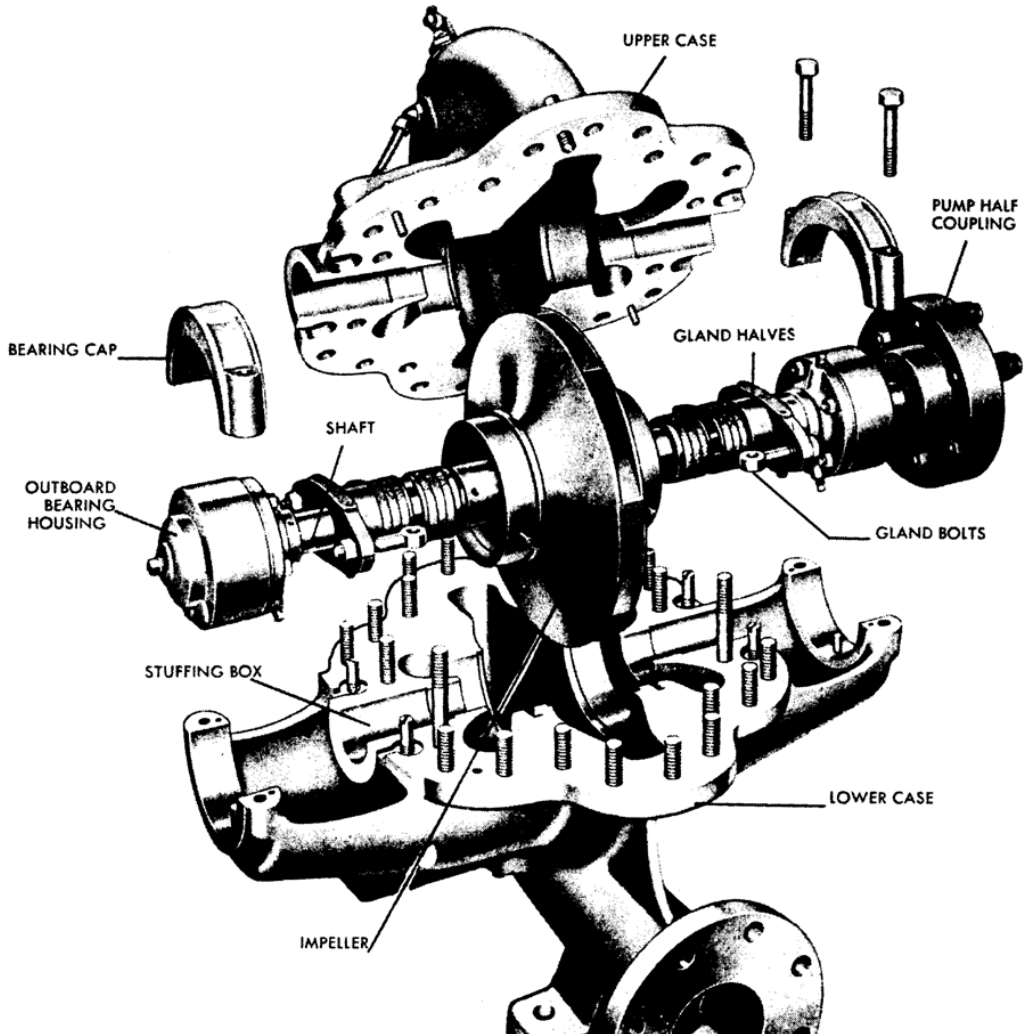
An impeller spins inside a centrifugal pump. It is the heart of the pump. Water enters the center, or suction eye, of the impeller. As the impeller rotates, the veins pick up the water and sling it out into the pump body under pressure. It is the pressure exerted by the vanes that moves the water out of the pump and into the system. The suction created as the water leaves the impeller draws more water into the impeller through the suction eye.

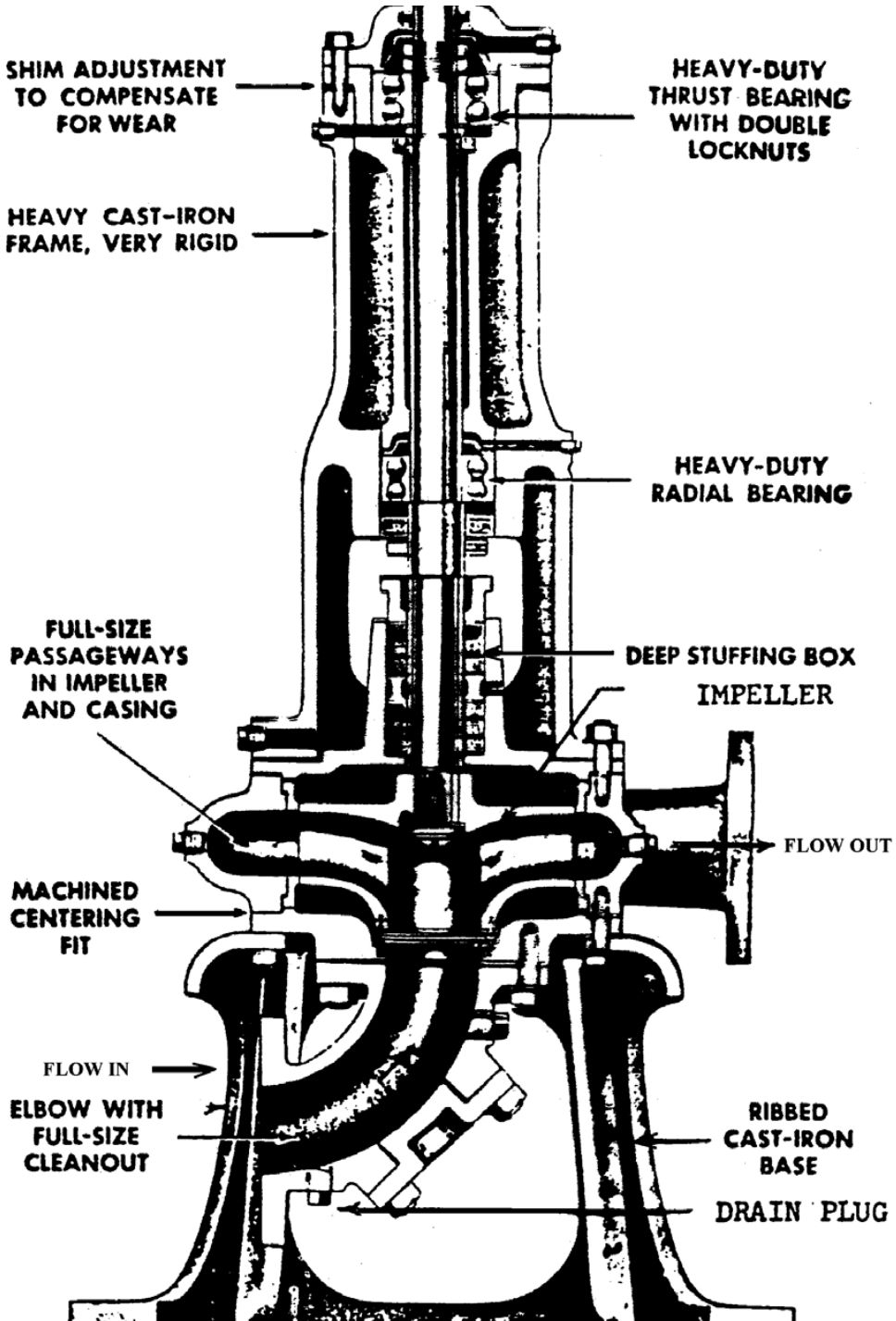
The number of vanes and the sweep of the veins determine the performance characteristics of the impeller. As vanes are added, the impeller will produce higher discharge pressures and lower flows. The same situation applies to increasing the length or sweep of the vanes. Reducing the number of vanes or the sweep of the vanes will increase the flow and reduce the pressure.

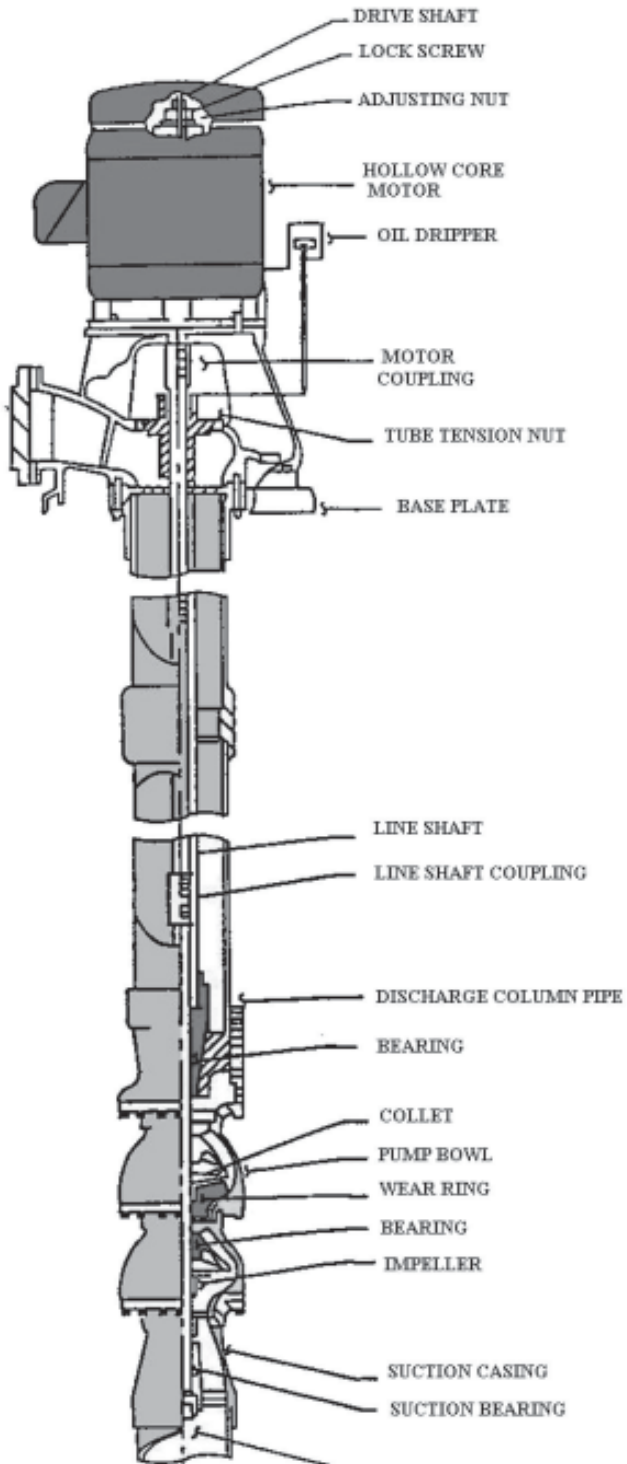
Types of Centrifugal Pumps

There are three basic types of centrifugal pumps. Although they differ in design, all three have the same basic components. The first centrifugal pumps were called horizontal split case pumps. [See Figure 9.2] The shaft is horizontal and the casing is split in half. With the top half of the casing removed, the entire rotating assembly can be removed for maintenance. The problem with horizontal pumps is the floor space they require.

End suction centrifugal pumps were designed to take up less floor space. [See Figure 9.3] The suction piping enters at the end of the pump and discharges at a 90° angle to the suction. This allows more flexibility in installation and, since the pump can be mounted vertically, more pumps can be placed in a given floor space.




SHIM ADJUSTMENT TO COMPENSATE FOR WEAR
HEAVY-DUTY THRUST BEARING WITH DOUBLE LOCKNUTS
HEAVY CAST-IRON FRAME, VERY RIGID
HEAVY-DUTY RADIAL BEARING
FULL-SIZE PASSAGEWAYS IN IMPELLER AND CASING
DEEP STUFFING BOX
IMPELLER
FLOW OUT
MACHINED CENTERING FIT
FLOW IN
ELBOW WITH FULL-SIZE CLEANOUT
RIBBED CAST-IRON BASE
DRAIN PLUG



A vertical turbine centrifugal pump consists of multiple impellers that are staged on a vertical shaft. [See Figure 9.4] The impellers are designed to bring water in the bottom and discharge it out the top. This results in axial flow as water is discharged up through the column pipe. Staging the impellers in these pumps can create very high discharge pressures, since the pressure increases as the water moves through each stage.

Centrifugal Pump Components

Before we can discuss operation and maintenance of a centrifugal pump, it is important to understand how a pump is put together and what each pump component does. A centrifugal pump is constructed from about a dozen major components. Let's take a look at how these pieces fit together to make a pump.

The impeller is attached to the pump shaft. The shaft must be straight and true so that it will not cause vibration when it rotates. The shaft should be protected from potential damage caused by the failure of other pump parts. A shaft sleeve is used to protect the shaft in the area where the shaft passes through the pump casing.

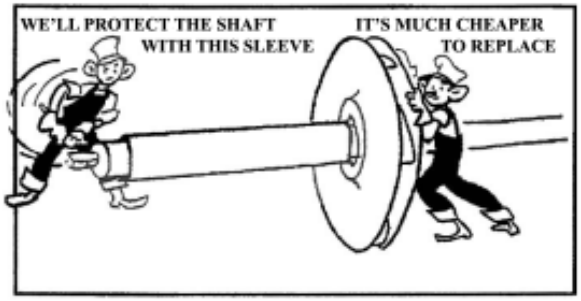
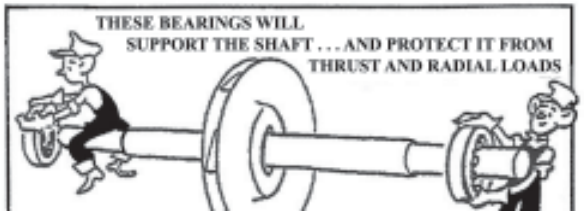


Figure 9.5 - ***Shaft Sleeve***

This rotating assembly must be supported as it spins in the pump. Bearings hold the spinning shaft in place. There are two types of anti-friction bearings normally found in centrifugal pumps. One type of bearing is



designed to keep the shaft from wobbling from side-to-side as it spins. This side-to-side motion is referred to as radial movement. The bearings used to prevent radial movement of the shaft are called radial bearings. The most common variety of radial bearing is the standard ball-type roller bearing

As the impeller spins, water entering the suction eye pushes against the top of the impeller exerting force in the same axis as the pump shaft. This is referred to as upthrust. The pressure developed inside the pump also pushes against the impeller in the opposite direction. This downward force is referred to as downthrust. Bearings designed to support the shaft against this type of force are called thrust bearings. The most common variety of thrust bearing is an angular contact ball bearing.

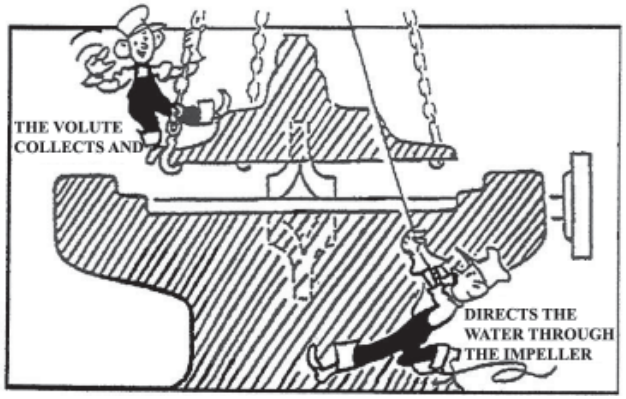
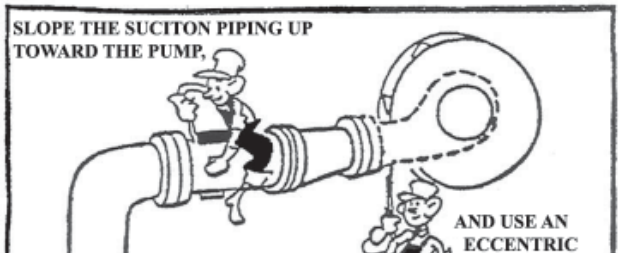


Figure 9.7 - ***The Volute***

The rotating assembly is placed in a pump casing. Part of the pump casing is specially designed to collect and direct the flow of water as it enters and leaves the impeller. This part of the pump casing is called the volute.

The suction and discharge piping are attached to the pump casing. The suction piping will always be larger than the discharge piping. Suction piping is designed to bring water into the pump at 4 ft/sec in order to minimize the friction



loss on the suction side of the pump. The discharge piping is designed to carry water away from the pump at 7 ft/sec. There are several important aspects to suction piping installation. Horizontal runs of piping should slope upward toward the pump. Any reducers on the line should be horizontal across the top instead of tapered. A reducer that is flat on one side is known as an eccentric reducer. A reducer that is tapered on both sides is called a concentric reducer.

These installation features are used to prevent the formation of air pockets in the suction piping. Air trapped in the suction piping can create restriction of flow into the pump. It is also important to make sure there are no leaks in the suction piping that might allow air to be drawn into the pump. The pump must never support the piping. Placing that kind of stress on the casing can cause it to crack or become sprung enough to cause damage to the rotating assembly.

Now that the casing is assembled and the piping is in place, we can spin the impeller and begin moving water. Water will enter from the suction side of the volute and will be slung out of the impeller into the discharge side of the volute. Unfortunately, the water will try to pass from the high-pressure side back to the suction side and recirculate through the impeller again.

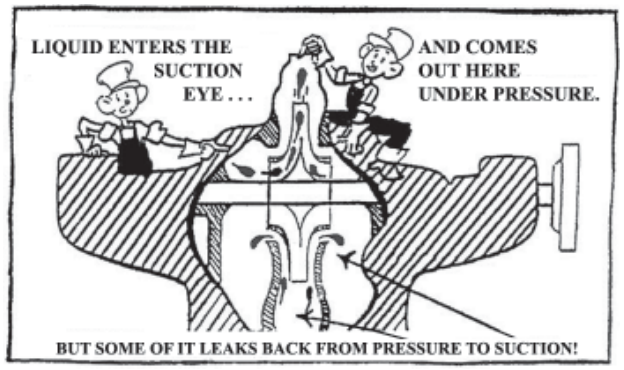


Figure 9.9 - ***Leak Back***

The pump casing could have been machined to close this gap, but the fit would become worn and widened over time. To prevent this internal recirculation, rings are installed between the pump and the impeller that reduce the clearance between them to as little as 0.010". Unlike the casing, these rings are removable and can be replaced when they become worn. Because they wear out and get replaced, they are called wear rings.

There is another area of the pump that will require some attention. Something must be done to plug the hole where

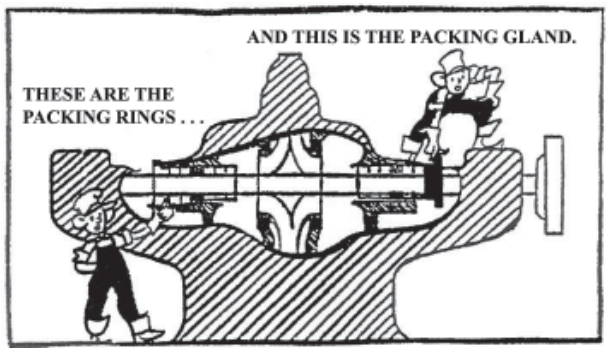


Figure 9.10 - ***Stuffing Material***

This "stuffing" will usually be rings of pump packing. Several rings of packing are placed in the stuffing box. A metal insert ring fits on top of the stuffing box and is used to adjust or tighten the packing down to minimize water leakage. It is called a packing gland.

Since the packing rings touch the shaft sleeve as it rotates, friction and heat are generated in the stuffing box when the pump is running. Water is generally used to cool the packing rings during operation. This means that some water must leak out of the stuffing box when the pump is running. Water may simply be allowed to leak through the packing rings from inside the pump to cool them.

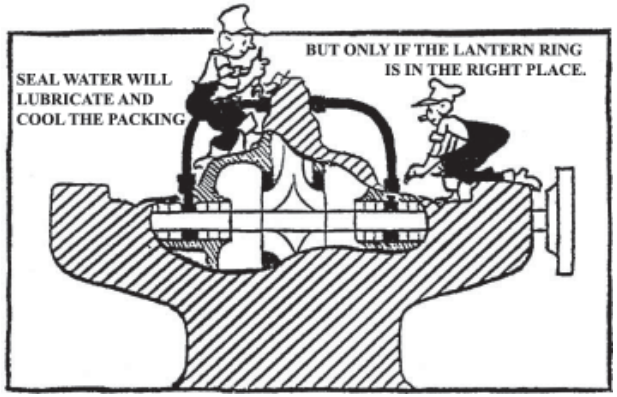


Figure 9.11 - ***Seal Water***

This water may be coming from the low-pressure side of the pump and may not be under enough pressure to leak past the packing rings when the packing gland it properly adjusted. If this is the case, high-pressure water from the discharge side of the pump may have to be piped into the stuffing box. Seal water piping is used to supply this water to the packing. The seal water enters the stuffing box from the outside, but it's needed on the inside.

box to make sure that water will get to the center of the stuffing box. Whenever a potable supply is used for a pump that is pumping non-potable water, an air gap or reduced pressure backflow preventer must be used to prevent a possible cross-connection.

If there isn't enough seal water moving past the packing and rotating pump shaft to cool them properly, the packing will overheat. If the packing is allowed to overheat, the lubricant in the packing will be driven away from the shaft and the packing will become glazed, much like nylon cord that has been burned at the end. The glazed packing will then start cutting into the shaft sleeve, creating more friction

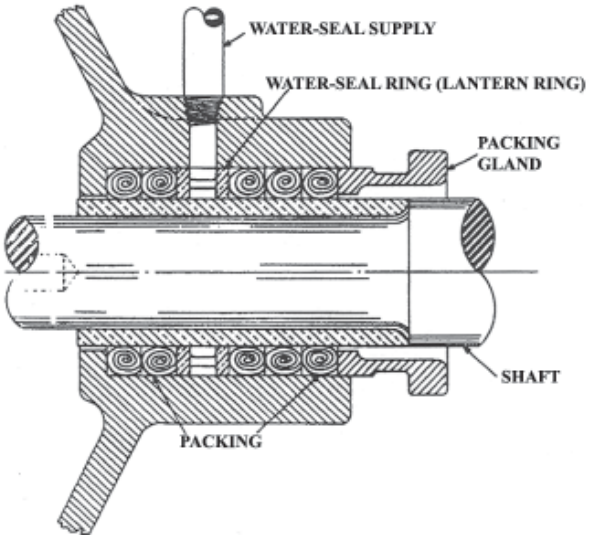


Figure 9.12 - ***Stuffing Box Cross-Section***

and heat. The result will be packing failure and a severely damage shaft sleeve.

Pumps that do not have packing in the stuffing box will be equipped with a mechanical seal. [See Figure 9.13.] Mechanical seals are comprised of two highly polished seal faces. One seal face is inserted in a gland ring that replaces the packing gland on the stuffing box. The other seal face is attached to the rotating shaft. It is held in place with a locking collar and is spring loaded so that there is constant pressure pushing the two seal faces together.

When the pump runs, seal water is piped into the stuffing box under enough pressure to force the seal faces apart. The seal faces don't touch when the pump is running, but the friction loss created as the water pushes them apart prevents any leakage from the gland plate. Failure of the seal water system

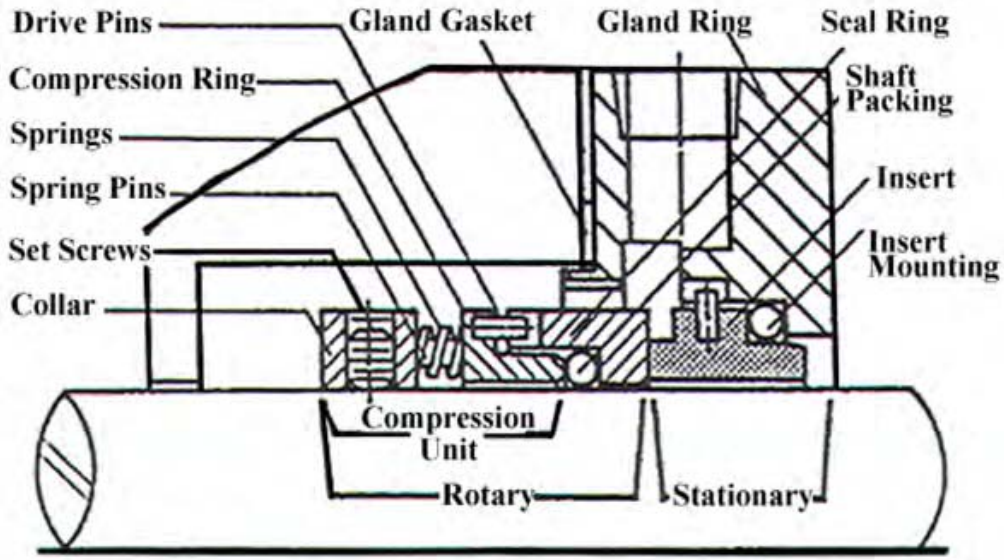


Figure 9.13 - ***Mechanical Seal Components***

PUMP HYDRAULICS

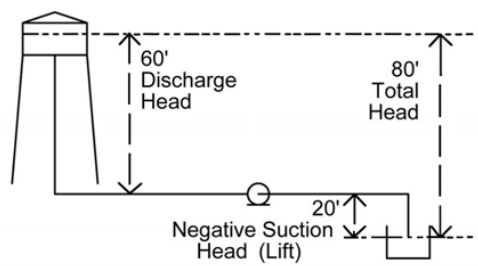
When a pump is installed, it is important to make sure that it is designed to pump the proper amount of water against the correct head pressure. Pumps that are not properly sized for a specific application will fail to give satisfactory performance. The majority of complaints regarding pump performance usually result from placing a pump in an application that requires it to operate outside its designed flow or pressure ratings.

In order to get the right pump for the job, you must know not only how much water must be moved, but also how much pressure it is going to have to pump against. Determining how much water needs to be pumped is the easy part. A pump dealer may have fifteen different pumps that are rated for 500 gpm. Some of them will pump 500 gpm against 500 feet of head and some will only pump 500 gpm against 50 feet of head pressure. The trick is figuring out how much pressure the pump will have to work against.

The following steps should be taken when sizing a pump:

1. ***Determine the gpm:***
   The pump should be able to meet the peak daily demand that will be encountered.
2. ***Determine the suction head:***
   The suction head is the vertical distance from the surface of the water supply to the centerline of the pump. If the water supply is below the centerline of the pump, the distance is negative suction head, or suction lift. If the water supply is above the centerline of the pump, it is known as positive suction head. The illustration shows both positive and negative suction heads of 20 feet.
3. ***Determine the discharge head:***
   The discharge head is the vertical distance from the centerline of the pump to the overflow of the storage tank. The illustration shows a discharge head of 60 feet.
4. ***Determine the total head:***

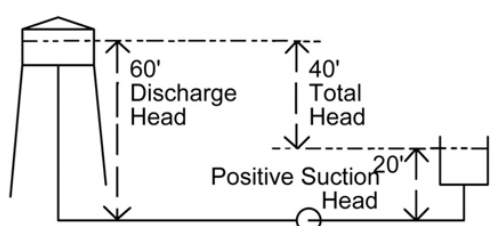
The total head can be determined by **adding** a **negative suction head** to the discharge head:



Total Head = Discharge Head + Negative Suction Head

or

by **subtracting** a **positive suction head** from the discharge head:



5. ***Determine the friction loss:***
   The total head represents the vertical distance that the pump must lift the water. The horizontal distance the water must move will also impact the pressure against the pump. As water moves through a pipe, it rubs against the inside of the pipe. This creates friction that will reduce the available pressure at the end of the pipe. A pump must produce a pressure higher than total head to overcome this friction loss and still move the required amount of water. There are four factors to consider when determining friction loss. They are the size of the pipe, the flow through the pipe, the length of the pipe, and the "C factor". The "C factor" is also known as the coefficient of friction. It represents the roughness of the inside of the pipe wall.
6. ***Determine the Total Dynamic Head***
   Once the friction loss has been determined, it is added to the total head to calculate the total dynamic head. The total dynamic head (TDH) is the head at which the pump should be rated. The pump can now be sized according to the gpm demand and the total dynamic head that it must work against.

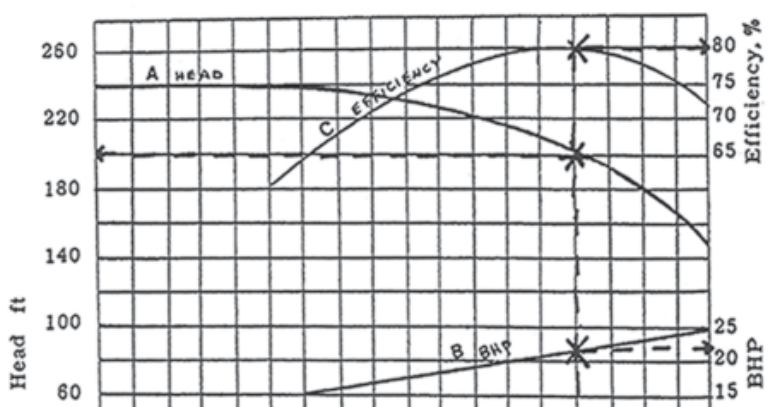
T.D.H = Discharge Head +/- Suction Head + Fricion Loss

Pump Characteristics Curves

Every pump has certain characteristics under which it will operate efficiently. These conditions can be illu-strated with pump characteristic curves. The graph of the pump curve should show:

1) The head capacity curve (A)
2) The brake horsepower curve (B)
3) The efficiency curve (C)

The graph may contain a curve labeled "NPSH" (Net Positive Suction Head) instead of a BHp (Brake Horsepower) curve. NPSH represents the minimum dynamic suction head that is required to keep the pump from cavitating.



To use the pump curve:

1. Start at the particular head pressure that is desired and then travel across the chart to the point where it crosses the head capacity curve (A).
2. Drop a straight line from this point down to the bottom of the chart to determine the gpm output at that particular head pressure.
3. The brake horsepower can be determined by starting at the point where the vertical line crosses the horsepower curve (B) and going across to the right side of the chart. Use the same procedure for NSPH if it is used instead of BHp.
4. The efficiency of the pump at this flow and pressure is determined by starting at the point where the vertical line crosses the efficiency curve (C) and going over to the right side of the chart.

When the head pressure of the pump represented by this curve is 200 feet, the output is 350 gpm. The brake horse-power under these conditions is about 22 BHp and the efficiency is 80%. If the impeller or the speed of the pump changes, all of the pump's characteristics will also change.

Shut Off Head

The highest head pressure that the pump will develop is called the "shut off head" of the pump. The shut off head for the pump in this curve is 240 feet of head. When a pump reaches shut off head, the flow from the pump also drops to 0 gpm. This is a valuable piece of information for conducting a quick check of the pump's performance. If the pump cannot generate its rated shut off head, the pump curve is no longer of any real value to the operator. A loss of shut off head is probably caused by an increase in recirculation inside the pump due to worn wear rings or worn impellers.

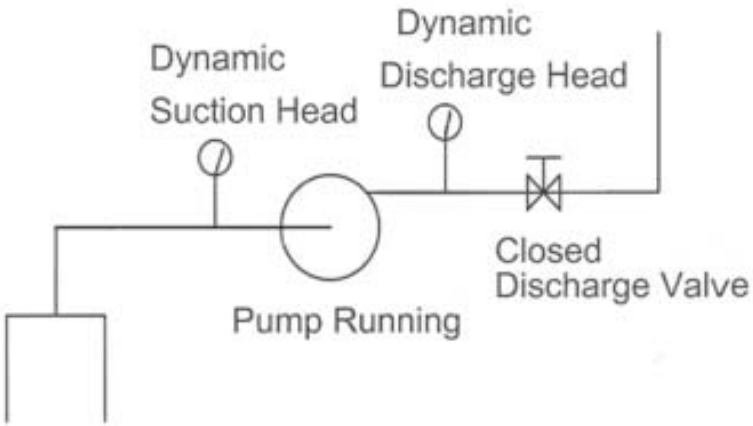
There is another factor that might affect the shut off head of the pump. The pump curve assumes that the pump is running at design speed. If a pump that is supposed to spin at 1750 rpm and it is only turning at 1700 rpm, the shut off head will be lower than the pump curve too. However, if the pump speed is checked with a tachometer and found to be correct, the wear rings or impellers are probably in need of repair.

Checking Shutoff Head

It is fairly easy to check the shut off head on a pump if it has suction and discharge pressure gauges:

NOTE: NEVER attempt to create shut off head conditions on a multi-staged turbine well. The shut off head may be several hundred feet higher than normal operating pressure, which can cause damage to piping.

2. With the pump running at shut off head, read the suction and discharge pressure gauges. Subtract the suction pressure from the discharge pressure to get the shut off head. Compare the field readings to the pump curve to see if the wear rings are in need of replacement.



Shut off Head = Dynamic Discharge Pressure – Dynamic Suction Pressure

Figure 9.16 - ***How to Determine Shut-Off Head***

If the shut off head matches the curve, the same calculation can be used, when the pump is running normally, to estimate the Total Dynamic Head (TDH) and determine the flow when a meter is not available.

Common Operational Problems

The operator should check all pumps and motors every day to insure proper operation. After spending a certain amount of time with these pumps and motors, an operator should be able to tell just by listening to them whether they are working properly. The vast majority of pumping problems are either a result of improperly sizing a pump for the job or one of the three following operational problems.

Cavitation

One of the most serious problems an operator will encounter is cavitation. It can be identified by a noise that sounds like marbles or rocks are being pumped. The pump may also vibrate and shake. In severe cases, piping can be damaged. Cavitation occurs when the pump starts discharging water

As the water surges into the impeller, the partial vacuum is destroyed and the cavities collapse, allowing the water to slam into the impeller vanes. These cavities form and collapse several hundred times a second. As they collapse, they draw the water behind them into the impeller at about 760 mph! The impact created by the water slamming into the impeller is so great that pieces of the impeller may be chipped away.

When cavitation occurs, immediate action must be taken to prevent the impeller, pump and motor bearings, and piping from being damaged. Cavitation can be temporarily corrected by throttling the discharge valve. This action prevents damage to the pump until the cause can be found and corrected. Remember that the discharge valve is there to isolate the pump, not control its flow. If it is left in a throttled position the valve face may become worn to the point that it won't seal when the pump must be isolated for maintenance.

If you suspect that low suction pressure is the problem, check the pump curve to see what the Net Positive Suction Head (NPSH) is for the pump. If there is no NPSH curve, check with the pump supplier.

Air Locking

Table 9.2 - *Causes of Cavitation*

- Loss of discharge pressure due to open hydrants or line breaks
- Closed suction valve
- Obstruction in the suction line
- Low suction head due to drop in water level

Air locking is another common problem with pumps. It is caused by air or dissolved gases that become trapped in the volute of the pump. As the gas collects, it becomes compressed and creates an artificial head pressure in the pump volute. As more air collects in the pump, the pressure will continue to build until shut off head is reached. Air locking is most often caused by leaks in the suction line. The failure of low level cut off switches, allowing air in from the wet well, may also cause air locking.

An air locked pump will overheat in a matter of minutes. The shut off head conditions mean that no water is moving

Air relief valves are used to prevent air locking. They are located on the highest point on the pump volute and automatically vent air as it accumulates in the pump. It is also a good idea to repair leaking gaskets and joints on the suction piping. If the pressure in the line drops below atmospheric pressure when the pump is running, air will leak in instead of water leaking out.

Loss of Prime

Loss of prime happens when water drains out of the volute and impeller. The impeller can't create any suction at the impeller eye unless it is filled with fluid. This occurs only when negative suction head conditions exist. Pumps that operate with negative suction lift are usually installed with a foot valve or check valve at the bottom of the suction pipe. This valve holds the water in the suction pipe and pump when the pump is off.

When a pump loses its prime it must be shut down, reprimed, and all the air bled out of the suction line before starting the pump again. Worn packing and a defective foot valve normally cause loss of prime. The best way to prevent loss of prime is to design a pump installation so that there is positive suction head on the pump.

Electric Motors

Very few operators do electrical repairs or trouble shooting because this is a highly specialized field and unqualified operators can seriously injure themselves or damage costly equipment. For these reasons, the operator must be familiar with electricity, know the hazards, and recognize his own limitations when working with electrical equipment. Most water systems use a commercial electrician for major problems. However, the operator should be able to explain how the equipment is supposed to work and what it is doing or not doing when it fails. Electric motors are commonly used to convert electrical energy into mechanical energy. A motor generally consists of a stator, rotor, end bells, and windings. The rotor has an extending shaft, which allows a machine to be coupled to it. Most large motors will be three phase motors rated from 220 or 4160 volts.

Vertical turbine line shaft pumps will often have a hollow core or hollow shaft motor. The rotor is hollow and the motor shaft can slide up and down to allow adjustment of impeller clearance. This lateral adjustment is accomplished by raising and lowering the shaft with the adjusting nut on top of the upper bearing.

Phases

The term "phase" applies to alternating current (AC)

Single Phase Motors

Single-phase motors are normally operated on 110-220 volt A.C. single-phase systems. A straight single-phase winding has no starting torque so it must incorporate some other means of spinning the shaft. A single-phase motor requires a special start circuit within the motor to make sure it runs in the right direction. Several different types of starter windings are available in these motors. Single-phase power leads will have three wires, like a three-prong extension cord.

Three Phase Motors

Three-phase systems refer to the fact that there are three sets of windings in the motor and three legs of power coming in from the distribution system. This type of motor is used where loads become larger than single-phase circuits can handle. With three legs to carry power, more amps can be delivered to the motor. Three phase motors are the most common types used in water and wastewater systems. Three major types of three phase motors are the squirrel cage induction motor, synchronous motors, and wound rotor induction motors.

Squirrel cage induction motors are widely used because of its simple construction and relative low maintenance requirements. The windings are stationary and are built into the frame of the motor. The power supply is connected to the windings in the stator, which creates a rotating magnetic field. The rotor is made up of bars arranged in the shape of a cylinder and joined to form a "squirrel cage." Squirrel cage induction motors make up approximately 90% of all motors used in industry today.

Three-phase motors do not use a start circuit. The direction of rotation is determined by how the three leads are wired to the motor. If any two of the leads are switched, the motor rotation will be reversed.

Single Phasing

Anytime a lead becomes grounded, a dead short develops, or one of the contacts opens in a three-phase motor, single phasing will result. When this occurs, the speed of the motor will drop and it will begin to overheat. The single phase will draw too many amps and it will quickly burn up. When single phasing occurs while the motor is not running, it simply will not start up again. Special circuit protection is available that will shut the motor off if single phasing occurs.

Circuit Protection

Motors need to be protected from power surges and overloads. Fuses and circuit breakers are designed to open the circuit when the current load threatens to damage the motor. Fuses are generally sized at 120-150% of motor capacity. Circuit breakers can be reset when they trip, instead of being replaced like a fuse. Circuit breakers can

References
Office of Water Programs, California State University, Sacramento, *Water Treatment Plant Operation*, Volume 2, 3rd ed., 2000, Chapter 18
Office of Water Programs, California State University, Sacramento, *Water Distribution System O&M*, 3rd ed., 1996, Chapters 5 & 7
Office of Water Programs, California State University, Sacramento, *Small Water System O&M*, 4th ed., Chapter 3
Groundwater and Wells, 2nd ed., Chapter 17

Basic Study Questions

1. What are wear rings?
2. What three factors determine total dynamic head?
3. What happens when you increase the pressure on a centrifugal pump?
4. What are some of the possible causes of cavitation?
5. What does single phasing in a three-phase motor mean?

Basic Sample Test Questions

1. A lantern ring:
   A. Must be located in line with the seal water port
   B. Is used to put cooling water to the center of the stuffing box
   C. Will be found in the stuffing box
   D. All of the above

2. The discharge piping of a centrifugal pump will be larger than the suction piping.
   A. True
   B. False

3. Air trapped in the volute of the pump will cause:
   A. Cavitation
   B. Air locking
   C. Loss of prime
   D. All of the above

4. Which type of pump would be used in a well?
   A. Vertical turbine centrifugal
   B. Split case horizontal centrifugal
   C. End suction centrifugal
   D. Positive displacement

Advanced Study Questions

1. What does the term "C" factor refer to?
2. What is the best way to prevent loss of prime?
3. What are four conditions that could cause cavitation in a centrifugal pump?
4. How do you reverse the rotation of a three-phase motor?
5. What kind of information is found on a pump curve?

Advanced Sample Test Questions

1. The maximum pressure a centrifugal pump can generate is called:
   A. Shutoff head
   B. Total dynamic head
   C. Total head

2. Negative suction head should never exceed:
   A. 10 feet
   B. 20 feet
   C. 30 feet
   D. 40 feet

3. Which of the following would make a centrifugal pump stop cavitating?
   A. Throttle the suction valve
   B. Throttle the discharge valve
   C. Decrease the TDH
   D. Decrease the NPSH

Like any other business, a water system spends a great deal of money on infrastructure and capital improvements. These expenses include piping, storage and all of the mechanical equipment required to produce, treat, and deliver water. A maintenance program is essential to insuring that the mechanical components of the system stay in good working order and provide the longest possible service life. A preventive maintenance schedule should be utilized to make sure that each piece of equipment gets the proper attention. Most preventive maintenance consists of inspecting, cleaning, and lubricating the equipment. The equipment operators can usually complete these tasks. Specially trained personnel that possess the necessary mechanical skills should handle major maintenance, including component replacement and overhaul.

PUMP MAINTENANCE

The most common piece of equipment in a water system is the centrifugal pump. There are several maintenance procedures that must be performed periodically for any centrifugal pump. Pump packing wears out, bearings must be lubricated or replaced, mechanical seals need replacing, couplings must be maintained, and motor and pump shafts must be aligned.. These procedures are not difficult to learn. Some of the procedures may require the use of a few special tools. Once an operator understands the basic procedures and has a chance to put the theories into practice, it doesn't take long to become proficient at each task.

PUMP PACKING

Pump packing is one of the biggest problem areas for operators in charge of pump maintenance. Poor maintenance of pump packing is responsible for more pump damage than any other maintenance item. Improperly maintained packing can cause several problems including:

Table 10.1 - ***Damage Caused by Packing Failure***

- **Loss of prime or suction due to an air leak**
- **Shaft and sleeve damage**
- **Water contamination of bearings**
- **Flooding of pump stations**

lubricants such as Teflon. Prices for packing range from several dollars a pound for graphite-impregnated jute to hundreds of dollars a pound for pure Teflon and other synthetics.

A rule of thumb is to buy the most expensive packing that you can afford, provided that you are taking care of the rest of the pump properly. If scored or damaged shaft sleeves and out of round or bent shafts are not going to be repaired, use the cheapest packing you can get. Expensive packing will not last any longer than the cheap stuff if the sleeve is scored or the shaft is bent. If the rest of the pump is properly cared for, the more expensive types of packing will last several times longer than the cheap packing and will usually pay for itself with a longer life.

REMOVING OLD PACKING

It's time to replace the packing when there is no more adjustment left in the packing gland and there is too much leakage from the stuffing box. When this occurs, all of the packing rings must be replaced. Adding an additional ring or just replacing one or two rings will only lead to premature packing failure and damage to the shaft and sleeve. Use the following procedure to remove the old packing:

1. Tag the pump in the "OFF" position and lock it out so that it can't be accidentally restarted.
2. Isolate the pump by closing the suction and discharge valves.
3. Drain the pump by opening the drain cock or removing the drain plug in the bottom of the volute.
4. Remove the packing gland. If it is not split for removal from the shaft, it should be tied off so that it is out of the way.
5. Remove the packing rings with a packing puller (corkscrew on the end of flexible T-handle) taking care not to score the shaft sleeve.
6. Measure the distance to the lantern ring and then remove it with the packing puller. It may take a puller on each side of the lantern ring to pull it out without getting it cocked sideways. If the lantern ring is split, it can be removed from the shaft. If you're not sure that the lantern ring was in the right placed to begin with, measure the distance from the face of the stuffing box to the seal water port or refer to the vendor's engineering drawing of the stuffing box for the correct position.
7. Remove the remaining packing rings and clean the stuffing box and shaft.
8. Disconnect, inspect, and clean the seal water line

Repacking the Pump

Before new rings are cut, it is important to determine the size and number of packing rings that are needed for the stuffing box. This information should be available in the vendor's engineering drawings. If these drawings are not available, measurements of the stuffing box and shaft can be used to make the determination. The correct packing size is determined using the following procedure:

1. Measure the inside diameter of the stuffing box and the outside diameter of the shaft.
2. Subtract the shaft diameter from the stuffing box diameter.
3. Divide the difference by two. (See Figure 10.1)

The correct number of rings can be determined using the following procedure:

1. Measure the depth of the stuffing box.
2. Divide the depth of the stuffing box by the size of the packing to get the total number of rings.
3. Subtract one from this total if a lantern ring is used in the stuffing box.

Once the size and number of rings has been determined, the new packing can be cut and installed. Great care should be taken to keep the packing material clean and free from dirt. Packing spools should be stored in plastic bags to prevent contamination. Dirt and grit in the packing rings will lead to serious shaft and sleeve damage. The two most important aspects of cutting packing rings involve cutting them the right length and cutting them so the ends will butt together squarely. Cutting rings the same length with ends that butt together squarely can be accomplished using the following procedure:

1. Cut the packing to the proper length and shape using a very sharp knife or carton cutter. Wrap the packing material around the shaft, an old sleeve, or even a piece of hardwood turned to the proper diameter. Cut all of the rings at once with the packing on the shaft to insure that the ends will butt together squarely.
2. Wrap each ring of packing around the shaft and seat it in the stuffing box completely before adding the next ring. Open the ring by twisting it instead of pulling the ends apart. A light coat of grease on the outside of the ring will make it much easier to push into the stuffing box. Stagger the joints of the rings so that they are 90 degrees apart. Make sure the lantern ring lines up with the seal water port when it is installed.
3. Install the packing gland. Make sure the gland tightened down evenly. It is usually made out of

locks and tags have been removed, the dis-charge and suction valves are completely opened, and the pump has been primed. More packing jobs have been ruined by improper gland adjustment than any other single reason. Adjust the packing gland using the following procedure:

1. Tighten the gland one half turn a time on each side until it just begins to put pressure on the packing.
2. Start the pump and tighten the gland until the flow of water is reduced just enough to prevent flooding the drain line. Allow the pump to run for at least five minutes while the packing rings seat. Never allow the packing to get hot during this "breaking in" period. If the packing heats up and lubricant is seen oozing from the gland, the packing is already ruined and should be removed and replaced immediately.
3. After five minutes, adjust the packing slowly until the leakage is reduced to the desired level. The appropriate amount of leakage will vary with the size of the pump and type of packing, but a general rule of thumb is 20-60 drips per minute. Tighten the gland and checking the water temperature periodically. When the water turns lukewarm there is not enough flow to cool the packing properly. Loosen the packing gland just enough to cool the water back down to room temperature. The packing gland will probably need to be checked again, as the packing rings get properly seated. This may have to be done several times over the next 24 hours of run time.

Bearing Maintenance

Proper bearing lubrication is a critical part of getting the designed life out of pump and motor bearings. As strange as it may sound, more bearings have failed from over-lubrication than from lack of lubrication. In fact, some bearings never require lubrication and may fail if they are greased. Shielded and sealed bearings come factory-lubricated and have sufficient lubricant to last the life of the bearing. Shielded bearings have a metal skirt that is attached to the outer race. It covers the rollers but doesn't touch the inner race. Sealed bearings have a rubber skirt that does touch the inner race. Bearings that do require periodic grease lubrication use a surprisingly small amount of grease when compared to the bearing housing size. A properly greased bearing will have a bearing housing that is never more than 25-30% full. The grease is responsible for lubricating <u>and</u> cooling the bearing.

Grease that is inside the bearing will get hot as the bearing

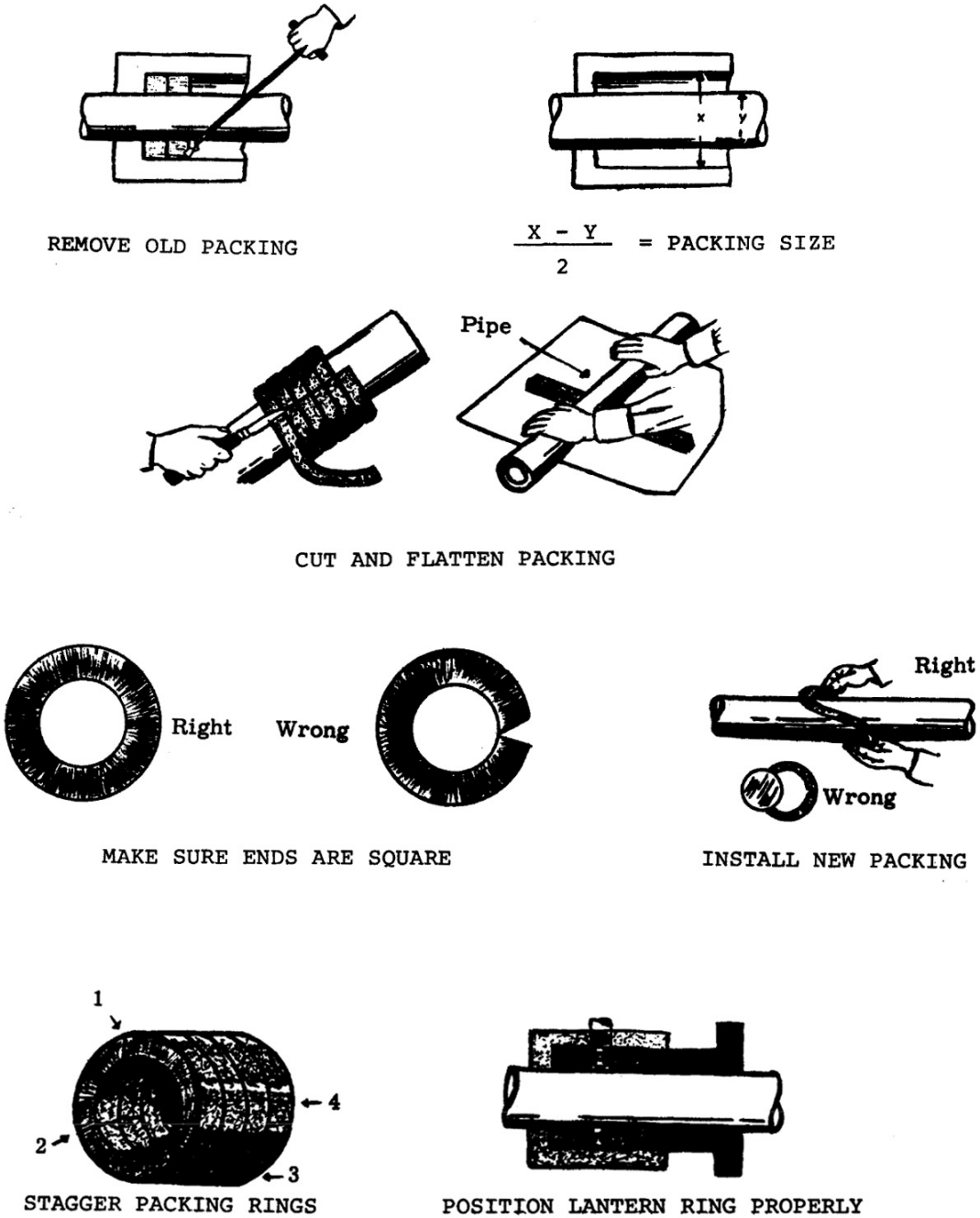


Figure 10.1 - ***Repacking A Pump***

and removes heat from the bearing. If the bearing housing is full of grease there is no way for the hot grease to get out of the bearing. The lubricant inside the bearing overheats to about 250^0 F. This means they will assume their original dimensions as long as the temperature does not rise above 250^{0}F. This is the reason small electric motors should not

Couplings

Couplings connect the motor shaft to the pump shaft. The exception to this would be a close-coupled pump. A close-coupled pump will have the impeller mounted directly to the motor shaft. Couplings can be rubber or steel. Steel couplings are most commonly gear-type or grid couplings.

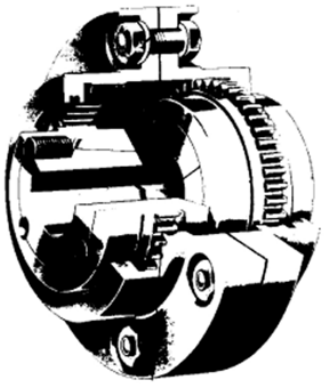


Figure 10.2 - ***Gear Coupling***

Couplings are mounted and removed by pressing or heating the coupling. They should never be mounted using a hammer. The halves of the coupling should be separated by a gap large enough to accept the thermal expansion as the shaft and motor heat up. Couplings flex as the two shafts spin. This movement generates friction and heat in the coupling and requires grease lubrication. The main problem with lubrication in a coupling is centrifugation. As the coupling spins, it tries to throw the grease out of the housing.

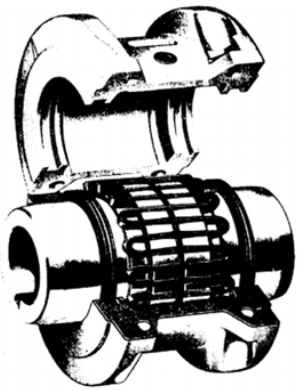


Figure 10.3 - ***Flexible Grid Coupling***

Couplings should be inspected periodically. The housing should be removed and the old grease removed using a solvent. Care must be taken not to get solvent in the bearings or seals. Broken or worn teeth and wear or pits on the grids are indicators that the coupling should be replaced. Gear-type housings are usually cast material. The housing bolts must be tightened carefully in a crossing pattern to avoid cracking the assembly. Vibration occurs in a coupling when it is misaligned.

Alignment

If the pump and motor shafts are not aligned properly, the is off center. Misalignment can also be in the horizontal plane, requiring a side-to-side movement of the motor. It can also be in the vertical plane, requiring raising the motor with shims. This means that measurements must be taken at the top, bottom, and both sides of the coupling.

A crude check of the misalignment can be done using a straight edge on the coupling halves. A dial indicator is used to more accurately gauge the amount of offset or angularity. A dial indicator is capable of precise measurements down to 0.001".

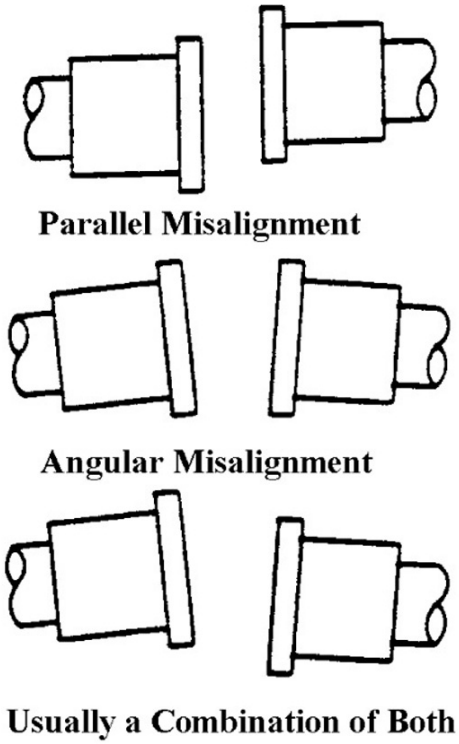


Figure 10.4 - ***Types of Misalignment***

Instrumentation

Instrumentation in water systems allows the operator to maintain and monitor water levels, flows, pressures, and chemical feed rates at a distance. This use of telemetry gives constant readings of changes in the system and allows operational changes to be made from remote locations. This allows the operator to maintain better control and respond more quickly to changes in the process. The best instruments are those that provide stability, accuracy, and repeatability when monitoring these parameters. Instrumentation equipment can range from simple devices like float switches and pressure gauges to complex systems like on-line

chorine dosage based on a change in well field flow. The meter would be located forward of the chlorine feed point and change the stroke when the flow changed. An example of a feedback loop would be a chlorine analyzer changing the chlorine dosage based on a change in residual downstream of the chlorinator. It would be located downstream and feed the information back to the chlorinator.

Three things determine the rate at which an instrument makes a change in the process. One is the amount of change for each reading. This is referred to as the span. Another is how often readings are taken. This is called the rate. The third is the deadband. Deadband means that there is a range around the setpoint where no action is taken. For instance, a chemical feed instrument may be set to maintain a pH of 7.0. But the deadband may be set so that no action is taken until the pH rises to 7.2 or falls below 6.8. If the rate is too fast or the span too large, the control conditions may fluctuate as the instrumentation "hunts" for the setpoint.

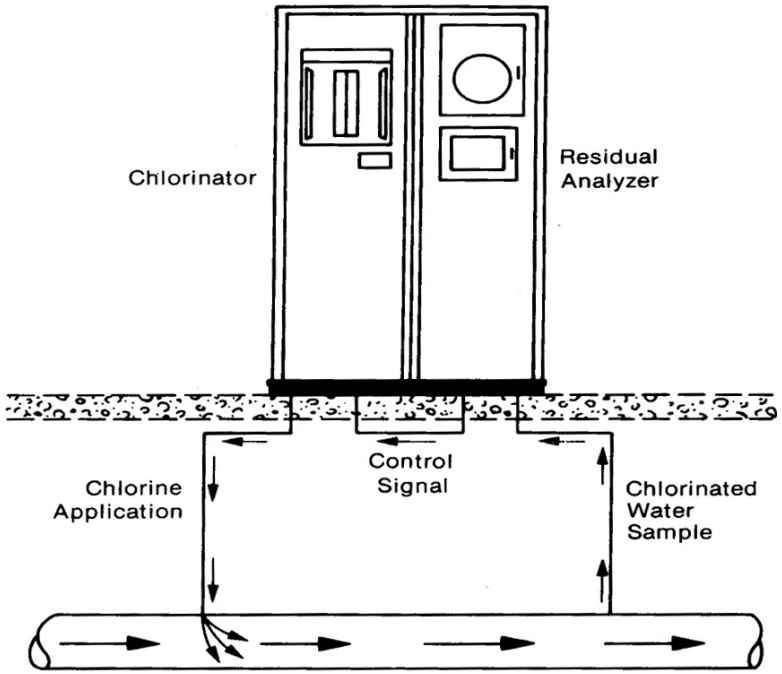
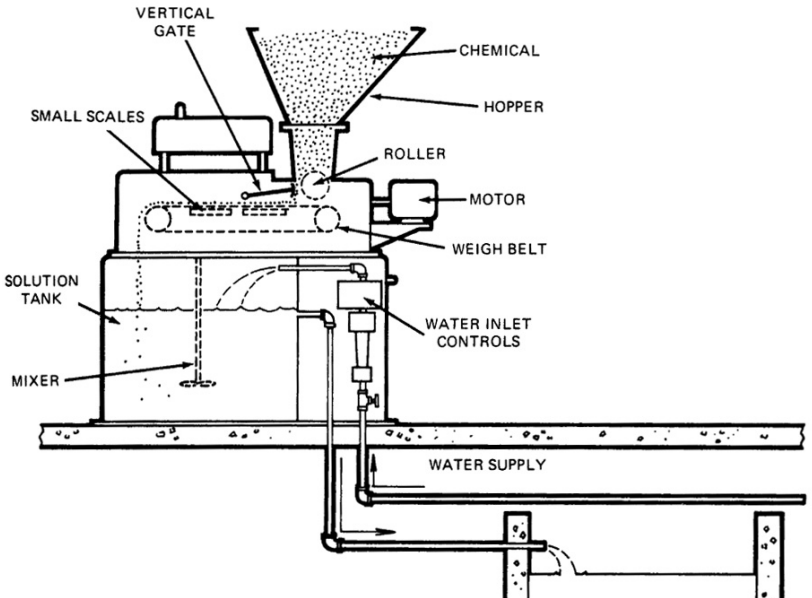


Figure 10.5 - ***Feedback Control Loop***

Chemical Feed Systems

Chemical feeders are necessary to assure that the proper amount of each chemical is added to the water on a continuous basis. Each feeder must have a storage bin, a device that feeds the chemical into a solution tank where it is dissolved, and a delivery system to add the chemical at the proper point in the treatment process. Chemical feeders are either gravimetric or volumetric. Gravimetric feeders usually have a conveyor that uses a set of scales to maintain a constant weight of material on the belt. They are not used in water treatment much because most treatment chemicals are corrosive and will damage the scale mechanism. Volumetric feeders are the most common. They include auger feeders and positive displacement metering pumps.



The actual feed device may be a screw auger, a rotating disc, an oscillating shelf, or a variable speed conveyor belt. The feeder control may be calibrated in pounds per day, but usually the scale simply reads from 1 to 10 or 1 to 100. The manufacturer may provide a chart

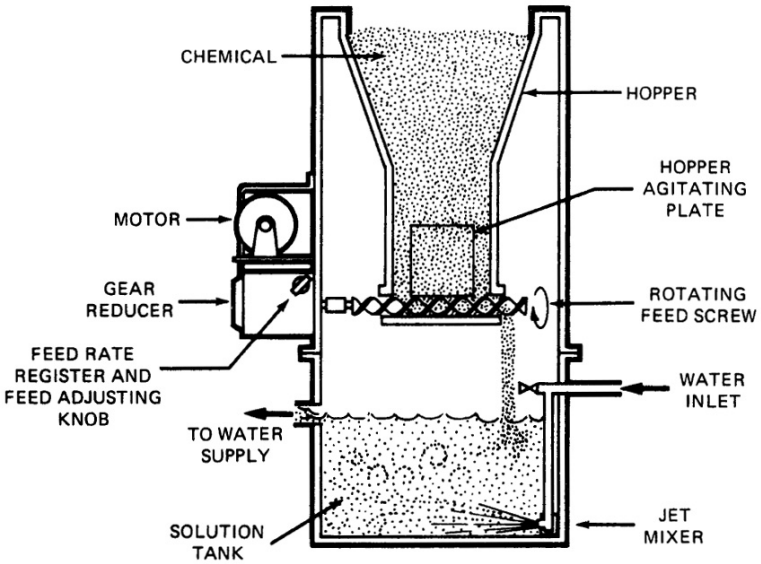


Figure 10.7 - ***Volumetric Chemical Feeder***

is in need of cleaning or maintenance due to clogging or belt slippage. The first step is collecting and weighing the amount of chemical fed in one minute at several different settings. These figures multiplied by 1,440 minutes per day will give pounds per day feed rate. These points can be plotted to create a straight-line graph that can be used to accurately set the feed rate.

Chemical feed pumps are small positive displacement pumps. They are usually diaphragm pumps, but peristaltic pumps are becoming popular for very small systems. Peristaltic pumps consist of a circular pump head that contains a piece of rubber tubing and a roller assembly. As the pump motor turns the roller, fluid is squeezed out of the tube. These pumps can meter flows as low as 3-4 drips per minute (0.1-0.15 ml/min).

The diaphragm feed pump consists of a diaphragm driven pump chamber, and two check valves. The check valves, that provide the one-way flow through the pump, can get clogged with lime deposits. The strainer on the pump suction line should be located several inches above the bottom of the solution tank to prevent lime and grit from being drawn into the pump and fouling the check valves.

If the check valves get fouled, the pump will not pump any solution. Flushing the line with clean water or a weak acid, like vinegar, may also correct the problem. In severe cases the valves may have to be disassembled and cleaned. Always make sure the pump is primed before putting it back into service. It may also be advantageous to locate the pump so that it has a positive suction head.

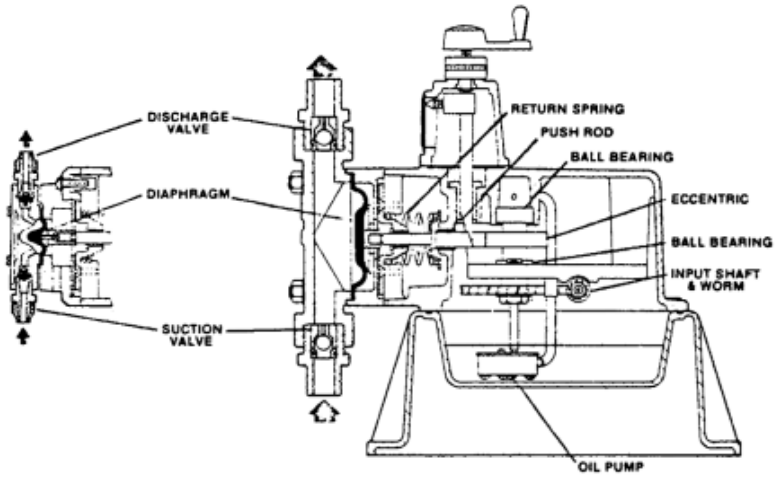
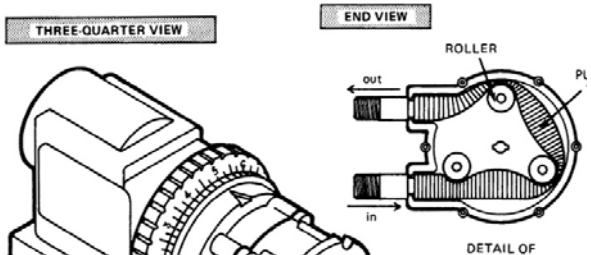


Figure 10.9 - ***Diaphragm Pump***



References

Office of Water Programs, California State University

Basic Study Questions

1. Why is a maintenance program important?
2. What would indicate that it is time to change the pump packing?
3. Why would a bearing that has just been lubricated run too hot?
4. What conditions indicate that a coupling should be replaced?
5. What are the advantages of instrumentation and telemetry?

Basic Sample Test Questions

1. What would a dial indicator be used for?
   A. Measuring temperature
   B. Measuring vibration
   C. Measuring flow
   D. Measuring shaft misalignment

2. Connect a motor to a pump using:
   A. A sleeve clamp
   B. A coupling
   C. Mechanical seals
   D. Bailing wire and bubble gum

3. Which of the following would be a good application for a peristaltic pump?
   A. Booster pump
   B. Well pump
   C. Chemical feed pump
   D. Air compressor

4. Which component in a diaphragm pump causes the most maintenance problems?
   A. Shaft
   B. Check valves
   C. Diaphragm
   D. Pump head

5. A straight edge can be used as an initial check of coupling alignment
   A. True
   B. False

Advanced Study Questions

1. What is an instrumentation feedback loop?
2. What causes an instrument to “hunt” for a setpoint?
3. How many places must readings be taken to check motor alignment?

Advanced Sample Test Questions

1. Misalignment of the pump and motor can cause damage to:
   A. The coupling
   B. The bearings
   C. The mechanical seal
   D. All of the above

2. An important quality of an instrumentation sensor is:
   A. Reliability
   B. Repeatability
   C. Accuracy
   D. All of the above

3. Graduated cylinders can be used to:
   A. Calibrate chemical feed pumps
   B. Store chemicals
   C. Adjust mechanical seals
   D. Prevent surges in the system

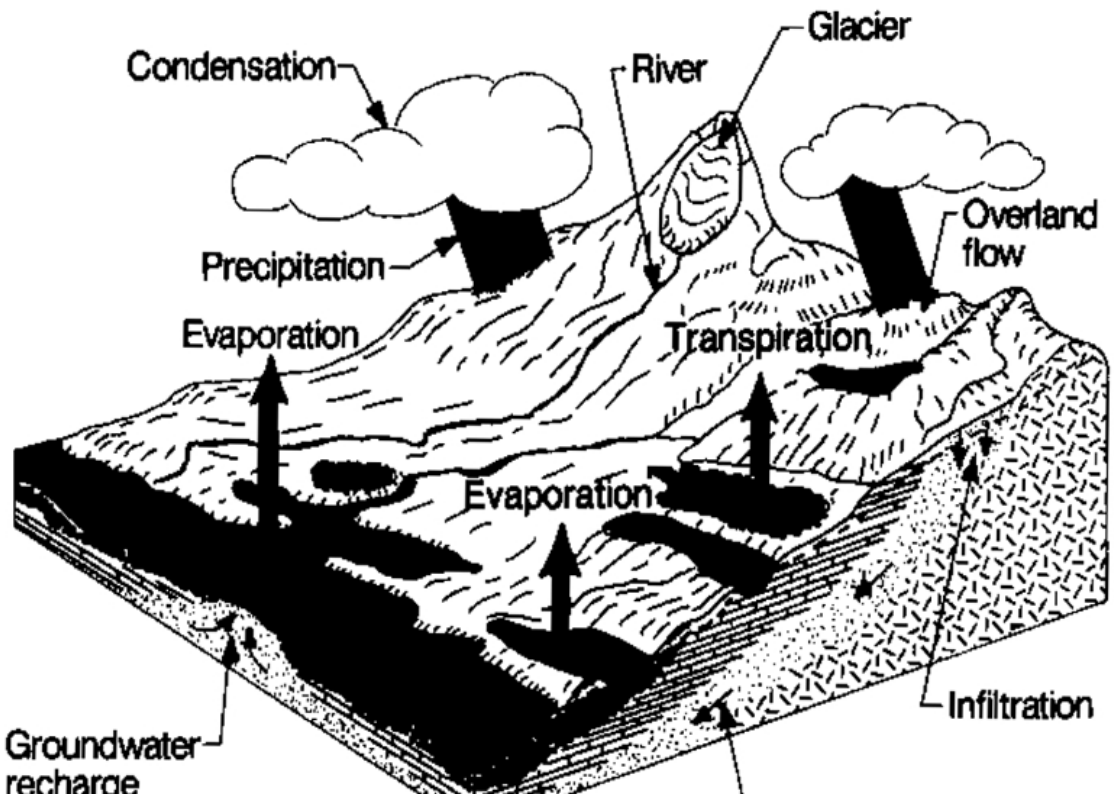
HYDROLOGIC CYCLE

Water is being exchanged between the earth and the atmosphere all the time. This exchange is accomplished with energy supplied by the heat of the sun and the pull of gravity. Water that enters the atmosphere from wet ground, lakes, rivers and the ocean is known as evaporation. Plants also release water to the atmosphere. This process is known as transpiration. It is carried in the air as water vapor. When the water vapor cools and condenses, it changes from a gas to a liquid and falls back to earth as precipitation in the form of rain, sleet, snow, or hail. Evaporation from land and ocean puts water back in the atmosphere, and the exchange goes on continually as water goes from earth to atmosphere to earth. For this reason, the exchange of water between earth and atmosphere is called the Hydrologic Cycle.

When precipitation falls, part of the water runs off into natural channels, part of it evaporates, and the remainder seeps or infiltrates into the ground. The amount of water that percolates farther into the ground water supply depends on the type of soil it must pass through and how much water is retained in the root zone. Plants retain the water in the root zone and release it back to the atmosphere as transpiration. Percolation is the most common means of recharging ground water supplies.

GROUND WATER SUPPLIES

Water will continue to percolate down through the earth until an impervious stratum is reached. An impervious stratum is a layer of material in the earth that will not allow water to pass through it. This material is usually made of rock formation or clay. As the water reaches the impervious stratum, it will begin to collect and saturate the surrounding soil, forming an aquifer. It is a common belief that the water quality of an aquifer is constant throughout the aquifer. In fact, the water quality can change dramatically within the confines of a given aquifer. This can be attributed to changes in the medium or mineral deposits in the zone of saturation. Aquifers are generally classified as Water Table (unconfined) and Artesian (confined).



Water Table Aquifer

An aquifer that is formed from a single impervious stratum and has an upper surface that is free to rise and fall with seasonal changes of recharge rate is known as a water table or unconfined aquifer. This condition allows the free flow of water in the aquifer generally in the same direction as surface water. The water level in a well located in a water table aquifer will not rise above the initial point of encounter.

A perched aquifer is a very small, unconfined aquifer that doesn't contain much water and is only recharged by local precipitation.

Artesian Wells

Artesian wells originate from groundwater that is trapped between two impervious strata (See Figure 11.2). As the water flows between these strata it becomes confined and, as recharge continues, the water backs up creating pressurized conditions in the aquifer. Water in a well located in an artesian aquifer will rise above the point at which it is first located. If the water rises to the surface it is a free-flowing artesian well. If not, it is called a non-flowing artesian well.

Types of Ground Water Formations

The saturation zone of an aquifer may be any one of several different materials. Most aquifers occur in formations of sand or gravel. Others may be found in limestone, dolomite, sandstone, shale, clay, or even silt. The type of formation will influence the water quality and yield of a well.

Water Well Location

Several factors are involved in selecting a site for a new well. The most important of these is finding adequate quantities of water that will meet SDWA drinking standards with the minimum amount of treatment. Potential pollution of the water supply is another major concern. Economics related to purchasing easement and connecting to the system, and population or demand within the system will also be factored into the decision. Finally, politics can become an issue in some cases.

Consulting engineers will rely on well logs from other wells in the area, geological data, and test holes to determine where the best chance of finding the appropriate quantity and quality of water exists. But even then, drilling a water well is still a hit or miss proposition.

Sanitary Considerations

Sanitary hazards must be considered when locating a well. Areas of limited permeability, flood prone areas, chemical or radioactive disposal sites, and industrial waste treatment facilities may require special consideration as far as well location is concerned. Wells should never be located in a 100-year flood plain.

Water Well Construction

Water wells may be classified according to the method of construction. The type of construction will depend on the depth of the well, the geological formations to be encountered, and the amount of water needed for the system.

Small wells, particularly private wells, may be dug or driven. Public water systems usually require more water than either dug or driven wells can produce. The most common method of construction used by public water systems is the drilled well. These wells are ideally suited to deep water bearing formations where larger yields are available. This type of well, when properly constructed offers good protection against contamination from the surface. Two different methods of constructing drilled wells are the cable tool or percussion method and the rotary drilling method.

Cable Tool Method

The impacts created by raising and dropping a heavy drill bit and stem crushes and dislodges pieces of the formation as the well is drilled. The up and down motion of the drill bit mixes the cuttings with water to form slurry and a bailer is used periodically to remove the slurry. A bailer is made of a 10 to 20 foot section of pipe with a foot or check valve at the bottom. The casing is usually put in place as the well is drilled, especially in loose formations such as sand and sandy loam. Wells drilled by the cable tool method are more likely to have problems with vertical alignment than those drilled by the rotary method.

Rotary Drilled Wells

These types of wells use power driven drill stems, which in most cases are hollow. The drill bit is attached to the lower end of the drill stem and breaks up the material as it advances. Water or drilling mud is pumped down the drill stem to cool the bit. It also picks up the cuttings or drilling fines and carries them to the surface. The mixture of mud cuttings is discharged to a settling pit where the cuttings are removed and the drilling mud is recirculated. When the well hole is completed, the drill stem is withdrawn and the casing is put in place.

Vertical Casing Alignment

It is important that the casing is in proper vertical alignment

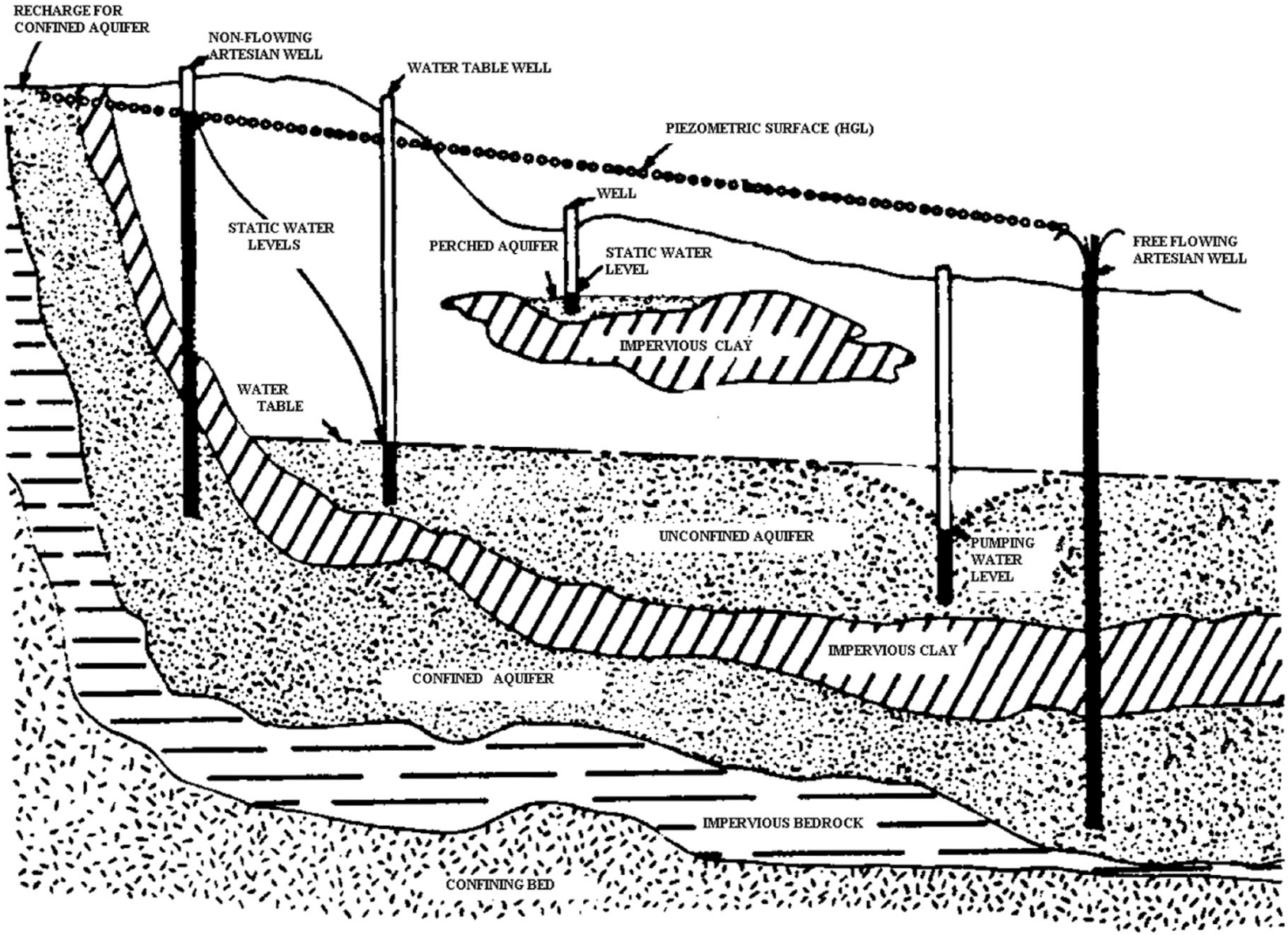


Figure 11.2 - ***Artesian & Water Table Aquifers***

ways to check casing alignment. Down-hole TV inspection is popular because the condition of the casing and screen can be checked at the same time.

Sanitary Protection of the Well

After a well has been drilled, care must be taken to prevent any surface contamination from entering the water supply. First, the casing is set to prevent the well from caving in or becoming contaminated from undesirable water sources located above the aquifer. The casing should be grouted with concrete on the outside to a depth of at least 50 feet or until an impervious layer of clay or rock is encountered. It may be necessary to grout deeper than this to seal off any undesirable water formations from the well. The depth of grout is determined by NMED on a case-by-case basis. In most instances, grouting will be required to extend to the water table. The grout must be pumped into the well from the bottom to the top. Otherwise, air will be trapped and prevent proper sealing of the cavity.

The casing should extend at least 6 to 12 inches above the well pad, depending on whether the well is located in a well house or out in the open, to prevent standing water from entering the well. The well pad should be sloped away from the casing. A sanitary well seal must be used to connect the well head and motor to the casing. Well seals are usually made of rubber or neoprene. A welded seal is also approved and used in some cases.

Well casing and discharge column pipe vents should extend at least 18" above grade. The outlets should be turned down to prevent rainwater from entering, and screened to keep bugs out. Well housings should never be located in a pit. Abandoned wells should be plugged to a depth of at least 10 feet. In some states they must be completely cemented.

Developing A Well

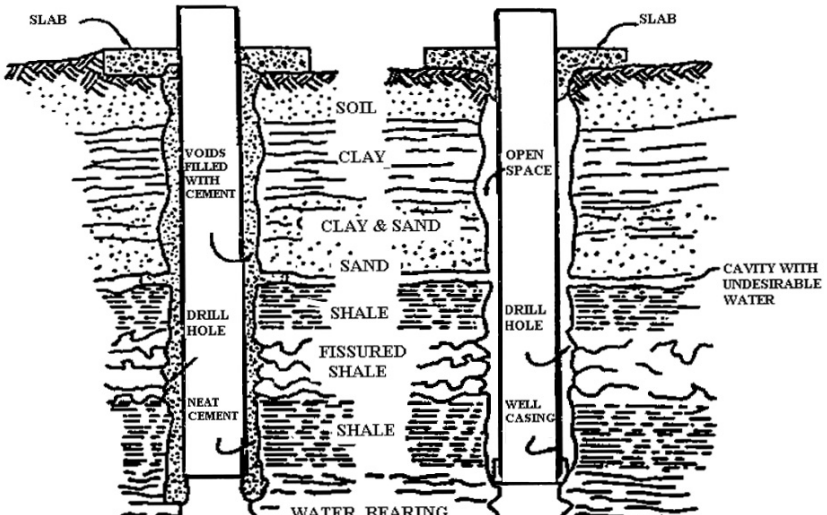
Once construction is complete, the well is developed to remove the very small sand, shavings, and drilling mud from the surrounding aquifer. Two methods used to develop the well are surging and backwashing. Water is forced in and out through the screen as it flushes out the drilling mud and fine sand. Usually a pump much larger than the actual production pump is used. The well is pumped at the highest rate possible. This is done not only to remove the loosened mud but also to determine the well log data such as the yield, static and pumping levels, and specific capacity. The development of this data may re-quire that this pumping rate be maintained for at least 8 hours.

It may take much longer to clear the well of drilling mud prior to disinfection. It is also important to determine the well recovery rate after the test is completed. The pump used to develop the well should never be the pump that is to be installed upon completion.

Gravel Packed Wells

Wells that are located in fine sand formations, where sand pumping presents a problem, are usually gravel packed. If gravel packing is not used, the screen openings may have to be so small that the yield of the well is dramatically reduced. A layer of gravel is placed around the screen to hold the sand back and allow a larger well screen to be installed. The gravel packing is usually three times the diameter of the well screen or a minimum of 4" thick. The selection of the size of the gravel to be used depends upon the type of sand formation that is encountered and the type of screen that is being installed.

The gravel does not filter the sand. It is the increasing velocity, as the water gets closer and closer to the screen, which draws the sand into the well. The gravel pack holds the sand out away from the screen where the velocities are significantly lower than they are at the point



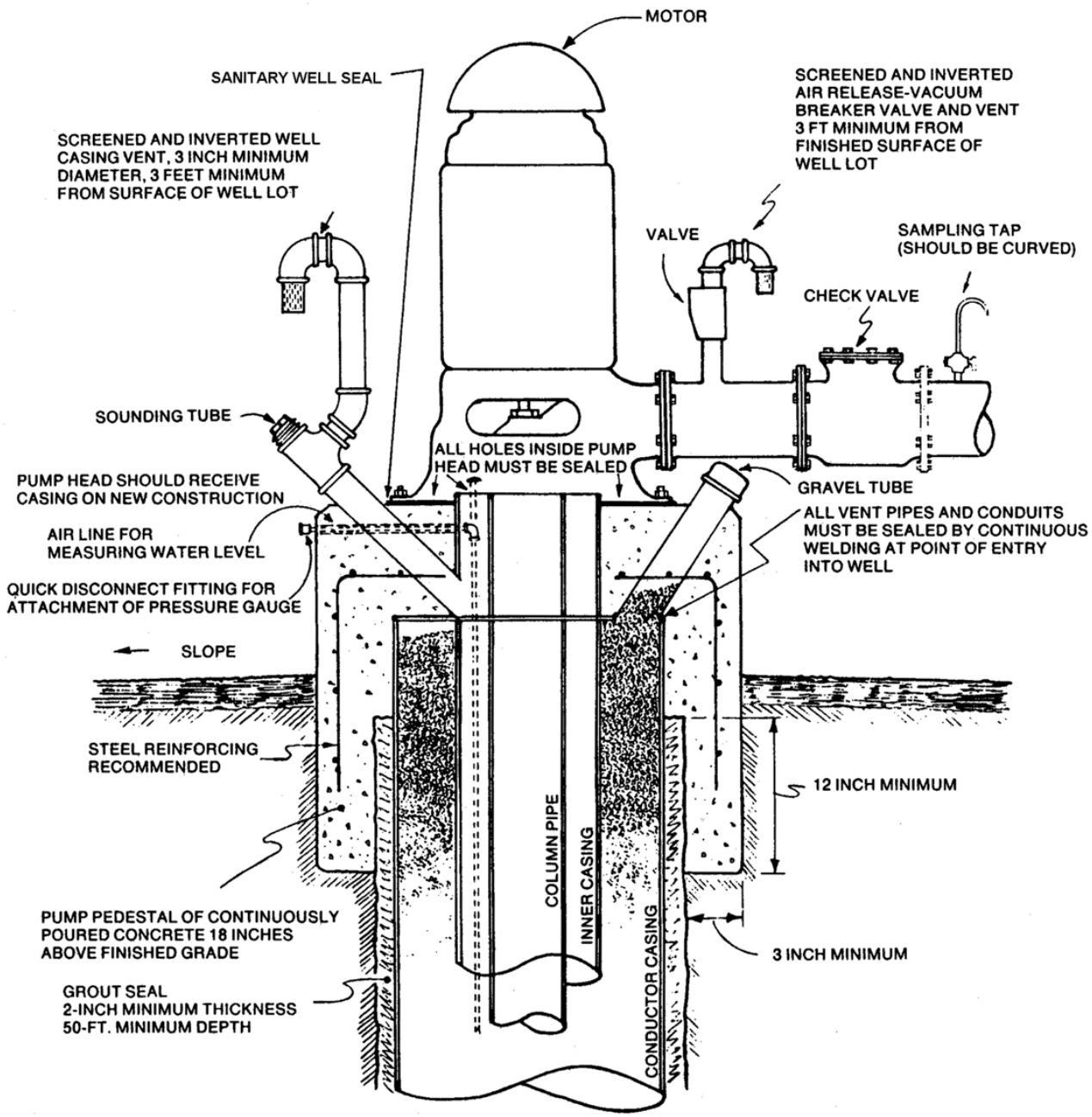


Figure 11.4 - ***Gravel Pack Well Construction***

As sand is pumped out of the well, the gravel will fill in the cavity that is created and the gravel level will drop. This can result in exposing the well screen if gravel is not added periodically. The gravel is usually added to the well through a gravel packing pipe. This pipe is usually about 4

Gravel should be cleaned and disinfected with a strong chlorine solution before it is added to the well. The level should be rechecked as the new gravel is added. Gravel should never be allowed to stand in the packing pipe. The

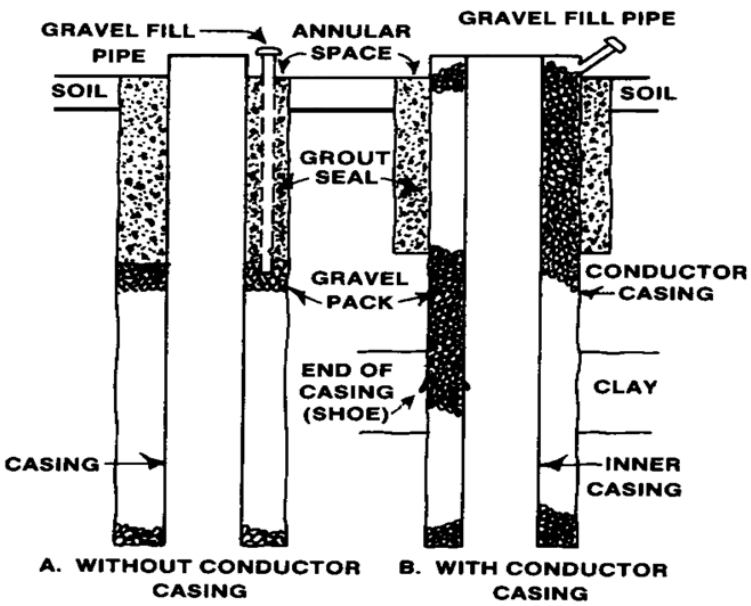


Figure 11.5 - ***Gravel Packed Well Types***

Disinfecting Water Wells

The final step prior to putting any new well or an old well that has had major cleaning or repair into service, is disinfection and testing for bacteriological quality. The well should be flushed or redeveloped to remove drilling mud and debris prior to disinfection. (It is always easier to flush dirt out of the system than it is to burn it up with chlorine.)

Disinfection is achieved by the addition of a strong solution of chlorine to the well. The chlorine dosage should be at least 50 mg/l. If dosages in the range of 200 400 mg/l are added, less contact time will be required. The well should then be agitated periodically by surging. The contact time at a dosage of 50 mg/l should be 18 to 24 hours, but at 200 mg/l only about 2 hours is needed. However, with longer contact times, the chlorine will move farther out into the surrounding aquifer.

The well should be flushed to remove the remaining chlorine once disinfection is completed. The bacteriological (Bac T) samples should then be taken from the well and submitted for testing. These samples must be taken daily until they are negative on two consecutive days.

Well Pumps

shaft. These pumps can generate the high discharge pressures needed to pump water several hundred feet out of the ground.

"Staging" (stacking several impellers on the shaft) generates high pressures required to lift water out of the well. As the water passes from the discharge of one impeller to the suction of the impeller above it, the pressure that the pump develops is increased. For example, if five impellers that generate 100 feet of head each are staged in a pump, the pump will generate a total of 500 feet of head pressure. Anytime pumps are operated in series, where one pump or impeller discharges to the suction of another pump, the pressure will increase while the flow remains constant.

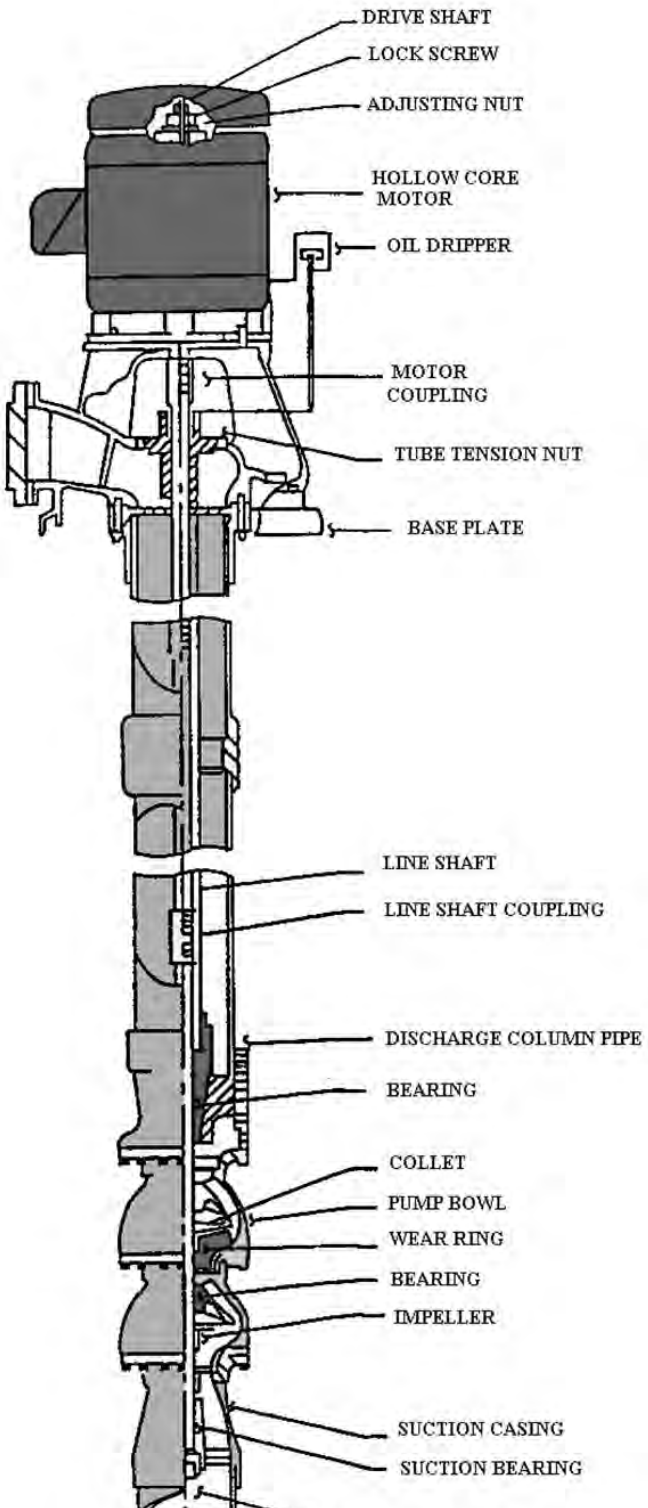
In some very small, shallow wells airlift pumps may be used. These are normally not suitable for wells supplying most public water systems.

Vertical Turbine Installations

There are two kinds of vertical turbine pumps installed in wells. One of these is known as a submersible pump. A submersible pump will have the motor located beneath the pump. In a small well, it is the least expensive centrifugal well pump to purchase and install. Because there is no pump shaft running to the surface, the submersible is also the ideal pump installation in wells where vertical casing alignment problems exist. The biggest disadvantage of submersible pump installations is that the pump must be pulled from the well when the motor needs repair. Since this is usually the most common well type of repair for water wells, the cost of maintenance for submersible pumps is very high.

The other type of vertical turbine well pump is known as a line shaft pump. Line shaft pumps have the motor located on the well head. A line shaft runs down the discharge column pipe to the pump. The shaft is supported by line shaft bearings that center and stabilize the shaft in the column pipe. Line shaft pumps will cost more than submersible installations.

Vertical casing misalignment may make a line shaft pump installation impractical. The stress placed on the shaft and bearings can lead to chronic maintenance problems. The biggest advantage of a line shaft installation is that the motor can be repaired without pulling the pump and column pipe from the well.



feet, there are 5-8 bearings for every 100 feet of shaft. These bearings must be lubricated. There are two methods of lubricating line shaft bearings. One method utilizes water to lubricate the bearings while the other uses an oil-lubricated system.

Line Shaft Bearings

Water lubricated line shaft bearings rely on the water that is pumped through the column pipe for cooling and lubrication. When the water table is very shallow, water in the column pipe will reach the bearing almost immediately. If the water table is deeper it can take several seconds for water to reach the uppermost bearings. If these brass or rubber bearings are allowed to spin for even a few seconds without lubrication they will fail prematurely. This type of installation will normally have some type of pre-lubrication system that allows water to run down the shaft and lubricate the top bearings before the pump starts. It may be set on a timer or it may drip continuously. Even with this type of pre-lubrication system, it is difficult to guarantee that all of the bearings that are located above the water table are properly lubricated before the pump starts.

Oil lubricated line shaft pumps are normally installed when water table depths exceed 100 feet. In an oil-lubricated system, the shaft spins inside a tube that is kept full of oil. The oil used in these systems must be EPA approved. These oils can be either vegetable or mineral based. Line shaft bearings are located inside the tube. Spider supports stabilize the tube inside the discharge column pipe.

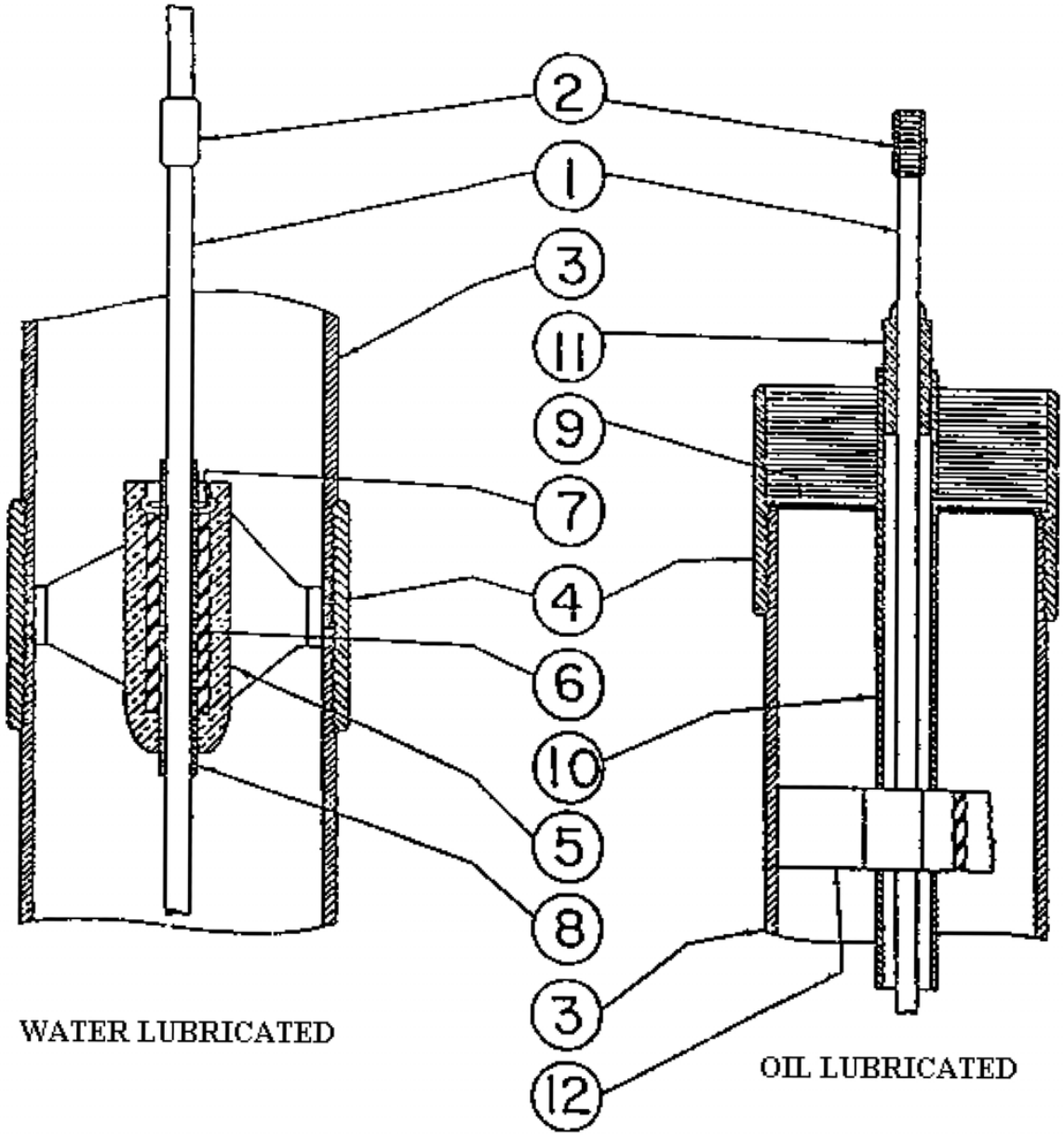
Oil Dripper Systems

Oil lubricated line shafts will usually be supplied with a dripper system to keep the shaft tube full of oil. The dripper system will consist of two dripper assemblies. One dripper will be setup to drip constantly and the other will be activated by a solenoid and will drip only when the pump is running. The solenoid-activated dripper will normally be supplied with a cooling water jacket that helps to maintain a constant oil temperature in the dripper.

The cooling water is needed because temperature fluctuations will cause the viscosity or thickness of the oil to change. As the viscosity changes the drip rate will also change. The effect that these changes will have on the drip rate must be taken into consideration when the drip rate is adjusted. The drippers should be checked and adjusted at least twice a year, in the early summer and early winter.

Adjusting Dripper Systems

The constant dripper should be adjusted when the well has not been running for several hours. The oil temperature will be about the same as the ambient air temperature. This



1 - Line Shaft
2 - Shaft Coupling
3 - Column Pipe
4 - Column Pipe Coupling
5 - Stabilizer Support (Spider)
6 - Rubber Shaft Bearing
7 - Snap Ring
8 - Shaft Sleeve
9 - Column Pipe Spacer Ring
10 - Oil Tube
11 - Line Shaft Bearing
12 - Tube Stabilizer (Spider)

Figure 11.7 - ***Shaft Lubrication Systems***

The automatic dripper should be set after the well and the cooling water lowers the oil temperature. In most wells

Well Screens

There are several types of well screens that can be installed in most wells. They range from well casing that is perforated on-site with a cutting torch to continuous-slot well screens made of steel or sometimes plastic strips that are wrapped around a wire cage. Louvered or perforated casing is also used in many installations. Continuous-slot screens are the most expensive and generally considered to be the best choice because of the low friction loss encountered as the water enters the well. These screens typically have openings that are equal to 40-50% of the total surface of the screen.

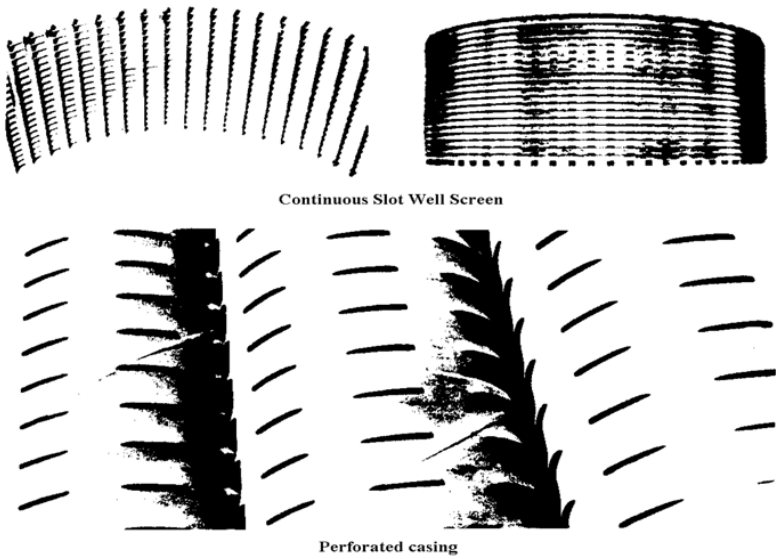


Figure 11.8 - ***Well Screens***

Well Hydraulics

The amount of water a well will produce depends mainly on the type of aquifer, well construction, and the depth of the zone of saturation. The annual recharge rate from percolation, along with the ability of the water bearing formation to transmit water to any given point, will also influence well production. The performance of a well can be determined by taking readings of the hydraulic conditions. An operator must be familiar with these terms and definitions* in order to accurately troubleshoot problems that may be discovered.

- Static level is the water level in a well when the pump is not operating.
- Drawdown is the difference between the static level and the level of the water in the well when it is pumping. Drawdown is a measure of the resistance to water flow in the aquifer. It is also a measure of the head loss encountered in moving the water into the well. Water bearing formations of gravel, limestone and course sand will usually provide more water with less drawdown than formations containing fine sand or clay.
- Specific capacity is the relationship between the yield of a well and the amount of drawdown in the well. It can be expressed as a ratio of the yield, in terms of gallons per minute, to the drawdown in feet. A well producing 100 gpm with a drawdown of 20 feet would have a specific capacity of 5 gpm per foot of drawdown.

$$\frac{\textbf{100 gpm}}{\textbf{20 feet}} = \textbf{5 gpm/foot}$$

In this particular case every time the yield is increased by 5 gpm the drawdown will increase by one foot. This relationship will exist until the yield exceeds the aquifer's ability to deliver water to any single point. When this limit is reached, the drawdown increases dramatically with little or no increase in the yield.

- Cone of depression is directly related to the drawdown in the well. As the pump draws down the water level, a portion of the aquifer surrounding the well is drained of water. A cone shaped depression is formed in the water table around the well. The shape of the cone will vary depending on the type of formation in which the well is located. A fine sand formation will usually create a steep cone of depression, while a shallow cone is usually found in coarse sand and gravel formations.
- Radius of influence is the farthest distance from the well that the cone of depression affects the water table. This distance can be determined by sinking test holes around the well and monitoring the water levels in them while the well is pumping.
- Recovery time is the amount of time required for the aquifer to stabilize at its static water level once pumping has stopped. This can also be determined by monitoring the water levels in the test holes used to determine the radius of influence.

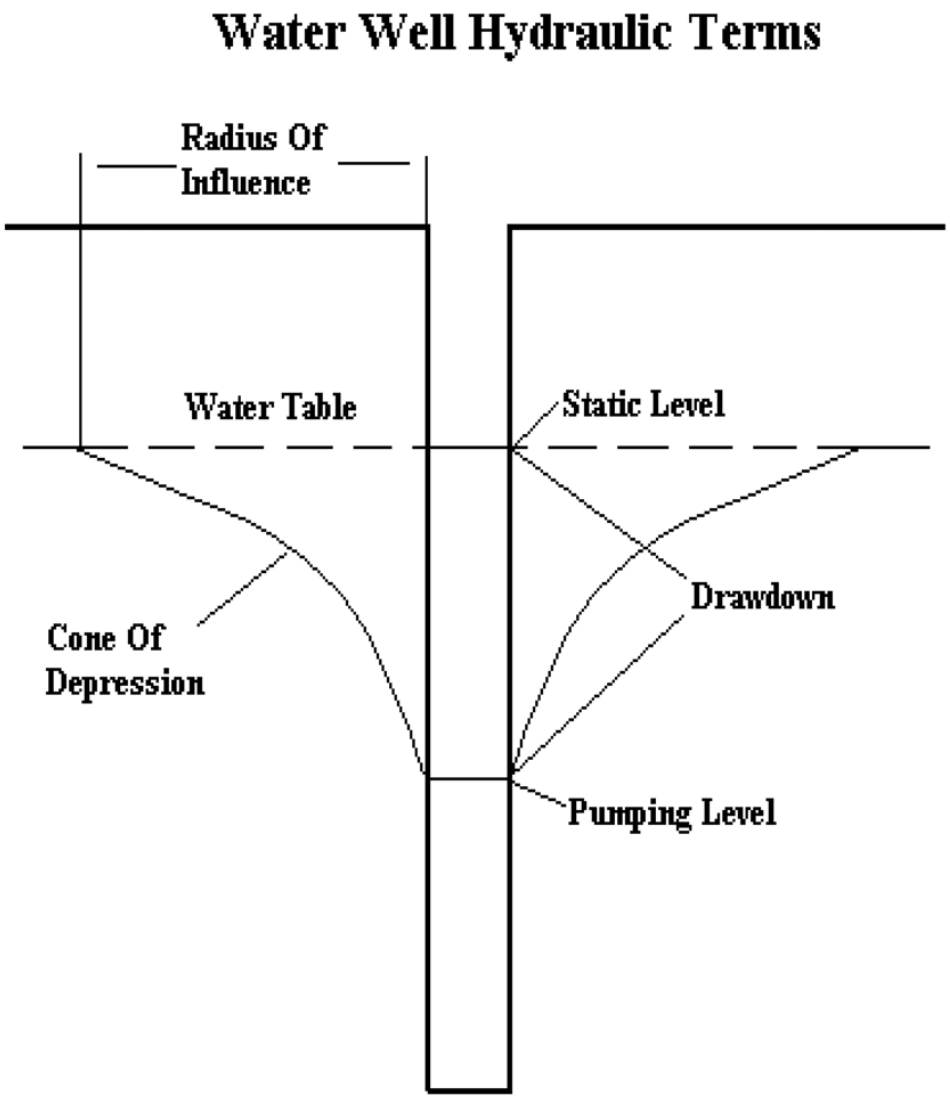


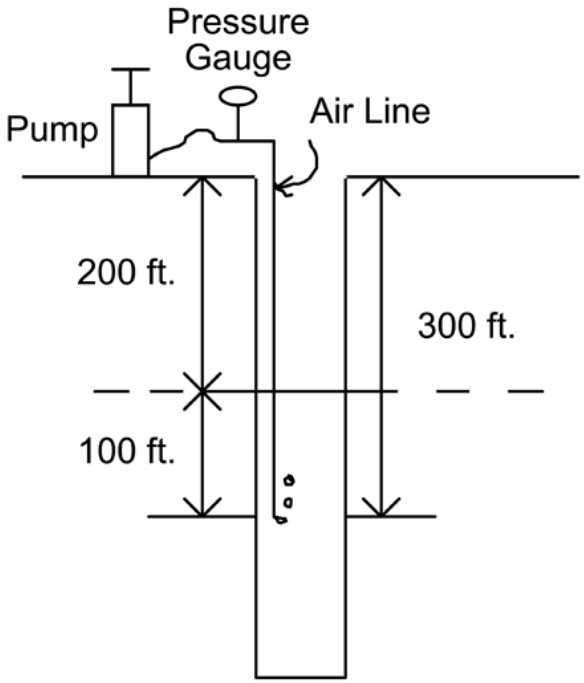
Figure 11.9 - ***Water Well Hydraulic Terms***

Measuring Static and Pumping Levels

Several methods can be used to determine the elevation of water in the well. This can be accomplished by lowering some type of measuring device into the well casing through a sounding tube (sometimes called a drawdown tube) that can locate the water level. A chalk line can be used if the approximate level is known. The bottom five to ten feet of the line is chalked and then lowered into the well to the estimated water level. The amount of line that is wet (easily identified by the wet chalk) is subtracted from the total amount lowered into the well, effectively locating the water with water closes the electrical circuit and lights an indicator lamp on the power supply. The length of the cable that is in the casing is measured to determine the water level. The biggest disadvantage to using this type of "sounding" device is that the cable may wrap itself around the column pipe, making removal a real problem.

Another effective method of determining these levels involves using an air line. The air line is installed inside the casing and extends down to a point just above the bowls of the pump. A pressure gauge, installed at ground level, and an air pump (bicycle or hand pump) are all the equipment

air. This gauge reading will represent a column of water the same height as the distance the line extends below the surface of the water. Subtracting this distance from the total length of the line will locate the elevation of the water in the well. The gauge reading may be used directly if the gauge is calibrated in feet of head. If the gauge reading is in pounds per square inch (psi), it must be multiplied by a factor of 2.31 ft/psi before being subtracted from the length of the air line. In the example below, the air line is 300 feet long and the gauge reading is 100 feet of head when the pump is not running. By subtracting 100 feet from 300 feet, we find the depth to water is 200 feet.



300 ft. (air line) - 100 ft. (head) = 200 ft. to the water

Figure 11.10 - ***Measuring Static & Pumping Levels***

The static level is determined after the pump has not been running for several hours or overnight. The pumping level should not be determined until the well has been pumping long enough to insure that the pumping level has stabilized. It could take from 30 minutes to several hours to stabilize the pumping level.

The Well Log

Table 11.1 - ***Well Log Data***

- **Depth of the Well**
- **Length of Screen**
- **Pump Setting**
- **Yield**
- **Static Water Level**
- **Pumping Water Level**
- **Drawdown**
- **Specific Capacity**
- **Other Geological Data Regarding the Aquifer**

everything is working right. Without this data, it is very difficult to determine what, if anything, is wrong with current well performance. If a well is over 20 years old, there is a good possibility that the well log can't be located. This is no reason to panic yet. Contractors are responsible for filing a copy of every public water supply well log with the State Engineer's Office. Copies of well logs can be obtained by contacting the State Engineer. Information on surrounding wells may also be obtained to assist in gathering data used to locate new wells.

Troubleshooting Well Problems

There is little information that can be gathered that will indicate how a well is performing. Changes in the static level, the pumping level or the yield of a particular well will generally indicate a problem has developed. In addition to this information, the current draw (amps) on the motor is the only other indicator of poor well performance. It is important to check static and pumping levels periodically to prevent any problems that may develop from becoming serious. The well log is used as a reference for each set of readings. Anytime there is a well problem, both the yield and the specific capacity will be reduced.

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Well Related Problems

Let's take as look at the example illustrated in Figure 11.11. From the well log and current measurements, it has been determined that the static level has remained the same but the pumping level has dropped several feet.

Under these conditions it should be noted that the drawdown has increased. The drawdown is equal to the head loss encountered in moving water into the well. Since the

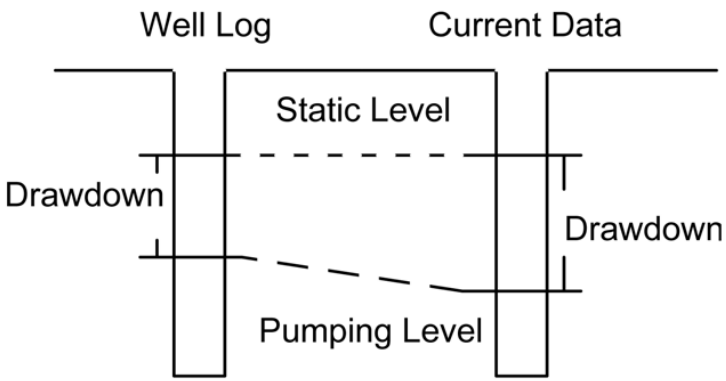


Figure 11.11 - ***Well Problem - Clogged Screen***

Clogged Well Screens

There are several ways that a well screen can become clogged. The most common cause is chemical scaling or lime encrustation on the screen. Newer wells may develop a condition called "sand bridging." Another possibility is clogging due to iron bacteria colonies that are growing on the screen.

Sand Bridging

Sand bridging is a condition that is normally only found in new wells. It occurs when sand, drawn toward the well, blocks the screen by forming an arch across the openings.

Sand bridging is usually a result of improper development of the well or inadequate gravel packing. Surging water through the screen may break up the bridging. If surging doesn't work, it may be necessary to pull the pump and mechanically clean the screen with high-pressure jets to correct the condition. The well should be re-developed before replacing the well pump.

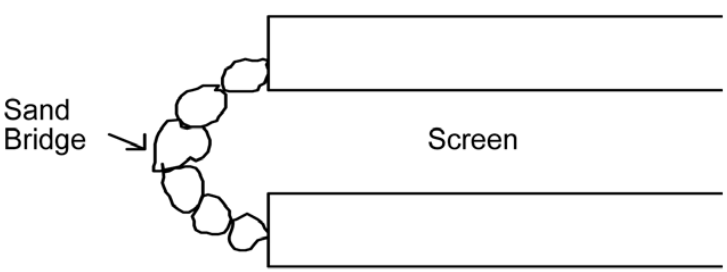


Figure 11.12 - ***Well Problem - Sand Bridging***

Iron Bacteria

Clogging caused by iron bacteria is a problem for many wells in the Southwest. If the well has been in service for

Clogging caused by iron bacteria is very difficult to remove. Chemical treatment with massive doses of chlorine (200-300 mg/l) followed by surging or even mechanical cleaning may be the only means of clearing clogged screen openings. Even then, it is unlikely that the entire colony has been removed. The remaining bacteria will begin to grow, causing a recurrence of the problem. Wells with iron bacteria should be treated with chlorine periodically to inhibit the regrowth for as long as possible.

Lime Scaling

Lime scaling is most likely to occur when the water contains high amounts of alkalinity and hardness. Like iron bacteria, lime scaling will tend to be a chronic problem where the conditions that promote its formation exist. There are several ways to clean a screen of lime scale.

Cleaning Incrusted Well Screens

Well screens that are clogged with scale can be cleaned using one of several techniques. The four most commonly used methods are listed below:

1. Surging water through the screen may break up loose scale that is just beginning to form. This is accomplished by starting and stopping the pump to allow water in the column pipe to fall back into the well and create a surge out through the screen. This is sometimes taken a step further by holding the check valve open when the pump is stopped so that more water will rush down the well and out into the surrounding aquifer. In order for this method to be effective, the condition must be identified before the scaling becomes very severe.
2. The percussion method may be the most dangerous method of cleaning a well screen. It involves the detonation of some type of explosive within the well casing. The theory behind this process is that the explosion will create shock waves that will vibrate the screen enough to shake the scale loose. This is sometimes accomplished by firing a blank down the well. This is only effective in very small, shallow wells where there is not much water standing above the clogged screen.

   In most public supply wells a larger charge is needed, and it is usually placed down the well in the vicinity of the screen. Blasting caps and primer cord are the most common

3. The acidizing method will clean all but the most severely scaled screens. Acid is poured down the well casing and allowed to stand for 8 to 12 hours. The acid will react with the lime and dissolve the deposits on the screen. The well is then surged to help loosen the remaining scale and flushed.

   Always use inhibited acid! Inhibited acid is chemically weakened. In this weakened state, it will dissolve the lime without attacking the screen or pump parts. There are inhibited acids available in solid forms that can make the acidizing process much easier and more effective. The pelletized acid can be poured into the casing where it will sink to the bottom of the well and dissolve in the area of the screen. Sulphamic acid, for example, is one such acid.

4. Mechanical cleaning may be the only method that is effective in situations where severe clogging exists. Mechanical cleaning will require the removal of the pump from the well. The screen will be cleaned using a larger wire brush or high-pressure water jets and then bailed to remove the debris that is knocked loose. In extreme cases, the screen may have to be pulled and cleaned or replaced. Not only is this very expensive, but it can also result in the collapse of the gravel pack around the screen. Anytime the pump is pulled from the well and maintenance is performed, the well must be disinfected prior to being put back into service.

Pump Related Problems

From the well log and current measurements, it is determined that the static level is the same, but the pumping level has risen several feet. Water production from the pump has also decreased. This reduced drawdown and yield from the well indicates a problem with the pump.

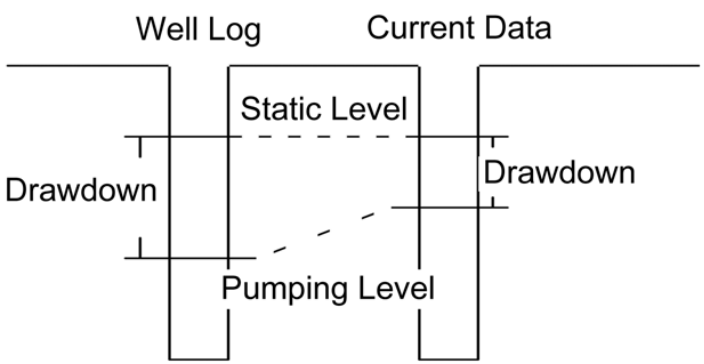


Figure 11.13 - ***Well Problem - Mechanical Pump***

If the impeller clearance is properly set, the only other cause of this type of condition is some type of mechanical problem with the pump or line shaft. Mechanical problems will require pulling the pump, so the first step in troubleshooting this situation is to adjust the impeller clearance. Adjusting the impeller clearance is also referred to as adjusting the "lateral setting" or "setting the stretch" on the pump.

Adjusting Impeller Clearance (Lateral Setting)

When the pump is operating, the proper clearance between the wear rings and the impeller should be between 1/32-1/4" (depending on the impeller design). Wear rings, as the name implies, are designed to eventually wear out. The clearance between the impeller will increase as wear occurs. Specific adjustments can be made to raise or lower the impellers and bring the clearance back within acceptable tolerances.

Line shaft stretch must also be taken into account. Even though the shaft is made of hardened steel, it will stretch under load. There are several factors that will determine how much the shaft will stretch. See Table 11.2.

Table 11.2 - ***Forces That Cause Shaft Stretch***

- **The Weight of the Shaft**
- **The Weight of the Impellers**
- **The Downthrust Exerted Against the Impellers**

The most common means of raising and lowering the shaft is by adjusting the top shaft nut or adjusting nut, located on the top of a hollow core motor. The rotor in a hollow core motor is hollow and the pump shaft can slide up and down through the rotor. The adjusting nut prevents the shaft from slipping down through the motor. Tightening and loosening the top shaft nut will then raise and lower the pump impellers. Smaller shallow wells may not have hollow core motors. If this is the case, the adjustment is made at a special motor coupling or by shimming the motor. After a lateral adjustment is complete, motor amps can be used as a tool to check the adjustment.

Table 11.3 - ***Well Troubleshooting Flow Chart***

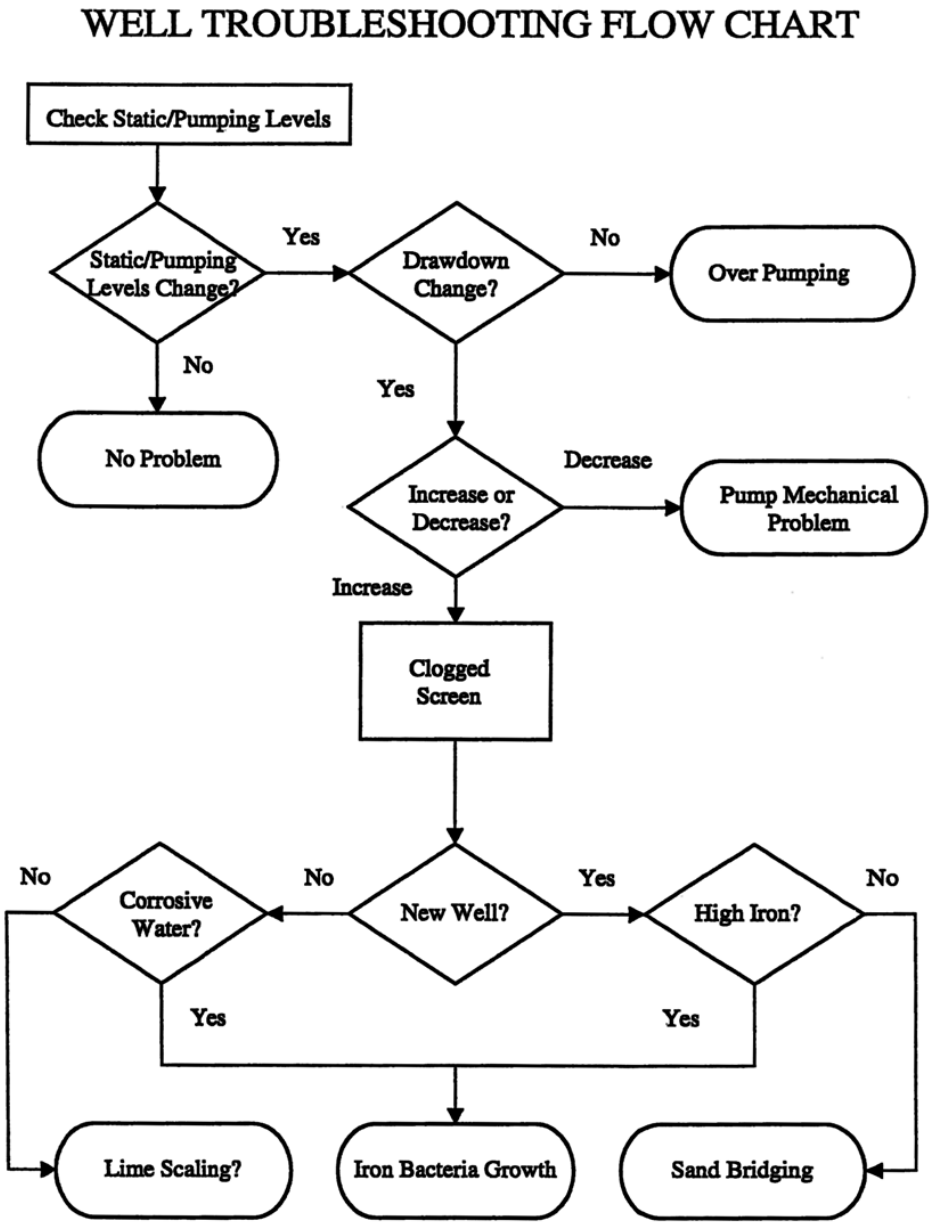
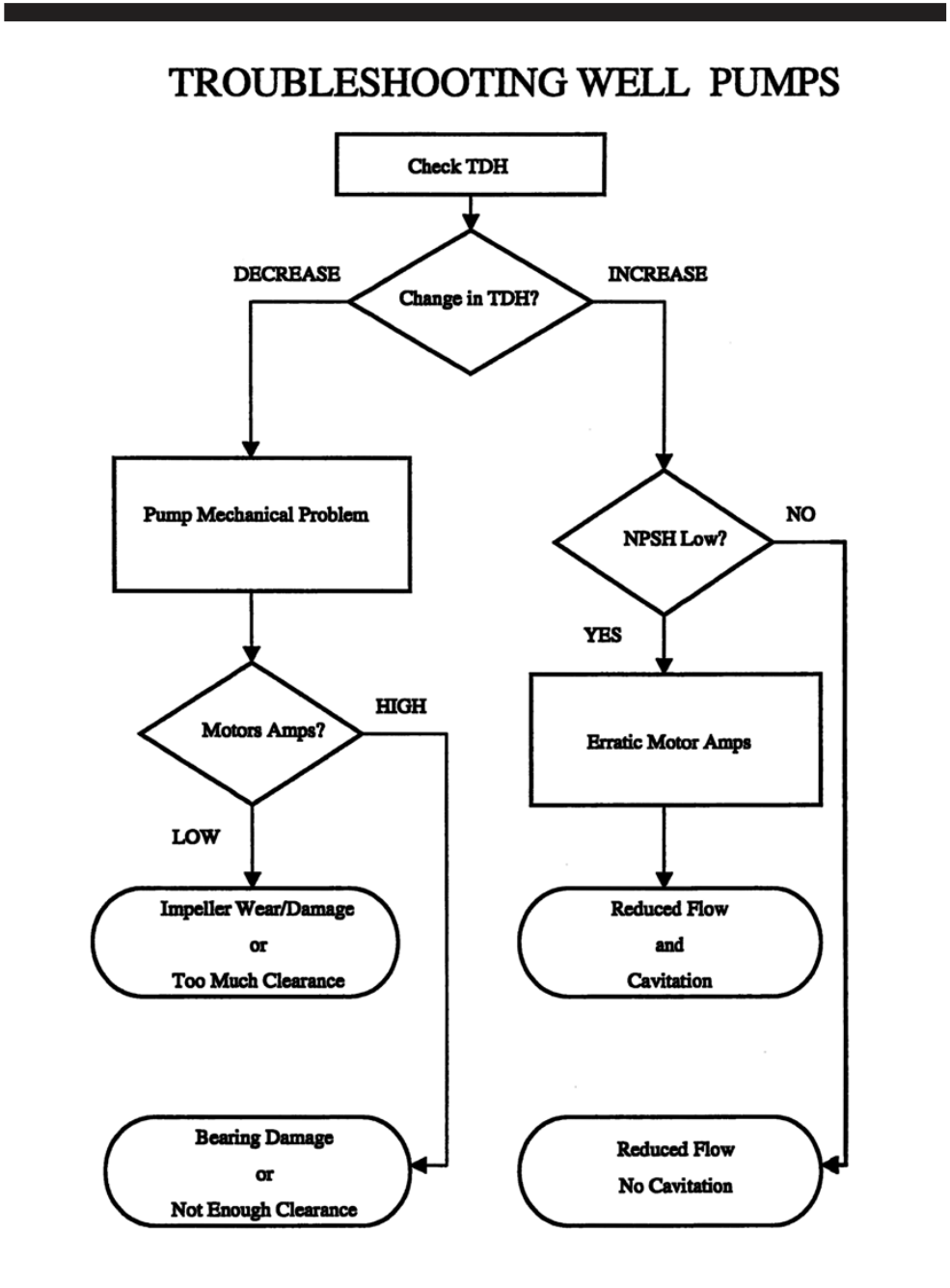


Table 11.4 - ***Troubleshooting Well Pumps***



References

Office of Water Programs, California State Univ. Sacramento, *Groundwater & Wells*, 2nd ed., Chapters 4, 10, 15, 17, & 19.
Office of Water Programs, California State Univ. Sacramento, *Small Water System O&M*, 4th ed., Chapters 3 & 19.

Basic Study Questions

1. What is meant by the term percolation?
2. What is the primary reason for grouting a well casing?
3. What is the drawdown in a well?
4. What are the requirements for disinfecting a well?
5. Which type of well pump will help minimize the problems caused by well casing misalignment?

Basic Sample Test Questions

1. The distance from the well to the edge of the cone of depression is:
   A. Drawdown
   B. Radius of influence
   C. Infiltration
   D. Zone of saturation

2. If the drawdown increases, the screen is becoming clogged.
   A. True
   B. False

3. Sand production is usually at highest
   A. During startup
   B. After it has run for several hours
   C. When there is a pump-related problem.
   D. All of the above

4. Which of the following does not provide contamination protection for a well?
   A. Grout
   B. Well pad
   C. Motor coupling
   D. Sanitary seal

Advanced Study Questions

1. What are the limitations for water lubricated line shafts?
2. Why is a gravel pack used in wells?
3. What is specific capacity?
4. Public wells should be located how many feet from potential pollution sources?
5. What should be done when treating a well for iron bacteria?

Advanced Sample Test Questions

1. If the pressure gauge on an air line reads 25 psi and the air line is 400 feet long, how far is it to the water level?
   A. 25 feet
   B. 58 feet
   C. 342 feet
   D. 375 feet

2. The friction loss on the suction side of the well pump is equal to:
   A. The drawdown
   B. The specific capacity
   C. The pumping level
   D. The lateral setting

3. When the drawdown in a well increases:
   A. The screen is clogged
   B. The pump impellers may be worn
   C. The specific capacity increases

4. The drawdown in a well has decreased and the motor amps are high. The most likely problem is:
   A. The screen is clogged
   B. The pump impellers are worn
   C. The line shaft bearings are failing
   D. The TDH has increased

Water that is taken from lakes, rivers, or impoundments is known as surface water. Many large systems make use of surface supplies because these rivers and lakes offer storage of large amounts of water. The chemical characteristics of surface water differ from ground water in several ways and generally require a greater degree of treatment to meet the Drinking Water standards. The minimum treatment required for surface water is filtration and disinfection.

As ground water percolates through the soil, the natural filtering action removes much of material responsible for turbidity in surface waters. This filtration and the tremendous retention time in the aquifer provide for the removal of many of the bacteria in ground water. The mineral content of the ground water may be greater than that of surface water. These minerals are dissolved in the water as it percolates through the soil.

Some systems that were once considered groundwater are now defined as "groundwater under the influence of surface water" by the amended SDWA regulations. These systems must now treat their water like other surface supplies and filter and disinfect. Surface or boxed springs are now considered to be surface water supplies. Infiltration galleries are also considered surface supplies. These wells are located so close to a river or stream that the water in the surface supply percolates directly into the wells because the radius of influence overlaps the riverbed.

Surface waters will generally have more bacteria and turbidity present than ground water. Taste and odor problems are usually greater in surface water due to algae, bacteria, and fungi that are present in the water. Ground water may also have taste and odor problems that are usually caused by hydrogen sulfide gas and minerals like iron.

SURFACE WATER SOURCES

LAKES AND RIVERS

There are certain advantages and disadvantages related to taking water from rivers or lakes. Lake supplies maintain a more constant quality of water. The turbidity, temperature, and pH do not fluctuate as much from day to day as a river supply. Minerals tend to concentrate in lakes. Iron, manganese, and other dissolved metals are retained in the lake aids in the natural bacteria removed. The detention time also aids in the natural removal of suspended material or turbidity by sedimentation.

The quality of the water in lakes is affected by an occurrence known as "Turnover." This happens once or twice a year, generally in the springtime, as the water temperature of the lake begins to change. The density or "Specific Gravity" of the water changes as the water temperature changes. Water is heaviest or most dense at 4 degrees Centigrade or about 39 degrees Fahrenheit. In a deep lake the water at the bottom will always be about 4 degrees C because of its higher Specific Gravity. Stratification occurs as layers of water at different temperatures form in the lake. In the spring as ice on the surface melts, it becomes warmer (and heavier) and begins to sink. As this happens water at the bottom is forced to the surface. This mixing action stirs up silt and decaying organic material and as a result can cause serious taste and odor problems. In the late fall as water at the surface cools it also gets heavier and sinks to create the same situation. Changes in water temperature and density also affect chemical treatment and settling in surface water treatment plants.

The turbidity, temperature and pH of water taken from rivers may fluctuate on a daily, or sometimes on an hourly basis. Rainfall and run-off usually contribute to these changes. Changes in the quality can also result from waste discharged from upstream sources. Minerals do not accumulate in rivers as they do in lakes. Mainly, because any water that is not used is carried downstream rather than being retained as it is in a lake. Jar testing should be done when the raw water quality changes. A jar test will help the operations staff determine what adjustments must be made in the treatment process when these changes occur.

INTAKE STRUCTURES

The type and location of the intake structure in the surface supply will determine the kind of treatment necessary for production of potable water. Ordinances should be passed to protect the water around the intake structure. Boating, swimming, and fishing should be discouraged in the area of the intake. Floating buoys should be placed as markers around the intake structure.

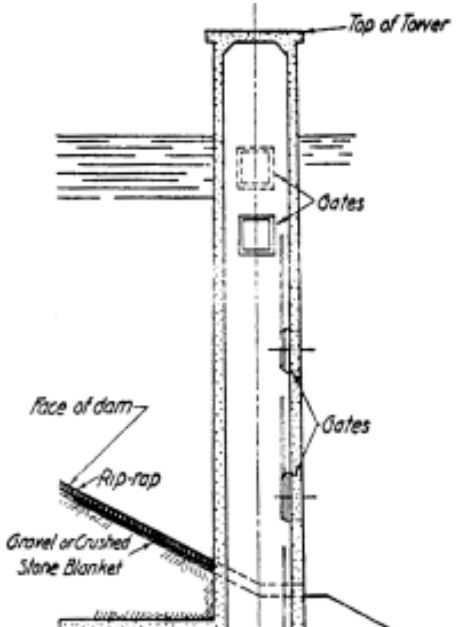
In some systems this is accomplished by flushing or backwashing the screen with water pressure supplied by a backwash water line located within the structure. Water is forced through the screen, washing the debris away from the structure.

River And Stream Intakes

The most common type of intake in flowing water is a simple pipe extended into the water. This pipe or intake line feeds water to low service pumps usually located in a pump house on the bank. Provisions should be made to prevent floating material from clogging the intake screen. Intake screens should be small enough to prevent clogging and large enough to allow adequate intake flow. The intake line should be located perpendicular to the flow or at a forty-five degree angle downstream. Intake lines that are pointed directly downstream may experience problems during high flows. A low-pressure area will develop around the intake restricting the flow of water into the structure. The intake pipe should be elevated off the bottom to avoid heavy concentrations of sand, silt and dissolved minerals.

Lake And Reservoir Intakes

Intakes in lakes and reservoirs are generally located in 15 feet or more of water to provide multiple intake levels. These inlets are usually located 4 to 6 feet from the surface and at 5 to 10 feet intervals depending on the depth of the water. This will allow the operations staff to select water from different levels in the lake and minimize treatment costs by obtaining the best quality raw water. Inlets should never be located near the bottom of the lake to avoid high concentrations of dissolved minerals and gases, turbidity, and tastes and odors. Inlets are controlled by gate valves and operated from the top of the intake structure. These gate valves should be operated periodically to keep the valve in good working order.



Surface Water Quality

The type of treatment needed for surface water supplies depends on the contaminants present. These contaminants are grouped into five general categories: minerals, turbidity, bacteria, tastes and odors, and color. Before treatment processes can be discussed, the contaminants associated with each of these groups must be identified.

Minerals

The mineral problems in water are caused by inorganic contaminants. These are usually dissolved metals and dissolved gases. Some of the more common mineral problems include iron and manganese, famous for causing "red water" problems and hardness. Carbon dioxide gas can cause corrosion problems and hydrogen sulfide gas is noted for the "rotten egg" odor that is sometimes found in water. All of the inorganic chemicals are listed under the SDWA Primary and Secondary standards are also included in this category.

Turbidity

Silt and clay are primarily responsible for the turbidity in water. However, any suspended material that will not readily settle is considered to be turbidity. Some clay particles are so small that they will not settle at all. These particles in suspension are known as "colloids." Most turbidity particles carry a slight negative electrical charge that causes them to repel each other. Zeta Potential is the term used to identify this electro-chemical repulsion. The treatment to remove these particles must neutralize the negative charges and bring them together until a large enough particle is formed that will settle.

Bacteria

Bacteriological contamination has been covered in a previous chapter. It should be noted at this time

reason turbidity is a primary contaminant in the SDWA. The possible presence of *Giardia* or *Cryptosporidium* can affect treatment strategies due to the need for higher free residuals and extended contact times.

Tastes And Odors

The main source of taste and odor problems in surface supplies is algae (small floating water plants). These are organic compounds that impart a mossy or fishy odor. The most common source of taste and odors in ground water supplies are inorganic chemicals. Hydrogen sulfide gas (H_2S) causes a "rotten egg" odor. Iron and manganese can also impart a rusty taste to the water when present. Tastes and odors are less noticeable when the water temperature is colder.

Color

Organic compounds released into the water by decaying vegetation cause true color. Unlike turbidy, these organic "dyes" are dissolved in the water and cannot be removed by filtration. As leaves fall into the water, tannic acid is leached out giving the water a brownish color. Decaying aquatic plants or humus can create a green color in the water. Apparent color is caused by small particles of oxidized iron or manganese that create red or black water problems respectively. This type of "color" is actually small red flakes of rust that can be removed by filtration.

Solubility Of Salts

Most methods of chemical treatment rely on the solubility of different salts to remove undesirable minerals from the water. A salt is formed when a metal combines with a non-metal. For instance, when a metal like sodium combines with a non-metal like chlorine, sodium chloride, NaCl, or table salt is formed. The most common metals and non-metals that combine to form soluble salts in drinking water supplies are listed in Table 12.1.

Some salts dissolve very readily in water while others may not dissolve at all. Those that do not dissolve in water are known as insoluble salts. For instance, alum (aluminum sulphate) will dissolve in water but aluminum hydroxide, $Al(OH)_3$, is insoluble in water. Calcium bicarbonate, $Ca(HC0_3)_2$, is very soluble but

Table 12.1 - ***Chemical Names & Symbols***

Chemical Names and Symbols	
METALS	NON-METALS
Calcium – Ca	Carbonate – CO_3
Magnesium - Mg	Bicarbonate - $HC0_3$
Manganese – Mn	Hydroxide – OH
Iron – Fe	Sulphate - SO_4
Aluminum – Al	Chloride – Cl
Sodium – Na	
Copper - Cu	
CHEMICAL COMPOUNDS	
Calcium carbonate -	$CaC0_3$
Magnesium hydroxide -	$Mg(OH)_2$
Aluminum sulphate -	$Al_2(SO_4)_3$
Ferric (iron) chloride -	$FeC1_3$
Copper Sulphate -	$Cu\ SO_4$

Many of the undesirable minerals in water are present in the form of soluble salts. By adding certain other chemicals and adjusting the pH of the water, chemical reactions will take place that will change those soluble salts into insoluble salts. These insoluble salts can then be removed by either sedimentation or filtration.

Common Names For Water Treatment Chemicals

There are a number of water treatment chemicals that are better known by their common names than their chemical names. See Table 12.2.

pH

Table 12.2 - ***Water Treatment Chemicals***

Chemical Name	Chemical Symbol	Common Name
Aluminum Sulphate	$Al_2(SO_4)_3$	Alum
Calcium Hydroxide	$Ca(OH)_2$	Lime

The pH of the water is the measurement of the acidity or alkalinity of the water. Water is considered to be acid when it has more hydrogen ions (H^+) in it than hydroxide ions (OH^-). Some of the chemicals that add hydrogen ions (H^+) to the water are hydrochloric acid, HCl, sulfuric acid, H_2SO_4, nitric acid, HNO_3, and carbonic acid, H_2CO_3,

Water is considered to be alkaline when there are more hydroxide ions (OH^-) present than hydrogen (H^+). Sodium hydroxide, NaOH, calcium hydroxide, $Ca(OH)_2$, and magnesium hydroxide, $Mg(OH)_2$ all add hydroxide ions (OH^-) to the water. When the number of hydrogen ions and hydroxide ions are the same the water has a neutral pH. Pure water, H_2O or H-OH, has a neutral pH because the number of hydrogen ions (H^+) and hydroxide ions (OH^-) are equal.

The pH of water is measured on a scale that reads from 0 to 14. The midpoint of the scale is 7. Water with a pH of 7 is neutral. If the water has a pH less than 7, the water is acidic and if the pH is greater than 7 it is alkaline. For every whole number that the pH changes the strength of the acid or alkaline properties of the water will change by a factor of ten times. Water that goes from a pH of 9 to a pH of 10 becomes 10 times more alkaline and water at pH of 5 is 10 times more acidic than water at a pH of 6.

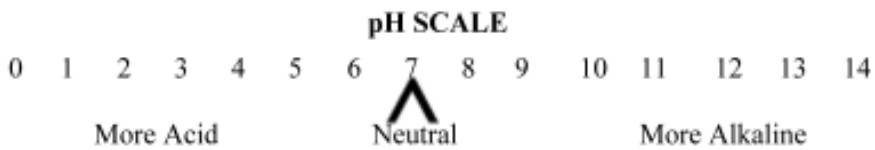


Figure 12.2 - ***pH Scale***

Physical/Chemical Treatment

The purpose of chemical treatment is to remove any undesirable contaminants and produce water that is safe and acceptable to consumers. Removing undesirable impurities using conventional treatment requires the use of various treatment processes including: Pretreatment, Coagulation, Flocculation, Sedimentation, and Filtration.

Pretreatment refers to treatment of the raw water before it enters the treatment plant. It usually occurs at the raw water intake and involves some type of chemical addition with no physical treatment other

Coagulation is the chemical reaction that changes soluble salts into insoluble salts. This is accomplished by adding certain chemicals, known as coagulants, to the raw water. Coagulant aids are used to adjust pH and help in the formation of insoluble salts. These salts are referred to as floc. The formation of floc is accomplished by the even and thorough dispersal of the coagulant in the raw water by “rapid” or “flash” mixing. Changes in water quality or water temperature can have an adverse affect on the coagulation process.

Flocculation is the process that follows the rapid mix. The velocity of the water is reduced and a gentle mixing action is created to allow the formation of insoluble salts, clay, and other suspended matter into floc particles. The negatively charged colloids are attracted to a positively charged coagulant and begin colliding to form a large neutral floc particle that will settle out during the sedimentation process. "Agglomeration" is the process of bringing positive and negative charged particles together to form a floc that has a neutral charge and is large enough to settle.

A flocculation tank will usually incorporate baffles or mechanically driven paddles for mixing. It is important to keep the velocity of the water slow enough to prevent “hydraulic shear” This will prevent the floc particles from breaking up before they reach the sedimentation tank. One of the more common problems occurring in flocculation basins is formation of pin floc. Underfeeding or overfeeding the coagulant chemicals usually causes pin floc. Pin floc can also be a problem when the raw water has a low turbidity or cold temperature. The addition of coagulant aids such as bentonite clay, activated silica, and polymers can improve the flocculation process.

Sedimentation is the process of slowing the water velocity to allow the floc to settle out. Clear water is then drawn off the top of the basin for filtration. Sedimentation basins are usually the largest tanks in the treatment process. These basins should have

effluent weir in less time than it would take if the flow were distributed evenly across the tank.

In circular basins the flow is directed down and in rectangular basins it is spread evenly across the influent end of the tank. As the water flows through the basin, the floc settles to the bottom forming a sludge blanket. Sludge is removed by means of a raking device that pushes the sludge to the center of circular basins or the end of rectangular basins where it is pumped out of the tank. Bulking occurs when sludge is not removed from the process often enough. This is a result of decomposition of organics in the sludge that causes gases to form and sludge to float to the surface. This decomposition can also create taste and odor problems.

FILTRATION is the final step in the removal of chemical impurities in water. Any organic or inorganic particles that have not been removed during the sedimentation process must be filtered out in order to meet the SDWA standards of 1.0 NTU or less in the finished water. The turbidity of the water in the filter influent should not exceed 15 NTU's, and should actually be less than 5 NTU's, or filter runs will be reduced dramatically. When the filter becomes dirty it must be backwashed. Since the backwash water is treated potable water, the length of the filter run directly impacts the cost of the filter operation. The backwash water must either be returned to the head of the plant or mixed with the raw water flow or impounded so that sludge can be separated.

Removal of Color

The dissolved organic compounds that cause true color in water can be removed if the pH of the water is lowered to between 3.5 and 5.5. Under these acidic conditions the color compounds become gelatin-like solids that will settle out in the sedimentation tanks. This pH adjustment can be accomplished by adding alum or acids. Most of the other treatment processes will require a pH of 6.5 to as high as 11.5. If color is to be removed, the pH must be lowered first. If the pH is raised, the color may become set (much the same way that hot water will set laundry stains) and will be nearly impossible to remove. Older treatment plants are usually not equipped to handle this type of treatment. However, some up-flow units can be adapted to remove color because alum can be added to lower the pH prior to raising the pH for other types of treatment.

Other oxidizing agents such as ozone or potassium permanganate do a better job and do not create the THM byproducts associated with the use of chlorine.

Removal Of Bacteria

Pathogenic bacteria tend to die out in surface water supplies. Sedimentation and filtration can also remove about 90% of these bacteria. However, those that are not removed during the treatment must still be destroyed with oxidizing agents. The possible presence of *Giardia* in surface waters is the main reason that filtration is now mandatory for all surface supplies. Higher chlorine residuals may also be necessary to meet the new C x T standards for *Giardia*. Using ozone as a disinfectant can reduce the difficulties created by the increased contact time needed to kill Giardia. Chlorination may still be required to meet secondary contamination considerations.

Removal of Taste and Odors

Taste and odors in water can come from several sources. Both organic and inorganic compounds can cause tastes and odors. The most common source of organic taste and odors is algae. These algae can be divided into two main groups that are responsible for most of these problems. They are classified, according to their color, into green algae and blue-green algae. Green algae are usually responsible for grassy or musty odor in water while the blue-green algae cause rotten fish type of odor.

Algae problems develop during hot, dry weather in the early summer. Algae blooms will begin in shallow coves as the water temperature rises. These blooms spread so rapidly that, in a week or two, enough algae is present to cause serious taste and odor problems. Some blue-green algae release poisonous by-products that can result in fish kills in severe cases. Algae blooms can also result in pH fluctuations in the impoundment as the CO_2 uptake increases during the daylight hours driving the pH higher. Diatoms are another group of algae that may be present in surface waters. They do not cause the offensive odors that the blue-green algae do, but their shells tend to plug filters.

Tastes and odors can also be caused by inorganic compounds and dissolved gases. Iron and manganese can cause rusty tastes. Hydrogen sulphide gas can cause a rotten egg odor.

Copper Sulphate Treatment

Algae in lakes and reservoirs can be killed with copper sulfate, $CuSO_4$. It usually requires dosages of about 0.5 to

Table 12.3 - ***Hardness Compounds***

HARDNESS COMPOUNDS			
Carbonate		**Non-Carbonate**	
Calcium carbonate	$CaCO_3$	Calcium sulfate	$CaSO_4$
Magnesium carbonate	$MgC0_3$	Magnesium sulfate	$MgSO_4$
Calcium bicarbonate	$Ca(HCO_3)_2$	Calcium chloride	$CaCl_2$
Magnesium bicarbonate	$Mg(HCO_3)_2$	Magnesium chloride	$MgC1_2$
Calcium hydroxide	$Ca(OH)_2$		
Magnesium hydroxide	$Mg(OH)_2$		

sulfate in dosages higher than 1.0 mg/l. Copper sulfate will kill many game fish at very low concentrations. Brown trout will not survive concentrations greater than 0.14 mg/l. Always contact state health officials before attempting this type of treatment.

In-Plant Treatment

There are three methods of removing taste and odors at the treatment plant. Activated carbon can be used to adsorb the organic compounds that cause the problem. A dosage of 15 to 25 mg/1 is usually required to accomplish this. In severe cases, dosages may need to be as high as 100 mg/1. Activated carbon should be added as far upstream as possible from the point where coagulant chemicals are added. If it is added at the same time as coagulant chemicals, it may become tied up in the floc particle before it has time to adsorb the organic taste and odor compounds. Activated carbon is very expensive and difficult to feed. It is also dangerous to handle because it can create an explosion if dispersed in the air and ignited.

The other method of taste and odor removal is by the addition of an oxidizing agent such as chlorine. The oxidizing agent will react with and chemically alter organic compounds so that they no longer cause taste and odors. The problem again is the creation of THM's as a byproduct of the chlorination process. The use of other oxidizing agents like chlorine dioxide or ozone should be considered instead of chlorine.

Tastes and odors caused by inorganic compounds like iron or hydrogen sulphide may be removed by aeration. Diffused air bubblers or stripping towers are the most common means of aeration. The dissolved oxygen will oxidize the iron and in the system. Oxidizing agents can also be used to remove inorganic tastes and odors.

Removal Of Minerals

Mineral problems can be grouped into two major categories. These are problems related to hardness and problems related to other metals and gasses not associated with hardness such as iron, manganese, hydrogen sulfide, ammonia, and carbon dioxide.

Hardness

Metals that are dissolved in water cause hardness. (See Table 12.3) Calcium (Ca) and Magnesium (Mg) are the two metals that dissolve the most easily in water. They are considered to be the main cause of hardness. Other metals also cause hardness in water but very few are soluble enough to contribute to hardness problems. The two metals that do not cause hardness in water are (Na) sodium and (K) potassium. Water with hardness of 0-60 mg/1 is considered to be soft water. Moderately hard water is considered to be between 60-120 mg/1, while very hard water has hardness of 150 mg/1 and up.

Hardness causing compounds are broken into two groups: carbonate hardness and non-carbonate hardness. Carbonate hardness is hardness that can be removed by boiling water. Non-carbonate hardness cannot be removed by boiling water. Carbonate and non-carbonate hardness are both a result of dissolved calcium and magnesium in water. It is the non-metals that combine with the calcium and magnesium that will determine whether it is carbonate or non-carbonate hardness.

Carbonate hardness is formed when calcium or magnesium combines with a form of alkalinity (carbonate, bicarbonates, or hydroxides.) Non-carbonate hardness is formed when calcium

Softening Chemical Reactions

Carbonate hardness is removed by adding lime, $Ca(OH)_2$, to the water. The lime softening process requires the addition of enough lime to raise the pH to a point where the reaction can take place. The pH must be between 9.0 - 10.5 to remove carbonate hardness. Calcium compounds are removed at a pH of 9.0-9.5. Magnesium compounds require a pH of 10.0-10.5.

The reaction between lime and calcium bicarbonate results in the formation of calcium carbonate and water. At the proper pH, calcium carbonate has a solubility of about 40 mg/l. The rest of the calcium will settle out as a floc.

Calcium bicarbonate +	Calcium hydroxide >	Calcium carbonate +	Water
$Ca(HCO_3)_2$ +	$Ca(OH)_2$ >	$2\ CaCO_3$ +	$2\ H_2O$

Magnesium hydroxide is the least soluble of the magnesium compounds. First magnesium bicarbonate reacts with lime to create magnesium carbonate and calcium carbonate. The calcium carbonate precipitates out and then the magnesium carbonate reacts with lime to create calcium carbonate and magnesium hydroxide that will both precipitate out.

Magnesium Bicarbonate +	Calcium Hydroxide >	Calcium carbonate +	Magnesium Carbonate +	Water
$Mg(HCO_3)_2$ +	$Ca(OH)_2$ >	$CaCO_3$ +	$MgCO$ +	$2H_2O$

Magnesium Carbonate +	Calcium Hydroxide >	Calcium Carbonate +	Magnesium Hydroxide
$MgCO_3$ +	$Ca(OH)_2$ >	$CaCO_3$ +	$Mg(OH)_2$

Non-carbonate or permanent hardness can be removed by the addition of sodium carbonate or soda ash, Na_2CO_3. Lime is usually added to adjust the pH of the raw water. This lime-soda ash process requires a pH of 10.0-10.5 to remove calcium compounds and a pH of 11.0 - 11.5 to remove magnesium compounds. When the proper pH conditions are met, the reaction between the sodium carbonate and the calcium sulphate results in the formation of sodium sulfate and calcium carbonate. The reaction is basically the same for calcium chloride, except sodium chloride is created instead of sodium sulphate. The sodium does not cause hardness and the calcium carbonate that is insoluble will settle out. Magnesium compounds react directly with lime to precipitate as magnesium hydroxide. This results in the formation of calcium chloride or sulphate which must then react with soda ash to form calcium carbonate.

Calcium sulphate +	Soda ash >	Calcium Carbonate +	Sodium Sulphate
$CaSO_4$ +	Na_2CO_3 >	$CaCO_3$ +	Na_2SO_4

Magnesium Sulphate +	Calcium Hydroxide >	Magnesium Hydroxide +	Calcium Sulphate
$MgSO_4$ +	$Ca(OH)_2$ >	$Mg(OH)_2$ +	$CaSO_4$

Re-Carbonation

After non-carbonate softening has taken place, the finished water will likely have pH of 10-11. This is a result of the lime addition that was needed to drive the softening reaction. If this water is pumped to distribution at this pH, the excess lime will cause calcium deposits in pipes and fixtures. Recarbonation is the process of stabilizing the water by lowering the pH and precipitating the excess lime as calcium carbonate. In large systems the amount of lime needed may make reclamation of the lime from the calcium carbonate sludge feasible. The sludge is heated in a furnace. The heat causes calcium carbonate to breakdown and calcium oxide, CaO, and carbon dioxide gas, CO2, are the result. The calcium oxide is "slaked" with water to form calcium hydroxide that is then reused in the softening process. The carbon dioxide gas is then used to react with the excess lime to lower the pH and precipitate more calcium carbonate. Recarbonation also requires additional coagulation, flocculation and sedimentation since it occurs after the initial softening process.

Calcium hydroxide +	Carbon dioxide >	Calcium carbonate +	Water
$Ca(OH)_2$ +	CO_2 >	$CaCO_3$ +	H_2O

Other Softening Processes

Systems that do not have the clarification equipment necessary for this type of treatment may soften water using the zeolite process. This is called an ion exchange process. Water is passed through a filter containing zeolite granules. A reaction takes place that removes calcium and exchanges it with sodium. The hardness can be lowered to O mg/1 this way, since sodium does not cause hardness. The sodium that is put in the water may cause problems for people on the system who have high blood pressure or heart trouble, especially those on a salt-free diet. When the zeolite bed becomes saturated with calcium it must be regenerated, by backwashing it with a saturated brine solution.

Reverse-osmosis (RO) may also be used in cases where chemical equipment is not available. RO is a process in which water, under pressure, is forced through a semi-permeable membrane (a distant cousin of the hot dog skin). The membrane will allow the water to pass through it but will trap the calcium, magnesium, and any other dissolved solids. The unit is periodically backwashed to clean the membrane. Electrodialysis may be used where water with very high concentrations of hardness (500+ mg/l) is found, removed from the water. Both RO and electrodialysis are very expensive from both an equipment and operation standpoint.

Iron and Manganese

Iron and manganese (Fe & Mn) can be found in reservoirs and lakes that are used for furnishing water to municipal systems. These minerals are also found in undesirable concentrations in waters from shallow wells or from wells drilled into shale or sandstone formations. The presence of large amounts of Fe and Mn can cause stains on plumbing fixtures, a rusty appearance and taste in the water (red water). Iron in excess of 0.3 mg/l will cause red water problems and manganese in excess of 0.05 mg/l will cause black water problems.

The least expensive means of controlling Fe and Mn in surface water supplies is to raise the raw water intake so that the water is taken from a point nearer the surface of the supply. This may reduce concentrations of Fe and Mn in the raw water because the concentrations of these minerals are normally higher at greater depths in the reservoir. The second alternative is to artificially supply dissolved oxygen by means of aeration. This can be accomplished by installing a small aeration tower prior to the coagulation process. Aeration may also be achieved by forcing air into the water with blowers. Either method can provide the dissolved oxygen necessary to oxidize the Fe and Mn so it will settle out in the sedimentation tanks. Aeration requires longer contact time than other forms of oxidation. If it is used in a direct filtration process, a holding tank may have to be added after aeration to allow time for the reactions to take place. The remaining three alternatives require the addition of chemicals.

Pre-chlorination, or the addition of chlorine to the water before it reaches the sedimentation tanks, is an effective means of removal. In this case the chlorine acts as the oxidizing agent to precipitate the Fe and Mn. To achieve satisfactory percentages of removal, enough chlorine must be added to provide a one part per million residual at the point of filtration.

Another oxidizing agent that can be added to remove Fe and Mn is potassium permanganate, $KMnO_4$. It should also be added prior to coagulation. Enough potassium

The final method of control is the addition of a sequestering agent. Polyphosphates, including sodium hexametaphosphate, also known as Calgon, are the most common sequestering agent used. This should be done as far in advance of the sedimentation process as possible if this is used by itself. If it is used in a conventional treatment plant, it should be added after sedimentation and before filtration. Polyphosphates should be used in small dosages, usually less than 5 mg/l. If excessive amounts are added, it will begin to soften rust deposits in the distribution system and cause them to break loose. When this happens, serious plugging of hydrants or services can occur. It should be noted that polyphosphates do not remove Fe and Mn, but they do surround or sequester these ions and keep them in solution rather than allowing them to be oxidized and precipitate in the distribution system. Over time the polyphosphates will break down and release the Fe and Mn. They will then oxidize and create red or black water. The proper dosage is just enough to keep the iron or manganese tied up for 4 days.

Dissolved Gases

Carbon dioxide and hydrogen sulfide are the main causes of problems related to dissolved gases. Carbon dioxide will react with water to form carbonic acid and can create corrosive conditions in the water.

Carbon Dioxide + Water > Carbonic Acid
$CO_2 + H_2O > H_2CO_3$

Carbon dioxide can be removed by aeration down to concentrations of 5 mg/1. Hydrogen sulphide can be completely removed by aeration. Lime may be added to further reduce the CO_2 concentration. The lime will react with the CO_2 and precipitate out as calcium carbonate.

Carbon Dioxide + Calcium Hydroxide > Calcium Carbonate + Water
$CO_2 + Ca(OH)_2 > CaCO_3 + H_20$

Other Mineral Problems

The inorganic primary contaminants listed in SDWA must also be removed if the MCL is exceeded. The addition of lime and alum or one of the iron-based coagulants such as ferric chloride or ferrous sulfate can remove most of these metals. A high pH is usually required to produce insoluble salts from these dissolved metals. Radioactive metals can also be removed in this manner. Ion exchange processes are also used to remove some non-metal contaminants. Activated alumina, AlO_3, can be used for arsenic and fluoride removal in a process that is similar to zeolite softening.

Control of Turbidity and Color

The control of turbidity, color, microorganisms, and to some extent, taste and odor is commonly accomplished through some type of filtration[1] system. The Surface Water Treatment Rule describes five different types of filtration systems; conventional treatment[2], direct filtration[3], slow sand filters, diatomaceous earth filters and alternate filtration systems such as cartridge filters. The basic system used in this discussion is the conventional treatment plant, also called rapid gravity filtration.

Conventional Filtration

The conventional treatment plant is composed of four processes (see Figure 12.3 - *Conventional Treatment Plant Schmatic*):

- *Coagulation*[4] - a process where chemicals are added in order to destabilize small particles held in suspension
- *Flocculation*[5] - a slow mixing process where the coagulated particles are formed into feather-like material called floc[6]
- *Sedimentation* - is a physical process that allows the majority of the floc to settle, removing a large portion of the material in the water
- *Filtration* - the process of straining the remaining floc from the water.

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[1] Filtration - The process of passing liquid through a filtering medium (which may consist of granular material such as sand, magnetite, or diatomaceous earth, finely woven cloth, unglazed porcelain, or specially prepared paper) to remove suspended colloidal matter.

[2] Conventional Treatment - A standard treatment process involving coagulation, flocculation, sedimentation, filtration, and disinfection.

[3] Direct Filtration - A gravity or pressure filter system involving coagulation, filtration, and disinfection.

These processes are used to remove or reduce organic and inorganic material that cause turbidity, color and odor and taste.

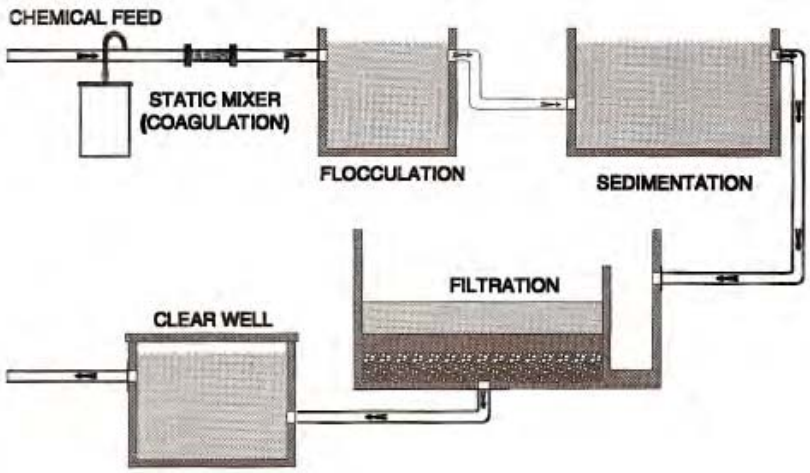

Figure 12.3 - ***Conventional Water Treatment Plant Diagram***

Contaminants

Organic Contaminants

The organic component of this material contributes to color, odor, taste and disease. The organic component includes microorganisms, (viruses, bacteria, protozoa), algae, and organic material from plants and animals.

Inorganic Contaminants

The inorganic portion of this material is the primary contributor to turbidity. The inorganic portion includes silt, sand and inorganic chemical complexes.

Settling

Table 12.4 - ***Settling Rates***

Particle Diameter mm	Representative Particle	Time Required to Settle in 1 ft. (0.3 m) Depth
		Settleable
10	Gravel	.03 sec
1	Coarse Sand	3 sec
0.1	Fine Sand	38 sec
0.01	Silt	33 min
		Considered Non-Settleable
0.001 (1 μ)	Bacteria	55 hours
0.0001	Color	230 days
0.00001	Collodial Particles	6.3 years
0.000001	**Collodial Particles**	**63 years minimum**

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Most organic and inorganic material is suspended in the water and not dissolved and, therefore, will settle out if given enough time. However, the main materials that contribute to color and turbidity are too small to settle. The basic problem comes from material that is less than one micron in size, called *colloidal*[7] material. The Greek letter "μ", called "mu" is used to identify a micron. One micron would be written 1μ.

Colloids

For instance, a particle 0.01 mm in diameter will settle 1 foot in 33 minutes but a particle 0.0001 mm in diameter (a colloid) will only settle 1 foot in 230 days. This is hardly a reasonable settling time.

Colloids do not settle in a reasonable length of time due to electrical charges on their surface. At one micron in size the influence of the surface charges offsets the attraction due to gravity and the particles stay suspended.

Types of Colloidal Material

There are two types of colloidal material *hydrophobic*[8] and *hydrophilic*[9].

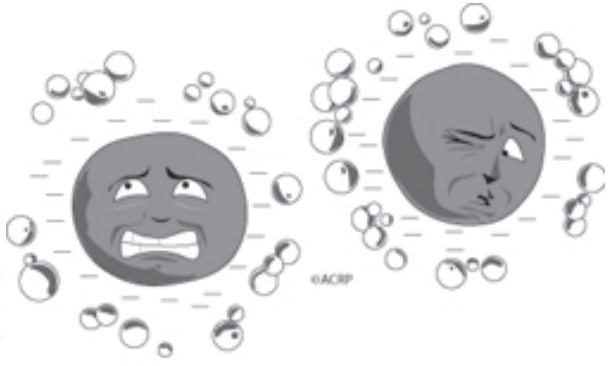

Figure 12.4 - ***Hydrophobic Particles***

Hydrophobic

Hydrophobic means water-fearing. Hydrophobic colloidal material is mostly inorganic material that contributes to turbidity. Hydrophobic colloidal material generally carries a negative electrical charge.

Hydrophilic

Hydrophilic means water-loving. Hydrophilic colloidal material is mostly composed of organic material which is the common source of color. Hydrophilic compounds are surrounded by water molecules and because of their polarization, they tend to make these particles negatively charged.

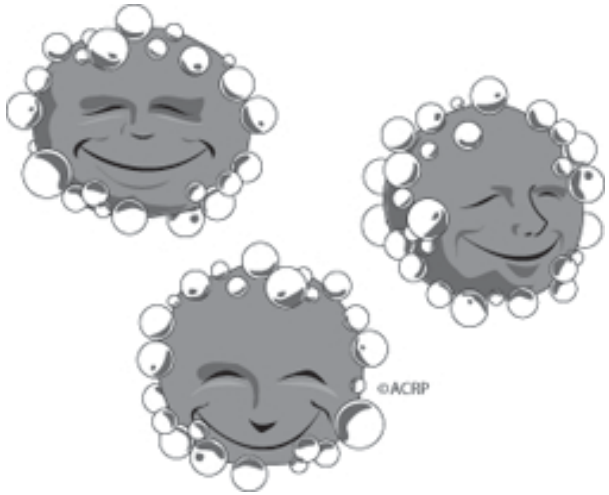

Figure 12.5 - ***Hydrophillic Particles***

Opposing Forces

There are two opposing forces that impact the removal of colloidal material. These are stability factors and instability factors. Stability factors are those factors that help to keep colloids dispersed. Instability factors are those that contribute to the natural removal of colloids.

COAGULATION - THEORY

THE CHEMICALS

The process of decreasing the stability of the colloids in water is called coagulation. Coagulation results from adding salts of iron or aluminum to the water. Common salts are:

- *Alum*[10] - Aluminum Sulfate $Al_2(SO_4)_3 \cdot 18H_2O$
- Sodium Aluminate - $NaAlO_2$
- Ferric Sulfate - $Fe_2(SO_4)_3 \cdot 9H_20$
- Ferrous Sulfate - $FeSO_4 \cdot 7H_20$
- Ferric Chloride - $FeCl_3$
- Polymers[11]

Coagulation

The reaction between one of these salts and water is called coagulation. The simplest coagulation process to explain occurs between alum and water. When alum is placed in water, a chemical reaction occurs that produces positive charged aluminum ions.

The Reaction

The overall result is the reduction of electrical charges and the formation of a sticky substance. These two destabilizing factors are the major contributions that coagulation makes to the removal of turbidity, color and microorganisms.

Factors that Influence Coagulation

There are a number of factors that influence the coagulation process. Five of the most important are: pH, turbidity, temperature, alkalinity and the use of *polymers*[11]. The degree to which these factors influence coagulation is dependent upon the coagulant used. The following discussion is based on the use of alum as the coagulant.

Other Considerations

The raw water conditions, optimum pH for coagulation and other factors must be considered before deciding which chemical is to be fed and at what levels.

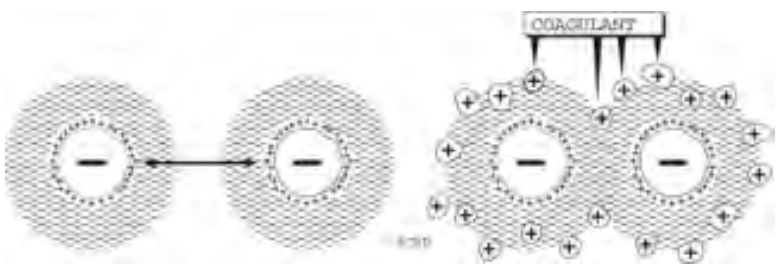

Figure 12.6 - ***Alum in Water***

POLYELECTROLYTES OR POLYMERS

Polyelectrolytes, or polymers as they are commonly called, can be used as an aid to coagulation. In some waters they have been successfully used as the primary coagulant instead of alum