

Water System Operations

A young boy is shown from the waist up, wearing a dark long-sleeved shirt with the number '68' and 'DEPARTMENT OF' printed on it. He is drinking from a clear plastic water bottle and holding a soccer ball in his left arm. He is standing in front of a soccer goal. The entire image has a blue tint.

State of Oklahoma
Certification Study Guide

DEQ WATER\WASTEWATER WORKS OPERATOR AND DISTRIBUTION/COLLECTION EXAM APPLICATION

Class _____	Water Exam - Score _____ %	Class _____	Water Lab Exam - Score _____ %
Class _____	Sewer Exam - Score _____ %	Class _____	Sewer Lab Exam - Score _____ %
Dist\Coll Operator Exam - Score _____ %		Dist\Coll Technician Exam - Score _____ %	
Date Results Mailed _____		Internet exam DEQ OFFICE USE ONLY	

Please return the application and application fee to: Dept. of Environmental Quality
Financial & Human Resources
PO Box 2036
Oklahoma City, OK 73101-2036

PLEASE PRINT CLEARLY

1. Are you applying for this certification by reciprocity? _____ From what state? _____ What classification? _____

Reciprocity may be granted when certification held in another state is current, in good standing and is comparable to Oklahoma Operator Certification rules.

2. **LOCATION and DATE OF EXAM YOU WISH TO TAKE:** Location _____ Date _____

3. **Name-Last:** _____ **First :** _____ **MI:** _____

Address _____ **City** _____ **State** _____ **Zip** _____

Social Security# _____ / _____ / _____ **Birthdate** _____ **Home Phone # ()** _____

4. **Your Job Title** _____ **License #** _____

Do you supervise other operators or helpers? _____ If yes, how many? _____

Name of Immediate Supervisor _____ **License #** _____

5. **Employer** _____ **Address** _____ **City** _____

State _____ **Zip** _____ **Office Phone # ()** _____

6. **Water Facility ID#** _____ **Wastewater Facility ID#** _____

7. Please place an X in the box to the left of the exam you are applying for. The **non-refundable and non-transferable application fee is \$40.00** per exam. The application **must be postmarked at least 3 weeks prior to the exam date**. Please include payment with this application. **Payment form is on the second page.**

	WATER	WASTEWATER	MINIMUM APPROVED TRAINING	MINIMUM EXPERIENCE
<input type="checkbox"/>	D	D	16 HOURS	NONE
<input type="checkbox"/>	C	C	36 HOURS	1 YEAR
<input type="checkbox"/>	B	B	100 HOURS	3 YEARS*
<input type="checkbox"/>	A	A	200 HOURS	5 YEARS**
<input type="checkbox"/>	CLAB	CLAB	32 HOURS	NONE
<input type="checkbox"/>	BLAB	BLAB	32 HOURS OF C & 32 HOURS OF B LEVEL***	6 MONTHS
<input type="checkbox"/>	ALAB	ALAB	32 HOURS OF B LEVEL****	1 YEAR
DISTRIBUTION/COLLECTION				
<input type="checkbox"/>	C OPERATOR		36 HOURS	1 YEAR
<input type="checkbox"/>	TECHNICIAN		8 HOURS	NONE

*must include one year of actual hands-on operating experience **must include two years of actual hands-on operating experience
An Associates Degree or greater in chemistry, biology, engineering, physical science, hydrology, geology, math, env. science, microbiology, toxicology, or civil, chemical, sanitary or env. engineering may be substituted for the 32 hours of DEQ approved C level training. *must include a Bachelor of Science degree in chemistry, microbiology, instrumental analysis or other field of science approved by the DEQ

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8. Experience: List your experience in water and/or wastewater system operations or maintenance. List your present job first. Attach additional sheets if needed.

1. From _____ To _____ Name of Employer _____

Employer's Address _____ City _____ State _____ Zip _____

Describe your duties in detail: _____

2. From _____ To _____ Name of Employer _____

Employer's Address _____ City _____ State _____ Zip _____

Describe your duties in detail: _____

9. Training Credit: You must list below the water and/or wastewater classes you have attended which were approved by the Oklahoma Department of Environmental Quality Operator Certification Section. Applicants requesting training or experience credit for technical school or college hours must attach an official transcript for credit to be granted.

PLEASE NOTE-If you are planning to attend an approved training class before the date of your exam session, you must list it below and bring a copy of your attendance record to the exam sessions to verify attendance.

Class Title and Location	Class Date(s)	Training Hours	Class Number
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

Total hours approved training _____

Highest school grade or degree completed: _____

10. Statement of understanding: I hereby certify under penalty of law that this application and any attachments contain no willful or negligent misrepresentation or falsification and that all information is true, accurate and complete. I understand that any misrepresentation or falsification may result in rejection of my application or in revocation of any certificate issued as a result of this application.

Signature of Applicant _____ **Date** _____

Please Choose Form of Payment

___ Check Made Payable to DEQ

___ Money Order Made Payable to DEQ

___ Credit Card No: _____

(Must be Visa or Mastercard ONLY)

Exp. (mm/yy) ____/____

Authorized Signature: _____

___ Purchase Order No.: _____

Rev. 7/2005

Routine Monitoring

Sampling Plan: All systems must submit a site sampling plan to the DEQ for approval. The sites must be representative of the whole distribution system. Contact your District Engineer to modify site plans. Old inactivated location codes should never be used.

Community Systems must comply according to their plan, with the following number of samples:

<u>Population</u>	<u>Monthly Total Coliform Samples</u>
Up to 1,000	1
1,001 to 2,500	2
2,501 to 3,300	3
3,301 to 4,100	4
4,101 to 4,900	5
4,901 to 5,800	6
5,801 to 6,700	7
6,701 to 7,600	8
7,601 to 8,500	9
8,501 to 12,900	10
12,901 to 17,200	15
17,201 to 21,500	20
21,501 to 25,000	25
25,001 to 33,000	30
33,001 to 41,000	40
41,001 to 50,000	50
50,001 to 59,000	60
59,001 to 70,000	70
70,001 to 83,000	80
83,001 to 96,000	90
96,001 to 130,000	100
130,001 to 220,000	120
220,001 to 320,000	150
320,001 to 450,000	180
450,001 to 600,000	210

Non-community systems using surface water and serving more than 1,000 population during any month, must sample as a community system.

Non-community systems using only ground water and serving more than 1,000 population during any month, must sample as a community system.

Non-community systems using only ground water and serving 1,000 population or fewer must sample each calendar quarter.

Minor water systems must be sampled at least annually.

Additional Monitoring

Repeat samples: Collect within 24 hours of being notified that a routine sample is total coliform positive. The DEQ may extend the 24-hour period limit if the system cannot collect and submit repeat samples for reasons beyond its control. Sample results will also be available on the website 72 hours after receipt at <http://sdwis.deq.state.ok.us>.

Number: Systems that are required to collect more than one routine sample per month based on population must collect at least three repeat samples for each positive sample and all others must collect at least four.

Location: Take at least one repeat sample from the original coliform positive site (OS) and from taps within five service connections upstream (UP) and down-stream (DWN) of the original sampling site. If necessary, the fourth sample may be collected from a collection site of choice (OTH). The DEQ may waive one sample if the site is within one tap of the end of the distribution system. Collect all repeat samples on the same day, or within four days for systems with a single connection.

Repeat this process until total coliform are not found in any repeat sample. Systems that collect five or fewer samples per month or quarter must collect at least five routine samples during the next month following an initial positive sample, unless waived by the DEQ following a site visit or if the problem is deemed corrected by the DEQ before the end of the next month.

Any positive total coliform sample must be analyzed for fecal coliform. If a fecal coliform-positive sample is identified, retakes must be collected and submitted within 24 hours of notification of the water system. Repeat samples must be collected in accordance with the above procedures.

Minor water systems must collect only one repeat sample. Repeat this process until total coliform are not found in any repeat sample.

Results of all routine and repeat samples not invalidated by the DEQ must be used to determine compliance with the MCL for total coliform.

This Study Guide is Dedicated to the
Certified Water System Operators
of the State of Oklahoma
"Protectors of Public Health"



For information concerning Oklahoma operator certification
requirements or application procedures, please contact:

Oklahoma Department of Environmental Quality
Operator Certification Section
P. O. Box 1677, 707 N. Robinson
Oklahoma City, OK 73101-1677

(405) 702-8100

INTRODUCTION

This study guide has been prepared for persons interested in obtaining or upgrading their Oklahoma water system operator certification. The chapters in this guide offer information designed to help with each level of certification. Class D is entry level, and Class A is the most advanced of the certifications.

This guide is not intended to be a reference manual for technical information or Occupational Safety and Health Administration (OSHA) regulations. Its purpose is to help guide operators in their studies of each of the major subject areas. Each chapter in this guide covers a different subject. Suggested guidelines for each subject area are listed by certification level at the beginning of each chapter. A brief discussion is then provided primarily for the benefit of entry level operators, followed by suggested references, other study suggestions and sample questions. The study guide is used by both instructors and students of approved operator training classes.

Components of Each Chapter in this Study Guide

Suggested Study Guidelines

The *Suggested Study Guidelines* describe knowledge that may be needed by operators of community water systems. These suggestions are designed to help direct study but do NOT address every item of information that an operator may need to know when taking a certification exam or when performing actual job duties. The guidelines are designed to be used as a “checklist” when studying for a certification exam to help ensure sufficient preparation. **Operators preparing to take a Class C, B, or A level certification exam should follow the guidelines listed for their exam as well as those listed for all lower levels of certification.**

Entry Level Discussion

The *Entry Level Discussion* is offered only as an introduction to the chapter subject. It should be used as a starting point for all persons preparing to take an exam. The answers to most of the questions that may be on the Class D exam can be found within these readings. Persons studying for higher levels of certification should concentrate most of their efforts on the *Suggested References for Study* in each chapter. **Please remember that the *Entry Level Discussion* should never be used as a reference for actual system operation or maintenance.**

Suggested References For Study

These are the primary references for questions found on Oklahoma operator certification exams. A complete listing of all the *Suggested References for Study* and a “Reference Source Sheet” can be found at the back of this study guide. References listed in *Italics* are needed for certification purposes only if preparing to take a Class A exam. Although many reference manuals are worthwhile and helpful, most of the references listed are taken from the manuals prepared by California State University at Sacramento (CSUS) for the U.S. Environmental Protection Agency.

Other Study Suggestions

These suggestions include individual exercises that will help the operator fully understand the material referred to in the *Suggested Study Guidelines*. Operators who can perform these various exercises, in addition to studying all the suggested materials, should be well prepared for their exam.

Sample Questions

These are questions representing the approximate difficulty level and format of the questions found on certification exams. The answers to the questions can be found within either the *Entry Level Discussion* or the *Suggested References for Study* for the chapter. Answers to the *Sample Questions* are listed near the back of this guide. Additional practice questions can be found within many of the *Suggested References for Study*.

How to Use this Study Guide to Prepare for State Certification Exams

Class D Certification

Preparation for the Class D exam should include the use of this guide for both personal study and during attendance at an approved standard entry level class. Begin studying by familiarizing yourself with the entire study guide. Next, completely read the *Entry Level Discussion* offered within each chapter. Finally, read the *Suggested Study Guidelines* for Class D operators listed at the beginning of each chapter and read the *Entry Level Discussion* for the chapter again.

All operators are encouraged to obtain and read additional study material whenever possible. Some of the *Other Study Suggestions* that are listed in each chapter may also be helpful. APPENDIX A includes practice problems and explanations that may help to refresh basic math skills.

Other Levels of Certification

Students preparing to take a Class C, B, or A level operations exam are strongly encouraged to use the *Suggested References for Study* listed in each chapter. The higher the level of certification being sought, the more important these references become. Although there are many excellent reference books available, the suggested references should be used whenever possible as these are the primary references used to prepare state certification exams.

It is recommended that persons preparing to take these certification exams utilize extensive personal study to become knowledgeable in all the items listed in the appropriate *Suggested Study Guidelines*. Also recommended is attendance at training classes including an approved standard entry level, intermediate level and/or advanced level class shortly before taking the exam. APPENDIX B should be reviewed to become familiar with the math formulas that will be provided with the certification exam. APPENDIX C is a starting point for those needing an introduction or re-introduction to chemistry.

Oklahoma Certification Exam Qualifications

Examination applications are available from the DEQ Operator Certification Section and County DEQ offices. Examination sessions are offered throughout the State on a regular basis. The dates and locations of all examination sessions as well as most approved training classes are published in *The Main Event* newsletter. The newsletter is mailed to all certified operators three times per year. To obtain a current copy, please call the Operator Certification Section at (405) 702-8100 or go to the DEQ website at <http://www.deq.state.ok.us/WQDnew/opcert/index.html>.

Properly completed and signed exam applications must be received by the Operator Certification Unit at least three weeks before the exam is to be taken. An application fee is charged for each exam taken. Payment of the application fee must be made by check or money order made payable to the Operator Certification Section and must be submitted with the exam application.

Minimum qualifications for operator certification exams are listed in the table below.

MINIMUM QUALIFICATIONS FOR CERTIFICATION EXAMS		
CLASSES	TRAINING ¹	EXPERIENCE ²
WATER/WASTEWATER OPERATORS		
C Operator	36 hrs of DEQ approved training	(a) For water works or wastewater works operators, one year of waterworks or wastewater works operation (b) For distribution/collection operators, one year of distribution/collection operation
B Operator	100 hrs of DEQ approved training or its approved equivalent	3 years of waterworks or wastewater works operation including one year actual hands-on operating experience
A Operator	200 hrs of approved training, including at least 40 hrs of DEQ approved courses in advanced treatment and managerial training or its approved equivalent ³	5 years of waterworks or wastewater works operation including two years actual hands-on operating experience
DISTRIBUTION/COLLECTION OPERATOR AND TECHNICIAN		
Technician	8 hrs of DEQ approved training	none
C Operator	36 hrs of DEQ approved training	1 year distribution collection operation
¹ Training credit will be granted only for courses or workshops listed as approved by the DEQ or for courses, workshops or alternative activities which have been approved in writing by the DEQ in advance. ² Experience that is used to meet the experience requirement for any class of certification may not be used to meet the education or training requirements. ³ Approved equivalents are listed in 252:710-36.		

ONLINE EXAM SESSIONS

The online exams are scheduled to take place directly after most regularly scheduled training classes. In order to take an online exam the student must complete the entire training class that is associated with that exam. As soon as each individual completes the exam, they will be able to view and print their results. All students should contact the training facility/sponsor to confirm that an online exam will take place after the class. The requirements necessary to be approved for the online exam are the same as for the written exams: an exam application must be completed and mailed with the application fee (\$40 per exam) to the DEQ three weeks prior to the exam date.

All approved training hours are cumulative. **All certified operators should keep permanent records of all approved training they have received.** Any requests for experience credit for completion of classes in higher education must be accompanied with an official transcript. There is a separate Distribution/Collection Manual, that may also be purchased from the Operator Certification Section.

Oklahoma Operator Certification Exam Information

All operator certification operator examinations consist of 100 multiple-choice questions. Each question on these exams is worth one point. The distribution/collection technician examination consists of 50 multiple-choice questions. Each question on this exam is worth two points. At least 70% of the questions must be answered correctly in order to pass the exam. When you take your exam, you are given an exam booklet, an answer sheet, formula sheet and scratch paper. The only items you should bring into the exam session are photo identification, a calculator, and a pencil.

Each operator exam is divided into 12 subject areas or “areas of competency” which correspond with the chapters in this study guide (line maintenance exams may vary). **All levels of certification exams include questions from each area.** However, because potential job duties will change as higher level certification is achieved, the priority and number of questions for each subject area will vary between certification levels. The chart below shows the suggested emphasis or priority to use when studying for certification exams.

Usually within three weeks of exam completion, a report of your exam results will be mailed to your home. **Please do not call for exam results, as they are never given out over the phone.** Your exam report will specify the number of questions which were included for each category on the exam taken and the percentage that were answered correctly. Exam categories correspond directly to the chapters and/or sections in this study guide. **Your exam report is designed to help direct your future studies and professional development.** For example, if you passed the exam but scored only 60% in the category of Operator Safety, you would be encouraged to review the corresponding chapter (Chapter 6) in this study guide.

If you did not pass your exam, you should carefully re-study all categories in which you scored below 70%. You may also want to review all the chapters in this study guide and/or attend additional training before retaking your exam.

AREA OF COMPETENCY	SUGGESTED STUDY EMPHASIS			
Study Guide Chapter	Class D	Class C	Class B	Class A
Section I				
1. Basics of Water Treatment	High	Low	Low	Medium
2. Characteristics of Water	High	Medium	Low	Medium
3. General Regulations and Management	High	Medium	Medium	Medium
Section II				
4. Reservoir Management and Intake Structures	Low	Low	Low	Medium
5. Coagulation/Flocculation/Sedimentation	Medium	High	High	Medium
6. Filtration	Low	High	Medium	Medium
Section III				
7. Disinfection	Medium	High	High	High
8. Supplemental Treatment	Low	Medium	High	High
9. Ground Water Systems	High	Medium	Medium	High
Section IV				
10. Distribution Systems	High	High	Medium	High
11. Maintenance	Low	Low	Medium	High
12. Operator Safety	High	High	High	High

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WATER CERTIFICATION STUDY GUIDE CREDITS AND ACKNOWLEDGMENTS

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This *Water System Operations Certification Study Guide* ("Guide") is not intended to be used as a manual for technical information regarding system operation or maintenance or to change, supersede, or replace any statute, rule, regulation, standard or other legal requirement currently in effect or that may be in effect subsequent to publication of this Guide. The purchase, use and/or study of this Guide shall not be considered a guarantee that the user will successfully complete the certification examination. Any mention of trade names or commercial products does not constitute an endorsement or recommendation for use by the State of Oklahoma, the Oklahoma Department of Environmental Quality or the Waterworks and Wastewater Works Advisory Council.

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Chapter 1

Basics of Water Treatment

SUGGESTED STUDY GUIDELINES

All certification levels

Be prepared to answer questions concerning:

- The fundamental purpose of all public water supply systems
- The importance and role of the water system operator
- The definitions of each of the following terms
 - aquifer
 - coagulation
 - community water system
 - contamination
 - corrosivity
 - disinfection
 - distribution system
 - effluent
 - filtration
 - flocculation
 - fluoridation
 - ground water
 - hard water
 - hydrologic cycle
 - influent
 - inorganic
 - organic
 - potable water
 - primary contaminants
 - Safe Drinking Water Act (SDWA)
 - secondary contaminants
 - sedimentation
 - soft water
 - supplemental treatment
 - surface water
 - water-borne disease
- The average domestic water usage per person per day
- How to perform area and volume calculations for cylindrical and rectangular basins
- The common conversion factors used in water systems and how to use them
- How to convert between common volume-time units
- The most commonly used metric system units in water systems and their values

ENTRY LEVEL DISCUSSION

People need safe and pleasant water to drink. Many sources of water are not directly suitable for drinking purposes without treatment because of pollution and contamination by man and nature. Before modern society, water was purified only by the sun, wind, filtration through soil, and time. Today, nature is assisted by public water facilities and a team of professionals that includes engineers, builders, and operators. However, engineers and builders are on the scene for only a short time. Operators go on forever. Water system operators must operate, maintain, and manage these facilities.

In 1974, the **Safe Drinking Water Act (SDWA)** was passed by the U.S. Congress and was signed into law. As directed by the Act, the Environmental Protection Agency (EPA) researched and developed drinking water regulations designed to ensure safe drinking water for consumers. The contaminants identified by the EPA as harmful to human health are called **primary contaminants**. In order to protect public health, a primary contaminant must not exceed a certain specified level known as the **maximum contaminant level (MCL)**. If an MCL is exceeded, public notification is required.

The EPA also has identified contaminants in drinking water that are not harmful to human health but are unpleasant. These are called **secondary contaminants**. Secondary contaminants include substances that cause unpleasant tastes and odors or color the water. A **recommended maximum level (RML)** has been set for each of the secondary contaminants to make sure the water is pleasant to drink.

By meeting the current primary and secondary standards for public water supplies, the water provided to the public is both **safe** and **pleasant** to drink. Providing a source of safe and pleasant water is the fundamental purpose of all public water supply systems. Operators must also operate their systems in a cost effective and safe manner and be sure that adequate amounts of water and pressure are available during times of emergency, such as a fire. All certified water system operators are considered **Public Health Professionals** who have a very important role in protecting public health in their communities.

The following definitions should be helpful in gaining a better understanding of the fundamental purposes, processes, and functions of water treatment. Subsequent chapters in this study guide and the suggested reference materials will address these terms in more detail.

aquifer - A natural underground layer of porous water-bearing materials (such as sand, gravel, or fractured rock) usually capable of yielding a large amount of water. Aquifers may be either artesian aquifers or water table aquifers.

coagulation - A chemical reaction causing small clumps of particles (floc) to begin to form. This reaction takes place when a coagulant (such as alum) is added and mixed into the water.

community water system - A public water supply system that has at least 15 service connections or serves 25 or more persons on a regular basis.

contamination - The introduction into water of microorganisms, chemicals, toxic materials, wastes or wastewater in a concentration that makes the water unfit for its next intended use.

corrosivity - An indication of the corrosiveness of water. The corrosiveness of water can be determined by the water's chemical and physical characteristics including pH, alkalinity, and hardness.

Cryptosporidium - A microscopic parasite that can be found in water. It produces cysts that are very resistant to harsh environmental conditions. It is responsible for an intestinal illness called cryptosporidiosis. The most common symptoms include diarrhea, abdominal cramps, gas, bodily discomfort, fatigue, and weight loss. Vomiting, chills, headache, and fever may also occur. Symptoms begin approximately one week after exposure and can last from one week to one month.

disinfection - The process designed to kill or inactivate most microorganisms in water, including essentially all pathogenic (disease-causing) bacteria. There are several ways to disinfect, with chlorine being the most frequently used method in both water and wastewater systems.

Disinfectant Byproducts (DBPs) - A compound formed by the reaction of a disinfectant with naturally occurring organic material in the water. The most common DBPs formed when chlorine is used are trihalomethanes (THMs), and haloacetic acids (HAAs).

Disinfection Profiling - A water system assesses the level of disinfection currently provided and then determines the impact that a proposed change in disinfection practice would have.

distribution system - The network of pipes that transports potable water from the treatment plant and/or ground water well to the consumers.

Escherichia coli (E. coli) - *E. coli* is a bacterium that is commonly used as an indicator of the human health risk from harmful micro-organisms that can be present in water. *E. coli* causes an intestinal illness. Most identified cases develop severe abdominal cramps and diarrhea. Blood is often seen in the stool. The symptoms begin within one to 9 days after exposure and usually last a week or less.

effluent - Water or other liquid flowing OUT of a reservoir, basin, treatment process or treatment plant.

filtration - The process of passing water through material such as a bed of sand, coal, or other granular substance to remove particulate impurities. Filtration preceded by coagulation, flocculation, and sedimentation is commonly referred to as conventional filtration.

flocculation - A process of gentle stirring to gather together the small particles of floc formed during coagulation in order to form larger or heavier floc particles.

fluoridation - The addition of fluoride compounds to increase the concentration of fluoride ions in drinking water to a predetermined optimum level (about 1 mg/L) to reduce the incidence of dental caries (tooth decay) in children.

Giardia - A microscopic parasites that can be found in water. It produces cysts that are very resistant to harsh environmental conditions. *Giardia* causes an intestinal illness called giardiasis. The symptoms of *giardiasis* and *cryptosporidiosis* are very similar. The most common symptoms include diarrhea, abdominal cramps, gas, bodily discomfort, fatigue, and weight loss. Vomiting, chills, headache, and fever may also occur. Symptoms begin approximately one week after exposure and can last from one week to one month.

ground water - The water that has drained downward from the surface (percolated) to an aquifer.

ground water under the influence of surface water - Any water beneath the surface of the ground with significant occurrence of insects or other macroorganisms, algae, or pathogens such as *Giardia lamblia* or *Cryptosporidium*, or significant and relatively rapid shifts in water characteristics such as turbidity, temperature, conductivity, or pH that closely correlate to climatological or surface water conditions.

hard water - A characteristic of water caused mainly by the salts of calcium and magnesium. Excessive hardness in water is undesirable because it causes the formation of soap curds, increased use of soap, scale deposits in boilers and hot water heaters, damage in some industrial processes, and sometimes causes objectionable tastes in drinking water. Hard water is generally defined as water having a hardness of 100 milligrams per liter (mg/L) or more.

hydrologic cycle (*also known as the water cycle*) - The process of evaporation of water into the air and its return to earth by precipitation (rain or snow). This process also includes transpiration from plants, ground water movement, and runoff into rivers, streams, and the ocean.

influent - Water or other liquid flowing INTO a reservoir, basin, treatment process, or treatment plant.

inorganic - Material such as salts, metals, and all other substances of mineral origin.

maximum contaminant level (MCLs) - The maximum permissible level of a contaminant in water that is delivered to any user of a public water system. MCL's are enforceable standards established by the U.S. Environmental Protection Agency.

maximum residual disinfectant level (MRDLs) - The highest level of a disinfectant allowed in drinking water. MRDL's are enforceable standards established by the U.S. Environmental Protection Agency.

microbial pathogens - Micro-organisms that cause disease are microbial pathogens. Microbial pathogens can be found in wastewater from such sources as sewage discharges, leaking septic tanks, and runoff from animal feedlots/pastures.

nontransient noncommunity (NTNC) water system - A public water system that is not a community water system and that regularly serves at least 25 of the same persons over six months per year, including schools, day care centers, factories, restaurants and hospitals.

organic - Material that comes mainly from animal or plant sources and contains carbon (C).

potable water - Water that is fit to drink.

primary contaminants - The contaminants identified by the EPA as harmful to human health. In order to protect public health, the primary contaminants must not exceed certain specified levels known as Maximum Contaminant Levels (MCL).

Safe Drinking Water Act (*commonly referred to as SDWA*) - An Act passed by the U.S. Congress in 1974. The Act establishes a cooperative program among local, state, and federal agencies to ensure safe drinking water for consumers.

secondary contaminants - Contaminants in drinking water that are not harmful to human health but are unpleasant. Secondary contaminants include substances that cause unpleasant tastes and odors or color the water. A Recommended Maximum Level (RML) has been set for each of the secondary contaminants in order to make sure the water is pleasant to drink.

sedimentation - The water treatment process in which the floc particles are allowed to settle out of the water in a large clarifier or sedimentation basin.

soft water - Water having a low concentration of calcium and magnesium ions. Soft water is generally defined as water having a hardness of 100 milligrams per liter (mg/L) or less.

supplemental treatment - Additional treatment processes used at water treatment plants and/or ground water systems including—but not limited to—softening, corrosion control, iron and manganese removal, and fluoridation.

surface water - Water that accumulates mainly as a result of direct runoff from precipitation (rain or snow). Precipitation that does not enter the ground or evaporate into the atmosphere flows over the ground and ultimately collects on the surface in rivers, lakes, and reservoirs. Surface water requires filtration and disinfection, and may require other special treatment processes such as coagulation, flocculation and sedimentation. Surface water will also require additional monitoring and reporting.

water-borne disease - Diseases that are caused by biological life forms carried by water. The organisms causing these diseases include certain bacteria, viruses, and parasites.

The **average water usage per person per day** in most communities is between 100 and 130 gallons, depending upon a variety of factors including the season of the year and local water rates.

Common conversion factors are needed by all operators working in this increasingly technical field. These include the conversions of cubic feet (ft³) to gallons; from gallons to pounds; and from feet of head to pounds per square inch (psi). **Volume-time unit** conversions between **MGD** (million gallons per day) and **gpd** (gallons per day) and **gpm** (gallons per minute) are other examples of basic math performed on a frequent basis at water systems. The most commonly used **metric system units** and their values are also very important for operators to understand.

Other specific math skills needed by operators are identified by certification level in the suggested study guidelines of the other chapters in this study guide. Some assistance with common conversion factors and an introduction to basic math skills can be found in APPENDIX A in this study guide.

SUGGESTED REFERENCES FOR STUDY

California State University, Sacramento - **Water Treatment Plant Operation - Vol. 1**

Chapter 1	The Water Treatment Plant Operator
Chapter 2	Water Sources and Treatment
Appendix	How to Solve Water Treatment Plant Arithmetic Problems

California State University, Sacramento - **Water Distribution System Operation & Maintenance**

Chapter 1	The Water Distribution System Operator
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OTHER STUDY SUGGESTIONS

- Be able to draw the essential components of the hydrologic cycle including flow patterns and key terms such as precipitation, percolation, run off, zone of saturation, evaporation, aquifer, and water table.
- Draw a simple diagram of a typical surface water treatment plant which includes:
 - reservoir and intake
 - coagulation and flocculation
 - sedimentation
 - filtration
 - disinfection
 - supplemental treatment (softening, corrosion control, iron and manganese removal, and fluoridation)
 - distribution systems and water storage facility
- Identify typical raw surface water influent characteristics (see also Chapter 2) and determine where each of these is removed in the process sequence that you have drawn.
- For a review of basic math skills, read and work the problems in APPENDIX A in this study guide.
- To help prepare for a Class C, B, or A exam, practice using the appropriate formula sheets found in APPENDIX B in this study guide.

SAMPLE QUESTIONS

Class D

One gallon of water weighs

- A. 3.14 lbs
- B. 7.48 lbs
- C. 8.34 lbs

Class C

The average domestic water usage per person per day is usually somewhere in the range of

- A. 50-80 gallons
- B. 100-130 gallons
- C. 150-200 gallons

Class B

Probably the most important source of information to use when implementing changes in process control at a water plant is

- A. methods of previous operation
- B. laboratory results
- C. suggestions from reference manuals
- D. complaints from customers

Class A

The most important duty of a water plant operator is to

- A. keep households supplied with running water at any cost
- B. educate the public as to what is involved in technical water treatment processes
- C. help to protect the health and well-being of the community
- D. maintain the outward appearance of a clean and well-operated plant
- E. obey the directions of all city officials in operational and treatment decisions

Chapter 2

Characteristics of Water

SUGGESTED STUDY GUIDELINES

Class D

Be prepared to answer questions concerning:

- Physical, chemical, and microbiological characteristics of water
- The definitions of each of the following terms and their significance
 - apparent color
 - true color
 - turbidity
 - pH
 - acid
 - base
 - neutral
 - total alkalinity
 - p-alkalinity
 - total hardness
 - carbonate hardness (temporary hardness)
 - non-carbonate hardness (permanent hardness)
 - total solids
 - total dissolved solids (TDS)
 - total suspended solids (TSS)
 - microbiology
 - pathogenic
 - non-pathogenic
 - indicator bacteria
 - coliform
 - fecal coliform
 - aerobic bacteria
 - anaerobic bacteria
 - facultative bacteria
- The proper units of measurement for each of the general characteristics of water
- The names of the major water-borne diseases in the past and today
- The basic sampling procedures and requirements for the “bac-t” sampling program
- The general procedures for properly collecting water samples

Class C

Be prepared to answer questions concerning guidelines listed for Class D certification and:

- The chemical symbols for the various chemical constituents of water
- The endpoints for total alkalinity and p-alkalinity
- The relationship between hardness and alkalinity
- What gases are produced under aerobic conditions
- What gases are produced under anaerobic conditions
- The effects carbon dioxide has on pH levels
- The two scales of temperature measurement commonly used at water systems and how to convert from one scale to the other
- The proper preservatives and holding times for different types of water samples

Be prepared to answer other questions that require additional personal study

Class B and Class A

Be prepared to answer questions concerning guidelines listed for lower levels of certification and:

- How to determine the different types of hardness from laboratory data
- The three types of chemicals that contribute to total alkalinity and their associated pH levels

Be prepared to answer other questions that require a combination of actual experience and additional personal study

ENTRY LEVEL DISCUSSION

A basic understanding of the characteristics of water is essential to the understanding of why and how water treatment is performed. The following discussion will address the characteristics, describing the fundamental concepts of each. Where appropriate, the basic method(s) used to analyze water for these characteristics will also be briefly discussed.

Color and Turbidity

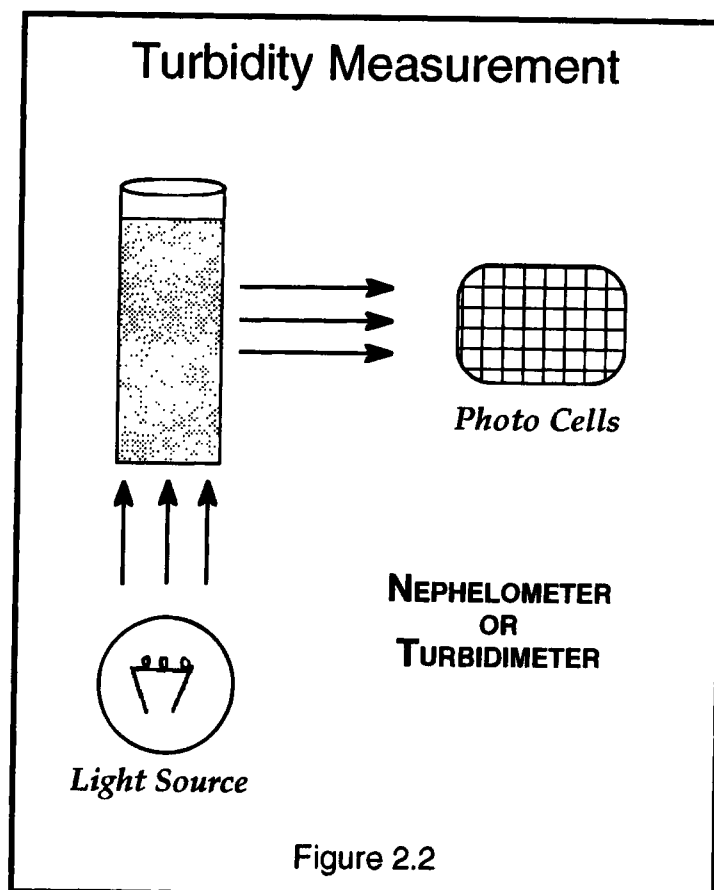
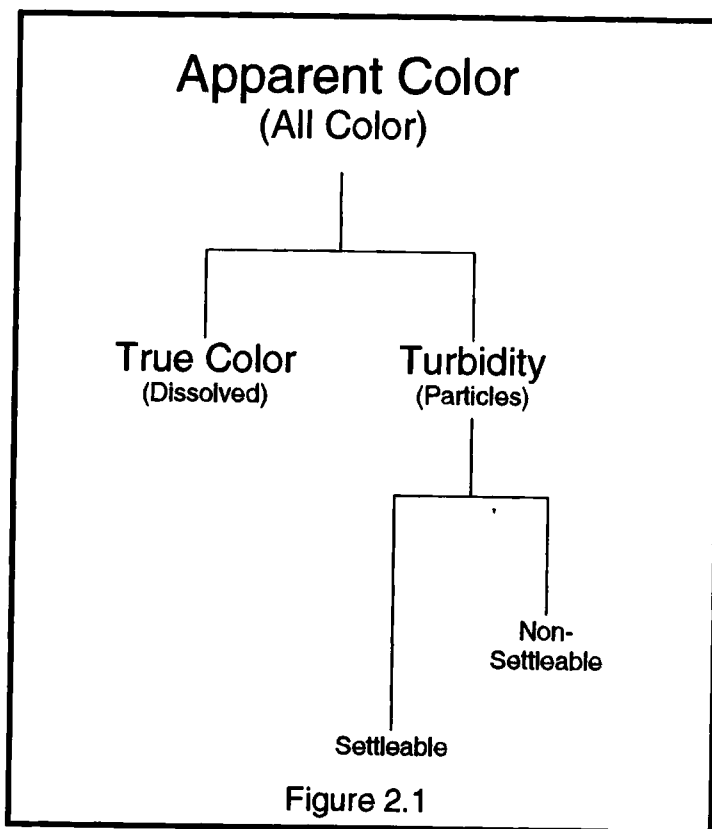
All of the color visible in water is referred to as the **apparent color** of the water. The apparent or total color usually consists of a combination of both true color and turbidity (*see Figure 2.1*).

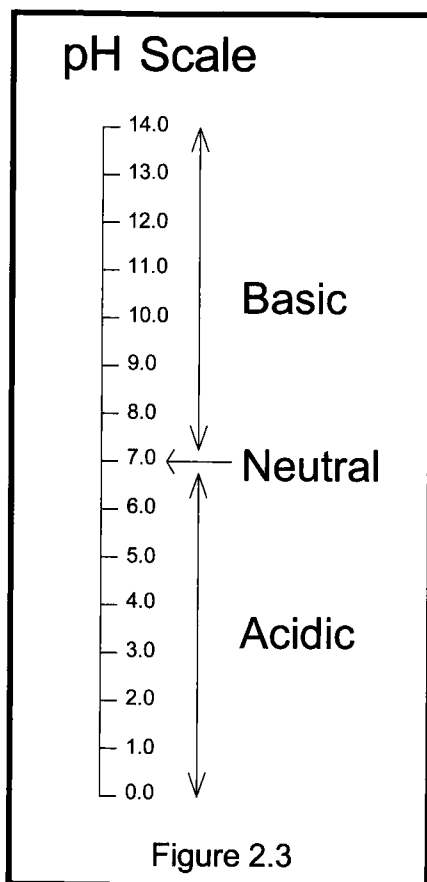
True color is the dissolved material contributing to color. When a water sample containing true color is poured through a filter, the color will generally not be removed. An everyday example of this is instant tea dissolved in water. When instant tea is stirred into a glass of water, the water will turn brown. When you pour the tea through a filter it remains brown. This color is true color because it was dissolved and was not removed by filtration.

True color can be caused by either organic or inorganic substances. True color is measured in **color units (CUs)** and is measured using round, clear glass tubes called **Nessler tubes**. A water sample being analyzed for true color is first filtered or centrifused and poured into a Nessler tube. It is then compared to other tubes that contain known amounts of true color. True color can be removed by proper treatment.

Turbidity refers to particles suspended in the water. Unlike dissolved substances, these “particles in suspension” can be removed by filtration processes. Turbidity is considered a primary contaminant by the Environmental Protection Agency (EPA) and is therefore strictly regulated. Particles are a serious concern; they can surround and protect harmful microorganisms from being destroyed by chlorination. The chlorine is not able to kill the microorganisms unless it comes into direct contact with them. By removing turbidity in water to levels required by regulations, water system operators can feel more confident that their chlorination practices are effectively removing dangerous microorganisms.

Turbidity is measured in **nephelometric turbidity units (NTUs)**. NTUs are measured by an instrument called a **nephelometer** or **turbidimeter** (see Figure 2.2). The term nephelometer is derived from two Greek terms: “nephelos” and “meter.” Nephelos means *to scatter* and meter means *to measure*. Thus, a nephelometer is a *scatter measurer*. A nephelometer or turbidimeter measures the amount of light that is scattered by the particles as a light beam passes through the water sample.





pH

The **pH** measurement is a way to determine how acidic or how basic the water is. The **pH scale** is from 0.0 to 14.0 (*see Figure 2.3*). A pH of less than 7.0 means the water is **acidic**. A pH of greater than 7.0 means the water is **basic**. A pH of exactly 7.0 is considered **neutral**.

To really understand the meaning of pH, it is necessary to discuss the basic chemistry that determines pH levels. The water molecule (H_2O) has a tendency to disassociate or “split apart” into two parts; the **hydrogen ion** (H^+) and the **hydroxide ion** (OH^-). The hydrogen ion (H^+) is related to acidic conditions while the hydroxide ion (OH^-) is related to basic conditions.

*Note: An **ion** is a molecule with either a positive or a negative electrical charge.*

Water is sometimes referred to as the **universal solvent**. Because of its tendency to dissolve most substances it comes in contact with, water usually contains many impurities. Even distilled or deionized water is not absolutely 100% pure. The presence of different types of impurities in water causes differences in pH.

If there are high concentrations of impurities in the water that combine with or “tie up” hydroxide ions, a surplus of hydrogen ions will be left over or “free.” This condition will cause the pH to be less than 7.0 (acidic). On the other hand, if the impurities tend to “tie up” the hydrogen ions, a surplus of hydroxide ions will be “free” and the pH will be greater than 7.0 (basic). If a water sample contains equal concentrations of OH^- and H^+ , the pH will be exactly 7.0 (neutral).

The most common method used for pH measurement is a pH meter using an hydrogen ion-sensitive electrode. The **pH scale** consists of 15 pH units (0.0 to 14.0). Each **pH unit** on the scale is very significant because it actually represents a ten-fold increase or decrease in how acidic or basic the water is. It is for this reason that pH measurements are always reported in tenths of a pH unit instead of just “rounding off” to the nearest whole number. pH measurements should never be averaged together.

Hardness

Hardness in water is mainly caused by the presence of **calcium** (Ca^{++}) and **magnesium** (Mg^{++}) metallic ions. Iron and manganese can also add to the hardness content, but the concentration of these substances is usually so low that their contribution is insignificant.

The average consumer is usually aware of hardness only because of the effects that it produces. If the hardness level is high enough, these effects can be quite pronounced, such as an increase in soap and detergent usage, and increase in scaling conditions in boilers, hot water tanks, and plumbing systems. Hard water is generally defined as water having a hardness of 100 milligrams per liter (mg/L) or more. On the other hand, soft water has a low concentration of calcium and magnesium ions. Soft water is generally defined as water having a hardness of 100 milligrams per liter (mg/L) or less.

There are two types of hardness (*see Figure 2.4*). One type is **carbonate hardness** and is also known as temporary hardness, which is always alkalinity. The other is **noncarbonate hardness** and is also known as permanent hardness, which is never alkalinity. The two types have several differences in chemical makeup and characteristics. Calcium and magnesium ions combine with **carbonate**, **bicarbonate**, and **hydroxide** ions to form carbonate (temporary) hardness. When calcium and magnesium combine with **sulfate** and **chloride** ions the result is noncarbonate (permanent) hardness.
Note: noncarbonate hardness = total hardness-total alkalinity

Carbonate hardness is sometimes called temporary hardness because it will come out of solution or “precipitate out” when the water is heated. The light-colored substance that forms on the inside of a pan of boiling water is actually carbonate hardness that has precipitated as a result of heating. This substance can also form scale on the inside of hot water tanks and pipes, causing problems for the homeowner. Noncarbonate hardness is sometimes called permanent hardness because it does not precipitate when heated.

At water treatment facilities, heating is not a cost-effective method of removing either type of hardness. Therefore, removal of both carbonate and non-carbonate hardness is accomplished by a chemical treatment process known as softening (see Chapter 8).

The most common method used for hardness analysis is called titration. **Titration** is a laboratory procedure that adds a specific chemical to a sample until a specified observable change occurs. The amount of the chemical needed to cause this change is noted and calculated in a formula to obtain the values to be reported. Hardness values are reported in mg/L (milligrams per liter) or ppm (parts per million), as equivalent calcium carbonate.

Note: mg/L and ppm are just two different ways of saying the same thing.

Alkalinity

Alkalinity can be defined as the ability to resist changes in pH in response to dilute acids or dilute bases. In other words, the alkalinity in the water is caused by certain chemicals that act as a **buffer**. It should be noted that the presence of alkalinity does not necessarily indicate basic pH conditions. Although the chemicals producing alkalinity in water do tend to keep the water at a high pH, it is possible to have acidic pH conditions and still have some alkalinity present or to have basic pH conditions but not have a significant amount of alkalinity present.

The chemical ions that form alkalinity are **hydroxide** (OH^-), **carbonate** (CO_3^{2-}), and **bicarbonate** (HCO^-) (*see Figure 2.5*). The pH of the water determines which of these three ions are present. The

Total Hardness

CARBONATE HARDNESS

Calcium Bicarbonate	$\text{Ca}(\text{HCO}_3)_2$
Calcium Carbonate	CaCO_3
Magnesium Bicarbonate	$\text{Mg}(\text{HCO}_3)_2$
Magnesium Carbonate	MgCO_3

NONCARBONATE HARDNESS

Calcium Sulfate	CaSO_4
Calcium Chloride	CaCl_2
Magnesium Sulfate	MgSO_4
Magnesium Chloride	MgCl_2

Figure 2.4

Total Alkalinity

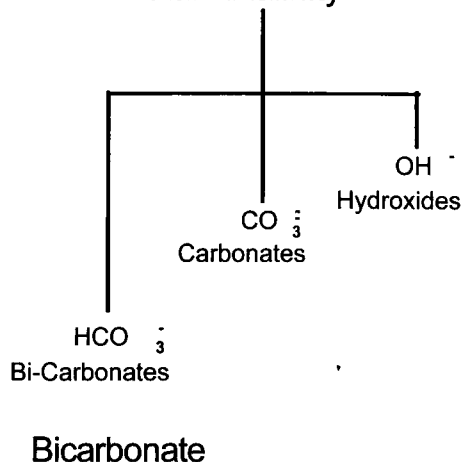


Figure 2.5

Hardness and Alkalinity

Sodium Bicarbonate
Sodium Carbonate
Sodium Hydroxide

NaHCO_3
 Na_2CO_3
 NaOH

Calcium Bicarbonate
Calcium Carbonate
Calcium Hydroxide
Magnesium Bicarbonate
Magnesium Carbonate
Magnesium Hydroxide

$\text{Ca}(\text{HCO}_3)_2$
 CaCO_3
 $\text{Ca}(\text{OH})_2$
 $\text{Mg}(\text{HCO}_3)_2$
 MgCO_3
 $\text{Mg}(\text{OH})_2$

— — Alkalinity

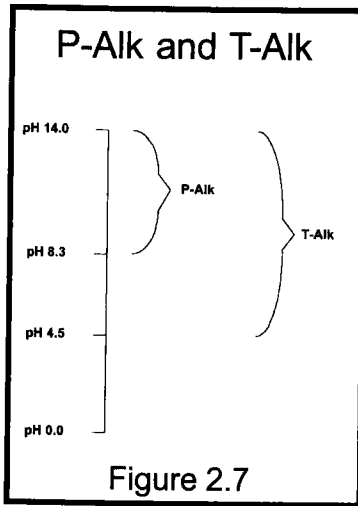
Calcium Sulfate
Calcium Chloride
Magnesium Sulfate
Magnesium Chloride

CaSO_4
 CaCl_2
 MgSO_4
 MgCl_2

— Hardness

Figure 2.6

Table 2320:II. Alkalinity Relationships*

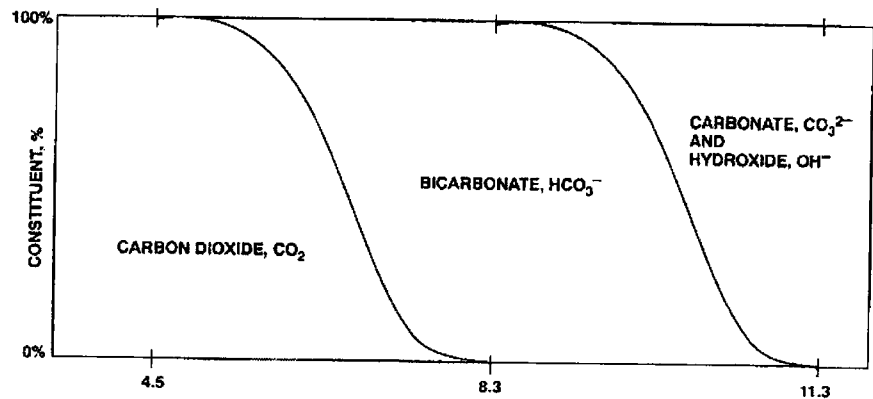


Result of Titration	Hydroxide Alkalinity as CaCO_3	Carbonate Alkalinity as CaCO_3	Bicarbonate Concentration as CaCO_3
$P = 0$	0	0	T
$P < 1/2 T$	0	2P	$T - 2P$
$P = 1/2 T$	0	2P	0
$P > 1/2 T$	$2P - T$	$2(T - P)$	0
$P = T$	T	0	0

* Key: P - phenolphthalein; T - total alkalinity

Table 2.1

P = 0 Chart
Figure 2.8



hydroxide, carbonate, and bicarbonate ions combine with calcium (Ca^{++}), magnesium (Mg^{++}), sodium (Na^+), and potassium (K^+) ions to form the chemical compounds that contribute to alkalinity.

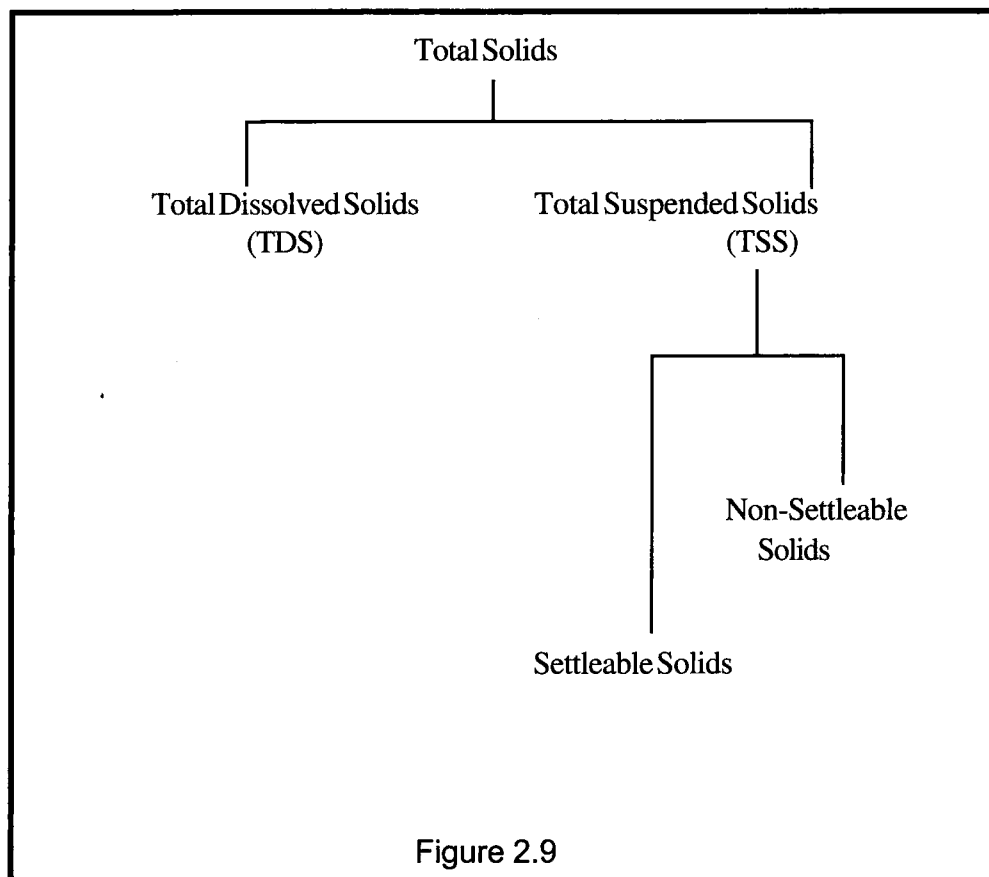
When calcium or magnesium happen to combine with carbonate or bicarbonate, both alkalinity and hardness are created. In other words, some chemical substances contribute to both hardness and alkalinity (*see Figure 2.6*). The “common ground” that alkalinity and hardness share is the carbonate or temporary hardness.

There are two types of alkalinity measurements. These measurements are referred to as total alkalinity and P-alkalinity.

Just as it sounds, the **total alkalinity** test measures the total amount of alkalinity present. Total alkalinity is usually called T-alkalinity or **T-alk**. Some operators may also refer to total alkalinity as M-alk. Total alkalinity only exists between pH 4.5 and pH 14.0. This means that if a water sample has a pH of less than 4.5, the alkalinity content is zero.

Another alkalinity measurement is the **p-alkalinity** or **p-alk** test. The “p” in p-alkalinity is an abbreviation for phenolphthalein, a chemical used in the lab test. There is no p-alk in the sample if the pH is less than 8.3. The p-alk test is often performed to help determine the relative concentrations of hydroxide, carbonate and bicarbonate in the sample. It should be remembered that p-alkalinity (if it is present) is only part of the total alkalinity, not an entirely separate measurement (*see Figure 2.7*).

Table 2.1 shows the ranges of pH and concentration as they relate to the relationship of alkalinity. **Figure 2.8** shows the breakdown of alkalinity into constituents of carbonate, bicarbonate, and hydroxide. The most common method used for alkalinity analysis is **titration**. In alkalinity titrations, a dilute acid is added to the sample until the pH reaches the “**endpoint**” as indicated by a pH meter or a color indicator. The endpoint for T-alk is a pH of 4.5. The endpoint for p-alk is a pH of 8.3. The amount of dilute acid that was needed to reach the endpoints is then noted and calculated in a formula to determine alkalinity values. Alkalinity values are reported in mg/L (milligrams per liter) or ppm (parts per million).



Solids

The **total solids** in water consist of both dissolved solids and suspended solids (*see Figure 2.9*). The **total suspended solids** (TSS) is the portion of the total solids consisting of particles. Total suspended solids contribute greatly to the turbidity levels in water supplies. In surface water treatment, coagulation, flocculation, sedimentation, and conventional filtration methods are utilized to lower the suspended solids and turbidity concentrations to acceptable levels. Total suspended solids can be further categorized as either settleable solids or nonsettleable solids. Nonsettleable solids are also known as colloids.

The remaining portion of the total solids are the **total dissolved solids** (TDS). This is the portion of the total solids that is entirely dissolved in the water and cannot be removed by simple filtration. Substances contributing to the total dissolved solids levels include dissolved forms of calcium, magnesium, and sodium, as well as other common mineral salts.

Solids analysis is performed by use of a drying oven set at a specific temperature and a very sensitive weighing scale. After prescribed sequences of initial weighing, oven drying, cooling, and re-weighing have been completed, the final weight of the dry residue is recorded. The results are reported in mg/L or ppm.

Microbiology

Microbiology is the study of very small forms of life. Microbiological organisms can only be seen with the aid of a microscope. These organisms include bacteria, virus, protozoa, rickettsia, fungi, algae, and other forms of microscopic life. The average-sized bacterial organism is so small that 20,000 could fit side-by-side in one inch. Viruses are much smaller.

Oxygen Requirements of Microbiological Organisms

Microbiological organisms can be classed by their oxygen requirements and are referred to as either aerobic, anaerobic, or facultative. **Aerobic** organisms require dissolved “free” oxygen (DO). Aerobic organisms use free oxygen (O_2) and produce carbon dioxide (CO_2).

Anaerobic organisms obtain oxygen from oxygen-containing compounds such as the sulfate molecule (SO_4). One of the many by-products of anaerobic organisms is hydrogen sulfide (H_2S). Hydrogen sulfide is a gas that has a sulfur-like “rotten egg” odor. Unfortunately, it is not only smelly, it is also very dangerous due to its toxicity to humans (see Chapter 12).

Facultative organisms can live with or without the presence of dissolved oxygen. If free oxygen is available in sufficient quantities, they will act like an aerobic organism. On the other hand, if there is not enough free oxygen they will actually convert and begin to use other sources of oxygen (act like an anaerobic organism). Actually, most bacteria are facultative and how they “act” is dependent upon the level of dissolved oxygen available to them.

Pathogenic or Non-Pathogenic

Organisms can also be classed as pathogenic or non-pathogenic. **Pathogenic** organisms are organisms that cause disease. **Non-pathogenic** organisms do not cause disease. Diseases caused by pathogens (pathogenic organisms) that can be transmitted by water are sometimes called **water-borne diseases**. The organisms causing water-borne disease are found in the intestinal tract of all persons that are infected with the disease. The disease can be transmitted to other persons if any waste material from infected persons is allowed to enter drinking water supplies.

Historically, the five major water-borne diseases have been **typhoid, cholera, dysentery, polio, and hepatitis** (jaundice). Currently, the most common water-borne disease is **giardiasis**. Fighting water-borne diseases is an ongoing battle for all operators of community water and sewage systems. Water-borne disease can only be managed by proper sanitation and regular monitoring practices. Proper sanitation practices in a community are just as important today as they were 75-100 years ago when many of them were first implemented.

Coliform Bacteria

One group of non-pathogenic bacteria that plays a very important role in the monitoring of public waters and drinking supplies is known as Coliform group bacteria. **Coliform bacteria** live in everyone's intestinal tract. In fact, warm-blooded animals (including humans) can't live without them. Most types of these coliform bacteria also live in the open environment. Coliform bacteria are considered non-pathogenic.

It would be very expensive and time-consuming to monitor and test the water for all pathogenic organisms that could possibly be present. What is done instead is to monitor all public water supplies for coliform bacteria. Although the coliform bacteria themselves usually do not cause disease, they serve as excellent **indicators** of possible environmental or wastewater contamination. A lab test is often performed to see what levels of a particular type of coliform—known as **fecal coliform**—are present. Because the fecal coliform (also known as *Escherichia Coli* or *E. Coli*) are only found in fecal material this test can be used as an indicator of direct contamination from wastewater or other sources of fecal material.

Probably the most common procedure used by microbiological laboratories to detect coliform bacteria is known as the **colilert** method. This recently developed test is used because of its speed and convenience in detecting the simple presence or absence (P/A) of coliform in water supplies.

In the colilert method, a specially formulated powdered substance is added directly to the water in the bac-t sample container. After mixing thoroughly, the sample is incubated at 35°C for 24 hours. If the sample develops a yellow color after 24 hours, it is considered positive for coliform bacteria. Federal regulations state that all public water supply samples that test positive for total coliform bacteria must also be tested for fecal coliform. In the colilert method, this is done very easily and quickly by holding a fluorescent lamp to the positive (yellow) samples. If the sample is also positive for fecal coliform, it will appear as a milky white fluorescent color under the lamp.

In some situations, other laboratory tests are used to check for coliform bacteria. One of these is known as the **MPN** (most probable number) method. This method uses several tubes which are each “inoculated” with sample. They are then incubated at 35°C for 48 hours. If a gas bubble is produced in one of the tubes, the sample may be positive for coliform bacteria. A separate procedure to confirm the results is then performed. A “most probable number” of coliform is reported based on the number of tubes that tested positive.

Total coliform and fecal coliform are sometimes analyzed by **MF** (membrane filter) methods. In these separate tests, a measured portion of the sample is passed through a very fine filter. This filter has such a small pore size that the organisms are caught on the filter as the water passes through. The filter is then placed in a small dish that contains a fluid especially formulated to grow coliform bacteria (or only fecal coliform bacteria). After incubation, the number of coliform colonies (groups of bacteria) that grew on the filter are counted. Each colony represents one coliform bacteria that was present in the original sample. The results are reported as the actual number of organisms present per 100 mls (milliliters) of sample.

Sampling Procedures for Coliform Bacteria

One very important responsibility of operators at community water systems is the proper collection and submission of samples to be tested for coliform bacteria (bac-t samples). If these samples are not collected correctly, it could result in accidental contamination. In addition, the Environmental Protection Agency (EPA) requires all labs that analyze bac-t samples to reject any sample that does not meet certain strict requirements. To avoid the possibility of accidental contamination and/or sample rejections, all bac-t samples should be collected and submitted with great care. Some of the most important instructions and requirements for proper collection of bac-t samples are given below. For more information, please contact the laboratory where your bac-t samples are tested.

1. All water systems must have a **pre-approved site-sampling plan** that includes sampling sites. Samples may be collected from these sites only.
2. A separate sample form must be completed for each sample. Any pre-printed information on the form that is not complete or accurate should be corrected. The following information must also be provided on the form:

The **date** the sample was collected.

The **time** the sample was collected. 24-hour clock-time (military time) should be used.

The **initials** of the person collecting the sample.

The **location code**. Each site in the site-sampling plan has an assigned location code.

The **chlorine residual** at the sample site (if chlorinating).

3. Always remove screens or aerators from faucets before starting sampling procedure. Wash hands thoroughly and leave water running for at least three minutes to clear lines before taking sample.

3. Always remove screens or aerators from faucets before starting sampling procedure. Wash hands thoroughly and leave water running for at least three minutes to clear lines before taking sample.
4. The containers that are supplied by the labs are the only containers that should be used. Remove the plastic seal on sample container by tearing out the perforated section. Open the lid of the container, being careful not to touch the bottom of the lid or the inside of container. If this happens, throw away the container and start over.
5. Check for the **sodium thiosulfate** pill in the container. The sodium thiosulfate neutralizes the chlorine residual in the sample at the time of collection. If this isn't accomplished, the sample is invalid
6. The sample container must be carefully filled to a volume of exactly **100 milliliters (mls)** There is a "plus or minus" allowance of only two mls (*see Figure 2.10*). If there is less than 98 mls or more than 102 mls of water in the container, the laboratory must reject the sample.
7. Close the container being careful to not touch the inside rim or the bottom of the lid. If this happens, throw it away and start over. Close the lid tightly to avoid leaks. Tape shouldn't be used to seal the container because the lab technician must be able to open the container without danger of contaminating the sample. A rubber band stretched from top to bottom is a good alternative. If the container leaks, it must be rejected because it could have become contaminated.
8. The most common type of lab accident that results in sample rejection is when a lab technician becomes unsure which sample form belongs to which sample. Samplers can help prevent this problem by writing the system name and location code on the container tape or tape you have added with a waterproof marker.
9. Using the mailing labels and special mailing boxes provided by the labs, mail the sample and sample form to the lab by First Class mail. **30 hours** is the absolute maximum time allowed between sample collection and analysis. If the sample is over 30 hours old, it is invalid because the bacteria may not be alive and be detected. Operators are encouraged to "play it safe" and make sure their samples are received within 24 hours.

The number of bac-t samples required to be submitted depends upon the type of system and the size of the population that it serves.

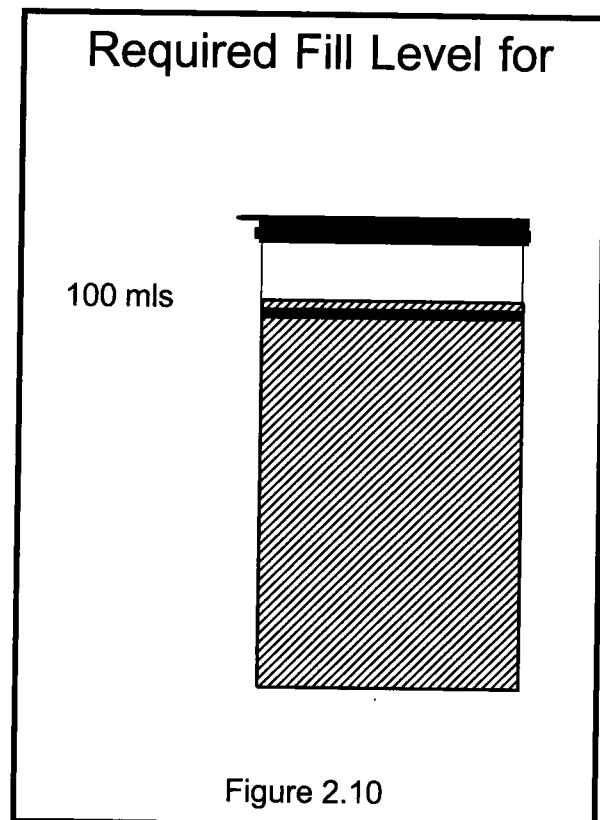


Figure 2.10

When no coliform bacteria are found, the water system or portion of the system where the sample was taken is referred to as bacteriologically **safe**. However, if ANY coliform are found, the sample and the water system it represents are bacteriologically **unsafe**. If an unsafe bac-t sample is reported, the system must follow strict regulations regarding retakes. Repeat samples must be collected within 24 hours of notification. Three (3) or four (4) repeat samples are required, depending on the system. At least one repeat must be taken from the original site and others must be taken within five (5) service connections both upstream and downstream of the original site. Public notice is also required.

General Procedures for Other Types of Water Samples

Because there is a separate training and certification program for laboratory technicians in the State of Oklahoma, no detailed discussion concerning laboratory procedures for water analyses is included within this study guide. However, collecting water samples is very often the direct responsibility of plant and distribution system operators.

Sampling is a vital part of studying the quality of water in a water treatment process, distribution system, or water supply source. A major source of error in the overall process of obtaining water quality information often occurs during sampling. In any type of testing program where only small samples are withdrawn from perhaps millions of gallons, there is potential uncertainty because of possible sampling errors. Water treatment decisions based upon incorrect data may be made if sampling is performed in a careless manner. Obtaining accurate results will depend to a great extent upon the following factors.

1. Ensuring that the sample taken is truly representative of the water under consideration
2. Using proper sampling techniques
3. Protecting and properly preserving the samples until they are analyzed by the lab technician
4. Proper completion of sampling forms

SUGGESTED REFERENCES FOR STUDY

California State University, Sacramento - **Water Treatment Plant Operation - Vol. 1**

Chapter 2 Water Sources and Treatment

Chapter 11 Laboratory Procedures

Note: Questions concerning step-by-step lab procedures are NOT on operations exams.

California State University, Sacramento - **Water Treatment Plant Operation - Vol. 2**

Chapter 21 Advanced Laboratory Procedures

Note: Questions concerning step-by-step lab procedures are NOT on operations exams.

OTHER STUDY SUGGESTIONS

- Become familiar with typical values at the influent and at the effluent of the water treatment plant for each of the characteristics listed in the *Suggested Study Guidelines* for this chapter.
- Identify water characteristics and identify what happens to each characteristic as it goes through each process unit (see also Chapter 1).
- Study sampling techniques and locations, containers and holding times, required sampling frequency, and proper sample identification.
- Using any good microbiology or bacteriology textbook, study the characteristics of different microorganisms including their oxygen requirements and pathogenicity.
- Using any good chemistry or laboratory textbook, study the fundamentals of chemistry.
- Study APPENDIX C in this study guide.

SAMPLE QUESTIONS

Class D

The organisms used as an indicator of microbiological contamination are

- A. coliform bacteria
- B. total suspended solids
- C. viruses

Class C

The substance CaCO_3 in water will contribute to the

- A. non-carbonate hardness
- B. permanent hardness
- C. total alkalinity and carbonate hardness

Class B

The chemical preservative normally used for water samples that are to be tested for metals is

- A. CaCO_3
- B. Na_2CO_3
- C. NCl_3
- D. HNO_3

Class A

The primary concern when a treated water exceeds the MCL for turbidity is that

- A. the water will have an undesirable appearance
- B. the turbidity is harmful to many industrial processes
- C. the turbidity may harbor pathogenic organisms preventing proper disinfection
- D. turbidity kills coliform bacteria, thus giving false results of disinfection accomplished
- E. it will deposit in the distribution system leaving a sediment

Chapter 3

General Regulations and Management

INTRODUCTION TO CHAPTER 3

There are many references made throughout this study guide to legal requirements regarding water treatment and operation of system equipment. The requirements are designed to protect public health and to help ensure operator safety.

This chapter is designed to serve as an introduction to some of the more fundamental legal requirements of system operation and to provide references to sources for additional information concerning regulations. The suggested references for this chapter also address the management-related skills especially needed by the supervisors and superintendents of community water systems.

SUGGESTED STUDY GUIDELINES

Class D

Be prepared to answer questions concerning:

- Who must be certified and how to renew a certificate
- The basic requirements for certification including temporary certification
- The regulations concerning Monthly Operational Reports (MORs)
- How long to keep records at water systems
- The importance of and need for records
- The penalties for falsification of records

Class C

Be prepared to answer questions concerning guidelines listed for Class D certification and:

- The basic criteria concerning the classification of water works
- The levels of certification required for supervisors and superintendents at different systems
- The rules and regulations concerning laboratory technician certification requirements
- The parameters and frequencies of laboratory tests required at different types of facilities
- What information is required to be reported on the Monthly Operational Report (MOR)
- The proper way to complete and submit a MOR

Be prepared to answer other questions that require additional personal study

Class B and Class A

Be prepared to answer questions concerning guidelines listed for lower levels of certification and:

- The different types of records that should be kept
- The regulations concerning Discharge Monitoring Reports (DMRs) for water treatment plants with discharge permits
- How to organize and write a report

- The importance of and need for maps in water system management
 - How to implement and maintain safety programs
 - The basic differences in responsibility for water works owners and operators
 - Some common uses of computers in water systems
 - How to recognize questionable data on operational reports and laboratory data
 - How to perform a variety of management-related calculations and analyze and present data using:
charts and graphs
tables
numbers
 - The recommended methods of communication with employees
 - The best ways to handle customer complaints
 - The meaning of the public water supply identification number (PWS ID#)
 - The proper procedures for major changes or extensions in the water system
- Be prepared to answer other questions that require a combination of actual experience and additional personal study

ENTRY LEVEL DISCUSSION

Operator Certification Requirements

State law requires that all operators of community water systems be certified within ten days of employment or appointment as an operator. An **operator** is a person who performs work on, or determines the method of working on, water works or who changes water quality either directly or by order. This includes a person who sets or removes meters, makes service connections, or repairs lines. “**Water works**” means all facilities used in the procurement, treatment, storage, pumping, or distribution of water for human consumption.

Every certified operator should understand the operator certification requirements found in **Title 252:710 Waterworks and Wastewater Works Operator Certification Rules**. This document may be obtained from the Department of Environmental Quality (DEQ) Operator Certification Unit. Some of the more important rules and policies concerning operator certification are discussed here.

Level of Certification Required

Operators who are not supervisors or superintendents may hold any level of current certification. All operators are encouraged to obtain the highest level of certification for which they qualify. The superintendent must hold at least the same level of certification as the classification level of the water works that he or she is responsible for. The **superintendent** is the operator in direct responsible charge of an entire plant or distribution system. This is true even if other official titles are sometimes assigned by employers.

Determinations concerning classification of water works are made by the Operator Certification Unit based on complexity and population served. Population categories are listed in the box below.

Class "D"	1,500 or less
Class "C"	>1,500 - <15,000
Class "B"	15,000 - 50,000
Class "A"	>50,000

All water works utilizing surface water must be operated by a superintendent with at least a Class C certification for populations less than 15,000. A population over 15,000 requires a Class B or A certification, depending on the specific population and/or complexity of the water plant. Temporary certification is not available to superintendents, assistant superintendents, supervisors, or managers of superintendents who make decisions regarding the daily operational activities of water/wastewater works:

Persons who are in direct responsible charge of their system or laboratory must hold a valid certification equal to or greater than the classification of the system or laboratory. Employers may require their employees to hold a higher certification level than is required by state law.

Temporary Certification

If permanent certification is not already held, **temporary certification** must be applied for within ten days of employment or appointment as an operator. Applications are available at County DEQ offices, and the Operator Certification Section. Individuals who have temporary certificates must work under the general supervision of a permanently certified operator. Direct, constant supervision is not required. Temporary certificates expire one year from the date of initial employment and cannot be renewed.

After receiving temporary certification, the operator should immediately begin to make plans to attend an approved entry level standard water operations training course and an exam session in order to obtain at least Class D certification before the temporary certificate expires.

Laboratory Operator Certification

All surface water plants must have a properly certified designated laboratory operator. The designated certified lab operator is required to give general supervision of all laboratory tests performed and is held responsible for all test results. Certified laboratory operators are authorized to work in laboratories only. They are not certified to operate or make decisions concerning the operation of the plant. However, many individuals are certified as both operators and laboratory operators and perform work in both areas at their facilities.

Owners of water facilities that contract for laboratory services must notify the Operator Certification Unit within ten (10) days of the contract and state the analyses to be performed. Also, the contracting laboratory must notify the Operator Certification Unit within ten (10) days of the contract and state what analyses are performed by them.

One of the requirements of the laboratory operator certification program is that the results of all laboratory analyses shall be recorded in a bound volume at the time of analysis. Each entry in this volume shall be signed and dated by the person who performed the analysis. These volumes will be kept on file at the laboratory for ten (10) years for water systems.

Annual Renewal of Certificates

All permanent certificates expire on June 30 of each year and must be renewed by June 30 to remain current. Operators are responsible for renewal of their certificates regardless of notification. Before renewing a certificate, the operator must have completed at least four hours of approved training within the last fiscal year (July 1 - June 30). The renewal application should not be submitted until the training requirement has been met. Renewal applications/invoices are mailed to all certified operators during late spring of each year. The application must be completed and then submitted with payment of renewal fees. Expired (delinquent) certificates may be reinstated for up to two years after the expiration date. After two years, the examination must be retaken to become certified. *A temporary certification is valid for one year from the date of employment and is not renewable.*

Other Requirements

It is the responsibility of the operator as well as the employer to see that his or her certification is the proper certification according to operator certification regulations. Owners of water works must give their operators reasonable opportunity to obtain the necessary hours of training for their required certification upgrades and renewals. Owners must also furnish the necessary equipment and materials for adequate maintenance and operation of the treatment plant, laboratory, and supporting facilities. Possible penalties for violation of the Operator Certification Act are loss of certification, a fine, and/or a jail term.

Operational Rules and Standards

There are at least three other documents that every operator should be aware of that specify legal requirements involved in the operation of public water systems. These are:

Public Water Supply Operation (Chapter 631)

Public Water Supply Construction Standards (Chapter 626)

Rules for Oklahoma Hazard Communication Standard

If you are not the operator-in-charge (superintendent) at your system, IT IS PROBABLY NOT NECESSARY THAT YOU HAVE YOUR OWN PERSONAL COPIES OF THESE THREE DOCUMENTS. However, you should have access to them at your facility or local Public Works Department. All superintendents should have their own current copies of these documents and be very familiar with the requirements found therein (see the “Reference Source Sheet” for information on how to obtain them). A brief summary of each of the documents is offered below.

Public Water Supply Operation (Chapter 631)

These regulations list requirements generally related to the actual operation of public water supply systems. They include the sampling, monitoring, reporting and public notice requirements for water supplies. They also include primary and secondary drinking water standards. These regulations are implemented by the Water Quality Division of the Oklahoma Department of Environmental Quality.

Public Water Supply Construction Standards (Chapter 626)

These standards list requirements generally related to construction and/or modification of the physical system of public water supply systems. This document is also implemented by the Water Quality Division of the Oklahoma Department of Environmental Quality.

Rules for Oklahoma Hazard Communication Standard

These rules include several requirements applicable to publicly-owned systems regarding the transmission of necessary information to employees about the properties and potential hazards of hazardous substances in the workplace. These rules are implemented and enforced by the Public Employees Health and Safety Division of the Oklahoma State Department of Labor.

Reports

With the exception of some very small purchased water systems, all community water systems must keep a **Monthly Operational Report (MOR)**. The MOR is a complete record of most of the major factors involved in plant operation for each day of the month. Entries should be made on a daily basis. It is the superintendent’s responsibility to make sure that the MOR is kept up-to-date, complete, and accurate. Blank MOR forms are available from the Water Quality Division. MOR forms are also available on the DEQ website (www.deq.state.ok.us).

Community water systems must submit the original of the MOR by the tenth day of the following month to the DEQ Water Quality Division. For example, the MOR for the month of May should be received by June 10. A copy of the MOR should be sent to the Local DEQ Office by the tenth day of the following month. A second copy should be kept on file at the facility for at least ten years.

Records

According to regulations, the records of all laboratory checks and control tests, including a copy of the MOR should be kept on file at the facility for at least 10 years. Other records concerning system operation should also be kept. These include plant performance records, personnel records, budget records, inventory records, maintenance records, and others.

Generally speaking, the more records that are kept, and the greater the accuracy of those records, the better the chances of the system being properly operated and maintained. Thorough and accurate records help operators see current problems and anticipate upcoming problems. Records are also important from a legal standpoint to protect the system (and the operator) from accusations or inquiries based on incorrect or incomplete information.

Safety Records (see also Chapter 12)

Another very important category of records that must be kept by all systems are those that concern safety. These records include—but are not limited to—**accident reports** and **safety checklists**, as well as **emergency guidelines and procedures**.

One of the most important sets of safety records required are the Material Safety Data Sheets (MSDS), this is part of the Oklahoma Hazard Communication Standard. An **MSDS** is required for each chemical used or stored in your system. These are available from the manufacturer or distributor of the product. The MSDS for each chemical must be readily available and fully understood by all persons who use the chemical and/or work around it.

Falsification

Sometimes frustration levels reach such a high point for some operators that they resort to a very dangerous practice known as **falsification**. This practice endangers public health and also puts the operator in personal jeopardy of criminal prosecution, and/or loss of certification. The best advice when frustrated is to inquire (and even complain when necessary) as you seek a positive, safe, and legal way to solve problems. Some may think that by falsifying records they are protecting their system from “getting into trouble.” Actually, they are making the situation much, much worse. If there is something that has not been done or has not been done properly, the best choice by far is to simply note the problem and the reason why it occurred in the remarks column on the required reports. **NEVER FALSIFY RECORDS OR REPORTS.**

Falsification of system records or reports is considered gross inefficiency and incompetence under the Oklahoma Operator Certification Act and is punishable by loss of certification, a fine, a jail term or all three of these penalties combined. Federal penalties for falsification of records may reach up to one year in prison and \$25,000 per violation.

SUGGESTED REFERENCES FOR STUDY

California State University, Sacramento - **Water Treatment Plant Operation - Vol. 1**

Chapter 10 Plant Operation

California State University, Sacramento - **Water Treatment Plant Operation - Vol. 2**

Chapter 22 Drinking Water Regulations

Chapter 23 Administration

Oklahoma Operator Certification Rules (Chapter 710)

Public Water Supply Construction Standards (Chapter 626)

Public Water Supply Operation (Chapter 631)

Rules for Oklahoma Hazard Communication Standard

OTHER STUDY SUGGESTIONS

- If you have any questions concerning system requirements, contact the office that has been assigned to implement them or your county environmental specialist for more information.
- As you work, think about the various requirements placed on public water systems and why you believe they are considered necessary.
- Using any good management textbook, study the various theories of organization, management, planning, public relations, and human resource development.
- Study the definitions for public water supply system, community water system and non-community water systems as provided in the Public Water Supply Regulations.

SAMPLE QUESTIONS

Class D

Records at water systems must be kept for

- A. 2 years
- B. 4 years
- C. 10 years

Class C

The superintendent of a water system treating surface water for a community of about 550 persons must hold at least

- A. Class D certification
- B. Class C certification
- C. Class B certification

Class B

If the Utilities Director selects which chemicals and what amount to be used in the community water system, he or she

- A. must be certified at the same level required of the superintendent
- B. does not need to be certified if the superintendent is properly certified and current
- C. does not need to be certified because certification is not needed to make those decisions
- D. does not need to be certified because certification laws don't pertain to the Director

Class A

Which of the following requirements is primarily concerned with keeping a permanent, unalterable record of laboratory data?

- A. the designated laboratory technician must be certified at the proper level
- B. the MOR must be submitted to DEQ
- C. the MOR must be submitted to the local DEQ office
- D. a bound volume must be kept for records of the test results, date, time, and signature of analyst
- E. laboratory work sheets should be kept on file for ten years at water facilities

Chapter 4

Reservoirs and Intake Structures

SUGGESTED STUDY GUIDELINES

Class D

Be prepared to answer questions concerning:

- The general characteristics of surface water
- The basic sources of water quality problems associated with surface water including
nutrient levels
algal blooms
thermal stratification
- The basic components of water transmission from the water source

Class C

Be prepared to answer questions concerning guidelines listed for Class D certification and:

- The basic methods used for control of algae including the use of copper sulfate
- The basic types of intake structures as well as their advantages and disadvantages

Be prepared to answer other questions that require additional personal study

Class B and Class A

Be prepared to answer questions concerning guidelines listed for lower levels of certification and:

- How to implement the appropriate methods of reservoir and watershed management and water quality improvements
- The terms used to describe nutrient levels in lakes and reservoirs
- The terms used to describe the three potential layers of thermal stratification
- How to calculate dosages involving copper sulfate

Be prepared to answer other questions that require a combination of actual experience and additional personal study

ENTRY LEVEL DISCUSSION

Use of Lakes and Reservoirs for Domestic Water Supplies

Although there are a large number of communities that rely on ground water supplies for drinking purposes, most of the larger communities use surface water sources including lakes and reservoirs. As populations have increased over the years, domestic, municipal, industrial, recreational, and agricultural water usage has also increased, creating demands on water supplies that cannot be met directly by ground water sources or diversions from streams or rivers. Therefore, these increased demands have been met to a large extent by constructing dams and reservoirs which provide a dependable water supply during dry seasons.

The capacities of reservoirs used as domestic water supplies range from several hundred acre-feet to several hundred-thousand acre-feet and the time water is stored ranges from several months to several years. Methods of managing lakes and reservoirs used for domestic water supplies also vary widely depending on local situations. In addition to serving domestic water needs, a reservoir may be used for flood control purposes, for hydroelectric power generation, for regulating downstream releases, for industrial uses, and for recreation.

Use of any surface water source will almost always require a greater degree of treatment than that required for ground water. This is due to the fact that surface water sources are very likely to have higher levels of turbidity, organic matter, as well as bacteria and other microorganisms.

Sources of Water Quality Problems in Surface Water

Nutrient Levels

Nutrients such as nitrate, phosphate, and other compounds are often responsible for water quality problems associated with surface water supplies. These nutrients will act as fertilizer and promote the growth of algae and other organisms. In fact, lakes and reservoirs can be categorized according to their nutrient levels. Lakes and reservoirs that have high levels of nutrients are referred to as **eutrophic**, which means that they will produce large populations of algae and other aquatic life. The term **mesotrophic** refers to lakes and reservoirs that have a moderate amount of nutrients. **Oligotrophic** lakes and reservoirs have very low nutrient levels.

Algal Blooms

Because of the high nutrient content of eutrophic lakes and reservoirs you will usually find an abundance of aquatic life, especially algae. **Algae** are microscopic plants that live in water. Like all plants, algae use carbon dioxide (CO₂) and produce oxygen (O₂). Because they require sunlight, they are most active during daylight hours.

As a result of these nutrients, algal blooms are likely to occur that will result in several types of treatment problems for the operator. The term **algal bloom** simply means a sudden increase in algae populations in surface water sources.

Many of the most common water quality problems associated with surface water supply systems can be traced directly back to algal blooms. Some of the most common problems are listed below and then briefly discussed.

1. Taste and odor problems
2. Increased pH levels
3. Increase in organic loading
4. Dissolved oxygen depletion

Taste and odor problems related to algae are possibly the most common water quality complaint that the operator will encounter. Algae can be responsible for a wide variety of taste and odor complaints with adjectives such as grassy, fishy, septic, musty, and earthy being the most common. Algae related taste and odor problems will usually be worsened if the plant intake is drawing water off the upper layers because this is where algal blooms occur.

High algae populations are often associated with an increase in pH levels, often as high as a pH of 9.0 to 9.5. This occurs because algae are **photosynthetic** organisms. This means that during daylight hours they remove carbon dioxide (CO₂) from the environment and produce oxygen, resulting in an increase in both the pH and the alkalinity levels. However, during nighttime hours, respiration by the algae removes oxygen and produces carbon dioxide which lowers the pH. These fluctuations in pH caused by the activity of algae can adversely affect both coagulation and disinfection.

Algal blooms will also significantly increase the organic matter content of the water being treated. This condition can result in a number of water treatment problems such as an increase in chlorine demand, and trihalomethane (THM) levels (see Chapter 7). Both of these conditions can greatly increase treatment costs for the water system.

As stated earlier, when an algal bloom occurs there will be an increase in dissolved oxygen levels due to photosynthesis by algae. However, as these huge algal populations begin to die off, the oxygen supply will diminish, resulting in anaerobic conditions. As the remains of the algae settle to the bottom layers of the lake or reservoir, anaerobic decomposition will occur resulting in hydrogen sulfide (H₂S) production. Hydrogen sulfide produces the rotten egg smell that most people associate with sewage, and will therefore cause taste and odor complaints by the public.

A common practice for controlling the growth of algae is to apply **copper sulfate** (CuSO₄). Copper sulfate, sometimes called bluestone, is an algicide (it kills algae). This chemical is usually applied by “broadcasting” it over the water surface from a motorboat.

Thermal Stratification

When layers of varying temperatures occur in a lake or reservoir it is referred to as **thermal stratification**. This occurs in many deep lakes and reservoirs as a result of temperature changes related to the different seasons of the year. Cold water is denser (thicker and heavier) than warm water. Therefore, colder water will settle to the bottom and warmer water will remain at the surface.

During the early winter months, temperatures are relatively uniform from top to bottom. Therefore, the densities of the water are also uniform and natural mixing occurs through wind action. As winter temperatures continue to decline, the surface layers become colder and denser and eventually sink to the bottom. This results in a vertical mixing action that continues until warming occurs.

As spring approaches bringing warmer temperatures, the sun's rays begin to warm the upper layers of the lake resulting in lower density of the water near the surface. This reduction in density of the upper layers will slow or stop the vertical mixing action and cause thermal stratification between warmer upper layers and the colder lower layers. The lake will remain in the stratified state until fall or winter when once again the cold temperatures will cool down the upper layers causing them to become as dense as the lower layers. At this time of the year, **destratification** will occur and mixing will take place resulting in a condition known as **turnover**.

A stratified lake or reservoir can cause some difficult treatment problems for the water plant operator. For example, if the operator decides to draw water off the upper layer of the lake, a high amount of algae may be in the raw water entering the plant. This will increase taste and odor complaints, and organic loading on the treatment plant process, resulting in an increase in treatment costs. On the other hand, if the operator chooses to draw water from the lower levels, anaerobic conditions may be encountered. This is because in a stratified lake the lower levels are not mixing with the oxygenated waters near the surface. The anaerobic conditions are further intensified as dead algal cells sink to the bottom and decompose.

Anaerobic conditions in the lower layers can also cause problems related to iron and manganese. If iron and manganese are present in the water supply, it can result in reddish-brown or black deposits forming on the consumer's plumbing fixtures and clothing. When significant concentrations of dissolved oxygen are present in the water supply, iron and manganese exist in the oxidized state (as particles) and will precipitate (settle) into the lake bottom sediments. Under anaerobic conditions however, iron and manganese can change into a soluble (dissolved) form. When these metals dissolve into solution under anaerobic conditions they will remain there until lake turnover occurs and they are once again oxidized and precipitate out. The problem arises when the water plant intake is placed at levels where this dissolved iron and manganese exist. The final result could be soluble iron and manganese being sent into the distribution system resulting in customer complaints.

In summary, at certain times of the year, especially when thermal stratification exists, it can sometimes be very difficult for an operator to find a trouble free level from which to draw water. The upper levels will have large quantities of algae and its associated taste and odor and higher pH levels. The lower levels will probably be anaerobic and may contain dissolved metals such as iron and manganese. As a result, operators may have to evaluate each water supply's individual conditions

and decide on the most effective and economical approach. By using data found on monthly operational reports (MOR's) from past years, operators can often make better operational decisions based on what has—or hasn't—worked in the past.

Water Transmission and Intake Structures

Water transmission is the controlled movement of water from the source to the treatment plant and from the plant to the distribution system. Water transmission starts with the intake structure. The water is then carried through **transmission lines** to the treatment plant and from the treatment plant to the distribution system (see Chapter 10). Depending on changes in elevation, pumping may be necessary. The flow in the transmission lines is controlled by valves and is constantly measured by flow meters.

An **intake structure** is a device that withdraws the raw water from its source for transportation to the treatment plant. Intake structures should be capable of supplying the maximum rate of flow required for the treatment facility. Modern intake structures are usually constructed in a manner that permits withdrawal from different levels in the lake or reservoir. This feature is highly desirable because it allows the operator to select a depth that withdraws the best quality of water. Intake structures should be constructed so that they prevent debris, logs, fish, algal scum, and other foreign objects from entering the system. To reduce the possibility of silt being drawn into the system, the water intake should not be located at low points where silt buildup might occur.

Single-Level Intakes

Single or **fixed-level** intake structures do not have the capability to raise or lower the level of water withdrawal. Although many single-level intake structures are currently in use, they are not necessarily desirable for many water systems. In fact, they can severely limit the control that the operator has over the quality of water that is allowed to enter the treatment plant. The single-level intake is usually located in the deepest portion of the lake or stream so that water service can still be provided when the body of water is down to its minimum operating level.

Single-level intake structures are most suitable for shallow lakes and reservoirs that do not readily stratify and which exhibit relatively uniform water quality from top to bottom throughout the entire year. These structures may also function adequately in deep oligotrophic (low nutrient level) lakes which do not experience water quality problems as a result of stratification. Flowing streams and rivers are usually well mixed and are not stratified; therefore single-level intakes may function well with these types of water supplies.

The only real advantage to single-level intake structures is that they are usually less complicated and therefore much less costly to construct and maintain than multi-level structures. The major disadvantage of single-level structures occurs when they are used in deeper, eutrophic (high nutrient level) lakes and reservoirs. If the intake is withdrawing water from the lowest layer of a thermally stratified lake or reservoir, several water quality problems including taste and odor could occur.

Multi-Level Intakes

The most versatile intake structures in water supply reservoirs are those that have the ability to draw water at depths ranging from near the surface to near the bottom. The most significant advantage of a **multi-level** intake structure is its ability to withdraw water from the depth where the best possible quality of water is located. In order to maintain the best quality of water entering a treatment plant it may be necessary to draw water from different levels during different seasons of the year.

Multi-level intake structures are usually constructed in a vertical tower located in the deeper portion of the reservoir and extending above the water surface. The inlets usually feed into a pipeline system extending from the bottom of the tower to the treatment plant. Each intake is equipped with an individually operated gate or valve at the point of inlet. An additional gate or valve is often located in the pipeline at some point downstream of the intake structure. This arrangement allows the operator to shut down the system if the gates or valves at one of the inlets should fail.

Only after considering data from monthly operational reports and other factors should a decision be made to withdraw from a particular level. Water quality should then be monitored regularly to detect any changes. Winds and sudden temperature changes can cause water quality at various depths to change very quickly. These conditions also need to be monitored by operators.

SUGGESTED REFERENCES FOR STUDY

California State University, Sacramento - **Water Treatment Plant Operation, Vol. 1**

Chapter 3 Reservoir Management and Intake Structures

OTHER SUGGESTIONS FOR STUDY

- List the causes of water quality problems in reservoirs, list the effects that such problems will have on surface water treatment capacity and efficiency.
- List causes and diagram and label the layers of stratification in an open reservoir.
- List reservoir and watershed management techniques.
- Draw out a pump control system for maintaining a set level in a water reservoir. Include basic and extra features that may be included.
- Practice calculations involving chemical dosages for algae control.

SAMPLE QUESTIONS

Class D

A surface water source is usually (in terms of taste and odor)

- A. higher quality water than ground water
- B. lower quality water than ground water
- C. the same quality as ground water

Class C

The chemical sometimes used to control algae populations in surface water sources is

- A. CuSO_4
- B. KMnO_4
- C. Al_2SO_4

Class B

What is the approximate volume of a reservoir in gallons for a reservoir of 58 acre/ft?

- A. 12.0 MG
- B. 14.2 MG
- C. 18.9 MG
- D. 21.4 MG

Class A

How much CuSO_4 is needed to dose a reservoir with 0.5 mg/L if the reservoir volume is 20 MG and the CuSO_4 solution is 25%?

- A. 125 lbs
- B. 165 lbs
- C. 335 lbs
- D. 835 lbs
- E. 1335 lbs

Chapter 5

Coagulation, Flocculation and Sedimentation

SUGGESTED STUDY GUIDELINES

Class D

Be prepared to answer questions concerning:

- The name of the most commonly used coagulant in water treatment
- Where coagulation, flocculation, and sedimentation each fit into the typical process sequence
- The basic role of each process unit including the
flashmix
flocculation basin
sedimentation basin
- The main purpose of coagulation, flocculation, and sedimentation
- What the alum reacts with to cause coagulation
- The major factors affecting sedimentation
- The best method of determining chemical dosage rates for optimum performance of treatment processes
- How to perform a basic detention time calculation for basins

Class C

Be prepared to answer questions concerning guidelines listed for Class D certification and:

- The chemical symbols for commonly used coagulant chemicals
- The causes and preventive actions that can be taken for typical problems including
short circuiting
secondary coagulation
- How to set up a jar test for determining optimum chemical dosages
- The normal average detention times and flow velocities for the various basins and tanks used in coagulation, flocculation, and sedimentation processes
- The pH range in which alum is most effective
- The various forms of alkalinity that might be used at water treatment plants to aid coagulation
- The other types of coagulant aids that are utilized at some facilities
- The basics of calibration for dry and wet chemical feeders.
- How to perform detention time and flow rate calculations
- How to perform chemical dosage rate calculations for coagulants and coagulant aids
- How to perform calculations to determine weir loading rates

Be prepared to answer other questions that require additional personal study

Class B and Class A

Be prepared to answer questions concerning guidelines listed for lower levels of certification and:

- The chemical reactions involved in coagulation using alum
- The chemical and physical reactions involved in flocculation and sedimentation processes
- How coagulation processes can be used to remove true color
- How coagulation, flocculation, and sedimentation interact with other treatment processes
- How to recognize normal and abnormal conditions using lab data and observation
- How to troubleshoot related problems and identify the corrective action needed
- The process controls available that are related to coagulation/flocculation/sedimentation
- How to perform calculations for calibration of chemical feeders
- The required methods of sludge handling at water treatment facilities

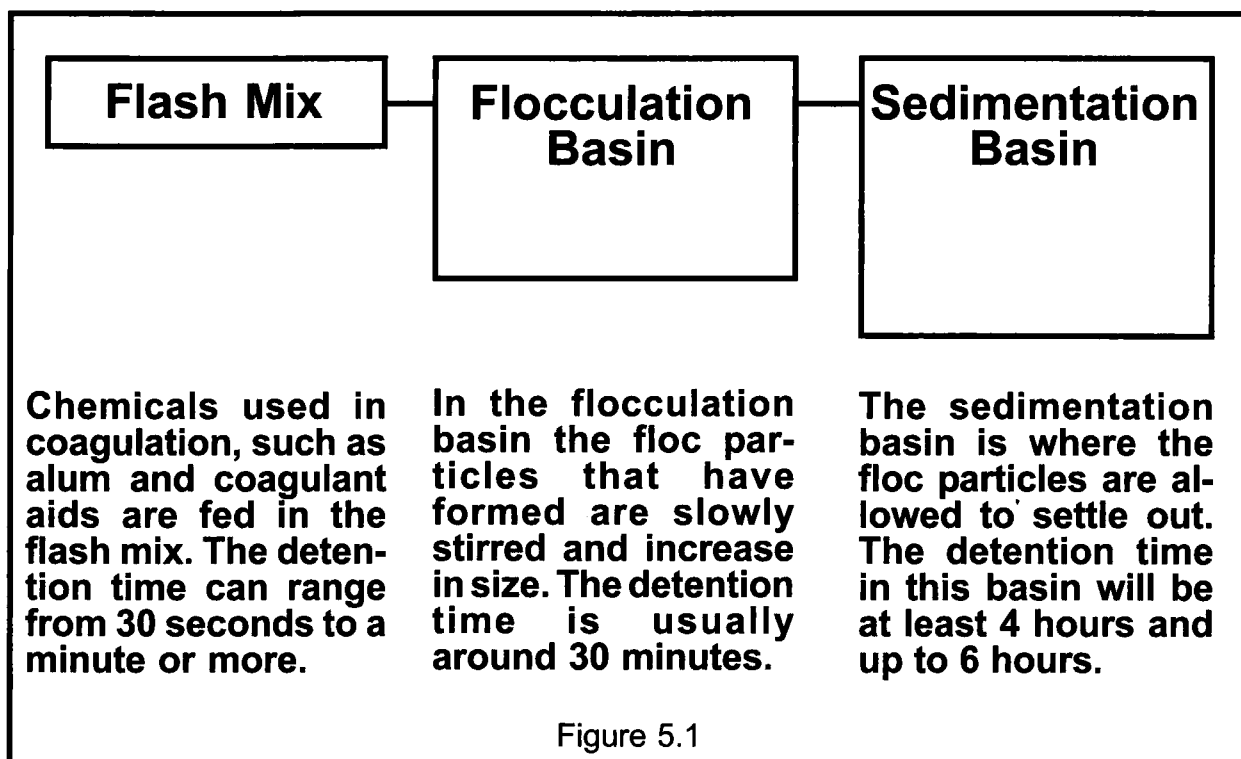
Be prepared to answer other questions that require a combination of actual experience and additional personal study

ENTRY LEVEL DISCUSSION

Treatment of surface water is necessary because of the relatively high amounts of impurities that are present. Impurities can come from a variety of sources, such as land erosion and run-off, industrial discharges, airborne contaminants, animal wastes, and decay of plant material. The impurities consist of dissolved and suspended solids as well as organic and inorganic solids. Many are organisms such as algae, bacteria, and plankton. With very few exceptions, all surface water treatment facilities in the State of Oklahoma provide coagulation, flocculation, and sedimentation as part of their treatment process to remove impurities.

Coagulation and flocculation are treatment processes that are primarily concerned with the removal of turbidity and organics. The larger, denser particles (settleable solids) will often settle out on their own if the flow of the water is slow enough. However, the smaller sized particles such as fine clays, silts, and bacteria will not settle out easily and require treatment. Coagulation and flocculation processes also help to remove other impurities, including some dissolved solids and true color.

The coagulation chemicals are added to water in the **flash mix** (*see Figure 5.1*). In the flash mix a reaction takes place that causes the formation of miniature **floc particles**. This is the beginning of the coagulation process. These particles are then slowly agitated in a **flocculation basin** where they come into contact with each other and with the impurities in the water. During this process, the floc particles clump together and grow in size. Finally, the floc particles are allowed to settle out in the **sedimentation basin**. The clarified water is sent to the filters for additional treatment before going to the distribution system.



Coagulation Chemicals and Reactions

Chemical coagulants are usually referred to as **primary coagulants**. Primary coagulants cause the initial coagulation reaction to take place and cause the particles to begin clumping together. Additional substances called **coagulant aids** are sometimes utilized when the floc particles that are formed with primary coagulation do not settle properly. The coagulant aids will add density and toughness to the floc particles that will prevent shearing (breaking up of the floc particle) and promote sedimentation. As with all chemicals, proper safety precautions should always be followed whenever coagulation chemicals are handled.

A commonly used primary coagulant is **aluminum sulfate**, usually referred to as **alum**. The chemical formula for alum is $\text{Al}_2(\text{SO}_4)_3 \cdot 14\text{H}_2\text{O}$. Because of growing concerns regarding the ultimate disposal of alum sludge and for other reasons, many plants that once used only alum are now choosing to use other chemicals for primary coagulation. Other inorganic primary coagulants sometimes used are ferric chloride ($\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$), ferric sulfate ($\text{Fe}_2(\text{SO}_4)_3 \cdot 9\text{H}_2\text{O}$), or ferrous sulfate ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$). In addition, there are new coagulant chemicals utilizing synthetic (man-made) polymers now available that are being used in place of inorganic primary coagulants.

Aluminum Sulfate

Because aluminum sulfate (alum) is still widely used, and because many of the concepts of how it acts as a coagulant also apply to other primary coagulants, alum will be discussed here in some detail. Alum is a metallic salt, which means that when it is dissolved in water, a series of reactions will occur

among the water, the alum, and other ions that are present. A sufficient, but not excessive, dose of alum must be added to the water in order to promote the formation of a floc particle. The particles of turbidity will then adhere (adsorb) to the surface of the alum floc particles that are formed. Overdosing with alum may cause sludge to build up in the storage tank.

Alum has a very strong positive electrical charge. Most of the particles that contribute to the turbidity in raw water will have negative electrical charges. Therefore, there is actually an electrical attraction between the opposite charges that works something like a magnet to help the turbidity attach to the floc particles. This is one of the main reasons that coagulation processes are so effective.

Coagulation with alum is most effective within a pH range of about 5.0 to 7.0. In some cases, alum is used successfully in treating waters with a pH as high as 8.5. All coagulants, including alum, react with the alkalinity in the water to form the initial miniature floc particles. Alum will consume about 0.5 mg/L of alkalinity for every 1.0 mg/L of alum that is dissolved in the water. Thus, alkalinity is necessary for the coagulation reaction to occur. Alum tends to lower pH.

The amount of naturally-occurring alkalinity in the raw water is usually sufficient for the coagulation reaction. However, many systems feed alkalinity to aid coagulation unnecessarily resulting in an increase in treatment costs and potential operational problems. When it is necessary, alkalinity levels can be increased through the addition of lime (CaO), hydrated lime (Ca(OH)₂), soda ash (Na₂CO₃) or caustic soda (NaOH).

Polymers

Polymers are synthetic organic compounds that are used at water plants as either the primary coagulant or as a coagulant aid to promote the formation of large, heavy floc particles. Polymers are often referred to as polyelectrolytes. They can be divided into three categories: cationic (positively charged), anionic (negatively charged), and nonionic (without charge). Because of their positive charge, cationic polymers are the most commonly used type of polymer. However, if impurities are present that have positive charges, such as red clays, an anionic polymer may be necessary to achieve a satisfactory floc formation.

Coagulation and Flocculation Processes

Flash Mix

As the raw water enters a water plant, the first stage of treatment is the **flash mix**, sometimes called the rapid mix. The function of the flash mix process is to introduce the coagulation chemicals to the raw water and mix them into solution as quickly as possible. Flash mixing is usually performed in a separate chamber or basin using one or more of a variety of mixing techniques. This process is comparable to the action of a kitchen blender where the coagulant is blended into the water at a high rate of speed.

The flash mix is where the initial coagulation reactions occur resulting in the formation of a miniature floc particle. It is then the job of the flocculation process to build these miniature floc particles into a particle that is large enough and dense enough to settle when the flow of water is sufficiently slowed.

Flocculation

Flocculation is a slow stirring process that causes the floc that was formed in the flash mix to clump together to form larger floc particles large enough and dense enough to settle out. The slow stirring action causes collisions between floc particles causing the particles to adhere (or stick) to each other. At the same time, much of the turbidity in the water attaches to the floc particles. The floc particles are allowed to grow in size and mass until they become large enough and heavy enough to settle out. Usually these collisions between floc particles result from a gentle stirring action caused by mechanical or hydraulic mixing devices.

Sedimentation

The primary purpose of **sedimentation** is the removal of the floc particles that have formed in the earlier processes. Sedimentation usually takes place in large rectangular or circular settling basins commonly referred to as **clarifiers**. Sedimentation is achieved by decreasing the velocity of the water flowing through the basin or clarifier to a point where gravity can take over and allow the suspended solids to settle out.

There are many physical and environmental factors that have an effect on the efficiency of the sedimentation process or sedimentation rate. The **sedimentation rate** is defined as the speed that a particle can move as it settles to the bottom of a clarifier. Some of the most important factors concerning this rate are discussed below.

Particle Characteristics

The size, shape, and density (weight) of the floc particle will all affect its sedimentation efficiency. Smooth, rounded particles are easier to settle out than rough jagged particles simply because they pass through the water easier due to less resistance. Also, the more heavy and compact the floc particles are, the better they will settle.

Water Temperature

Another very important factor when considering sedimentation efficiency is the temperature of the water. As the temperature of the water decreases the sedimentation rate also decreases. On the other hand, as the temperature of the water increases, the sedimentation rate will increase as well. This is due to the fact that cold water is more dense than warm water. In other words, it is thicker or more viscous. Therefore, it is more difficult for floc particles to settle in cold water.

Detention Time

Detention time can be defined as the actual time required for a volume of water to pass through a basin. Detention time is calculated by dividing the volume of the basin by the flow of water through the basin. Detention times in sedimentation basins will range from a minimum of four hours to as long as six hours. When a basin does not have adequate detention time the result will be excess solids passing out of the basin and possibly overloading the filters.

Detention times can be affected by a number of factors, but one of the most important is called **short circuiting**. Short circuiting is a condition that occurs when some of the water in the basin travels faster due to temperature differences, density currents, wind currents, or improper design of inlet and outlet structures. One example of how short circuiting might occur is when there is a difference between the temperature of the influent and the water already in the sedimentation basin. In this situation, the water in the basin would have a tendency to separate into warmer and cooler layers rather than mix together. This could result in the full volume of the basin not being utilized and cause a reduction in the actual detention time.

Solids-Contact Clarifiers

In most existing plants the flash mixing, flocculation, and sedimentation processes each occur in separate basins or chambers. In recent times, an increasing number of plants are being constructed with the flash mix, flocculation chamber, and sedimentation basin all built within a single self-contained unit referred to as a solids contact clarifier. Although it is difficult to define a **solids-contact clarifier** with a single sentence, it could be described as a coagulation/flocculation/sedimentation system based on the principle of recycling sludge to further promote the coagulation-flocculation process. To accomplish this, a sludge blanket must be maintained. The main process control for this type of unit is the volume over volume test.

The advantage of the solids-contact approach to water treatment is simply that under normal operating conditions it is much more efficient for turbidity and floc particle removal when compared to traditional methods. However, the solids-contact process is more sensitive and unstable than traditional treatment methods. The operator must have a thorough understanding of how the solids-contact process works and be able to anticipate changes in raw water quality so that problems can be avoided. Three major indicators must be monitored properly in order to properly maintain the solids-contact process. These factors are the flow rate and its rate of change; significant fluctuations in turbidity level; and any rapid changes in temperature.

Jar Testing

The purpose of the **jar test** is to give the operator an estimate of optimum chemical dosage levels for the coagulation-flocculation process. This test achieves this by simulating the processes that occur in the treatment plant starting with the flash mix and ending with sedimentation. However, it should

be kept in mind that it is virtually impossible to duplicate plant conditions exactly and the jar test is only an estimate of the optimum dosage.

One of the most important reasons for performing jar tests on a frequent basis is to improve plant efficiency and possibly save money. When the proper alum dosage is not being determined by jar testing, there is a general tendency to overfeed rather than underfeed. Often the high dosage levels are continued for months and years and the amount of money wasted on unneeded chemicals reaches into the thousands of dollars. Another serious problem that can occur if overfeeding alum is called **secondary coagulation**. This condition is a result of supersaturating the water with alum, allowing some of the alum to stay dissolved throughout the treatment process. When this water reaches the distribution system it will likely be given sufficient time and the proper conditions to form floc, creating a sludge blanket in the storage tank. This can cause taste and odor problems as well as require the professional services of tank cleaners.

General Procedure for Performing Jar Tests

To perform a jar test you must have a jar test apparatus. This is simply a mixing device that has multiple mixing paddles which each fit into a “jar” or beaker. A typical jar test apparatus will probably have six mixers, which means that you can test for six different dosage levels at the same time. The jar test is usually performed using one-liter samples of the raw water. For stock solutions and dilutions, see Appendix A, *Introduction to Basic Operator Math*.

The procedure can be used to test dosage levels for any chemical that is used in the coagulation process. It is recommended that you use the same chemicals in the jar test that are used in the plant. The following is the general procedure for performing a jar test.

1. Number the jars (beakers) from one to six and note the dosage level to be used in each.
2. Starting with jar number one, add enough stock solution of the chemical to each jar so that you have a range of dosage levels. The low dose might be in jar #1 with the highest dose in jar #6.
3. Turn on the machine and adjust the mixing speed to about 80 to 100 rpm. This simulates the flash mix process. The time spent in this mode should be about the same as the detention time in the flash mix at your plant.
4. After the flash mix simulation turn the mixing speed down to about 10 to 20 rpm to simulate the flocculation process. The time spent in this mode should be about the same as the detention time in the flocculation basin at your plant.
5. After the flocculation stage is completed, simply turn the machine off and allow it to settle for a period similar to the detention time in your sedimentation basin. Observe closely.

There are several observations that are made during the final stage of the jar test procedure that are very important in evaluating its results.

1. Rate of floc formation,
2. Type of floc particles formed,
3. Clarity of water between floc particles and above settled floc,
4. Size of floc,
5. Amount of floc formed, and
6. Settling rate of the floc.

The most important observation during the jar test is the clarity of the water. This is determined by running a turbidity test on each sample after the sedimentation stage is completed. However, the operator should keep in mind that the amount of chemical used to achieve a given turbidity level is also important.

For example, if jar #3 showed a turbidity level of 2.4 NTUs with a dose of 20 mg/L, and jar #4 showed a turbidity level of 2.2 NTUs with a dose of 30 mg/L, jar #3 would be declared the “winner.” In this case, the difference in the turbidity levels was not significant enough to justify the additional amount of chemical needed for the higher dosage level. If the dosage level is higher, the chemical costs and sludge production will also likely be higher.

SUGGESTED REFERENCES FOR STUDY

California State University, Sacramento - **Water Treatment Plant Operation, Vol. 1**

Chapter 4 Coagulation and Flocculation

Chapter 5 Sedimentation

Chapter 10 Plant Operation

California State University, Sacramento - **Water Treatment Plant Operation, Vol. 2**

Chapter 17 Handling and Disposal of Process Wastes

OTHER STUDY SUGGESTIONS

- If you work at a ground water or distribution system only, visit a surface water treatment plant if you get a chance. Ask a lot of questions.
- Draw a diagram of the process units and components necessary for coagulation, flocculation, and sedimentation and know how each process works.
 - Know where in the diagram to sample and for what.
 - Picture the interaction with the other plant processes.
- Study plant operations for surface water treatment facilities including the visual indicators to look for in an operating process.
- Use troubleshooting chart to identify typical problems and make adjustments to the process using operations tests and other process indicators.
- Study expected detention times and flow velocities and practice doing detention time calculations.
- Practice chemical dosage rate calculations.
- Review APPENDIX C in this study guide.

SAMPLE QUESTIONS

Class D

A commonly used coagulant in water treatment is

- A. calcium carbonate
- B. magnesium bicarbonate
- C. aluminum sulfate

Class C

The test performed at water plants to determine the optimum dosage levels of coagulants and coagulant aids is

- A. the jar test
- B. the hardness test
- C. the solids contact test

Class B

A solids contact basin has a surface loading rate of 0.75 gpm/ft². What is the rise rate in ft./min.?

- A. 0.05
- B. 0.1
- C. 0.2
- D. 0.5

Class A

A raw water has an alkalinity of 36 mg/l (as HCO₃). A dose of 52 mg/l of alum is needed to reduce the turbidity from 75 NTU to less than 0.5 NTU. At least 30 mg/l of alkalinity is required for complete precipitation of the alum. What dose of Ca(OH)₂ is needed to complete the reaction?

- A. 7.8 mg/l
- B. 10.2 mg/l
- C. 13.5 mg/l
- D. 18.0 mg/l
- E. 22.5 mg/l

Chapter 6

Filtration

SUGGESTED STUDY GUIDELINES

Class D

Be prepared to answer questions concerning:

- Where filtration fits into the typical process sequence
- The most common type of filter used by water treatment plants in the State of Oklahoma
- The basic process of gravity filtration including the purpose of backwash procedures
- The different types of media that might be used in rapid gravity filtration
- The guidelines for when to backwash a filter and what percentage of finished water is used

Class C

Be prepared to answer questions concerning guidelines listed for Class D certification and:

- Each of the processes that play a role in filtration and their relative importance
- The proper startup and shutdown procedures for gravity filters
- What causes filter problems including mudballs, air binding, algae growth, and overloading
- The typical ranges for filtration rates in both slow sand and rapid sand filters
- How to perform backwash percentage and filtration rate calculations

Be prepared to answer other questions that require additional personal study

Class B and Class A

Be prepared to answer questions concerning guidelines listed for lower levels of certification and:

- The controls and valving sequence for normal operating procedures
- What filtration rates, backwash rates, and head loss to expect in a typical rapid gravity filter
- How to recognize normal and abnormal filter conditions
- How to troubleshoot typical problems with filters and identify the corrective action needed
- The operating controls and process controls for gravity filtration and pressure filtration
- The requirements for handling backwash water
- How to perform calculations to determine filter efficiency, head loss, and flow volumes

Be prepared to answer other questions that require a combination of actual experience and additional personal study

ENTRY LEVEL DISCUSSION

Filtration is often the final step in the surface water treatment process before the water is disinfected and sent to the distribution system. The purpose of filtration is to remove any remaining suspended particles including any floc particles that were not removed during the sedimentation process.

Filtration is actually a chemical as well as a physical process. A common misconception is that the particulate impurities are removed in the filtration process by physical straining alone. Straining does help the filtration process. However, most of the particles removed during filtration are much smaller than the pore spaces in the media. Therefore straining is only one aspect of the total filtration process.

The processes that play a role in filtration are listed below in the order importance.

1. **Simple sedimentation.** Particles settling onto the media through the forces of gravity.
2. **Adsorption.** The gathering of a substance on the surfaces of the filtration media.
3. **Biological action.** The breakdown of a substance as a result of digestion by microorganisms.
4. **Absorption.** Taking in or “soaking up” of a substance into the media.
5. **Straining.** The removal of particles by passing the liquid through a filter that has pores small enough to “catch” the particles to be removed.

Types of Filters

In the State of Oklahoma the most common type of filtration process used in water treatment is **rapid gravity sand filtration** (see Figure 6.1). Some of the smaller water systems in Oklahoma use slow sand filtration. In all gravity filtration systems the water level or “head” above the media forces the water through the backwashed and must be cleaned manually. Therefore slow sand filters are rarely used by larger municipalities but have found a place in small systems such as resorts and trailer parks.

Rapid Gravity Filtration

There are several different types of filtration media that may be utilized in the rapid gravity filtration process. These are:

1. **Single media** (sand)
2. **Dual media** (anthracite coal and sand)
3. **Multi media** (anthracite coal, sand, and garnet)

Activated carbon is also sometimes used along with these filter media for its ability to remove taste and odor as well as various types of organic substances. Activated carbon will be discussed more later in this chapter.

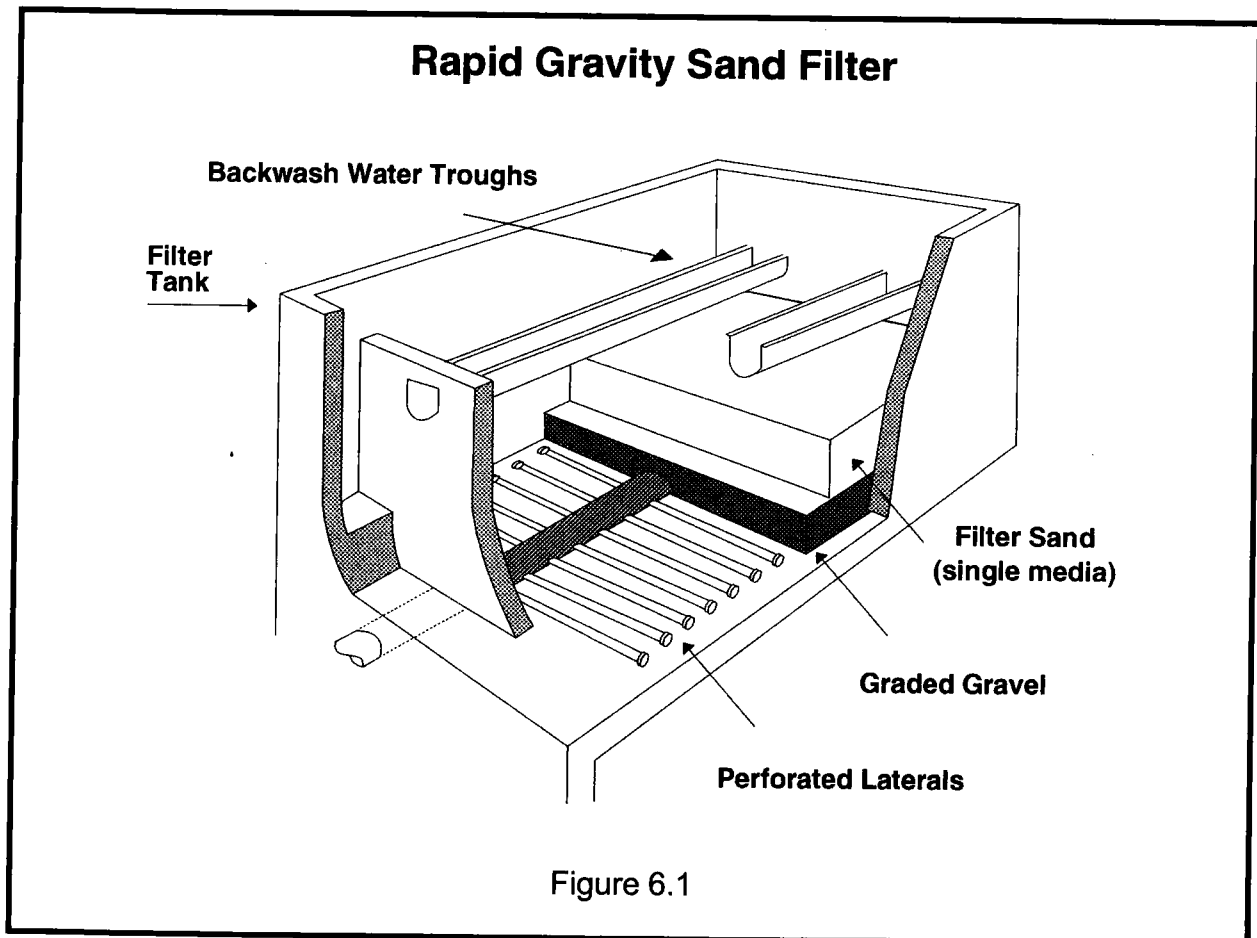
Rapid Gravity Filter Operation

Backwashing

Turbidity will build up on the surface and inside the media of the filter, eventually causing clogging of the filter media. Clogging of a filter leads to **breakthrough**, a condition in which solids are no longer being removed. The final result is an increase in the turbidity of the water leaving the plant.

Backwashing is simply reversing the flow of water through the filter to wash out the clogs and solids that have accumulated during filter operation. The filter is washed at specific design rates for at least 15 minutes. At most modern filtration plants, a device called the **surface wash** will be activated sometime during the backwash procedure. The surface wash is a device that sprays water down onto the surface of the filter to break up solids that have collected there.

Clogging of a filter can be defined as a build-up of **head loss** (pressure-drop) across the filter media. Design limits for head loss generally range from about 6 to 10 feet depending mainly on the depth of the water over the media. When the filter's design limit for head loss is reached, it is time to backwash the filter. The period of time between backwashing is called a **filter run**. A filter run may vary from several hours to several days. It is a good practice to always backwash the filter within every 72 hours of operation, even if significant head loss has not yet developed.



Most filters utilize backwash flow rates of about 20 gpm/ft² or other rates necessary to provide for a 50 percent expansion of the filter media. Backwash water troughs located above the filter media are used to collect the wash water. A typical water plant will use approximately 2 to 4 percent of the water produced at the plant for backwashing purposes.

In all gravity filtration systems the water level or "head" above the media forces the water through the filtration media (see Figure 6.1). The rate that the water flows through the media is called **filtration rate** and is expressed in gallons per minute (gpm) per square foot of surface area. In the rapid gravity filtration process the filtration rate will usually fall between 2 and 4 gpm/ft² depending on the type of filtration media used.

Slow Sand Filtration

In **slow sand filtration**, the water is poured through the filtration media by the same gravitational mechanisms as in the rapid filtration process. Other than this, there are very few similarities between the two processes.

With slow sand filtration, only sand is utilized as filtration media and the suspended impurities are removed by straining, adsorption, and biological action. The filtration rates for slow sand filters are much lower than rapid gravity filters and are usually in the .015 to 0.15 gpm/ft² range. The majority of the impurities are removed in the upper layers of the filtration media and the entire layer must be physically removed when it becomes too clogged for upper layers of the filtration media and the entire layer must be physically removed when it becomes too clogged for continued use. Slow sand filters cannot be backwashed and must be cleaned manually. Therefore slow sand filters are rarely used by larger municipalities, but have found a place in small systems such as resorts and trailer parks.

Some Common Filter Problems

Many of the problems associated with filters can be attributed to inadequate or improper backwashing procedures. One problem that is almost sure to occur in a filter that has not been backwashed often enough is mudball formation. **Mudballs** are pockets of sludge and other solids that build up in the filtration media. If not corrected they can do permanent damage requiring replacement of the media. Proper use of surface washers while backwashing is essential in preventing mudball formation.

Air binding is a situation where air enters the filter media as a result of differences in pressure between water and the pressure in the filter. Dissolved air is released from saturated cold water due to a decrease in pressure in the filter. This occurs more frequently when large head losses are allowed to develop in the filter or when the filter is not refilled with backwash water after draining the water below the media for inspection. Air binding can actually prevent the passage of water during the filtration process and can cause the loss of filter media during the backwash process.

Algae and slime growths have been known to grow on filter media, which will cause an increase in taste and odor complaints. This has become more of a problem recently because many operators have cut back or eliminated the practice of disinfecting the water early in the treatment process due to the possibility of producing excessive levels of trihalomethanes (see Chapter 7).

Activated Carbon

Although the primary purpose of filtration is to remove the remaining suspended solids and floc particles from the water being treated, when a form of **activated carbon** is used as a part of the filtration media a new aspect of treatment is introduced.

Granular activated carbon (GAC), is sometimes utilized as an activated carbon filtration media for removing taste and odor compounds from the water. In addition, GAC is used for removing or reducing volatile organic compounds (VOCs) and synthetic organic compounds (SOCs). Over time, the special properties of GAC media will be “spent” causing it to become ineffective. This periodic need for replacement or “reactivation” may cause GAC filters to be less cost-effective than filters using other types of media unless there is a great need for the special benefits they provide.

SUGGESTED REFERENCES FOR STUDY

California State University, Sacramento - **Water Treatment Plant Operation, Vol. 1**

Chapter 6

Filtration

OTHER STUDY SUGGESTIONS

- Draw a diagram showing how gravity sand filtration works including following factors:
 - where filtration fits in the surface water treatment process sequence for package treatment plants
 - and for full scale treatment plants
 - common process design variations
 - what is removed in the filtration process
 - where to sample and what to sample for
 - processes for performing backwash procedures
 - processes for handling and recycling and/or discharging of backwash water
- Diagram the pressure filtration process and trace the flows of process water and wastewater.
- Study troubleshooting charts for diagnosis of typical problems with filters.

SAMPLE QUESTIONS

Class D

The most common type of filter used by water plants in Oklahoma is the

- A. slow sand filter
- B. pressure filter
- C. rapid gravity sand filter

Class C

The most important removal process that takes place during filtration is

- A. sedimentation
- B. absorption
- C. straining

Class B

The most important filter effluent water quality change is

- A. chlorine demand
- B. color
- C. nutrients
- D. turbidity

Class A

A plant filters 2.2 MGD with a filter surface area of 600 ft². What is the filtration rate in gpm/ft²?

- A. 1.1
- B. 1.5
- C. 1.9
- D. 2.5
- E. 6.0

Chapter 7

Disinfection

SUGGESTED STUDY GUIDELINES

Class D

Be prepared to answer questions concerning:

- Where in the typical surface water treatment sequence the chlorination processes are located
- The purpose of disinfection
- The basic definitions of chlorine dose, chlorine demand, chlorine residual, and breakpoint chlorination
- The name of the testing procedure that should be used for measurement of chlorine residual
- The minimum chlorine residual required in potable water leaving the water treatment plant and the minimum required chlorine residual throughout the distribution system
- What concentrations of chlorine are in high-test hypochlorite (HTH) and liquid bleach
- The characteristics of chlorine gas including its color and its weight as compared to air
- The special safety considerations for working with chlorine and chlorine equipment
- The characteristics and hazards of the different forms of chlorine
- The proper procedures for safe storage and handling of chlorine
- The proper procedure for changing a chlorine gas cylinder
- The most common cause of chlorine leaks and how to prevent it
- How to check for chlorine leaks and what to do when a leak is detected
- Where the self-contained breathing apparatus (SCBA) should be located
- The procedures to prepare for emergencies in the chlorine room including the buddy system
- How to perform basic dosage calculations

Class C

Be prepared to answer questions concerning guidelines listed for Class D certification and:

- The chemical symbols for calcium hypochlorite, sodium hypochlorite, chlorine gas, hypochlorous acid, and hydrochloric acid
- The simple reactions of chlorine with water and chlorination chemicals
- The major factors in trihalomethane formation
- The major factors affecting the coagulation reaction including pH, temperature, concentration, mixing, and contact time
- Which substances may produce a chlorine taste and odor in water
- The basic processes of hypochlorination and gas chlorination including the equipment used
- How to perform a variety of dosage calculations involving chlorine gas and HTH

Be prepared to answer other questions that require additional personal study

Class B and Class A

Be prepared to answer questions concerning guidelines listed for lower levels of certification and:

- The principles of how and why chloramines are used
- The related reactions of chlorination including the different forms of chloramines, trihalomethanes, and other disinfection by-products
- The most effective method of removing THMs
- How taste and odor problems may be related to improper chlorination or chloramination
- How chlorine dioxide is produced, how it is used, and its advantages and disadvantages
- How ozone is produced, how it is used, and its advantages and disadvantages
- How to calculate dosages using a variety of disinfectants

Be prepared to answer other questions that require a combination of actual experience and additional personal study

ENTRY LEVEL DISCUSSION

Purpose of Disinfection

The purpose of **disinfection** is to make the water safe for human consumption. Water carries a host of dissolved as well as suspended materials. Among these suspended materials are microscopic organisms, many of which have the potential to produce disease in humans. Diseases transmitted through water supplies are referred to as **water-borne diseases**. Due to the growth of human populations, it would be very difficult to find a surface water supply that has not been contaminated by both man and animals to some degree. Therefore it is necessary to disinfect water in addition to the other treatments that have previously been discussed.

It is important to distinguish between disinfection and sterilization. **Disinfection** is the destruction of most of the pathogenic organisms whereas **sterilization** is the complete destruction of all organisms present in the water. Complete sterilization of drinking water is not only unnecessary, it is also not cost effective.

Reasons for Using Chlorine

Disinfection of water supplies in the United States is almost always accomplished by using chlorine. Disinfection with chlorine, combined with the other surface water treatment processes has greatly reduced the incidence of water-borne disease among humans in the United States. It is this proven record and the familiarity with chlorine that makes chlorine the disinfecting agent used at most systems. There are three basic reasons why chlorine is usually the disinfectant of choice.

1. Chlorine is the most cost-effective disinfectant available considering its disinfecting power.
2. Chlorine is easily obtained through a variety of sources.
3. Chlorine produces a disinfecting residual.

However, it should also be said that there are also two clear disadvantages or drawbacks to the use of chlorine.

1. Chlorine must be used and handled very carefully to prevent serious hazards to operators.
2. Chlorine can sometimes form trihalomethanes (THMs) in water supplies. Concentrations of THMs above the maximum contaminant levels (MCLs) are suspected of causing cancer.

Forms of Chlorine

There are three forms of chlorine that are commonly used as a disinfectant in the United States: chlorine gas, calcium hypochlorite, and sodium hypochlorite. **Chlorine gas** (Cl_2) is 100 percent available chlorine and comes in 150 pound and one ton cylinders.

Calcium hypochlorite ($\text{Ca}(\text{OCl})_2$), also known as **High Test Hypochlorite** or **HTH** can be purchased in tablet, powder or granulated form. HTH is often used as a back-up system for systems that normally use chlorine gas. At smaller systems it may be used as the primary disinfectant for continuous feed. HTH is about 65 percent available chlorine, depending on the manufacturer. HTH is fed by a device called a **hypochlorinator**.

Sodium hypochlorite (NaOCl) is also available in a powder form but it is usually purchased in the form of **liquid bleach**. Chlorine bleach is usually used for batch treatment, such as disinfecting a newly drilled well, but is also fed continuously by some very small community water systems. The concentration of common household bleach is about 5.25 percent available chlorine. However, most water (or wastewater) systems that use bleach will use a 10 to 15 percent concentration.

Of the three major sources of chlorine, chlorine gas is by far the most common source used for continuous disinfection of water supplies and will be the main focus of this discussion.

Characteristics of Chlorine Gas

Chlorine gas must be handled with care because it is very **toxic** and **corrosive**. This gas can cause severe injury to anyone who comes into direct contact with it, especially if it is inhaled or comes into contact with the eyes. Chlorine gas is also dangerous because it is approximately **2.5 times heavier than air**, which means it has a tendency to collect in low places and will not float away without forced ventilation. Chlorine gas has a **greenish-yellow color** and a very distinctive and pungent odor. Chlorine gas cylinders actually contain very concentrated chlorine gas in a liquid form. One liter of this concentrated liquid chlorine produces 450 liters of chlorine gas upon evaporation.

In addition, chlorine gas has a very high **coefficient of expansion**, which means that it has a tendency to expand even further if the temperature increases. For example, if there were a temperature increase of 50°F (28°C), the volume of the chlorine gas in the cylinder would increase by 84 to 89 percent.

This much expansion could easily cause enough pressure to rupture a chlorine cylinder or a line full of liquid chlorine. For this reason, chlorine gas cylinders are never filled to their total capacity.

Chlorine Gas Safety

Chlorine (Cl_2) reacts with water (H_2O) to form hypochlorous acid (HOCl) and hydrochloric acid (HCl). **Hypochlorous acid** is a weak acid that gives chlorine its disinfectant properties. **Hydrochloric acid** has very little disinfectant properties but is a very strong acid. Whenever chlorine comes into contact with moisture, this strong acid is formed. When chlorine gas is inhaled it will cause severe **lung damage** and can cause **blindness** if it comes into contact with the eyes.

IT IS EXTREMELY IMPORTANT FOR ALL FACILITIES THAT USE CHLORINE GAS OR ANY OTHER FORM OF CHLORINE TO FOLLOW ALL SAFETY PRECAUTIONS.

One of the most common problems with chlorination equipment is leakage. In this case, the best cure is prevention. For example, NEVER reuse the gasket and washer when replacing a chlorine cylinder, even if they appear to be in good condition. Reusing gaskets and washers on chlorine cylinders is probably the most common source of chlorine leaks.

Ammonia vapors can be used as a simple method of chlorine leak detection. If you place a clean rag that has been wetted with an ammonia water solution near a connection that has a chlorine leak, a visible white vapor will appear. Only a commercial grade of ammonia should be used for this purpose. Care should be taken to avoid applying the ammonia solution directly to the fittings because a strong acid will form that will corrode metal.

Improper storage temperature can contribute to the occurrence of leaks because of the high coefficient of expansion that chlorine gas possesses. Remember, chlorine will expand when heated. On the other hand, chlorine hydrate icing may occur on the connections of chlorine cylinders if the temperature in the chlorine room falls below 60°F (16°C). Chlorine containers should be stored away from heat or direct sunlight and the chlorine room should be kept in climate controlled conditions at normal room temperatures. Also, cylinders should never be connected to a common manifold unless special precautions are taken to prevent one cylinder from backfeeding to another.

Because of its weight, chlorine gas will have a tendency to collect in low places. For this reason, exhaust ducts for chlorine rooms are placed near the floor. Mechanical ventilation equipment (built-in fans) must be turned on and must provide at least one complete air change per minute whenever the chlorine room is occupied. A **self-contained breathing apparatus** (SCBA) or other respiratory air-pac protection equipment meeting the requirements of the National Institute for Occupational Safety and Health (NIOSH) must be available and stored at a location convenient to the chlorine room but NEVER inside the chlorine room. Instructions for using this equipment must be posted and comprehensive chlorine safety training including chlorine emergency drills using safety equipment should be held on a regular basis. The SCBA units should be compatible with those that are used by the local fire department. Individuals must be fit-tested while

wearing their SCBA to ensure a leak-proof seal, facial hair or scars may prevent an effective seal. Persons wearing an SCBA must undergo a medical evaluation consisting of a questionnaire and quite possibly a physical examination.

One of the most important safety precautions when working around chlorine gas or performing any other potentially dangerous job is to use the **buddy system**. Under the buddy system, a person is simply NEVER allowed to be left alone when performing dangerous work. Another person trained in emergency techniques and procedures must always be present and alertly watching the work being done from a safe position. All chlorine rooms must be equipped with an inspection window from which the buddy can safely observe the progress of the work without having to enter the room.

It is also very important that all equipment used for chlorination or chlorine safety be used and maintained properly. The manufacturer's instructions for using chlorine should be closely followed. Finally, the material safety data sheet (MSDS) for all chemical products should be understood by all persons who work on or around them.

Additional Safety Hazards When Using HTH

It should always be remembered that working with ANY form of chlorine can be very hazardous and that it must always be stored, handled, and used with extreme care. HTH is a strong oxidizer and is **extremely reactive** when it comes in contact with either organic material or water. If HTH is allowed to come into contact with petroleum products or organic solvents it can explode violently. HTH should be kept away from any source of organic matter including dirt, oils, or dirty rags.

When HTH is mixed with water, pure chlorine gas and heat is given off. Therefore, it is very important that HTH is stored and used properly. Storage of this chemical should only be in a cool, dry place separate from other chemicals and WITHOUT a sprinkler system.

All operators working at systems using HTH should be aware of the consequences of the substance coming in contact with small amounts of water. In order to disperse the heat generated, the HTH should always be added to the correct volume of water, rather than adding the water to the HTH. If HTH is introduced to large amounts of water, it's okay, but if it's improperly stored or handled and gets wet, watch out! A toxic chlorine gas cloud will likely result.

Improper handling of HTH can lead to skin, eye, and lung damage. Therefore, a face shield, long rubber gloves, a rubber apron, and a dust mask should be used at all times. A portable eye wash should also be available. HTH should never be handled with bare hands. Use only thoroughly clean, dry utensils and make sure that there is adequate ventilation when handling. Contaminated clothing should be washed before wearing again. HTH should be stored in the original container only. When the container is empty it should not be reused.

Principles of Chlorination

The exact mechanism of chlorine disinfection is actually not yet completely understood. One theory states that the chlorine exerts a direct action on the organism itself, thus destroying it. Another theory is that the toxic nature of chlorine destroys the enzymes that enable living microorganisms to use their food supply and the organisms die of starvation.

The total amount of chlorine added is called the **chlorine dose**. When chlorine is added to water that contains certain organic and inorganic substances, it will immediately begin to react with them to form compounds that do not have any disinfecting properties. These compounds, in fact, consume some of the chlorine that is added to the water. The amount of chlorine that is consumed by these compounds is referred to as the **chlorine demand**. After the chlorine demand has been “satisfied,” the remaining chlorine that is available for disinfection purposes is referred to as the **chlorine residual**. There are two types of chlorine residual; free chlorine residual and combined chlorine residual.

$$\text{Chlorine Dose} = \text{Chlorine Demand} + \text{Chlorine Residual}$$

$$\text{Chlorine Residual} = \text{Combined Chlorine Residual} + \text{Free Chlorine Residual}$$

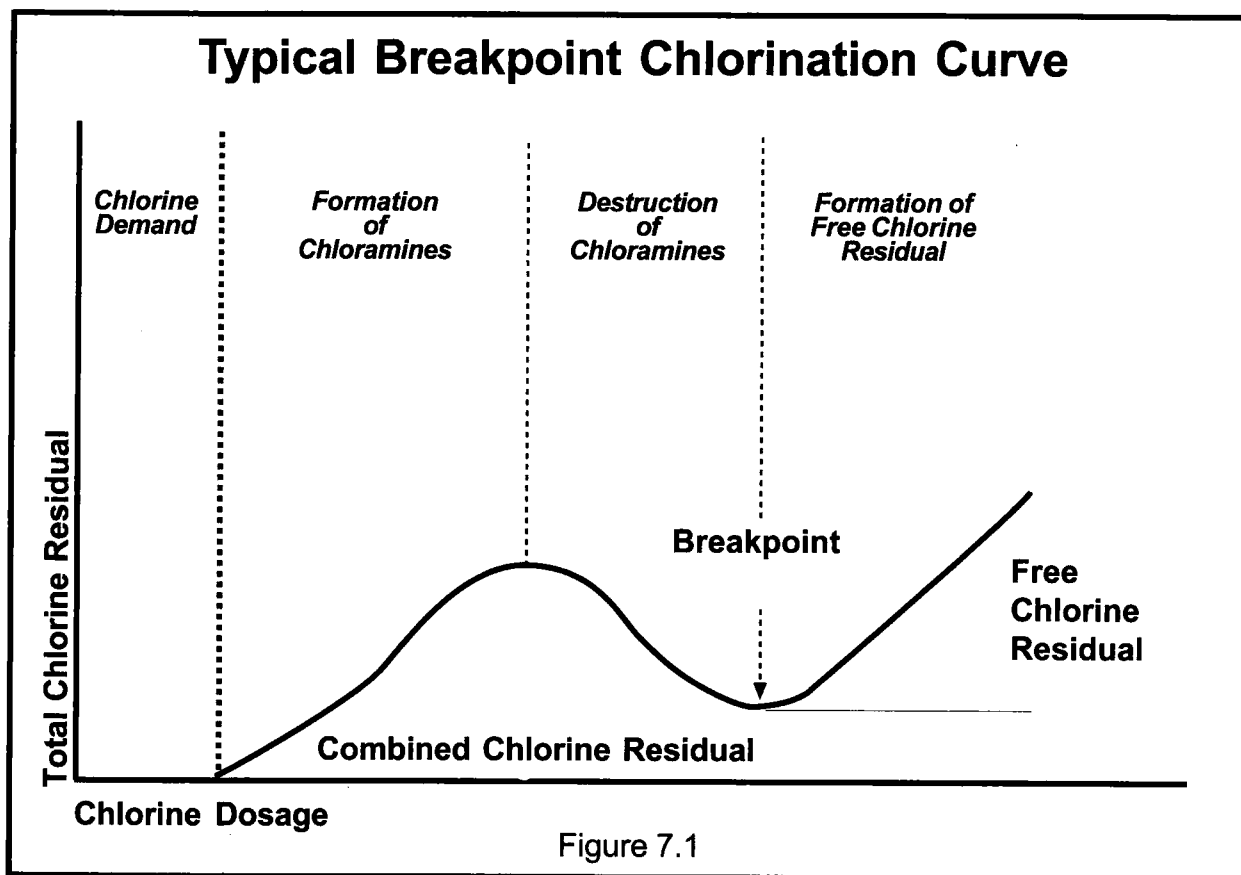
When chlorine is added to water, the hypochlorous acid that is produced will immediately react with ammonia to form a group of compounds called **chloramines**. Chloramines are in fact a disinfecting residual often referred to as the **combined residual**. Combined residuals such as chloramines are relatively weak disinfecting agents. In order to obtain a **free chlorine residual**, a chlorination technique called breakpoint chlorination must be utilized.

Breakpoint Chlorination

Breakpoint chlorination is the process of adding chlorine until a free chlorine residual is formed. Any chlorine added after this “breakpoint” will result in a free chlorine residual that is directly proportional to the additional dosage. The **breakpoint** is actually defined as the point of chlorine addition (dosage) where the chlorine demand and combined chlorine residual have been broken down and a free chlorine residual has formed.

When you look at a graph showing breakpoint chlorination (*see Figure 7.1*), you can begin to see what actually occurs during the chlorination process. Assume the water being chlorinated in this example contains various types of impurities such as iron, manganese, nitrate, organic matter, and ammonia. Every water supply will have a different breakpoint chlorination “curve” depending on the types and amounts of impurities present.

When a small amount of chlorine is added, it will react with the impurities and be consumed with no residual production and no significant amount of disinfection taking place. This is illustrated by the flat area on the far left side of the graph where no residual is present. This is the chlorine demand.



When more chlorine is added it reacts with organic material and ammonia to produce chlororganic compounds and chloramines. As mentioned earlier, the disinfection power of the combined chlorine residual is very weak. In addition, this type of residual may produce taste and odor problems.

When still more chlorine is added, the chloramines will be broken down as shown by the drop in the residual curve on the graph. As the dosage increases the curve will finally bottom out and begin to rise once again. The residual then being produced is called the free chlorine residual. This type of residual is both a strong disinfectant and is free of taste and odor.

Chlorine Residual Testing and Minimum Residuals Required

Chlorine residual testing has often been performed by one of two methods: the orthotolidine method or the **DPD** method. The DPD method should be used. **ORTHOTOLIDINE SHOULD NOT BE USED BECAUSE IT HAS BEEN DETERMINED THAT IT IS CARCINOGENIC (CAUSES CANCER).**

The DPD method of determining chlorine residual is **colorimetric** which means that the results are determined by the intensity of the color produced. The DPD method produces a pink color change. The more intense the color produced, the higher the chlorine residual. This method can be used to determine either the total chlorine residual or the free chlorine residual only.

All systems required to disinfect, including all surface water treatment plants and most groundwater systems, must provide a minimum free chlorine residual of 1.0 mg/L in the water entering the distribution system. There must also be a minimum of 0.2 mg/L of free chlorine residual maintained throughout the distribution system. For this reason, it may be necessary to leave the plant with a much higher chlorine residual or to provide supplemental points of chlorination in the distribution system.

Water systems that do not utilize breakpoint chlorination and rely completely upon a combined chlorine residual (chloramines) for disinfection must provide a total chlorine residual of at least 2.0 mg/L and maintain at least 1.0 mg/L throughout the distribution system. This higher level is required because a combined chlorine residual is not as effective as a free chlorine residual.

Chemical Reactions of Chlorine

Chlorine will react with many substances that are found in or added to the water as well as reacting with water itself. The following discussion offers a brief explanation of some of the most important reactions that involve chlorine. The actual chemical equations for the reactions are listed in APPENDIX C of this study guide.

Chlorine Gas with Water

Free chlorine (Cl_2) reacts with water (H_2O) to form **hypochlorous acid** (HOCl) and **hydrochloric acid** (HCl). Hypochlorous acid is the main disinfectant and is the reason why chlorine is utilized by water treatment operators. The hydrochloric acid has little disinfection properties but is important for operator safety considerations due to its toxic and corrosive nature.

Calcium Hypochlorite (or HTH) with Water

When calcium hypochlorite ($\text{Ca}(\text{OCl})_2$) is added to water it reacts to form hypochlorous acid (HOCl) and calcium hydroxide ($\text{Ca}(\text{OH})_2$). Since the major by-product produced in the reaction is a strong base — calcium hydroxide — the pH will have tendency to increase depending on the dosage used. This is just the opposite of what can be expected when using chlorine gas, as a major by-product of that reaction is hydrochloric acid (HCl) which tends to lower the pH.

Sodium Hypochlorite (Bleach) with Water

Sodium hypochlorite (NaOCl) reacts with water to form hypochlorous acid (HOCl) and sodium hydroxide (NaOH). Once again a major by-product of the reaction is a strong base that will tend to raise the pH of the water.

Chlorine with Ammonia

When chlorine is added to water, the hypochlorous acid (HOCl) that is produced will immediately react with any naturally-occurring ammonia to form chloramines (the combined chlorine residual).

The particular type of chloramines formed largely depends on the pH. At pH levels that are normally found in water (pH 6.5 to 8.5) monochloramine (NH₂Cl) will be the dominant type. At pH levels between 4.0 and 5.5 dichloramine (NHCl₂) is found by itself, and at pH levels below 4.0, trichloramine (NCl₃) is the only chloramine found.

However, chloramines do not react with organics in the water to form trihalomethanes, also known as THMs. Therefore, they have become a popular solution to the problem of high THM levels. The intentional formation of chloramines that are used as a disinfecting residual will be discussed later in this chapter.

Factors Affecting Chlorine Disinfection

pH

A simple fact to remember is that the lower the pH, the better free chlorine disinfects. However, the loss of disinfection power due to higher pH levels generally does not become significant until the pH exceeds a value of about 8.0 to 8.5.

Temperature

Temperature will also affect how well chlorine is able to disinfect the water. The higher the temperature of the water, the easier it is to disinfect. The colder the water, the longer the contact time required to achieve adequate disinfection. Another factor related to chlorination and temperature is that warmer temperatures cause more of the chlorine to dissipate out of the water and into the air.

Type of Residual

The **type of residual** is an important consideration for determining the disinfection potential for a water supply. A combined chlorine residual (chloramines) does not have near the disinfecting power that a free chlorine residual will have. Systems that are using combined residual disinfection, such as chloramines for trihalomethane control, will have to maintain higher residuals and more contact time to compensate for the disparity in disinfection capabilities. Fortunately, combined residuals do not dissipate as quickly as free chlorine, which makes it easier for the operator to maintain the higher residual levels required.

Contact Time

The final factor to be considered is **contact time**. The more contact time that a water supply has for disinfecting residuals, the better the disinfection. Contact time is especially important for systems that have a high pH or for colder periods of the year. Contact time is also critical for systems that use chloramines for disinfection because of their weaker disinfecting capabilities.

Points of Chlorination

Prechlorination is the application of chlorine ahead of any other treatment processes. Prechlorination is sometimes quite beneficial. The primary benefits of prechlorination are listed below.

1. Control of algae and slime growth.
2. Control of mudball formation in filters.
3. Improvements in coagulation.
4. Reduction of tastes and odors.
5. Increased chlorine contact time.
6. Increased in-plant safety and better disinfection when treating heavily contaminated and polluted waters.

Unfortunately, prechlorination will also increase the occurrence of trihalomethanes (THMs) because these substances are formed by a combination of organic material and free chlorine.

Postchlorination is the application of chlorine after the water has been treated and just before it enters the distribution system. This is the most important point of disinfection and is normally the last application of any disinfectant. Postchlorination may also be the last form of treatment provided before the water is consumed by the public.

Some plants find it necessary to practice **rechlorination**, which is the addition of chlorine at strategic points in the distribution system. The application point could be any place where there is adequate mixing available.

Trihalomethanes (THMs)

Trihalomethanes (THMs) are a group of organic compounds formed in water during the chlorination process. There are four possible combinations of THMs that form when treating water with chlorine: chloroform, bromoform, bromodichloromethane, and dibromochloromethane. Like many other organic compounds, THMs are considered carcinogenic (cancer-causing).

Significant amounts of THMs will only form in waters that have high levels of organic material. This means that THMs will rarely be a problem for ground water systems but are quite common in surface water supplies. For most surface water systems, the bulk of THM formation will occur during prechlorination because this is when the highest concentration of organic material is present. In other cases, the bulk of THM formation occurs in improperly maintained distribution systems.

For most systems, THM formation will be higher in the summer than other times of the year due to higher water temperatures. Also, the higher the pH the faster THMs will form. An additional important factor is the concentration of free chlorine in the water. The higher the concentrations of free chlorine and organic material, the higher and faster THM levels develop. Finally, the higher the bromide levels, the more “brominated” THMs will form.

Methods of THM Control

POINT CHLORINATION. **Point chlorination** means altering the point of chlorination to prevent the formation of THMs. For example, one of the most common approaches to point chlorination is the reduction or elimination of prechlorination since the highest concentrations of organic material exist in raw water. This has been known to significantly reduce the THM concentration in the finished water for some systems. However, altering the point of chlorination will have other effects on the treatment system as well, such as an increase in slime growths and algae in the plant, possibly resulting in taste and odor problems.

REMOVAL OF THM PRECURSORS. One approach to the control of THMs is the removal of THM “precursors.” THM precursors are the organic materials that promote the formation of THMs. There are several methods that might be used to remove THM precursors. Two of these methods are oxidation and adsorption. Oxidation by use of ozone or chlorine dioxide reduces THM precursors. However, using these oxidants results in the production of by-products that could potentially be more harmful than THMs. Adsorption using powdered activated carbon (PAC) is somewhat effective in removing THM precursors but only at very high dosages. Granular activated carbon (GAC) used as filtration media shows a wide range of removal efficiencies. High costs are usually associated with implementing and maintaining any treatment process for removal of THM precursors.

AERATION TO REMOVE THMs. **Aeration** may be the most effective method for the removal of THMs that have already formed, although each type of THM is removed at different efficiencies. THMs are volatile compounds and are poorly soluble in water. This means that THMs have a natural tendency to migrate from water into the atmosphere if given the opportunity. One method of accelerating the aeration process is by bubbling air into the water.

ADSORPTION TO REMOVE THMs. THMs can also be removed by **adsorption** by use of a wide variety of activated carbons and synthetic resins. The process of adsorption involves the individual THM compounds leaving the water and becoming attached to the surface of the carbon or resin. Usually, THMs are considered difficult to adsorb. The more chlorinated the THM is, the more difficult it is to remove by adsorption.

Alternative Disinfectants

Chloramines

Chloramine disinfection (chloramination) is the most commonly utilized alternative to free chlorine disinfection. When using this alternative, ammonia is added at a specific point in the treatment process and at a certain dosage level. Ammonia can be obtained for this purpose in three forms: liquid, aqueous, and solid. Liquid ammonia is probably the most cost effective of the three forms and is the most commonly used source of ammonia for large treatment plants.

Chloramine disinfection can be effective in reducing levels of THMs. Another advantage to a chloramine residual is that it is more stable and does not dissipate as rapidly as the free chlorine residual. Hence, it is easier to maintain a chloramine residual in the distribution system than a free chlorine residual.

Using chloramines as an alternative to free chlorine also has some drawbacks. For example, chloramines are a much weaker disinfecting agent than free chlorine and therefore a higher residual with longer contact time is necessary in most situations. Chloramines are not a powerful oxidizing agent and will not oxidize taste and odor causing substances, nor will they be of any aid for special purposes such as iron and manganese control. In addition, chloramines can easily produce their own taste and odor problems if not utilized properly. Finally, the stability of chloramines in the water supply also means it is more difficult to remove chloramine residuals, which can cause problems for persons on kidney dialysis machines and for persons who own fish aquariums.

Chloramines are formed in water by the reaction of ammonia with chlorine. During chloramine formation three species of chloramines will form: monochloramines, dichloramines, and trichloramines. Under the conditions normally associated with water treatment, monochloramine is the dominant and preferred form.

Ozone

Ozone (O_3) is produced by passing oxygen through an electrical discharge. Ozone is an extremely powerful oxidizing agent and disinfectant. It has been used as a primary disinfectant in both Europe and Japan for many years. In spite of its power to oxidize and disinfect, ozone may have too many disadvantages to be used by a large number of systems in this country. One major disadvantage is that ozone does not produce a disinfecting residual. In addition, ozone must be generated on-site using high-voltage electrical generators with high initial setup and operating costs. For these reasons, ozone is generally only used as a pre-oxidation system for THM precursor removal.

Chlorine dioxide

Chlorine dioxide (ClO_2) is produced by the reaction of free chlorine and sodium chlorite. Chlorine dioxide is a very effective oxidizing agent, producing a powerful disinfecting residual that will not produce THMs.

However, several problems are associated with the use of chlorine dioxide. The initial setup and maintenance of a chlorine dioxide system can be quite expensive, requiring additional training for the operators and new laboratory procedures. Another potential problem with the use of chlorine dioxide is that chlorite and chlorate may be produced as by-products. These compounds are considered highly carcinogenic.

Disinfection of drinking water was a major factor in reducing epidemics by lessening exposure of humans to microbial pathogens. Acute health effects from exposure to microbial pathogens are well documented. Associated illness can range from mild to moderate cases lasting only a few days to more severe infections that can last several weeks and may result in death for those with weakened immune systems. In recent years it has been discovered that specific microbial pathogens, such as *Cryptosporidium*, are highly resistant to traditional disinfection practices.

While disinfectants are effective in inactivating many microorganisms, the disinfectants can react with naturally-occurring materials in the source water and the distribution system to form potentially harmful Disinfection Byproducts (DBPs). DBPs have been shown to cause cancer in laboratory animals. Several epidemiological studies involving exposure to chlorinated surface water have documented adverse reproductive and developmental effects.

It is important to provide protection from microbial pathogens while also ensuring decreasing health risks to the population from DBPs. A major challenge for Oklahoma water suppliers is how to balance the risks from microbial pathogens and DBPs. There are several rules that have been promulgated or proposed by the U.S. Environmental Protection Agency (EPA) to help address this challenge. They are as follows:

- Interim Enhanced Surface Water Treatment Rule,
- Long Term 1 Enhanced Surface Water Treatment Rule,
- Long Term 2 Enhanced Surface Water Treatment Rule,
- Stage 1 Disinfectants and Disinfection Byproducts Rule,
- Stage 2 Disinfectants and Disinfection Byproducts Rule,
- Filter Backwash Recycling Rule, and
- Ground Water Rule.

Changes in the Arsenic Rule and the Radiological Rule will also add to the challenge of providing safe drinking water to Oklahoma citizens.

The Interim Enhanced Surface Water Treatment Rule (IESWTR) became effective on January 1, 2002 for systems using surface water or ground water under the direct influence of surface water, that serve 10,000 or more persons (**large systems**). The rule was built upon the treatment technique requirements of the Surface Water Treatment Rule with the following key additions and modifications:

No Cryptosporidium-

1. EPA has established a goal of no Cryptosporidium in drinking water.

Lowered Turbidity Limit-

2. Strengthened Combined Filter Effluent Turbidity (CFE) performance standards: less than or equal to 0.3 nephelometric turbidity units (NTU) in at least 95 % of measurements taken each month, using (CFE). The Maximum Contaminant Level of turbidity changed to 1 NTU (from 5 NTU). If CFE turbidity level exceeds 1 NTU at any time, the DEQ must be notified within 24 hours.

Increased Turbidity Measurement-

3. Individual filter turbidity monitoring must now be performed continuously (every 15 minutes) to assist treatment plant operators in understanding and assessing filter performance. If a filter exceeds 1 NTU in two (2) successive readings, it triggers special requirements.

Disinfection Profiling and Benchmarking-

4. A Public Water Supply (PWS) must develop a disinfection profile. For large systems, a disinfection profile is a graphical representation of the daily inactivation of Giardia lamblia. Calculations must be made daily over 12 consecutive months. Prior to making any significant changes to disinfection practices, systems are required to develop a profile, calculate a disinfection benchmark, and consult with the State. The benchmark is the calculation of the lowest monthly average of inactivation based on the disinfection profile.

Some Groundwater Systems Included-

5. Systems using ground water under the direct influence of surface water are now subject to the new rules dealing with Cryptosporidium.

Increased State Inspections-

6. More state inspections are required for all surface water systems regardless of size.

The Long Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR) applies to systems using surface water or ground water under the direct influence of surface water, that serve fewer than 10,000 persons (**small systems**). There are approximately 230 Oklahoma systems that were affected in January 2005. These systems must develop a disinfection profile. For small systems a disinfection profile is a graphical representation of the weekly inactivation of Giardia lamblia. Calculations must be made weekly on the same calendar day, over 12 consecutive months.

The Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) became effective January 2006. Under the proposed LT2ESWTR, systems initially conduct source water monitoring for Cryptosporidium to determine their treatment requirements. Filtered systems will be classified in one of four risk levels based on their monitoring results. It has been projected by EPA that the majority of systems will be classified in the lowest risk level, which carries no additional treatment requirements. Systems classified in higher risk levels must provide 90 to 99.7 percent additional reduction of Cryptosporidium levels. The regulation specifies a range of treatment and management strategies, collectively termed the “microbial toolbox,” that systems may select to meet their additional treatment requirements.

Cryptosporidium monitoring by large systems (serving at least 10,000 people) will begin six (6) months after the LT2ESWTR is finalized and will last for a duration of two (2) years. These systems will take one (1) sample every month for two (2) years. The projected cost for processing one (1) Cryptosporidium sample is \$500 or approximately \$12,000 per system. The cost does not include the dollars associated with recording, tracking, managing, and reporting the results. The projected date for sampling to begin is between October 2006 and April 2008, depending on exact population size. The systems serving the largest populations begin sampling first.

Small systems (serving fewer than 10,000 people) are on a delayed schedule and will start monitoring when the required large system monitoring is finished. Small systems will initially conduct one (1) year of monitoring for E. Coli, taking two (2) samples per month for one year. E. Coli is a bacterium that is less expensive to analyze for than Cryptosporidium. The projected cost for processing two (2) E. Coli samples is \$30 per month or approximately \$360 per system. However, it is probable that many small systems will exceed the specified triggering concentrations for E. Coli.

If the specified triggering concentrations are exceeded for E. Coli, the small water system must then monitor for Cryptosporidium. These systems will take two (2) samples per month for one (1) year. The projected cost for processing the Cryptosporidium samples is approximately \$12,000 per system. The projected date for sampling to begin is October 2008.

Small systems may grandfather equivalent previously collected data in lieu of conducting new monitoring, and are not required to monitor if they provide the maximum level of treatment required under the LT2ESWTR. All water systems must conduct a second round of monitoring beginning six (6) years after the initial level classification.

The LT2ESWTR proposal also contains disinfection profiling requirements to ensure that the systems maintain protection against microbial pathogens as they take steps to reduce the formation of DBPs. These requirements are needed because EPA concurrently developed a Stage 2 Disinfection Byproducts Rule [discussed in detail later in this chapter] that will establish more stringent standards for certain DBPs. Disinfection profiling involves a system's assessing the level of disinfection currently provided and then determining the impact that a proposed change in disinfection practice would have on this level.

The Stage 1 Disinfectants and Disinfection Byproducts Rule (Stage 1 DBPR) runs concurrent with the IESWTR and LT1ESWTR. Stage 1 DBPR became effective January 1, 2002, and initially only affected large surface water systems and large groundwater systems under the influence of surface water. In January 2004, all other systems that disinfect were included and must meet the requirements of the rule.

Initially there were 41 water systems in Oklahoma that were affected by the Stage 1 DBPR. In January 2004, systems that have no experience with DBPs were added. This included an additional 172 small surface water systems, 518 groundwater systems, 28 purchase water systems that chlorinate, and four (4) ground water systems under the direct influence of surface water. The total number of Oklahoma water systems that have been affected by the rule is 763. This is approximately 45 % of all public water systems in Oklahoma.

The Stage 1 DBPR is the first of a staged set of federal rules that will reduce the allowable levels of DBPs in drinking water. It establishes four (4) new Maximum Contaminant Levels (MCLs) and new three (3)

The Stage 1 DBPR is the first of a staged set of federal rules that will reduce the allowable levels of DBPs in drinking water. It establishes four (4) new Maximum Contaminant Levels (MCLs) and new three (3) Maximum Residual Disinfectant Levels (MRDLs) for a total of seven (7) new levels. It also establishes a new treatment technique. New MCLs have been established for the following regulated contaminants:

1. Total Trihalomethanes (TTHM), Chloroform, Bromodichloromethane, Dibromochloromethane, and Bromoform;
2. Five Haloacetic Acids (HAA5) Monochloroacetic acid, Dichloroacetic acid, Trichloroacetic acid; Bromoacetic acid, and Dibromoacetic acid
3. Bromate (plants that use ozone); and
4. Chlorite (plants that use chlorine dioxide).

MRDLs have been established for the following regulated disinfectants:

1. Chlorine,
2. Chloramines, and
3. Chlorine dioxide.

The treatment techniques for systems not meeting the new standards includes chlorine optimization (the most effective/efficient use of chlorine), Total Organic Carbon (TOC) reduction (can be achieved through use of activated carbon), and water age management (reducing the time that the water is in contact with the disinfectant).

Water systems that use surface water or ground water under the direct influence of surface water and use conventional filtration treatment are required to remove specified percentages of organic materials, measured as TOCs, which may react with disinfectants to form DBPs. Removal can generally be achieved through a treatment technique such as enhanced coagulation or enhanced softening. Alum and lime are common coagulants, which are used to clump particles together in water treatment processing. The clumped particles become tangled with microorganisms (such as bacteria) and suspended particles that are later settled out of the water. Softening is achieved by exchanging calcium or magnesium in the water for sodium.

In January 2006, the Stage 2 Disinfectants and Disinfection Byproducts Rule (Stage 2 DBPR), in conjunction with the LT2ESWTR, became effective and further tighten DBP limits. This rule affects all systems that use disinfected water, except where ultraviolet light is the disinfectant used. Under the Stage 2 DBPR, systems will conduct an evaluation of their distribution system, called an Individual Distribution System Evaluation (IDSE). The IDSE will identify the locations with high disinfection byproduct concentrations. These locations will then be used by the systems as the sampling sites for DBP compliance monitoring. Under the Stage 2 DBPR, compliance with the maximum contaminant levels for two groups of disinfection byproducts [total trihalomethanes (TTHM) and haloacetic acids (HAA5)] will be calculated for each monitoring location

samples from all monitoring locations across the system. The LRAA is expected to put more water systems out of compliance.

This rule would also require systems to determine if they are experiencing short term peaks in the DBP levels referred to as “significant excursions.” Systems experiencing significant excursions would be required to review their operational practices and work with their State to determine what actions should be taken to prevent future excursions. This rule will affect 763 water systems in Oklahoma that disinfect, plus approximately 450 additional water systems that purchase disinfected water.

The Filter Backwash Recycling Rule applies to public water systems in Oklahoma that use surface water and ground water under the direct influence of surface water, practice conventional or direct filtration, and recycle spent filter backwash, thickener supernatant, or liquids from dewatering processes. The purpose of the rule is to reduce the risk of illness from microbial pathogens in drinking water, particularly *Cryptosporidium*. This rule became effective June 8, 2004.

All Oklahoma water systems were to have submitted a Recycle Notification form to the DEQ by December 8, 2003. The recycle notification was necessary to determine which water systems were recycling. Over 95% of the systems have submitted the recycle notification form.

There are approximately 220 water systems in Oklahoma that are subject to the Filter Backwash Recycling Rule. All necessary capital improvements associated with relocating the recycle return location must be completed by June 8, 2006. This federal rule closely mirrors the existing Oklahoma Construction Standards; therefore, it is not expected to have a major impact on Oklahoma water systems.

The new Arsenic Rule will become effective January 2006. It will affect 634 systems with 2,235 sources and establish a health-based, non-enforceable Maximum Contaminant Level Goal (MCLG) for arsenic of zero (0) and an enforceable MCL for arsenic of 0.010 mg/L (10 µg/L). This regulation will apply to community water systems and 137 non-transient non-community water systems, which are not presently subject to standards on arsenic in drinking water. Ground water systems will need to take one sample every three years. Surface water systems will need to take one sample every year. Approximately 25 violations are expected in Oklahoma.

EPA is finalizing the Ground Water Rule that specifies the appropriate use of disinfection, and addresses other components of ground water systems to ensure public health protection. Groundwater wells will need to be evaluated (by sampling for total coliform) to determine the need for mandatory disinfection. There may be a heavy sampling load in response to this rule. There are 783 water systems and 2,987 wells in Oklahoma that may be affected.

A new Radionuclides Rule began to affect community water systems of all size categories on January 1, 2004. The rule requires radionuclide sampling from each source rather than from the distribution system. The rule retains the existing MCLs for combined radium 226 and radium 228, gross alpha particle radioactivity, and beta particle and photon activity. The rule adds an MCL for Uranium for the first time. In Oklahoma there are 634 systems with 2,235 sources that will be affected by this rule. Systems are required to collect radionuclide samples for four (4) consecutive quarters between January 1, 2004 and December 31, 2007. Based on the results, monitoring can be reduced to one (1) sample every nine (9) years.

for systems with the Running Annual Average (RAA) less than the detection level; one (1) sample every six (6) years for RAA greater than the detection limit and less than one-half ($\frac{1}{2}$) the MCL, and one (1) sample every three (3) years for RAA greater than one-half ($\frac{1}{2}$) the MCL and less than the MCL. Systems with a RAA that exceeds the MCL must continue on quarterly sampling. Surface water systems in Oklahoma are not expected to exceed the MCLs. However, it is expected that some of the 381 groundwater systems in Oklahoma will exceed the MCLs. If quarterly sampling confirms that the RAA exceeds the MCL, a new source of drinking water will need to be found.

SUGGESTED REFERENCES FOR STUDY

California State University, Sacramento - **Water Treatment Plant Operation, Vol. 1**

Chapter 7 Disinfection

California State University, Sacramento - **Water Distribution System Operation & Maintenance**

Chapter 6 Disinfection

California State University, Sacramento - **Water Treatment Plant Operation, Vol. 2**

Chapter 15 Trihalomethanes

OTHER STUDY SUGGESTIONS

- Be able to diagram the location of injection points and chlorine residual sampling locations in typical water production and distribution systems.
- Study the reactions to expect for chlorine in water including the dosage to demand relationship, the break point, and chlorinated organics.
- Study the relationships and effects of mixing, contact time, dosage, and flow on the effectiveness of chlorine.
- Be familiar with diagrams of sodium and calcium hypochlorite solution injection systems and gas chlorine injection systems.
- Be familiar with the complete gas chlorination set up including booster pump, strainers, pressure gauges, and ejector into mainline, and the details of gas chlorine flow through the chlorine gas regulator and ejector.
- For the best information on chlorine handling and safety, obtain the Chlorine Manual from the Chlorine Institute.
- Practice using the dosage formulas found in this study guide and in the suggested references.

SAMPLE QUESTIONS

Class D

The chlorine that remains after the chlorine demand has been satisfied is called the

- A. chlorine dose
- B. chlorine residual
- C. chlorine demand

Class C

The chemical that is mainly responsible for the disinfectant properties of chlorine is

- A. HOCl
- B. HCl
- C. NaOH

Class B

Estimate the chlorine demand if the dose is 3 mg/l and the total chlorine residual is 0.5 mg/l after a 30 minute contact time.

- A. 3.5 mg/l
- B. 3.0 mg/l
- C. 2.5 mg/l
- D. 2.0 mg/l

Class A

A flow of 400 gpm is treated by a hypochlorinator which has a pumping rate of 6 gpd using a 2% solution of available chlorine. What is the chlorine dosage in mg/l?

- A. 0.21
- B. 0.48
- C. 0.62
- D. 0.84
- E. 1.74

Chapter 8

Supplemental Treatment

SUGGESTED STUDY GUIDELINES

Class D

Be prepared to answer questions concerning the main purposes of:

- Corrosion control
- Taste and odor control
- Iron and manganese control
- Fluoridation
- Softening

Class C

Be prepared to answer questions concerning guidelines listed for Class D certification and:

- The fundamental chemical reactions involved in various supplemental treatment processes
- The main causes of taste and odor in raw and treated surface water
- The most common taste and odor control methods
- The recommended fluoridation range for public water supplies that fluoridate
- The common lab tests and indexes for determining the existence of corrosion in a system
- The basic steps taken to control tastes and odors
- The reasons for controlling iron and manganese
- The sampling procedures for iron and manganese
- The chemical compounds used for fluoridation
- The basic operation and maintenance procedures for chemical feeders

Be prepared to answer other questions that require additional personal study

Class B and Class A

Be prepared to answer questions concerning guidelines listed for lower levels of certification and:

- The chemistry of corrosion
- The methods for controlling corrosion including chemical methods and cathodic protection
- The description of basic taste and odor treatment processes and where they are located in the process sequence
- The remedial actions for removal of iron and manganese
- The basic operation and maintenance procedures for chemical feeders
- The chemistry of softening processes including the pH levels needed for hardness removal
- The basic description of ion exchange softening process
- The basic operation for ion exchange procedures
- How various water treatment processes effect pH levels

- How to convert hardness expressed in grains per gallon (gpg) to mg/l and perform related dosage calculations
 - How to perform dosage calculations involving fluoridation chemicals
- Be prepared to answer other questions that require a combination of actual experience and additional personal study

ENTRY LEVEL DISCUSSION

Corrosion Control

Generally speaking, corrosive water is characterized by pH and alkalinity values that are somewhat lower than they should be for the water to be considered “stable.” This combination of lowered pH and alkalinity means that the water is not only somewhat acidic but is also lacking in mineral content. Water with these characteristics will tend to corrode some of the materials with which it comes in contact. Corrosive water can cause the materials to deteriorate and dissolve in the water.

Corrosive water causes very serious problems in both distribution systems and water treatment plants. Corrosion of toxic pipe materials such as lead and copper can create serious health hazards for the public as well as noncompliance with federal drinking water standards. For example, the main cause of **lead and copper contamination** in drinking water is corrosive water. Although some water systems may still have some lead pipes in use in the distribution system, most of the problems are caused when the lead and/or copper is leached out of household plumbing and lead solder.

Corrosion of iron pipes may produce a flood of unpleasant telephone calls from consumers complaining about rusty water, stained laundry, and bad tastes. In fact, the most common indicators of corrosion problems are usually when the distribution system has an increasing number of leaks or the public is complaining about dirty or red water. You can also examine materials removed from your distribution system for signs of corrosion damage or perform chemical tests on the water to determine the corrosiveness of a water. Water is considered **stable** when it is just saturated with calcium carbonate. In this condition the water will neither be corrosive nor will it leave a deposit of calcium carbonate, also known as leaving a scale or **scaling**.

Economic losses resulting from corrosion damage can be very large. Water main replacement is often required when **tuberculation** reduces the carrying capacity of a main. Tuberculation is a protective crust of corrosion products (rust) that increases the pipe’s roughness which, in turn, causes increased pump energy costs and reduced distribution system pressures. Leaks in water mains are also usually caused by corrosion.

Probably the most commonly used chemical test for measuring the “stability” of water is the **marble test** (calcium carbonate stability test). The marble test is a relatively simple laboratory procedure that determines the “saturation level” of the water. If the water is shown to be undersaturated with calcium carbonate, it is considered corrosive and treatment for corrosion should be undertaken.

Treatment to Accomplish Calcium Carbonate Saturation

Reduction of corrosion is almost always accomplished by treating the water with certain chemicals so that the water is saturated or slightly supersaturated with **calcium carbonate** (CaCO_3) when it leaves the plant. Chemicals should be fed after filtration; otherwise a slight excess of chemical may result in cementing of filter sands. The chemical feed can take place before, after, or along with postchlorination. Samples should be taken only after postchlorination because the chlorine may react with the chemicals used. For example, chlorine gas will lower the pH of the water while hypochlorite compounds will raise the pH.

Selection of a chemical to achieve calcium carbonate saturation will depend on the water quality characteristics and the cost of the chemicals. **Quicklime** (CaO) and hydrated or “**slaked**” **lime** (Ca(OH)_2) might be used when treating waters that have low hardness and low alkalinity. **Caustic soda** (NaOH) or **soda ash** (Na_2CO_3) might be added to waters with already high levels of hardness and alkalinity when the pH level needs to be raised.

All plant chemicals should be handled with care. However, of the four chemicals used for corrosion control, caustic soda is by far the most hazardous. Caustic soda is a very strong base that literally dissolves human skin. It also generates heat when mixed with water and reacts with certain metals to form flammable, explosive gases.

Finding the actual chemical dosages needed to change the pH and produce calcium carbonate saturation requires the use of one of the several indices (indexes). Commonly used indices include the Langelier Index, Driving Force Index, and Aggressive Index. By using an index, the equilibrium point between pH, hardness, and alkalinity in a given water can be determined and the needed adjustments in the corrosion control chemical dosages can be made.

Taste and Odor Control

Taste and odor, along with “colored water” complaints, are the most common types of water quality complaints received by water system operators. This is because the average consumer uses three senses to evaluate water: sight, smell, and taste. If the water looks dirty or colored, smells bad, or has an objectionable taste, the consumer will rate it as poor quality water. This is true whether or not any health-related problem actually exists. Most water systems require at least occasional treatment for tastes and odors.

Common Causes of Tastes and Odors

Tastes and odors can be the result of natural or man-made conditions that exist anywhere within the total water supply system. Raw water sources, intake structures, treatment plants, chlorination stations, water storage tanks, distribution systems, and consumer plumbing have all been identified as sources of tastes and odors.

One very significant contributor to tastes and odors problems experienced by water systems are microbiological organisms that grow in water. Various types of bacteria, algae, diatoms, flagellates, and fungi have all been reported to cause problems. Such biological growths leading to objectionable tastes and odors can occur during any time of the year and in any area of a water system.

Tastes and odors may be directly caused by microbiological organisms in two ways. First, as the organisms grow and multiply, they produce very small quantities of **metabolic by-products**. These by-products are released into the water. Some may lead to unpleasant tastes and odors. The organisms may also affect the taste and odor of water when they die. As the cells rupture, either as a result of natural processes or treatment, **cellular materials** are released into the water, sometimes bringing with them unpleasant tastes and odors.

Another natural cause of taste and odor problems in water systems is low dissolved oxygen levels in surface water sources. This condition can be caused by increased nutrient levels (natural or man-made) or increased activity of algae. One result of low dissolved oxygen levels is the growth of anaerobic microorganisms capable of producing compounds such as hydrogen sulfide (H_2S), which is very objectionable to consumers.

Man-made causes of tastes and odors in water supplies include the introduction of inadequately treated municipal or industrial wastewater to surface water sources. Similarly, both urban and agricultural run-off may introduce undesirable characteristics into a community's water supply.

Inadequate or incomplete maintenance of water treatment plants and distribution systems can result in taste and odor problems, regardless of how clean the raw water supply may be. Even in the presence of a strong chlorine residual, microorganisms will grow in debris and sludges found in influent areas and treatment basins. Debris that accumulates in distribution system mains and lateral lines will also provide an environment for bacterial growth. Especially susceptible are low flow zones and dead ends in which no chlorine residual is maintained.

Finally, taste and odor problems are sometimes traceable directly to the consumers' plumbing system. The age and types of plumbing materials in some homes may contribute to unpleasant-tasting water.

Methods of Controlling Taste and Odor

When dealing with a taste and odor problem, or any water quality problem, an ounce of prevention is worth far more than a pound of treatment. Preventing problems, at least to the extent prevention is feasible, is usually both more economical and more effective than trying to treat for tastes and odors at the plant.

Taste and odor treatment methods can be divided into two broad categories: removal and destruction. Often methods from both categories are used. Multiple treatments, perhaps even three or four, may

be necessary to produce water of acceptable quality. Removal techniques include optimum coagulation/flocculation/sedimentation, degasification, and adsorption. Actual destruction of tastes and odors can be accomplished by various methods of oxidation.

OPTIMUM COAGULATION/FLOCCULATION/SEDIMENTATION. Depending upon the type of taste and odor, and on the raw water quality, improving these processes may produce a better tasting water. This is especially true if the taste and odor quality has deteriorated during a period when changes in raw water turbidity, color, or pH have suddenly occurred. Such changes might occur during spring or fall turnover of a lake, during high flows in a river due to storm runoff, or algae blooms in the raw water.

In order to determine if increased coagulant dosages will reduce objectionable tastes and odors, the standard jar test procedure can be used followed by tests for both settled water turbidity and threshold odor number. If improving coagulation/flocculation/sedimentation solves the problem, this may be the simplest and most economical approach available.

DEGASIFICATION. **Degasification** is a water treatment process that removes dissolved gases from the water. Probably the most used method of degasification is aeration. Most aeration systems are designed to operate in one of two ways. Some systems pass air through water, as in the case of air blowers. Others pass the water through the air, such as cascades (artificial waterfalls) and spray aerators. As the air comes into contact with the water, gases producing taste and odor problems escape into the air.

ADSORPTION. **Adsorption** is the process of removing materials from water by adding a material to the water to which the taste and odor-producing compounds will attach themselves. In water treatment this is accomplished in one of two ways: the addition of powdered activated carbon (PAC) to the treatment process, usually at the influent; or the use of granular activated carbon (GAC) as a filter medium. The carbon particles used in these materials have undergone a special treatment process that increased their surface area so more adsorption can take place. The surface area of just one pound of activated carbon may range from 2 million to 9 million square feet. Activated carbon does not create new products.

DESTRUCTION BY OXIDATION. **Chemical oxidation** is a technique that actually destroys tastes and odors instead of just removing them. This method is perhaps the most common taste and odor control process because of the widespread use of chlorine, a strong oxidant, for disinfection in water treatment. It is often necessary to increase the normal chlorine dosage or to institute a pre-chlorination process in order to obtain optimal taste and odor treatment.

In addition to chlorine, there are three other chemicals that are sometimes used as oxidants for the removal of taste and odor compounds. These are potassium permanganate (KMnO_4), Ozone (O_3), and chlorine dioxide (ClO_2). These are sometimes used as alternatives in taste and odor treatment in order to help avoid producing trihalomethanes (THMs).

Iron and Manganese Control

Iron and manganese are two different elements but are almost always mentioned together because they produce similar problems under similar conditions. Iron and manganese are in fact nutrients that are needed by humans. However, they are not present in high enough concentrations in water supplies to be beneficial. Furthermore, when clothes are washed in water containing even small amounts of iron and manganese they will become stained a reddish-brown or black color. If the concentration is high enough, plumbing and bathroom fixtures such as bath tubs, toilets, and sinks can become stained.

Possibly the most troublesome result of iron and manganese in the water supply is that they promote the growth of a group of microorganisms referred to as **chrenothrix** or **iron bacteria**. These organisms form thick slimes on the interior walls of well casings and distribution lines which will eventually cause customer complaints. The resulting slime will be reddish-brown or black in color depending on whether iron or manganese is dominant.

Iron and manganese will each generally exist in one of two chemical states or forms. When iron and manganese are dissolved in water, they are said to be in the **reduced** state. The reduced state is referred to as the **ferrous** state for iron and as the **manganous** state for manganese. When iron and manganese come into contact with oxygen, chlorine, or some other oxidizing agent, the iron and manganese are oxidized to the **ferric** and **manganic** states. The ferric and manganic states are insoluble in water. This means that the iron and manganese will no longer be dissolved and will precipitate out, producing stains and deposits on clothing and bathroom fixtures.

Iron and manganese are frequently encountered in ground water supplies because of the lack of dissolved oxygen in aquifers. Therefore, iron and manganese problems are most likely to be associated with ground water supplies. Surface water sources have relatively high concentrations of dissolved oxygen towards the upper levels. Therefore, significant concentrations of iron and manganese will be found only at the lower levels of deep lakes and reservoirs.

Methods of Controlling Iron and Manganese

POLYPHOSPHATE TREATMENT. If the water being treated contains no more than 0.3 mg/L of manganese and 0.1 mg/L of iron, an inexpensive and relatively effective method of control is **polyphosphate treatment**. Polyphosphate is only a **sequestering agent**. This means that it delays the precipitation of iron and manganese for a few days preventing deposits in the distribution system. In other words, the polyphosphate keeps the iron and manganese dissolved but does not remove it.

Chlorine should be fed along with polyphosphate because the dissolved iron and manganese in the water will promote the growth of iron bacteria. The chlorine should never be fed ahead of the polyphosphate because the chlorine will oxidize the iron and manganese resulting in almost immediate precipitation. Polyphosphate dosages are limited because a maximum of 10 mg/L, as phosphate, is the maximum allowable in Oklahoma.

OXIDATION BY AERATION. Aerating the water means increasing the dissolved oxygen content. Dissolved oxygen in water will oxidize iron and manganese to the insoluble ferric and manganic state. While this method is very effective for removal of iron, the reaction for manganese removal is too slow to be used on water supplies that have a high concentration of manganese. The iron removal reaction can be greatly accelerated by increasing the pH of the water being treated. Therefore, some water supplies may find it necessary to add lime in order to increase the pH.

There are several methods for the operator to choose from that will provide effective aeration. Aeration techniques include forced draft, multiple trays, cascades, and sprays. A reaction basin or contact basin as it is sometimes called, should follow the aeration process. The purpose of the **reaction basin** is to allow time for the oxidation reactions to proceed to completion. A minimum detention time of 20 to 60 minutes is recommended for the reaction basin. The precipitate is then removed by sedimentation and/or special filtration processes.

OXIDATION BY CHLORINATION. If significant amounts of manganese are present in the water supply, then it is probably more effective to use chlorination than aeration because it will oxidize both iron and manganese. The higher the chlorine residual, the faster complete oxidation will occur. Typically a chlorine residual of 5 to 10 mg/L is used followed by dechlorination to bring the residual down to a level suitable for the consumer. The water is dechlorinated by using reducing agents such as **sulfur dioxide** (SO_2), **sodium bisulfite** (NaHSO_3), or **sodium sulfite** (Na_2SO_3).

A typical chlorine oxidation process would be set up with a reaction basin for chlorine contact followed by filtration. Some systems might be constructed with a sedimentation basin between the reaction basin and filters.

OXIDATION WITH POTASSIUM PERMANGANATE. **Potassium permanganate** (KMnO_4) will oxidize iron and manganese and can be used in much the same manner as chlorine. Permanganate dosage must be carefully controlled because a dose that is too small will not oxidize all the manganese in the water and a dose that is too large will allow permanganate to enter the distribution system, which can produce a pink color in the water. Also, if the pH of the water being treated is below pH 7.5, this treatment can result in more manganese being added than removed. Potassium permanganate processes are constructed in a similar fashion to chlorine processes using a reaction basin followed by filtration.

SOFTENING PROCESSES TO CONTROL IRON AND MANGANESE. Many people are not aware of the fact that iron and manganese are also contributors to total hardness, though this contribution is usually very small. Therefore, just as the softening procedures remove calcium and magnesium they will also remove iron and manganese. Commonly used methods of softening will be discussed later in this chapter.

Fluoridation

Fluoridation is the upward adjustment of fluoride levels, in accordance with scientific and dental guidelines, for the purpose of improving public health through the prevention of tooth decay. Nearly everyone in the United States will suffer from **dental cavities** at some point in their lives. Some say that this affliction is the most common chronic disease of man. The evidence is clear that fluoride, at the optimal concentration in potable water, will reduce dental cavities up to 60 percent among children who ingest this water from birth.

It is known that fluoride is a “bone seeker.” About 96 percent of the fluoride found in the body is deposited in the skeleton. As the teeth are part of the skeleton, the use of fluoride in forming teeth is basically similar to that in other bones. Incorporation of fluoride is most rapid during the time of the child’s formation and growth. Therefore, it is important that children drink the proper amount of fluoridated water during the early development of the permanent teeth, starting at birth.

The effectiveness of fluoridation depends on how consistently the water treatment operator maintains the optimal fluoride concentration. Operators hold the key to better dental health in their communities. Water system operators are a vital part of the professional team fighting dental disease in a community. In fact, it has been recognized by many dentists and other experts that OPERATORS CAN DO MORE TO PREVENT CAVITIES BY WATER FLUORIDATION THAN CAN BE DONE BY ALL OF THE DENTISTS IN THE COMMUNITY COMBINED.

Fluoride Concentration

Fluoride (F^-) is present in widely varying amounts in practically all soils, water supplies, plants, and animals, and thus is a normal constituent of all diets. All public water supplies in the United States contain at least small amounts of fluoride from natural sources, the actual concentration depending primarily upon the fluoride mineral concentration in the area soils. The recommended range of finished water fluoride concentrations is between 0.8 and 1.3 mg/L with exactly 1.0 mg/L considered the optimum concentration.

Of all the chemicals used in the water treatment plant, fluoride concentrations are probably the most sensitive to correct maximum concentrations. It is important for operators to understand that if the fluoride concentration is increased significantly past 1.0 mg/L there is only a very slight increase in the benefits associated with fluoride. If fluoride levels in excess of around 1.5 mg/L are consumed for extended periods of time, a condition known as dental fluorosis (mottled teeth) may arise. **Dental fluorosis** is visible as whitish-to-brownish spots seen on teeth in areas with high levels of naturally-occurring fluoride. Operators should be certain that there is no overfeeding of fluoride. Gross overfeeding could cause other illnesses in the community as well as bad public relations.

Fluoridation Compounds

There are three compounds commonly used to fluoridate water supplies: sodium fluoride, sodium fluorosilicate, and fluorosilicic acid. All compounds used should meet the American Water Works Association (AWWA) standards for use in water fluoridation.

SODIUM FLUORIDE. Sodium fluoride (NaF) is a white, odorless material available either as a powder or in the form of crystal of various sizes. It is available in purities ranging from 97 to over 98 percent. Approximately 19 pounds of sodium fluoride will add 1 mg/L of fluoride to 1 million gallons of water.

SODIUM FLUOROSILICATE. Sodium fluorosilicate (Na_2SiF_6), also known as sodium silicofluoride, is a white, odorless crystalline powder. Sodium silicofluoride is available in purities of 98 percent or greater. Approximately 14 pounds of sodium silicofluoride will add 1 mg/L of fluoride to 1 million gallons of water.

FLUOROSILICIC ACID. Fluorosilicic acid (H_2SiF_6), also known as hexafluosilicic, silicofluoric, or hydrofluosilicic acid, is a 20 to 35 percent aqueous solution. It is a straw colored, transparent, fuming, corrosive liquid and has a pungent odor. It must be handled with great care. It will cause severe burns on skin and it poses special hazards for the eyes. Safety goggles must be worn at all times when working with this substance (see also Chapter 12). Approximately 46 pounds (4.4 gallons) of 23 percent fluorosilicic acid will result in a dose of 1 mg/L of fluoride in 1 million gallons of water.

Softening

Softening means reducing the hardness levels of water. As discussed in Chapter 2, hardness is caused by the presence of positively-charged calcium and magnesium ions. Several problems for the public are associated with high levels of hardness. These include excessive soap usage and scale deposits in water lines and hot water heaters. If hardness levels are high enough, it may be necessary to soften the water. There are two major categories of water softening: ion exchange and chemical precipitation.

Ion Exchange

Ion exchange is rarely used by full scale municipal water systems because it is not cost effective unless the water supply contains high levels of noncarbonate hardness. In the ion exchange process, calcium and magnesium ions are exchanged for sodium (Na^+) and potassium (K^+) ions. Sodium and potassium ions are not contributors to hardness levels but sodium ions in particular can have negative effects on people with cardiovascular disease. Individual home unit water softeners will usually utilize ion exchange resins. Ion exchange softening has the ability to reduce hardness levels to practically zero.

Chemical Precipitation

Chemical precipitation methods are the water softening methods most likely to be used by a municipal water treatment system. During these treatment processes, the substances that contribute to hardness are caused to **precipitate**, which means that they are made to “come out of solution” so they can be settled and removed from the water. The lowest hardness level that can be obtained using chemical precipitation methods is about 30 to 40 mg/L. The two most commonly used softening procedures in the United States are lime softening and lime-soda ash softening.

LIME SOFTENING. Lime softening is a cost effective method for hardness removal when the only type of hardness that is being removed is carbonate hardness. Lime softening involves adding enough lime (Ca(OH)_2) to reach the saturation point and cause precipitation of the excess hardness levels. It is important to note that it takes twice as much chemical to cause precipitation of magnesium carbonate hardness as it does to cause precipitation of calcium carbonate hardness.

LIME-SODA ASH SOFTENING. When the removal of noncarbonate hardness is necessary, the use of soda ash (Na_2CO_3) is required. Noncarbonate hardness caused by calcium only can be removed using soda ash alone. Noncarbonate hardness caused by magnesium requires both lime and soda ash for removal. The two major products or precipitants of the lime-soda ash softening process are calcium carbonate (CaCO_3) and magnesium hydroxide (Mg(OH)_2).

Recarbonation

During the lime-soda ash softening process, excessive amounts of lime must be used to remove magnesium hydroxide. This excess lime has the effect of raising the pH to about 10.9. Therefore, in the final step in the lime-soda ash softening procedure, the pH is lowered. This is done by a process known as **recarbonation**. Recarbonization is accomplished by adding carbon dioxide (CO_2) to the water forming carbonic acid (H_2CO_3). The carbonic acid causes the pH to be lowered and also neutralizes excess carbonate alkalinity. The lower pH aids in the final steps of precipitation.

The final result of recarbonation is more stable water for the consumers. Without this treatment, the water would likely cause the deposition of large amounts of calcium carbonate (scaling) in the plant, distribution system and home plumbing.

SUGGESTED REFERENCES FOR STUDY

California State University, Sacramento - **Water Treatment Plant Operation, Vol. 1**

Chapter 8	Corrosion Control
Chapter 9	Taste and Odor Control

California State University, Sacramento - **Water Treatment Plant Operation, Vol. 2**

Chapter 12	Iron and Manganese Control
Chapter 13	Fluoridation
Chapter 14	Softening
Chapter 16	Demineralization

OTHER STUDY SUGGESTIONS

- Study the definitions and specific uses of various indices including the Langelier Index, Driving Force Index, and Aggressive Index.
- List and understand the ways in which the potential for corrosion in a system may be measured.
- Study the methods of chemical stabilization of water in a distribution system.
- Locate where in a treatment sequence the activated carbon for taste and odor control should be added.
- Study procedures for handling and feeding to the process stream for PAC and GAC.
- Study what effects activated carbon addition will have on other treatment processes.
- Draw a diagram of various iron and manganese control methods.
- Practice dosage calculations for the various chemicals used in these control methods.
- Be familiar with the characteristics of the most common compounds used for fluoridation.
- Study diagrams of common chemical feeders and procedures for their operation.
- Study safety concerns and procedures for the handling of fluoridation compounds.
- Practice calculating fluoridation chemical dosages.
- Review chemical constituents of a water that could make softening necessary. Study the chemistry of the ion exchange process and the characteristics of the product water.
- Study the diagram of the process unit in which softening would take place. Trace flows and valving through the operation sequence.
- Practice converting hardness in grains per gallon (gpg) to mg/L and other related conversions.

SAMPLE QUESTIONS

Class D

Softening is done to remove

- A. hardness
- B. taste and odor
- C. THMs

Class C

The optimum concentration of fluoride in public water supplies has been determined to be

- A. 0.5 mg/l
- B. 1.0 mg/l
- C. 1.5 mg/l

Class B

One ml of a standard polyphosphate solution (0.1% solution) in a liter sample is equal to

- A. 1 mg/l
- B. 10 mg/l
- C. 100 mg/l
- D. 1000 mg/l

Class A

Estimate the percent recovery of a reverse osmosis unit with a 4-2-1 arrangement if the feed flow is 5.88 MGD and the effluent flow is 5.0 MGD.

- A. 95%
- B. 90%
- C. 85%
- D. 80%
- E. 75%

Chapter 9

Ground Water Systems

SUGGESTED STUDY GUIDELINES

Class D

Be prepared to answer questions concerning:

- The general characteristics of ground water as compared to surface water
- The basic definitions and characteristics of artesian wells and water table wells
- The definitions of static level, pumping level, cone of depression, drawdown, and radius of influence
- The minimum testing requirements of ground water systems
- The major factors affecting the well yield
- The general requirements of well construction including how deep the casings must be grouted
- The proper method of sealing abandoned wells to prevent ground water contamination

Class C

Be prepared to answer questions concerning guidelines listed for Class D certification and:

- The special physical, chemical and microbiological characteristics of ground water
- The definition of specific capacity
- How often static level and pumping level should be determined
- How the material that the water-bearing formation is composed of can affect radius of influence
- How to recognize normal and abnormal operation in a well system
- The functions of the various components of a typical well
- The basic disinfection procedures for wells and when they are required

Be prepared to answer other questions that require additional personal study

Class B and Class A

Be prepared to answer questions concerning guidelines listed for lower levels of certification and:

- The significance of recharge zones, aquifers and wells in the hydrologic cycle
- The different types, descriptions, operating characteristics, and applications of well pumps
- The sanitary characteristics of wells including pad, grouting, sanitary seal, and vents
- How to troubleshoot problems with well operation
- The basic operational procedures involving electrical controls
- The normal startup and shutdown sequences for well pumps
- How to measure pumping level, static level, drawdown, specific capacity, and pumping rates
- How to calculate dosages and pumping rates for chlorine solutions at ground water systems

Be prepared to answer other questions that require a combination of actual experience and additional personal study

ENTRY LEVEL DISCUSSION

Approximately 45% of the water used in the United States comes from underground sources. In many locations, water from wells or springs is the only water available to a community. Most of the small and many of the medium-to-large community water systems in Oklahoma use ground water as their primary or secondary water source. Ground water sources are often preferred due to relatively low maintenance and capital requirements. Most importantly, ground water usually provides a consistent source of **high-quality water**. In many cases, raw surface water is of relatively poor quality.

Characteristics of Ground Water

As discussed in Chapter 4, ground water differs greatly from surface water in its physical and chemical characteristics. As a general rule, ground water will have relatively high levels of total dissolved solids (TDS) and minerals. In other words, it will have higher levels of alkalinity and hardness as well as higher concentrations of naturally-occurring substances such as calcium, magnesium, iron, manganese, carbon dioxide, hydrogen sulfide, and fluoride.

On the other hand, ground water will usually have very low levels of suspended solids and turbidity. In addition, the organic content of ground water is very low. It also has very little bacteria. This means that little, if any, treatment is necessary for most ground water systems.

As a result of these differences, ground water systems will have very different types of customer complaints than those that may occur at surface water systems. For example, due to the high mineral content of ground water, it will often cause more scaling problems in household plumbing than surface water systems. Ground water is also more likely to have color problems; especially those related to iron and manganese. However, ground water is typically consistent in quality, safe, and a very valuable natural source of water.

Aquifers

Ground water is contained in water-bearing strata called aquifers. The aquifer may have originated as a result of precipitation, release from molten rock as it cooled, or even from former surface water sources trapped in ancient sediments. There are two major types of aquifers commonly encountered in the state of Oklahoma. They are the artesian aquifer and the water table aquifer.

An **artesian aquifer** is often referred to as **confined** because the water is confined between two impermeable layers of strata such as solid rock or dense clay. Because it is confined it is under pressure. An artesian well can therefore sometimes flow with little or no aid from pumps if the head (pressure) conditions are sufficient. Due to this pressure, the water level in an artesian well will always rise above the “point of encounter” (the point where the aquifer is tapped). Wells in artesian aquifers that are able to flow without any aid from pumps are commonly referred to as **flowing artesian wells**.

A **water table aquifer** is sometimes referred to as an **unconfined** aquifer because the water-bearing formation is not trapped between impervious rock formations. The water table generally follows the same topography as that found on the surface. In humid regions, the water table is usually less than 100 feet deep. However, the water table can be several hundred feet deep in desert climates. The water table in a swamp is at ground level. Changes in the water table are caused by temperature, moisture deficiency, evapo-transpiration (plant uptake), aquifer recharge, irrigation, streamflows, and pumping. Water table wells are probably the most common type encountered in the State of Oklahoma.

Ground Water Well Terms and Definitions

Some of the major terms and definitions related to well operation are listed below (*see Figure 9.1*).

static level - The water level in a well when the pump is not in operation.

pumping level - The water level in a well when the pump is in operation.

drawdown - The distance between the static level and the pumping level.

cone of depression - The cone-shaped area in an aquifer that is “dewatered” when a well is pumping.
The cone of depression may be as little as several feet or up to several miles across.

radius of influence - The radius of the cone of depression.

specific capacity - The actual yield of a well. The specific capacity is usually expressed as gallons per minute (gpm) per foot of drawdown.

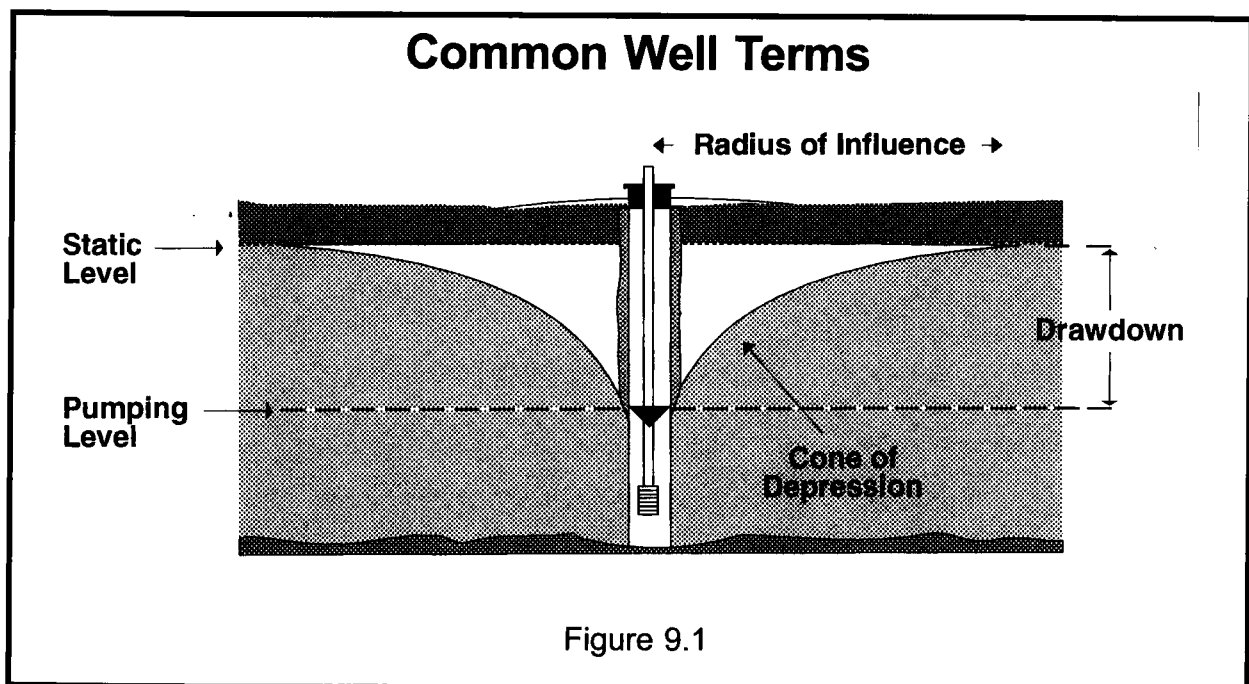


Figure 9.1

Well Characteristics and Yield

The drawdown, pumping level, yield, and radius of influence, are all directly related to the type of material that composes the water bearing formation. For example, the size and shape of the cone of depression is directly related to the type of aquifer formation. A gravel aquifer will display a broad, flat cone of depression while an aquifer in fine sand will produce a steeper, narrower cone.

The type of material that actually contains the water in any aquifer is sometimes referred to as either consolidated material or unconsolidated material. Consolidated materials are particles that are fused or cemented together, such as clay, shale, sandstone, conglomerates and limestone. Unconsolidated materials such as gravel and sand are often the result of ancient river beds and glacial action.

There are several types of water bearing formations found in Oklahoma, such as fractured rock, sand, and clay. Sand and clay formations are probably the most common types of water bearing formations in the State. The well characteristics of these two types of formations are quite different. The specific capacity of sand wells will usually be higher than for tightly packed clay wells. The highest yields come from very coarse sand, gravel, and fractured bedrock strata. Formations with fractures can yield enormous quantities of water.

Generally speaking, the major factors affecting well yield can be summarized in the following statements.

1. The well yield increases with the coarseness of the formation.
2. The well yield increases with increased radius of influence.
3. If the radius of influence of two wells overlap, the yield from each of the wells is decreased.

Recharge of Aquifers and Prevention of Ground Water Pollution

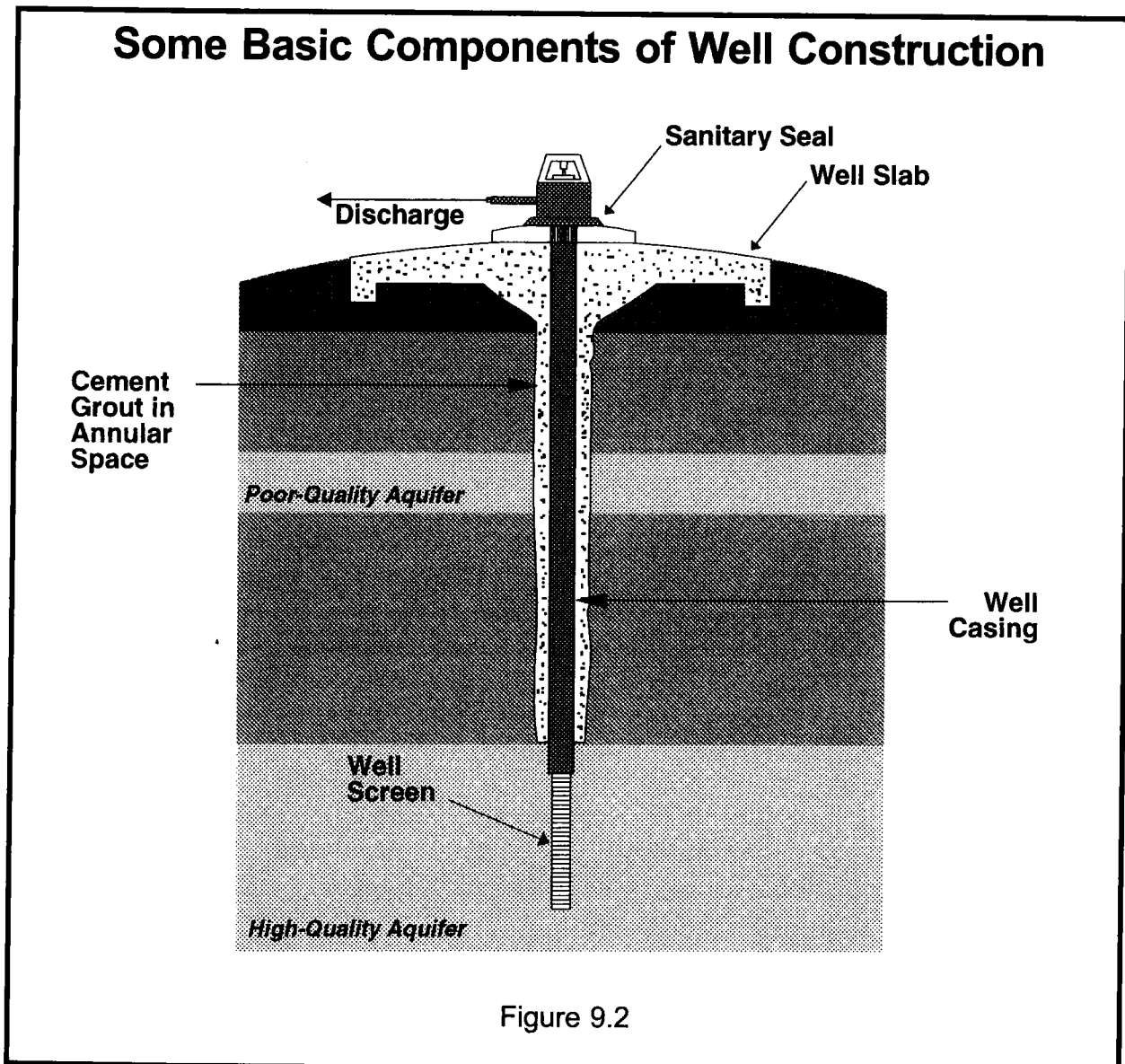
Natural methods of aquifer **recharge** include direct recharge, leakage from surface water, and inter-aquifer leakage. Direct recharge results from precipitation falling directly on the recharge zone of the aquifer and then filtering through the soil. The amount of water reaching the aquifer is usually about 30-70% of the precipitation. The recharge zone of an aquifer may be several miles from the well. This is particularly true with artesian aquifers. Factors that affect direct recharge are duration and intensity of the precipitation, type of precipitation, slope of the ground, type of vegetative cover, soil and strata compaction, temperature, soil porosity, and soil moisture deficit.

Unfortunately, aquifers are sometimes recharged in a manner that leads to pollution of the ground water supply. Waste injection wells that are not properly maintained or constructed are one source of pollution. Contaminants can be washed into aquifers through poorly maintained operating wells, or improperly sealed abandoned wells. Additionally, other pollutants such as agricultural chemicals when applied to the soil may leach into an aquifer. **PROTECTION OF THE RECHARGE AREA**

IS THE BEST DEFENSE AGAINST GROUND WATER POLLUTION. Recharge area protection is especially vital to aquifers with fractured formations. Ground water pollution plumes can move several thousand feet per day in such aquifers.

Well Construction and Siting Requirements

Sanitary hazards must be avoided when the wellsite is selected. Septic tanks and drainfields, wastewater treatment plants, livestock pens, landfills and dumps, and graveyards should not be located uphill from water wells. Wells should also not be located in flood plains, on river banks, or in cultivated fields where the chance of fertilizer, herbicide, or insecticide contamination could occur. Gasoline storage tanks cannot be located within 300 feet of a water well.



All wells must have a water-tight surface casing extending at least 20 feet below the surface. The **annular space** is the cavity or area immediately around the surface casing. In order to prevent water from a poor-quality aquifer leaking down to the high-quality aquifer, this space must be filled with neat cement grout to a depth of at least 20 feet (*see Figure 9.2*).

All abandoned wells should be properly plugged. The purpose of abandoning and plugging is to restore as nearly as practical, those subsurface conditions that existed prior to the construction of the well and to prevent the possible cross-contamination between different aquifers. Proper procedures for abandoning or plugging a well can vary depending upon the aquifer(s) involved. Neat cement grout should be used for sealing an abandoned well. A welded metal plate or threaded cap should be used when temporarily capping a well.

Minimum Control Tests

All community water systems that utilize ground water must determine static level and pumping level at least quarterly. Alkalinity, pH, and stability must be determined at least monthly and the chlorine residual must be checked twice daily (at chlorinating systems). If the system is utilizing iron and manganese removal, iron and manganese tests are required. Under some conditions, other tests may also be required.

The results of these tests must be reported on the Monthly Operational Report (MOR) and submitted to the proper agencies each month (see Chapter 3).

Where fluoridation is practiced, fluoride analyses must also be performed twice daily. A copy of the results from these tests and a treated sample must be submitted to the Oklahoma Department of Environmental Quality (DEQ) State Environmental Laboratory.

Well Maintenance (see also Chapter 11)

The well should be inspected as often as possible. Information on troubleshooting and simple repair of well components is provided within the *Suggested References for Study* listed for this chapter. **NEVER PERFORM WORK FOR WHICH YOU ARE NOT QUALIFIED.** If the maintenance that needs to be performed seems “over your head,” call a person who is qualified in that area.

The electrical system will probably be the primary type of maintenance required. Minimally, the electrical components of a new well should consist of starter controls, an electrical motor, a disconnect switch between the electrical meter and starter controls, and a small safe heater to prevent freezing and breaking of pipes and valves in the winter. Phase protection against under- and over-voltage conditions on the pump motor is also often used.

Another maintenance requirement at many wells will be to adjust the packing on lineshaft turbine pump wells. Packing in a pumphead may be the least understood component in the pump-to-motor drivetrain. A small amount of water should run around the shaft to keep it cool. If the packing is too

loose, a spray can develop causing the motor windings to short out and ruin the motor. If the packing is too tight, the shaft will be cut and the rate of discharge through the packing will be hard to control. More likely, the shaft will get hot, crystallize and break. Packing should contain no lead or asbestos, and be changed or adjusted as needed.

Static and pumping levels should be determined at least quarterly. These levels are used to determine the drawdown. These levels may be taken through air lines or by using electrical probes attached to lines with depth measurements marked on them. A record of these levels is used to troubleshoot hydraulic problems. Information necessary to troubleshoot common problems with the well can be obtained by carefully tracking these levels.

Disinfection of Wells and Ground Water Systems (see also Chapter 7)

Water wells must be disinfected when the well is newly drilled, when repairs to the well or pumping equipment are completed or when an unsafe bac-t sample from the well is reported. Any of these situations could mean that the well casing has become contaminated. Wells are usually disinfected using chlorine bleach or calcium hypochlorite (HTH).

Further information can be found in the appropriate sections of the *Suggested References for Study* listed in this chapter (or from similar references). The most complete directions for disinfecting wells, water mains and water storage facilities are listed in standards developed by the American Water Works Association (AWWA) and approved by the American National Standards Institute (ANSI). For information on how to obtain these documents see the “Suggested References Source Sheet” near the back of this study guide.

The most commonly used method for disinfection is to dose the well with 50-100 mg/L chlorine, for a contact time of 24 hours. The system must then be flushed thoroughly and two safe bac-t samples must be collected on successive days before the well is put into service. Disinfection of wells following repairs may require special procedures (such as swabbing) due to the likelihood of lime deposits, bacterial growth, or other debris above the water line.

In addition to using “batch treatment” to kill pathogenic organisms, this procedure is sometimes used to control another organism called **chrenothrix** bacteria (see Chapter 8). Also known as **iron bacteria**, this organism causes a slime growth inside the well that can eventually deteriorate the well casing and cause taste and odor problems.

Continuous feeding of chlorine is not currently required at all ground water systems in Oklahoma. This is true because some systems have never had unsafe bac-t samples (see Chapter 2). However, when there is no chlorine residual present, there is no protection against bacterial contamination in the distribution system that may be caused by a line break or other problem.

SUGGESTED REFERENCES FOR STUDY

California State University, Sacramento - **Small Water System Operation and Maintenance**

Chapter 3 Wells

California State University, Sacramento - **Water Treatment Plant Operation, Vol. 1**

Chapter 2 Water Resources and Treatment

OTHER STUDY SUGGESTIONS

- Study a comprehensive diagram of a well, and explain the purpose of each component. Include valving, pressure or storage tank, and distribution system in the diagram.
- Be able to draw a diagram of a typical well including components found above.
- Be familiar with the hydraulic changes that occur when a well is started.
- Be familiar with the operating characteristics of motor and pump assemblies.
- Look at procedures and devices for controlling sand intrusion in a well.
- Study the procedures for disinfection of a new or repaired well.
- Be able to draw the essential components of the hydrologic cycle.
- Be able to list all of the special characteristics of ground water including physical, chemical, and microbiological characteristics.
- For the most complete directions for disinfecting water mains, water storage facilities, and wells obtain and study a copy of the American National Standards Institute (ANSI) Standards available from the American Water Works Association (AWWA).

SAMPLE QUESTIONS

Class D

The mineral content of ground water is usually

- A. very low
- B. about the same as surface water
- C. higher than surface water

Class C

The difference between the static level and the pumping level is the

- A. specific capacity
- B. radius of influence
- C. drawdown

Class B

The valve at the bottom of the well tubing to prevent draining of the tubing is called the

- A. double ball valve
- B. foot valve
- C. motor valve
- D. pump valve

Class A

How many gallons of water must be added to 5 gallons of a 5% hypochlorite solution to make a 0.5% hypochlorite solution?

- A. 10
- B. 25
- C. 30
- D. 45
- E. 95

Chapter 10

Distribution Systems

SUGGESTED STUDY GUIDELINES

Class D

Be prepared to answer questions concerning:

- The basic design and operation of water distribution systems
- The definition and significance of a pipe's pressure rating and pipe schedule
- The proper distances of separation between water and sewer lines and the minimum soil cover
- The proper methods of laying pipe including bedding and backfilling requirements
- The minimum size water line required when fire protection is provided
- The minimum size water line sometimes allowed when fire protection is not provided
- The basic requirements for disinfection and bac-t samples for new or repaired lines and tanks
- The basic descriptions of various types of water storage facilities including advantages and disadvantages of each
- The basic advantages and disadvantages of the different types of piping materials
- Common problems that may occur in the distribution system and how to avoid them
- The special safety considerations for distribution system operators

Class C

Be prepared to answer questions concerning guidelines listed for Class D certification and:

- The basic operational and maintenance practices of water storage facilities
- The different types, descriptions, and applications of piping and joints
- The advantages and disadvantages of different types of lines
- The definition and significance of a pipe's C Factor
- The descriptions and uses for commonly used valves and their operational characteristics
- The basic descriptions of the various types of meters and their common applications
- The importance and basic setup of cross connection control programs
- How to calculate problems involving flow rates, water pressures, volumes, and chemical dosages involving disinfection of lines and tanks

Be prepared to answer other questions that require additional personal study

Class B and Class A

Be prepared to answer questions concerning guidelines listed for lower levels of certification and:

- The functions of the various components of water storage facilities
- The purpose and use of thrust blocks and anchors in the distribution system
- The proper installation procedures for hydrants

- The various types of backflow prevention devices and their applications
- The typical problems and troubleshooting procedures of water quality problems in distribution systems and storage
- The fundamentals of performing pressure and leakage tests
- The minimum distribution system pressures and typical variations, problems, and related troubleshooting procedures
- The different types of corrosion that can occur in the distribution system and their causes and methods of control
- How to recognize different types of cross connections and how to remedy them
- How to calculate advanced hydraulic problems involving flow rates, water pressures, and required pump and line sizes

Be prepared to answer other questions that require a combination of actual experience and additional personal study

ENTRY LEVEL DISCUSSION

The distribution system consists of a network that delivers water to homes, businesses and industries for drinking and other uses. The network must have sufficient capacity to meet maximum water demands—plus fire-fighting requirements—and still maintain adequate water pressures throughout the water distribution system.

Water Storage Facilities

The main purpose of a water storage facility is to provide a sufficient amount of water to equalize the daily demands on the water supply system. The storage facility should be able to provide water for both average and peak demands. Storage facilities also help to maintain adequate pressures throughout the entire distribution system.

Other important purposes of water storage include meeting the needs for fire protection, industrial requirements, and to provide reserve storage. During a fire or other type of emergency, sufficient storage should be available to meet fire demands, while still maintaining system pressures. In many communities the water supply system will serve some type of industry. Storage requirements will depend on the type of industry and the flow and pressure demands of the industrial activities of each facility served by the water supply system. Reserve storage requirements depend on standby requirements and alternate sources of water supply. Reserve requirements might be specified by fire insurance regulations. Reserve storage capacity may be provided to meet future growth and development demands of the area being served.

Types of Water Storage Facilities

ELEVATED TANKS. **Elevated tanks** are used primarily to maintain an adequate and fairly uniform pressure in the distribution system or area of the distribution system. They may be installed where the land is flat or on high ground. One limitation of elevated tanks is that the pressure in the distribution system may vary with the water level in the tank. Elevated tanks are used to:

1. Eliminate the need for continuous pumping.
2. Minimize variations in distribution system water pressures due to short-term shutdown of power or pumps.
3. Equalize the water pressure in the distribution system by the proper location of the tanks.
4. Provide a reserve amount of water in storage (especially to meet demands such as fires).
5. Reduce auxiliary power requirements.

STAND PIPES. A **stand pipe** is a storage tank that is set on the ground and has a height greater than its diameter. Stand pipes may be constructed of steel or concrete and are usually located on high ground, near a well field, or at a point in the system where storage is needed. When compared with elevated storage tanks, standpipes are sometimes preferred because they are:

1. Generally easier to maintain.
2. More accessible for observation and sampling to determine quality of stored water.
3. Safer to work around.
4. Less objectionable from an aesthetic viewpoint.

GROUND-LEVEL STORAGE TANKS. **Ground-level storage tanks** are usually constructed of concrete and are either circular or rectangular in shape. They may be buried in the ground or located on the ground surface. Some concrete storage tanks are built with parks, parking lots, or tennis courts on top of them.

PRESSURE TANKS. **Pressure tanks** are storage systems in which a water pump is controlled by the air pressure in a tightly sealed tank partially filled with water. Pressure tanks are used to maintain water pressures in the system and to control pump operation. This type of storage is usually found only at small ground water systems that do not have a large storage facility. The well provides the source of water pumped to the tank. Air in the tank then helps maintain water pressure in the distribution system. Extra care must be taken because of the high pressure in the tank when operating and maintaining these facilities, especially the pressure relief valves.

Operation and Maintenance of Storage Facilities

All storage tanks should be operated according to the design engineer's and manufacturer's instructions. Most distribution systems will establish a steady water usage pattern that the operator should study in order to better anticipate system demands. Extra water is supplied from storage during the hours that consumption is above average and the storage facility is refilled during the hours that consumption is below average. As a result, water levels in the storage facility will drop during peak demands and gain during low demands.

Water level indicators are essential to successful storage facility operation. Devices used for this purpose may be as simple as a float that is connected to an indicator on a gauge that the operator can then read and record. Many other water systems are fully instrumented and automated. At these systems, electronically-controlled instruments are used to measure water levels in storage tanks as well as measure water pressures automatically throughout the distribution system. Whenever water levels or water pressures drop below minimum target levels, pumps will automatically be started and will stay on until the maximum levels that have been set are reached. Operators at automated systems must still inspect and check the measuring instruments for proper measurement and must also make sure the pumps start and stop at the proper levels.

Care must be taken to ensure that runoff water and debris cannot enter the tank and contaminate the water. For this reason, all storage tanks should be covered and located above drainage areas and locations subject to flooding. All **overflow vents** and **air vents** should be screened so that birds, rodents, and debris cannot enter the tank. Vents must be adequate and never be blocked so air can flow freely without any obstruction. Properly functioning vents are essential to prevent pressure from developing in the tank when it is filled or a vacuum being created when it is emptied or partially drained. All storage facilities should be fenced to prevent access by vandals or other unauthorized persons.

Many water systems try to paint the outside of their steel tanks once every five years. A tank's interior coating will generally protect the interior for a three-to-five year period, depending on local conditions. **Routine inspection** is the best way to determine when a tank needs painting. Inspections of storage tanks for flaking, peeling, and rust should be made at least once a year. Special care must be used in the selection of the tank's interior coating. It must be nontoxic and not impart objectionable tastes or odors in the water. The paint should meet American Water Works Association (AWWA) specifications and be listed by the National Sanitation Foundation (NSF) or Underwriter's Laboratories (UL).

Cathodic Protection

The principle of **cathodic protection** in a storage facility is perhaps most easily understood by comparing the tank to a simple glass of water. Imagine a glass of water with rods of two different types of metal in it. If you were to hook a voltage meter between these two rods, you would find that a very low voltage reading (probably less than 1 volt) would be detectable. Voltage is actually the result of a flow

of electrons. Electrons are very small particles with electrical charges. In a storage tank, the impurities in the water (including metals) and the tank wall will often cause this same type of low voltage to be generated. The result, in most cases, is that the tank itself will lose metal into the water as the voltage goes from the tank to the water.

To eliminate this voltage or flow of electrons from the tank to the water, some type of cathodic protection is often installed. The basic theory of cathodic protection is to supply a small amount of D.C. electricity from an outside source through an **anode** into the tank. The anode is usually a aluminum, steel, or magnesium rod about 12 to 15 inches long. The **cathode** in this exchange of electrons is actually the tank itself. The voltage that is set up between the anode and the cathode (the tank) just barely compensates for the voltage between the tank and the water. The D.C. electricity causes the anode to give up metal to the tank replacing the metal that the tank has lost to the water. The anode usually needs replacement at least annually. Cathodic protection is also sometimes used for piping materials.

Pipes and Pipe Couplings

Many different materials are used for distribution system construction, including different types of piping used at different systems and situations. Each type of piping has advantages and disadvantages and serious consideration should be given before making decisions involving material selection.

One consideration when selecting piping is the C-factor of the pipe. The **C-factor**, also called the coefficient of roughness, is an indication of how much friction (slowing down of the flow) is caused by the pipe material itself. The higher the C-Factor, the smoother the inside of the pipe. Even when brand new, all piping materials have some roughness that resists water flow and causes a drop in pressure.

The **pressure rating** of a pipe is also an important consideration. The pipe must be adequate to handle the pressures that it may encounter in the system. Generally, only four classes of pressure ratings will be encountered — 100, 150, 200, and 250 psi (pounds per square inch). Pipes may rupture or be crushed when subjected to internal or external pressures that exceed its ratings. Another characteristic of pipe is the pipe schedule. The **pipe schedule** indicates the pipe's wall thickness. The higher the number, the thicker the wall.

Gray Cast Iron Pipe (CIP)

Gray cast iron pipe (CIP) offers a long service life and is relatively strong. Its main disadvantage is the brittleness of the pipe. Where corrosive soils are a problem, the outside of cast iron pipe should be protected by encasing it in a sleeve of polyethylene plastic or by using standard cathodic protection methods. The interior of unlined cast iron pipe is subject to tuberculation (the pitting and growth of nodules), which reduces the inside diameter and increases the pipe roughness. Methods of preventing tuberculation include a cement or bituminous tar lining as well as reducing the corrosivity of the water. Flanged or mechanical joints are used to connect lengths of pipe. Newer installations are using bell and spigot push-on joints that provide a more watertight seal.

Ductile Iron Pipe (DIP)

Ductile iron pipe (DIP) is very malleable (easily worked) as compared to CIP and has roughly twice the strength. DIP is particularly useful for buried water lines exposed to heavy loads, shocks, and unstable pipe bedding. Because of its strength it is sometimes used for transmission lines (see Chapter 4). Also because of its strength DIP is easier to install than CIP and is easily drilled and tapped for service lines. The disadvantage of DIP is similar to CIP in that it is subject to corrosion from both inside and outside often requiring preventive measures.

Steel Pipe

Steel pipe has been in use in the United States since the mid 1800s and is still often used where pressures are high and large diameter pipe is required. Steel pipe is much stronger than CIP and is slightly stronger than DIP. In addition, it is somewhat lighter than iron pipe. It is relatively inexpensive, easy to install, and is easier to transport. Steel pipe is resistant to shock loads and is somewhat flexible. However, steel pipe will not withstand the external loads that iron pipe will. A negative pressure, or vacuum caused by rapidly emptying steel pipe could result in distortion or total collapse.

Corrosion of steel pipe can often be more severe than in iron pipe. In fact, special linings and coatings may be required to prevent the thin walls of steel pipe from corroding. Bitumastic enamel, a coal-tar material, is commonly used to coat steel pipe for corrosion control. Cement-mortar lining and epoxy lining may also be used for corrosion protection. Caution should be taken to prevent damage to the coatings. Small scars or chips in the coating will result in accelerated corrosion rates in the area of the damage.

Plastic Pipe

ALL PLASTIC PIPING USED IN DISTRIBUTION SYSTEMS MUST HAVE THE NATIONAL SANITATION FOUNDATION (NSF) STAMP INDICATING THAT IT IS APPROVED FOR USE WITH POTABLE WATER.

Plastic pipe is a relatively new pipe material but it is rapidly gaining acceptance in the water distribution field. **Polyvinyl chloride (PVC)** is one of the most popular plastic pipes. Since PVC is non-metallic, it will not corrode from electrolysis or electrochemical action. Soil corrosion will also have very little effect on PVC. Therefore, corrosion resistant coatings, cathodic protection, and other corrosion protection devices are unnecessary. Plastic pipe is generally considered to be the piping material most resistant to corrosion. Another advantage of plastic pipe is that it is relatively light and is easily cut and assembled without the need for special tools.

Disadvantages of PVC include its relatively thin wall design, sometimes causing deflection in larger size pipe. Another drawback to plastic pipe is that ultraviolet rays will cause it to deteriorate. For this reason, plastic pipe should never be stored where it can come into direct contact with sunlight. If it is necessary to leave plastic pipe in an open trench for more than a few days, the pipe should be covered with a small amount of backfill or with black heavy plastic sheeting. Plastic pipe can also be damaged by rocks or other rough material if it is not properly bedded.

Finally, because of its composition, petroleum products will cause severe deterioration in plastic pipe. Therefore, it must be kept at a distance from gasoline storage tanks. The two joints used for PVC are solvent welds for smaller sizes (up to six inch diameter) and the rubber ring push-on joints for larger sizes.

Reinforced Concrete Pipe (RCP)

Reinforced concrete pipe (RCP) is widely used for large distribution and transmission lines. RCP can be classified into two general types: non-steel cylinder type and steel cylinder type.

NON-STEEL CYLINDER RCP. Non-steel cylinder RCP is constructed by forming from one to three cages of reinforcing steel. The cage(s) are then placed in a mold and are coated with concrete. This type of pipe is designed for low pressure applications. Because concrete is a somewhat porous material, non-steel cylinder RCP has a tendency to leak.

STEEL CYLINDER RCP. Steel cylinder RCP, sometimes referred to as pressure pipe, is constructed with a steel cylinder lined with cement mortar. Wire is then wrapped around the structure and a mortar coating is added over it. This pipe is capable of being used in high pressure applications.

RCP is used in large lines due to its high compressive strength and capability of being used under high backfill loads. It is also a low maintenance pipe and is usually not subject to tuberculation, although corrosive water can harm it. Many types of specialized interior coatings are available to ensure water tightness and to prevent any tuberculation. Because of its composition, RCP is resistant to electrolysis and corrosive soil conditions. It is somewhat difficult to tap and may be hard to repair if damaged. Bell and spigot or push-on joints are used for connections.

Asbestos Cement Pipe (ACP)

Asbestos-cement pipe (ACP) was a relatively popular pipe material until people became concerned about breathing asbestos fibers. Because of this serious health concern, ACP is no longer being installed in distribution systems. It is very important for operators to take special care to avoid health hazards when working with any existing ACP in their system, especially if it is being cut or machined. Respirators must be worn whenever there is a possibility of inhaling airborne asbestos fibers.

Valves

Valves have many uses in the distribution system. Valves are commonly used to stop flow, regulate flow, drain lines, or isolate a section of a line. These valves can be operated manually or by motorized controls that may be operated through a remote control circuit. Other types of valves include several specialized valves used to protect the line. These valves usually operate automatically to prevent backflow, bleed-off air, take in air, or prevent water hammer.

Valves should always be opened and closed slowly. All valves in the system should be exercised regularly according to the manufacturer's recommendations (see Chapter 11).

Shutoff and Flow Regulation

BUTTERFLY VALVES. The **butterfly valve** is constructed with a movable disc rotating on a spindle and housed in a valve body. When the valve is fully open it does create some head (pressure) loss, however, this **valve** is easy to operate and can be used to throttle flows. Under higher pressures (above 125 psi) the metal seats may not provide dripless closure. For high pressure situations, a rubber seat is recommended. Butterfly valves are relatively easy to open under high pressure because the pressure pushing on half of the upstream side of the disc tends to force it open, balancing the pressure on the other half which tends to force it closed (See Figure 10.1).

Butterfly Valve

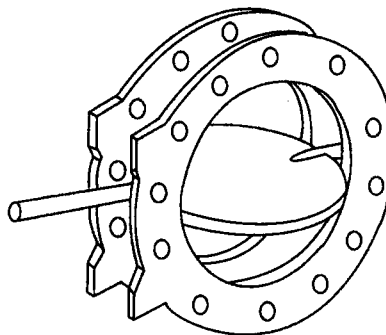


Figure 10.1

Gate Valve

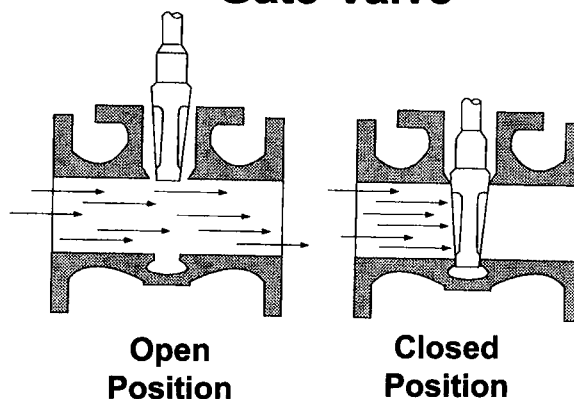


Figure 10.2

Plug Valve

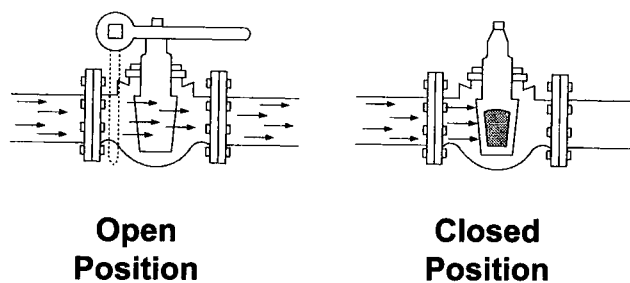


Figure 10.3

GATE VALVES. A **gate valve** uses either an iron disc plate or a gate made of resilient material (material that springs back into shape) that is moved upward and downward in the valve body by a standard operating nut (See Figure 10.2). Gate valves are commonly used in distribution lines to stop flow, isolate sections of a line, and to drain lines. They are very rugged, resistant to leakage, and are suitable for use under high pressure as they create no head loss when fully open. Because of the tremendous pressures that may be exerted against a gate valve, valves 16 inches or larger are usually provided with gearing to make opening the valve easier. In some instances a motor-driven operation is utilized.

There is a special type of gate valve known as a tapping valve. When used with a tapping sleeve it allows connection to the water main without shutting down the line.

GLOBE VALVES. **Globe valves** are often used for ordinary household water faucets. A globe valve has a circular disc that moves down into a port to shut off the flow. Because the water has to make several turns as it moves through the valve, the globe valve will produce high head loss even when fully open. For this reason, globe valves are not suitable where head loss is critical. Globe valves can be used to drain distribution lines if rapid drainage is not important.

PLUG VALVE. The **plug valve** is a machined-surface cylinder with a bored port or passageway. The cylinder is mounted on a shaft inside the valve body. When the shaft is turned 90 degrees the cylinder will move from an open position to a closed position (See Figure 10.3). There are different types of plug valves available. **Multiport plug valves** can be used to divert flow from one pipe branch to another without stopping the flow of water. **Round port plug valves** offer virtually no head loss when fully open and are not easily fouled by water with a high solids content (raw surface water).

Specialized Valves

CHECK VALVES. **Check valves** are valves that operate automatically to prevent backflow from pumps. When a pump is shut off, the discharge line contains water that has been pumped. If there is not a check valve in place the water will drain back through the pump, turning it backward and possibly causing severe damage to the pump and motor. Check valves prevent this type of damage by preventing the backflow. In addition, by keeping the water in the discharge line, it will provide pressure for the pump to work against when it is restarted. This will prevent the pump motor from burning out under no-load conditions. Backflow prevention will also save time and energy because the water that has drained back out of the discharge line won't need to be re-pumped.

PRESSURE RELIEF VALVES. When a flow of water is abruptly stopped, such as might occur when a fire hydrant is quickly shut, it will result in a rapid and sudden increase in pressure in the line that could result in damage in the form of breaks and leaks. This condition is commonly referred to as water hammer (water hammer will be discussed in more detail later in this chapter). Water hammer can be controlled by using **pressure relief valves**. These valves have a spring tension pre-set to a certain operating pressure. If the operating pressure is exceeded the valve will open, allowing water to escape thus preventing the buildup of excessive pressures. The pressure relief valve is used primarily on small pipelines. It is necessary to use surge tanks to protect large pipelines due to the excessive pressures that are encountered.

AIR AND VACUUM RELIEF VALVES. In long distribution lines air can accumulate at the high points in the line. This causes a condition referred to as air binding. Air binding is the partial blockage of flow due to the entrapped air. An **air and vacuum relief valve** can prevent air binding in distribution systems by automatically venting the unwanted air. Quite frequently, pipelines must be drained for routine maintenance or repair. As the water drains out through drainage valves a vacuum can be created inside the pipeline. If the vacuum becomes great enough it can cause a line to completely collapse. The air and vacuum relief valve will allow air into the pipeline to occupy the volume that was filled by water, thus preventing the formation of a vacuum. This will not only prevent pipeline collapse but will also reduce the amount of time required to drain the line.

Pumps

Pumps are also a very important part of the distribution system. Pump installations can vary in size from small, single pumps that deliver a few gallons per minute, to large, multiple-pump installations delivering thousands of gallons per minute.

Only one general category of pump is commonly used in distribution systems. These are called **centrifugal pumps**. Centrifugal pumps operate by the centrifugal force created when an impeller rotates inside its casing. They cannot operate unless the impeller is submerged in water. Therefore centrifugal pumps should NEVER be started until they are properly primed. The **volute pump** is the most common type of centrifugal pump used in water distribution systems (see also Chapter 11).

Hydrants

Hydrants are an important part of the distribution system that are used to fight fires and flush pipelines. Hydrants used for fire protection are usually located at street intersections so that they are accessible from four directions. These hydrants should always be spaced close enough that in the case of a fire the hose lines would not exceed 500 to 600 feet. In high value districts, fire hydrants might be spaced as close as 150 feet apart. If the hydrant is designed to fight fires, it will have a four and one-half (4.5) inch pumper outlet. To avoid collapsing lines when attached to a pumper unit, these hydrants MUST always be installed with service lines that are a minimum of six inches in diameter.

Hydrants with outlets of only two and one-half (2.5) inches are used only for flushing lines or for filling tankers and rural fire trucks. These smaller hydrants might be used at virtually any location in the distribution system, and are often found on dead-end mains for flushing purposes.

Flow Measurement

Flow measurement is one of the most useful measurements that an operator will make. It is important that operators know exactly how much water is being delivered to the treatment plant or to the

distribution system. Flow measurement will be used to determine the correct dosage rates for chemical treatment, to measure the loading on individual treatment units, to complete reports to local and state agencies, and to make sure that the community is being supplied the necessary amount of water.

Some meters are used to measure large flow volumes, such as the amount of water supplied to a community. Other meters are used to measure small flows, such as chlorine feed rates, chemical feed rates, and flows to individual households. This discussion will concentrate on the large-volume flow meters used in water distribution systems.

Pressure Pipe Flow Measurement

VENTURI METERS. **Venturi meters** fall into a category of meter known as pressure differential meters. The meter itself is an enclosed section of pipe shaped like an hourglass to create a throat and is equipped with pressure taps for manual or automatic sensing of pressure at two points. The rate of flow through a Venturi meter is determined by comparing the low pressure at the throat with the high pressure upstream of the throat. The difference in pressure can be converted to a flow rate in gpd. The flow conversion is usually done automatically using instruments that electronically convert the differential to a flow signal. The primary advantage of the Venturi meter is that it will perform reliably and little maintenance is required. The meter will create some head loss, but the loss is relatively small considering the advantages of this meter and its simplicity of use.

TURBINE METERS. **Turbine meters** for large flows are usually bypass meters, in which a small portion of the flow in the main pipeline is diverted through a bypass chamber. The diverted flow, which will vary in proportion to the main flow, turns a turbine wheel. The turbine wheel generates an electric current, which is also proportional with the main flow. This current is converted into a flow rate. Turbine meters are very accurate, and the bypass type will produce little head loss. However, bypass meters can sometimes be difficult to maintain.

PROPELLER METERS. The **propeller meter** uses a propeller instead of a turbine but otherwise operates on the same principle. The propeller is usually mounted in a bypass chamber similar to the turbine meter. Head loss with a bypass propeller meter is less than the turbine type. However, propeller meters are generally less accurate.

MAGNETIC FLOW METERS. The **magnetic flow meter** appears to be only a short section of flanged pipe. However, inside the pipe is a smooth insulating liner. Between this liner and the pipe are two magnetic coils. When an electric current is passed through the coils an electromagnetic field is generated around the pipe. The water flowing through the magnetic field induces a small electric current that increases in proportion to an increase in the flow of water through the pipe. The electric current that is produced is measured and converted electronically to a measurement of flow rate. Magnetic meters can be obtained in many pipe sizes. The primary advantage to the magnetic flow meter is that no head loss is created because there are no obstructions to flow in the section of pipe. The main disadvantage is high cost.

State Construction Standards

According to Oklahoma standards, all water lines must be laid to provide a **minimum horizontal separation** of 10 feet from existing or proposed sewer lines or storm sewers. A **minimum vertical separation** of 24 inches (2 feet) from the outside edge of a water line to the outside edge of a sewer line is also required at all pipe crossings. All water lines must also be located a minimum of 10 feet horizontally from other utilities including gas lines and buried electric lines. PVC water lines must be located a minimum of 50 feet horizontally from any gasoline storage tank.

All distribution systems must be designed to maintain a **minimum pressure** of 25 psi (pounds per square inch) at ground level at all points in the system and under all conditions of flow. A minimum water line size of six inches in residential areas and eight inches in high value districts is recommended where cross connecting mains are not more than 600 feet apart. Rural water systems that provide domestic water only and do not have full fire protection may be allowed to have a minimum size water main of 2 inches if the required pressure can be maintained.

A **minimum earth cover** of 30 inches or other sufficient insulation material is required for all water lines in order to prevent freezing. Select **backfill material** (free of large clods, stones, or other unstable material) must be used to fill at least six inches under the pipe, around the pipe, and to a sufficient height above the pipe to provide adequate support and protection.

Disinfection in the Distribution System (see also Chapter 7)

Whenever any part of the distribution system is subject to contamination, such as during repairs, additions, or modifications, disinfection procedures utilizing chlorine must be used before returning it to service. Although chlorine gas or chlorine bleach might sometimes be used, the form of chlorine most commonly used to disinfect sections of the distribution system is calcium hypochlorite $\text{Ca}(\text{OCl}_2)$, also known as HTH. As discussed in other chapters, HTH should be used with great care and according to the manufacturer's instructions.

The appropriate procedure to be used for disinfection depends on which part of the distribution system is involved and other factors. More information about "batch treatment" with chlorine can be found in the appropriate sections of the *Suggested References for Study* listed in this chapter (or from similar references). The most complete directions for disinfecting water mains, water storage facilities, and wells are listed in standards developed by the **American Water Works Association (AWWA)** and approved by the **American National Standards Institute (ANSI)**. For information on how to obtain these documents see the "Reference Source Sheet" at the back of this study guide.

Disinfection of New or Repaired Mains

Disinfection of new, cleaned, or repaired distribution lines is always required except when a repair is made with the line continuously full of water and under pressure. Although several methods are approved by AWWA and ANSI, probably the most commonly used method for disinfecting new

lines is to dose the lines with a **50-100 mg/L chlorine for a contact time of 24 hours**. Another approved method that is especially appropriate for disinfecting cleaned or repaired water lines is to increase the dosage to as much as 300 mg/L while reducing the contact time to as little as 15 minutes. In emergency repairs, any new piping or fittings used are sometimes disinfected by thoroughly (yet carefully) swabbing or spraying the inside of the mains with a very high concentration of chlorine (10,000 mg/L) just before they are installed.

In the case of new lines, **two bac-t samples** must be collected on successive days that are reported safe (no coliform bacteria found) before the line can be put into service. Bac-t samples should also be taken from lines that have been cleaned or repaired. If one of these samples is positive, daily sampling must continue until two consecutive safe samples have been obtained.

One of the most effective steps in disinfecting new or repaired water lines is to do everything possible to prevent them from becoming contaminated in the first place. Install **watertight plugs** in all open-end joints whenever the trench is unattended for any length of time (unless ground water would cause the closed pipe to float). All pipes, fittings, valves and other items that will not be disinfected by the filled line must be pre-cleaned and disinfected. **Clean tools** should also be used. Each service line should be disinfected before being connected to a water main.

Thorough **flushing** is also important to help remove contamination introduced during repairs. If valve and hydrant locations permit, flushing toward the work location from both directions is recommended. Flushing should be started as soon as the repairs are completed and should be continued until discolored water is eliminated.

Disinfection of Storage Facilities

There are several approved methods for disinfection of storage tanks. The best method to use depends on the particular situation. After the chlorination procedure is completed and before the tank is put into service, bac-t samples from the full facility should always be collected to ensure the tank has been sufficiently disinfected. Brief summaries of some of the approved methods used in different situations are provided below.

1. Scrubbing the walls and floors with a solution containing 100 mg/L chlorine. The tank is then rinsed and filled with water containing 2 mg/L and allowed to stand. If after eight hours has passed, a chlorine residual of 1 mg/L remains, the reservoir is ready for use.
2. Chlorination of the full storage facility with a chlorine dose sufficient to allow a 10 mg/L chlorine residual. The contact time for this method should be at least six hours if chlorinated uniformly using chlorine gas or at least 24 hours if using HTH or liquid bleach.
3. Filling approximately 5 percent of the total storage volume with water containing a 50 mg/L chlorine dosage and holding for at least six hours. The remainder of the tank is then filled to the overflow level and a free chlorine residual of 2 mg/L is maintained for at least 24 hours.

Heavily chlorinated water produced by disinfection procedures must be properly handled. In the case of storage facilities, heavily chlorinated water is sometimes able to be diluted as it flows out of the tank and into the rest of the system. Another possible means of disposal is sanitary sewers. If this alternative is used, there should be adequate dilution and travel time so that there will be no chlorine residual when the water reaches the wastewater treatment plant. Also, the operators of the wastewater plant should be notified in advance. If a storm sewer is used, no chlorine residual should reach the receiving waters. Land disposal may be acceptable in some situations if percolation rates are high. Finally, if there is any question of whether the water could cause any damage to persons, property, or the environment, an adequate amount of a reducing agent, such as sodium sulfite (Na_2SO_3) or sodium bisulfate (NaHSO_3) should be used to neutralize the chlorine.

Common Distribution System Problems

A **cross connection** is the connection between a potable (drinking) water supply and a water source that is either of unsafe or unknown quality. The best prevention for all cross connections is an **air gap**. A good rule of thumb is to provide a gap at least two times the width of the inside diameter of the pipe. Another less reliable but adequate device used in some situations is the reduced pressure principle (RPP) device. Double check valves are normally NOT acceptable. Vacuum breakers do not provide adequate protection in most situations. All distribution system operators should be constantly alert for situations where cross-connections are likely to exist. Operators must also watch for any illegal bypassing of backflow prevention devices.

Another common problem encountered in distribution systems is **galvanic corrosion**. This corrosion is caused by the connection of two different types of metal that react chemically when they are in contact with each other. Certain combinations of metals are more likely to react when connected than others.

As mentioned earlier, **water hammer** occurs when a flow of water is abruptly stopped. The sound created is similar to someone hammering on a pipe. Whenever a valve position is changed quickly, such as might occur when a fire hydrant is quickly shut, the water pressure in a pipe will increase and decrease very quickly. This rise and fall in pressure causes water hammer and can do serious damage to the distribution system in the form of breaks and leaks. Actually, any sudden change in the water pressure could result in water hammer. This includes when pumps are turned on or off. Operators can help protect against water hammer damage by using pressure relief valves and surge tanks. Even with protective equipment, valves should always be opened and closed slowly.

Water systems can experience significant revenue loss due to inaccurate meters. Meters very rarely over-register but older meters tend to **under-register**. Water systems should establish a schedule in which small meters are tested for accuracy once every five to ten years, and large ones every one to four years. It is also a good idea to test new meters before installation.

In too many systems, there has been a tendency to not keep current maps of the various components of the system. As a result, operators may not know or even be able to find the construction details in their distribution system. Comprehensive maps as well as sectional plats should be used. All

important structures should be shown, including water intakes, treatment plants, wells, reservoirs, mains, hydrants, and valves. Leak survey maps are also used that show the locations where leaks have been found and pinpoint problem areas. All maps should show the system “**as built.**” This means that whenever there is any change whatsoever in the original construction plans, the maps should be updated to clearly reflect these changes.

Special Safety Considerations (see also Chapter 12)

Probably the two most likely causes of serious injury or death to distribution system operators are contact with dangerous gases and trench cave-ins. Chapter 12 of this study guide provides a brief introduction to these and some of the other many potential dangers present in the distribution system as well as basic guidelines on how to avoid these dangers. In addition, personal study and on-the-job training (OJT) along with strict obedience to all safety-related requirements is absolutely essential to reduce the chances of injury or death among distribution system operators.

SUGGESTED REFERENCES FOR STUDY

California State University, Sacramento - **Water Distribution System Operation & Maintenance**

Chapter 1	The Water Distribution System Operator
Chapter 2	Storage Facilities
Chapter 3	Distribution System Facilities
Chapter 4	Water Quality Considerations in Distribution Systems
Chapter 5	Distribution System Operation & Maintenance

American Water Works Assn. - Reference Handbook: Basic Science Concepts and Applications

Hydraulics Section

OTHER STUDY SUGGESTIONS

- Be familiar with basic distribution system troubleshooting and what to look for when inspecting.
- Study diagrams of water storage tanks and be familiar with the purposes of fixtures and related equipment.
- Check the effect of varying water levels on pump controls and level indicator equipment.
- Study definitions related to corrosion control such as anode, cathode, electrochemical reaction, etc.
- Study the two types of cathodic protection.
- Be familiar with the pipes and fixtures used by the water distribution system in your community.
- Study pipe types and abbreviations such as ACP, DIP, CIP, RCP, PVC.
- Be able to identify undesirable water characteristics that would result from typical distribution system problems such as cross connections, corrosion, biological growth, dead end lines etc.
- Be able to describe meter types and to correctly interpret meter readings.
- Be able to identify valve types from diagrams and the application/operation of each valve type.
- Study valve and hydrant placement in the distribution system.
- Diagram a typical service connection and label all components.
- Study a diagram of a standard automatic valve, go through the operating cycle of the valve.
- Practice calculating storage tank capacities from dimensions for rectangular and cylindrical tanks.
- Practice calculating math problems on the relationship of feet of head to pounds per square inch (psi) in a diagram of a distribution system. Also practice converting psi to feet of head.
- Practice calculating chlorine dosages for disinfecting new or repaired lines or storage tanks.
- Study the contact times and residuals required for different dosage levels and situations.
- For the most complete directions for disinfecting water mains, water storage facilities and wells, obtain and study a copy of the American National Standards Institute (ANSI) Standards available from the American Water Works Association (AWWA).

SAMPLE QUESTIONS

Class D

The minimum horizontal separation required between sewer lines and water lines is

- A. 5 feet
- B. 8 feet
- C. 10 feet

Class C

A 200 foot run of 8 inch I.D. pipe will contain approximately how many gallons of water?

- A. 375
- B. 414
- C. 521

Class B

At the same flow, friction losses in a 12 inch line compared to a six inch line will be

- A. less
- B. the same
- C. a little more
- D. twice as much

Class A

The static pressure on a fire hydrant is 75 psi. A six inch line is attached to the hydrant. What is the overall pressure against the flange between the pipe and the hydrant?

- A. 4744 lbs
- B. 2121 lbs
- C. 1433 lbs
- D. 878 lbs
- E. 228 lbs

Chapter 11

Maintenance

INTRODUCTION TO CHAPTER 11

Maintenance procedures will vary for different pieces of equipment found at different systems. Therefore, questions regarding details of specific maintenance procedures are not asked on certification exams. Although you will not need to know specific procedures for exams, they must be understood by operators actually working with the equipment. On-the-job training (OJT) is essential for learning this information.

Questions of a general nature regarding the basic operation and maintenance of common pieces of equipment will be found on certification exams.

SUGGESTED STUDY GUIDELINES

Class D

Be prepared to answer questions concerning:

- The importance and the basic aspects of a good preventive maintenance program
- The names and purposes of the two types of maintenance cards that are kept for equipment
- What information should be recorded for each piece of equipment
- Where to find the most complete information on maintenance for a piece of equipment
- The condition under which centrifugal pumps should never be operated
- The condition under which reciprocating pumps should never be operated
- The special safety considerations when working around electrical or mechanical equipment

Class C

Be prepared to answer questions concerning guidelines listed for Class D certification and:

- The fundamentals of electricity (including how much you should do)
- The basic preventive maintenance procedures for electric motors including
 - lubrication
 - ventilation
 - bearing and motor temperature
 - amperage measurement
 - controls and wiring (including how much you should do)
- The basic procedures for proper alignment and maintenance of couplings and power drives
- How centrifugal and positive displacement pumps operate including starting, stopping, and valve control
- How to identify typical problems with centrifugal and positive displacement pumps
- The basic routine and preventive maintenance for pumps including inspection (what to look and listen for)

- packing and seals
 - lubrication
 - replaceable parts
 - The basic routine and preventive maintenance for compressors
 - The basic routine and preventive maintenance for valves
 - How to perform calculations involving volume and pumping rates
- Be prepared to answer other questions that require additional personal study

Class B and Class A

Be prepared to answer questions concerning guidelines listed for lower levels of certification and:

- The basic categories of instrumentation
- The basic operation and maintenance of instrumentation systems
- The basic descriptions and operating principles of the following controls
 - control panel (diagram of simple panel)
 - mercury floats
 - probes
 - bubbler
- How to develop a comprehensive maintenance program for a water treatment plant
- How to troubleshoot basic problems with hypochlorinators, gas chlorine ejectors, and regulators used for chlorine gas
- The preventive maintenance procedures for wells and repairs including casing and screen maintenance
- The basic maintenance procedures for distribution systems including valves, hydrants, storage facilities and other distribution system repairs and maintenance
- How to develop a program for regular distribution line cleaning and preventive maintenance
- How to develop and maintain a maintenance recordkeeping system that will provide information to protect equipment warranties and prepare budgets
- How to calculate horsepower and kilowatts

Be prepared to answer other questions that require a combination of actual experience and additional personal study

ENTRY LEVEL DISCUSSION

An important duty of an operator is plant and distribution system maintenance. A successful maintenance program will cover everything from mechanical equipment to the care of plant grounds, buildings and structures.

Mechanical maintenance is of prime importance as the equipment must be kept in good operating condition in order for the plant to maintain peak performance. Manufacturers usually provide the most complete information on the mechanical maintenance of their equipment. You should thoroughly read their literature on your plant equipment and understand the procedures. Contact the manufacturer or the local representative if you have any questions. Follow the instructions very carefully when performing maintenance on equipment. You also must recognize tasks that may be beyond your capabilities or repair facilities, and you should request assistance when needed.

For a successful maintenance program, your supervisors must understand the need for and benefits from equipment that operates continuously as intended. Disabled or improperly working equipment is a threat to the quality of the plant output, and repair costs for poorly maintained equipment usually exceed the cost of proper maintenance.

Preventive Maintenance Records

Preventive programs help operating personnel keep equipment in satisfactory operating condition and aid in detecting and correcting malfunctions before they develop into major problems.

A frequent occurrence in a preventive maintenance program is the failure of the operator to record the work after it is completed. When this happens the operator must rely on memory to know when to perform each preventive maintenance function. As days pass into weeks and months, the preventive maintenance program is lost in the turmoil of everyday operations.

The only way an operator can keep track of a preventive maintenance program is by **good recordkeeping**. Whatever record system is used it should be kept up to date on a daily basis and not left to memory for some other time. Equipment service cards are easy to set up and require little time to keep up to date.

Equipment Service Cards & Service Record Cards

An **equipment service card** or “master card” should be prepared for each piece of equipment in the plant and distribution system. Each card should have the name of the piece of equipment clearly written on it, such as “Raw Water Intake Pump No.1.” In addition, each card should include the following information.

1. List each required maintenance service with an item number.
2. List maintenance services in order of frequency of performance. For instance, daily service might be shown as items #1, #2, and #3 on the card; weekly items as #4 and #5; monthly items as #6, #7, #8, and #9; and so on.
3. Describe each type of service to be performed.

Make sure all necessary inspections and services are shown. Specific references should be listed for each of the items. The frequency of service and the day or month that service is due should also be listed for each item. See the *Suggested References for Study* in this chapter to find examples of how a service card can be set up to contain this information. Service card information may be changed to fit the needs of your plant or particular equipment as recommended by the equipment manufacturer. Make sure the information on the cards is complete and correct.

The **service record card** should have the date and work done, listed by item number and signed by the operator who performed the service. Some operators prefer to keep both cards clipped together, while others place the service record card near the equipment.

When the service record card is filled, it should be filed for future reference and a new card attached to the master card. The *equipment service card* tells what should be done and when to do it, while the *service record card* is a record of what you did and when you did it.

In addition to the use of service cards for scheduling and tracking maintenance procedures, many systems now use computer programs that have been created especially for this purpose.

Other Maintenance Records

All of the information on the nameplate of a piece of equipment including the serial and/or model numbers should be recorded and placed in a file for future reference. Many times the nameplate is painted, corroded, or missing from the unit when the information is needed to repair the equipment or replace parts. The date of installation and service startup for each piece of equipment should be logged and filed. A parts inventory is also essential for key pieces of equipment.

Buildings and Plant Grounds

Building maintenance programs depend on the age, type, and use of a building. New buildings require a thorough check to be certain essential items are available and working properly. Older buildings require careful watching and prompt attention to keep ahead of leaks, breakdowns, replacements, and changing uses of the building. Attention must be given to the maintenance requirements of many items in all plant buildings. For safety's sake, periodically check all stairways, ladders, catwalks, and platforms for adequate lighting, head clearance, and sturdy and convenient guardrails. Protective devices should be around all moving equipment. Whenever any

repairs alterations or additions are being built, avoid building accident traps such as pipes laid on top of floors or hung from the ceiling at head height which could create serious safety hazards.

All tools and plant equipment should be kept clean and in their proper place. Floors, walls and windows should be cleaned at regular intervals. A treatment plant kept in a neat, orderly condition makes a safe place to work and aids in building good public and employer relations. Plant grounds that are well groomed and kept in neat condition will greatly add to the appearance of the overall plant area. This is also important to the operator in building good public relations with plant neighbors as well as the general public.

Electrical Equipment

THIS DISCUSSION SHOULD NOT BE CONSIDERED A SOURCE OF TECHNICAL INFORMATION FOR ACTUAL OPERATION AND MAINTENANCE PROCEDURES. IT SHOULD BE USED ONLY AS A BRIEF INTRODUCTION OR REVIEW OF GENERAL INFORMATION.

ONLY QUALIFIED AND AUTHORIZED PERSONS SHOULD WORK ON ELECTRICAL EQUIPMENT OR CIRCUITRY

Fundamentals of Electricity

In all water systems, there is a need for the operators to know something about electricity. However, very few operators, even those operators who specialize in maintenance, ever do the actual electrical repairs or troubleshooting because it is such a highly specialized field. Unqualified persons can severely injure themselves and damage costly equipment.

VOLTS. Voltage (also known as electromotive force or E.M.F.) is the electrical pressure available to cause a flow of current (amperage) when an electrical circuit is closed. This pressure can be compared with the pressure or force that causes water to flow in a pipe. Pressure is required to make the water move. The same is true of electricity. A force is needed to push electricity or electric current through a wire. This force is called voltage. There are two types of current: Direct Current (D.C.) and Alternating Current (A.C.)

DIRECT CURRENT. Direct current (D.C.) flows in one direction only and is essentially free from pulsation. Direct current is seldom used in water systems except in electronic equipment, some control components of pump drives and stand-by lighting.

ALTERNATING CURRENT. An **alternating current (A.C.)** is one in which the voltage and current periodically change direction and amplitude. In other words, the current goes from zero to maximum strength, back to zero and to the same strength in the opposite direction. Most A.C. circuits have a frequency of 60 cycles per second. Alternating current may be classified as one of three types.

1. Single-phase
2. Two-phase
3. Three-phase (sometimes called polyphase)

The most common of these are single phase and three phase. Single-phase power is found in lighting systems, small pump motors, various portable tools and throughout residential homes. This power is usually 120 volts and sometimes 240 volts. Single-phase means that only one phase of power is supplied to the main electrical panel at 240 volts and it has three wires or leads. Two of these leads have 120 volts each and the other lead is neutral.

Three-phase power is generally used with motors and transformers found in water systems. Generally, motors above two horsepower are three-phase. Three-phase power usually is brought in to the point of use with three leads. There is power on all three leads. If a fourth lead is brought in, it is a neutral lead. Incoming power goes through a meter and then some type of disconnecting switch such as a fuse or circuit breaker.

FUSE. A **fuse** is a protective device having a strip or wire of fusible metal which, when placed in a circuit, will melt and break the electrical circuit when subjected to an excessive temperature. This temperature will develop in the fuse when a current flows through the fuse in excess of what the circuit will carry safely.

CIRCUIT BREAKERS. The **circuit breaker** is another safety device and is used in the same place as a fuse. Most circuit breakers consist of a switch that opens automatically when the current or the voltage exceeds or falls below a certain limit. Unlike a fuse that has to be replaced each time it “blows,” a circuit breaker can be reset after a short delay to allow time for cooling.

OVERLOAD RELAYS. Three-phase motors are usually protected by **overload relays**. This is accomplished by having heater strips, bimetal, or solder pots which open when overheated, stopping power to the motor. Such relays are also known as “heaters” or “thermal overloads.”

AMPS. Amperage is the measurement of current or electron flow and is an indication of work being done or “how hard the electricity is working.” The **amp** or **ampere** is the practical unit of electric current. The actual definition of an ampere is the current produced by a pressure of one volt in a circuit that has a resistance of one ohm. Most electrical equipment used in water systems is labeled with nameplate information indicating the proper voltage and allowable current in amps.

OHM. The **ohm** is the unit of measurement for electrical resistance.

WATTS AND KILOWATTS. **Watts** and **kilowatts** are the units of measurement of the rate at which power is being used or generated. 1000 watts is equal to 1 kilowatt. Power requirements are expressed in kilowatt hours. 500 watts for two hours or one watt for 1000 hours equals one kilowatt hour. The electric company charges so many cents per kilowatt hour.

Mechanical Maintenance

THIS DISCUSSION SHOULD NOT BE CONSIDERED A SOURCE OF TECHNICAL INFORMATION FOR ACTUAL OPERATION AND MAINTENANCE PROCEDURES. IT SHOULD BE USED ONLY AS A BRIEF INTRODUCTION OR REVIEW OF GENERAL INFORMATION.

The first step for any type of mechanical equipment maintenance is to get the manufacturer's instruction book and read it completely. Each piece of equipment is different and the particular manufacturer will provide its recommended maintenance schedules and procedures. If you do not have an instruction booklet, you might obtain one by contacting the manufacturer's representative in your area.

Pumps

Pumps serve many purposes in water systems. They may be classified by the character of the material handled such as raw or filtered water. Or, they may relate to the conditions of pumping: high lift, low lift, or high capacity. They may be further classified by principle of operation, such as centrifugal, propeller, reciprocating, and turbine.

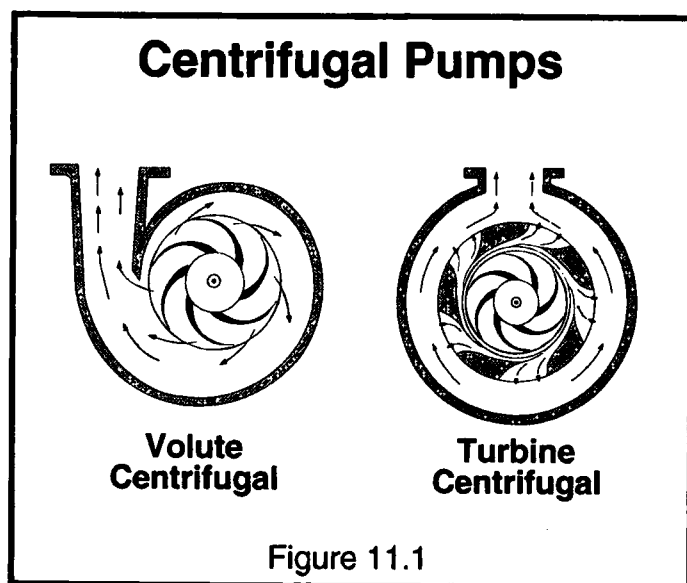
The type of material to be handled and the function or required performance of the pump vary so widely that the design engineer must use great care in preparing specifications for the pump and its controls. *Similarly, the operator must conduct a maintenance and management program adapted to the particular characteristics of the equipment.*

Two very commonly used types of pumps are centrifugal pumps and reciprocating pumps.

As discussed in Chapter 10, **centrifugal pumps** consist of an impeller rotating in a casing. The impeller (a paddle wheel device) is supported on a shaft that is, in turn, supported by bearings. Liquid coming in at the center (eye) of the impeller is picked up by the vanes and by the rotation of the impeller and then is thrown out by centrifugal force into the discharge. Centrifugal pumps cannot operate unless the impeller is submerged in water. Therefore they should NEVER be started until they are properly primed.

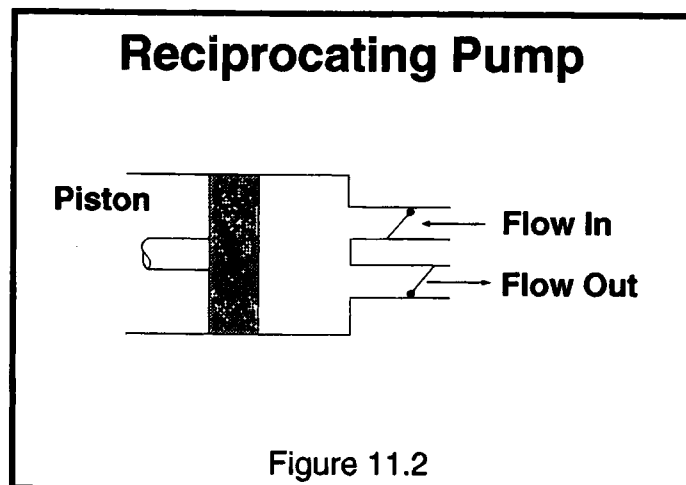
One common type of centrifugal pump is the **volute centrifugal pump** (see *Figure 11.1*). The term "volute" comes from the spiral-shaped interior of the casing. As the impeller spins the centrifugal force created throws the water outward into the volute. This creates a partial vacuum at the center of the impeller, which draws more water into the pump from the suction opening. Pressure will increase as more and more water is thrown into the volute, which forces water around the spiral and out of the discharge. The volute shape of the casing changes the high velocity and low pressure head of the water leaving the impeller to a lower velocity and higher pressure head at the discharge. The movement of water during pumping is radially outward, away from the shaft.

Another type of centrifugal pump is the **turbine centrifugal pump**. In this pump the impeller is mounted at the center of a circular casing. The pump has stationary diffuser vanes fixed to the inside



of the casing that convert the velocity of the outwardly-thrown water to pressure head. Turbine pumps are generally considered to be more efficient than the volute pump. Because of their efficiency they are especially useful in high-head applications. However, the turbine pump has small clearances between the impeller and diffuser vanes and can be easily fouled by dirt.

The word “reciprocating” means “moving back and forth,” so a **reciprocating pump** is one that moves water or sludge by a piston that moves back and forth (see Figure 11.2). Two check valves alternately open and close as the piston cycles. For obvious reasons, positive displacement pumps such as reciprocating pumps or piston pumps should NEVER be operated against a closed discharge valve.



Packing is used to keep air from being drawn into pumps. Water leakage rate around packing should be 20-60 drops per minute. Packing should be replaced periodically depending upon conditions of operation. Use the packing recommended by the pump manufacturer. The stagger of the packing joints can be determined by dividing 360° by the number of rings of packing used. Many pumps being produced today

use mechanical seals in place of packing. Mechanical seals serve the same purpose as packing; that is, they prevent leakage between the pump casing and the shaft.

Bearings should usually last for years if serviced properly and used in their proper application. There are several types of bearings used in pumps. These include ball bearings, roller bearings, and sleeve bearings. The type of bearing used in each pump depends on the manufacturer’s design and application. Whenever a bearing failure occurs, the bearing should be examined to determine the cause and then, if possible, eliminate the problem.

Unless **couplings** between the driving and driven elements of a pump or any other piece of equipment are kept in proper alignment, breaking and excessive wear in the pump and/or the motor can be the result. Burned out bearings, sprung or broken shafts, or ruined gears are some of the damages caused by misalignment. To prevent outages and the expense of installing replacement parts, regularly check the alignment of all equipment.

Many large systems have fully equipped machine shops staffed with competent mechanics. But for smaller plants, adequate machine shop facilities for rebuilding pumps and other mechanical equipment often can be found in the community. Most pump manufacturers maintain pump repair departments where pumps can be fully reconditioned.

Electric Motors

Electric motors are the machines most commonly used to convert electrical energy into mechanical energy. A motor usually consists of a stator, rotor, end bells, and windings. The rotor has an extending shaft that allows a machine to be coupled to it. Motors are of many different types. The most common of these is the squirrel cage induction motor. Some pumping stations use wound rotor induction motors when speed control is needed.

Electric motors generally require little attention and under average operating conditions the factory lubrication of the bearing will last approximately one year. Check with the manufacturer for the average number of operating hours for bearings. Pumps, motors, and drives should be oiled and greased in strict accordance with the recommendations of the manufacturer.

Most of the trouble encountered with electrical motors results from bad bearings, shorted windings due to insulation breakdown, or excessive moisture. The amperage and voltage readings on motors should be taken periodically by qualified persons to ensure they are operating properly.

A motor starter is a device or group of devices that are used to connect the electrical power to a motor. These starters range in complexity from manually controlled starters such as on/off switches to automatically controlled magnetic starters using timers and coils.

Compressors

Compressors are commonly used in the operation and maintenance of water treatment plants. A compressor is a device that is used to increase the pressure of air or gas. They can be of a very simple type such as the diaphragm or bellows type or extremely complex rotary, piston, or sliding vane type compressors. A compressor usually has a suction pipe with a filter and a discharge pipe that goes to an air receiver or storage tank. With proper maintenance a compressor should give years of trouble-free service.

Valves

Valves are the controlling devices placed in piping systems to stop, regulate, check, divert, or otherwise modify the flow of liquids or gases. There are specific valves that are more suitable for certain jobs than others. A brief introduction to the several different types of valves and their applications was offered in Chapter 10. All valves require regular maintenance as specified by the manufacturer to operate properly and minimize chance of failure.

Most valves suffer from lack of operation rather than from wear. A comprehensive program of inspection, exercising and maintenance of valves on a regular basis can help water systems avoid potentially serious problems when the need to use a valve arises. In general, it is recommended that all valves be exercised at least once a year. Exercising the valves verifies valve location, determines whether or not the valve works and extends valve life by helping to clean encrustations from the valve seats and gates. Valves should be exercised in both directions fully closed and fully opened and the number of turns and direction of operation recorded. Any valves that do not completely open or close should be replaced. Valves that leak around the stem should be repacked.

Chlorinators

All **chlorinators** can give continuous trouble-free operation if properly maintained and operated. Each chlorinator manufacturer provides with each machine a maintenance and operations booklet with line diagrams showing the operation of the component parts of the machine. Manufacturer's instructions should be followed for maintenance and lubrication of your particular chlorinator. Operators should never attempt maintenance tasks that they are not qualified to perform. There are considerable possibilities for serious accidents when operating or maintaining chlorinators.

Other Types of Mechanical Equipment

Many other types of equipment including flow metering devices, coagulation/flocculation equipment and other moving parts associated with various treatment processes also require regular maintenance. Manufacturer's and/or design engineer's instructions should be consulted for specific information on proper maintenance of each piece of equipment. Also helpful are operation and maintenance manuals and/or schedules that have been developed for your water system.

Special Safety Considerations (see also Chapter 12)

DO NOT OPERATE ELECTRICAL SYSTEMS OR CONTROLS UNLESS YOU ARE QUALIFIED AND AUTHORIZED TO DO SO. Even when qualified and authorized, caution should be used when operating electrical controls, circuits and equipment. Operate only those switches and electrical controls installed for the purpose of your job. **DO NOT OPEN OR WORK INSIDE ELECTRICAL CABINETS OR SWITCH BOXES UNLESS ABSOLUTELY NECESSARY AND ONLY IF YOU ARE QUALIFIED TO PERFORM THESE VERY SPECIALIZED SKILLS.**

Be aware of moving equipment, especially reciprocating equipment and rotating shafts. Guards over couplings and shafts should be provided and should be in place at all times. Do not wear loose clothing, rings, or other jewelry around machinery. Long hair must be secured. Wear gloves when cleaning pump casings to protect your hands from dangerous sharp objects.

When starting rotating equipment after a shutdown, everyone should stand away from rotating shafts. Dust and oil and loose metal may be thrown from shafts and couplings, or sections of a long vertical shaft could come loose and whip around, especially during start-up of equipment.

All equipment that could unexpectedly start-up or release stored energy must be locked out or tagged out to protect against accidental injury to personnel. Step-by-step instructions for lockout-tagout can be found in the next chapter of this study guide (Chapter 12) .

SUGGESTED REFERENCES FOR STUDY

California State University, Sacramento - **Water Treatment Plant Operation - Vol. 2**

Chapter 18 Maintenance
(especially sections 18.1, 18.2)

Chapter 19 Instrumentation

California State University, Sacramento - **Small Water System Operation & Maintenance**

Chapter 3 Wells

California State University, Sacramento - **Water Distribution System Operation & Maintenance**

Chapter 5 Distribution System Operation & Maintenance

OTHER STUDY SUGGESTIONS

- Study the chapters on mechanical maintenance of pumps, motors, couplings, and valves in all reference manuals available to you.
- Be able to draw a diagram of a centrifugal pump with its internal components, valves and pressure gauges. Know the location and function of the packing/stuffing box, volute wear rings, impeller, shaft sleeves, bearings.
- Be able to diagram a positive displacement pump with check valves and piping.
- Study basic maintenance procedures and intervals for pumps including lubrication, packing and adjustment, and priming.
- Study troubleshooting charts for operation of pumps. Know how to correct cavitation, loss of prime, and air lock.
- Trace the flow of water or pumped material through each of the two main types of pumps.
- Observe the sequence of operation of gate valves, check valves, pressure gauges, and electrical controls as each type of pump is started up or shut down.
- On study diagrams, point out the replaceable parts of pumps, motors, and valves.
- Review what to look and listen for in motor operation, such as overheating, vibration, and noise.
- Be aware of lubrication intervals for motors so that over or under lubrication is avoided.
- Be able to diagram the two principle types of misalignment of couplings and power drives.
- Identify specific safety practices used when working close to rotating equipment.
- Be familiar with section diagrams and names of valves used in water production and distribution.
- Study the operating characteristics of these valves and typical applications.
- List methods of measurement, principles of operation for measurement devices, signal transmission, and readout for common types of instrumentation systems.
- Study schematics and calibration instructions for instruments in the facility that you operate.
- Be able to identify and troubleshoot typical problems that may occur with the gas chlorine ejector and regulator system.
- Study proper maintenance procedures, where the items are on each system that have to be maintained, and where your operations failures are likely to occur on gas chlorination systems.
- Study diagrams of common chemical feeders and procedures for their operation and maintenance.
- Study troubleshooting procedures for problems with well screens, pumps, and electrical controls.
- Be familiar with basic distribution system maintenance procedures.
- Check procedures for distribution system maintenance including valve exercising, line flushing, hydrants maintenance, automatic valves inspection and cleaning.

SAMPLE QUESTIONS

Class D

A neat, orderly, and well maintained water facility is

- A. not very important as long as everything is working properly
- B. a good idea, but only if you have the time
- C. very important to help prevent equipment breakdowns and to help maintain good public relations

Class C

The maintenance card that is used to record what you did and when you did it is called

- A. the service record card
- B. the equipment service card
- C. the repair and maintenance card

Class B

When packing a pump with four rings of packing, the ring joints should be

- A. all at the same point on the shaft
- B. staggered 180°
- C. staggered 90°
- D. staggered 120°

Class A

A valve that includes allowance for high flow capacity, quarter-turn operation, no lubrication, excellent resistance to wear, and good throttling characteristics is the

- A. gate valve
- B. winged valve
- C. globe valve
- D. butterfly valve
- E. eccentric valve

Chapter 12

Operator Safety

INTRODUCTION TO CHAPTER 12

Much of the information in this chapter is referred to separately within this study guide. This chapter on safety is provided to concentrate special attention to this important topic.

SUGGESTED STUDY GUIDELINES

Class D and Class C

Be prepared to answer questions concerning:

- The general safety concerns and procedures as they apply to excavation and shoring
- Where the spoil should be placed
- When a trench or excavation SHOULD have adequate cave-in protection
- When a trench or excavation MUST have adequate cave-in protection
- The general safety concerns and procedures as they apply to confined space entry
- The requirements that must be met before entering a permit-required confined space
- The specific responsibilities for entry supervisors, attendants, entrants and rescue personnel
- The procedures regarding confined space entry permits including recordkeeping requirements
- The characteristics and dangers associated with gases found in confined spaces
- The general safety concerns and procedures as they apply to electrical hazards
- The procedures and significance of proper lockout-tagout practices
- The basic procedure for emergency rescue of victims of electrical shock
- The safety concerns and procedures as they apply to other dangers operators may face including
 - hazardous chemicals
 - noise
 - physical hazards
 - traffic
- The name of the service available in the case of an emergency involving hazardous chemicals
- The importance of and how to read a Material Safety Data Sheet (MSDS)
- The general guidelines for personal protective equipment and protective clothing

Be prepared to answer other questions that require additional personal study

Class B and Class A

Be prepared to answer questions concerning guidelines listed for lower levels of certification and:

- How to establish and maintain effective operator safety programs and emergency planning
- How to establish and maintain a hazard communication program as required by law

Be prepared to answer other questions that require a combination of actual experience and additional personal study

ENTRY LEVEL DISCUSSION

This chapter is provided as a general guideline to operator safety but is not all inclusive. Operators are required to follow the safety rules as stated by OSHA and the Oklahoma Department of Labor.

Why should safety be of such interest to water system operators? Stop and think of the wide variety of hazards associated with this work. In any one working day, operators could be exposed to any or all of the following.

1. Trenching and Excavation -- OSHA Regulation Title 29 (1926.650)
2. Confined Spaces -- OSHA Regulation Title 29 (1910.146)
3. Electrical and Mechanical Hazards -- OSHA Regulation Title 29 (1910.147)
4. Hazardous Chemicals -- Oklahoma Haz Com (O.S. 380.45)
5. Noise -- OSHA Title 29 (1910.95)
6. Physical Hazards -- OSHA Title 29 (1900-1926)
7. Traffic
8. Blood Borne Pathogens -- OSHA Title 29 (1910.151, .1030)

Ways operators deal with these day to day hazards may be detailed in a safety program. Aspects of a safety program may include the following.

1. Personal Protective Equipment -- OSHA Title 29 (1910.132-134)
2. Process Safety Management -- OSHA Title 29 (1910.119)
3. Chemical Hygiene Plan -- OSHA Title 29 (1910.1450)

We need to be aware of the potential for injury in all our activities. The best person to prevent an injury from occurring is YOU. By thinking ahead, being aware of the potential for an accident, and developing good work habits—many injuries will be eliminated. Poor work habits, those short cuts you may take, or the messes that are left behind ultimately won't pay off. Eventually it will catch up with you or someone else and an injury will result. The trip to the doctor and days of lost time will more than make up for any time you may have thought you were saving.

Injuries on the job have negative consequences for all involved. Injured operators not only suffer pain and discomfort, they may be unable to return immediately to work. This can result in a loss of full wages and a hardship to both the operator and his or her family.

The water system is also affected. Injuries rob the facility of needed operators. Others who may be less skilled may have to fill in. Even large crews may have to work shorthanded or on overtime. This creates fatigue among the operators and results in an overtime expense to the system.

Common Causes of Injuries

Most injuries involve either the back, legs, or hands. The vast majority of injuries are caused by one of the following three categories of accidents.

1. **Sprains and strains** result from improper lifting, awkward positions, pushing, and slips and falls.
2. **Being struck by objects** that are falling, moving, stationary, flying, sharp, or blunt.
3. **Slips and falls** from platforms, ladders, stairs, or from one level to another.

Years of experience is a factor in who is most likely to be injured. As the experience level increases, the worker is more likely to have become more highly certified and educated about the hazards of the job. He or she may have moved up to a supervisory level where exposure to hazards is less, or may have learned about certain dangerous activities through his/her own experiences or experiences of others.

Operator Safety Training Programs

On-the-job training (OJT) is a very valuable tool to not only upgrade operational skills, but also to protect the worker's health. Improvements in the safety programs at water treatment and distribution systems should be a constant goal. The desire for a good safety program must start at the very top of the organization. Without this support, many efforts will not be given the authority and financial resources to carry through. Some of the aspects of a good operator safety program are listed below.

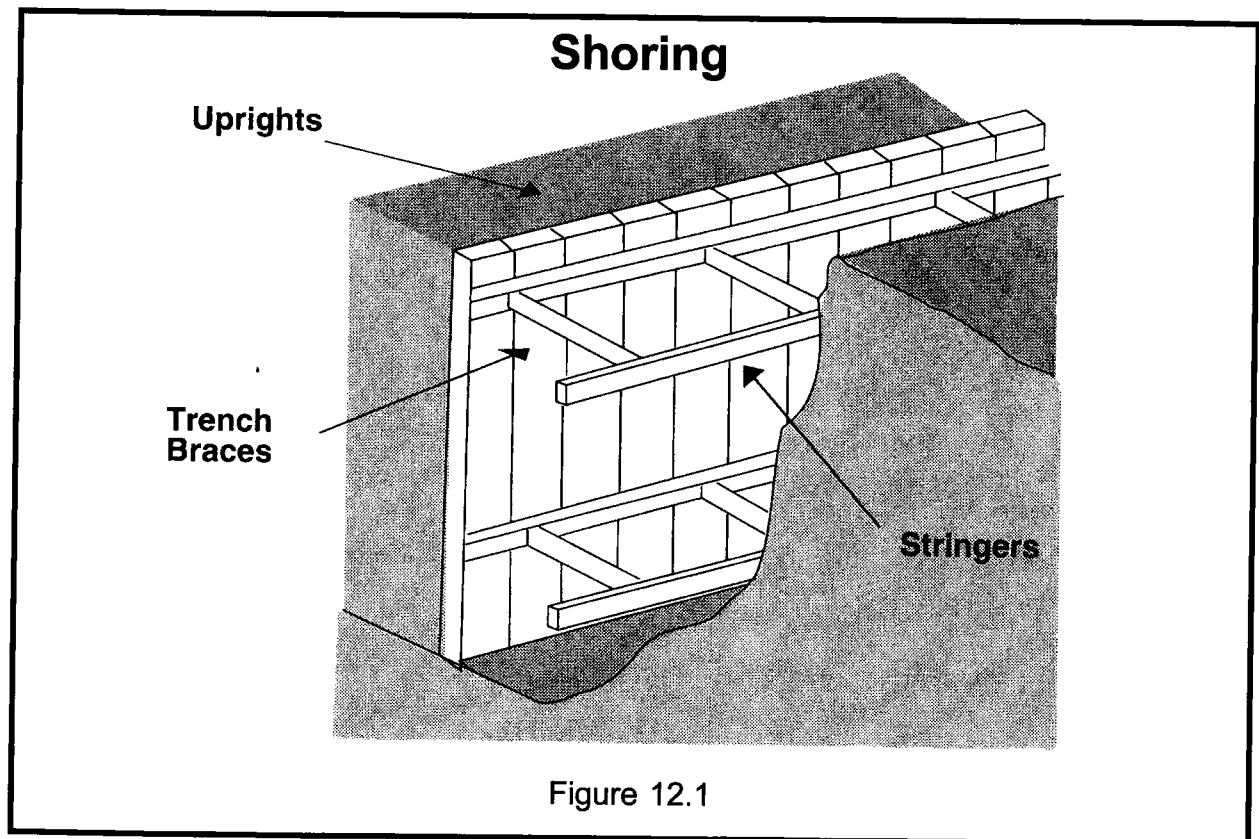
1. Develop a written **Standard Operating Procedure (SOP)** for routine duties or equipment operation and have regular training sessions over each SOP. This will not only point out safety aspects of the job, but will also be a way to train people in the most efficient way to work.
2. Have **safety meetings** for all workers at least once a month. Each supervisor should take turns presenting a meeting.
3. Form a **safety committee** to review accidents, inspect the facility for unsafe conditions, to post warnings or suggest improvements to risky areas, and enforce good work habits.

4. Have all personnel learn **CPR** and **First Aid** skills. This can be done through the Red Cross, the American Heart Association, or maybe even your local fire department or ambulance service. If the Operator Certification Unit is notified in advance in writing, these classes may be approved as training credit for certified operators.
5. **Recognize safe workers** with a certificate or some type of tangible recognition. Make safety and good work habits a part of annual evaluations and a factor in merit raises.

Trenching and Excavation Hazards

Accidents at the site of trenching and shoring activities are all too common. Almost anyone working for several years in this field can remember personally witnessing or being told about a real life incident where workers were injured or killed in a cave-in. It doesn't matter how short a time you might work in a trench, if there is no adequate cave-in protection provided you could easily be buried under tons of dirt. THERE IS USUALLY NO WARNING AND NO TIME TO ESCAPE.

It is strongly recommended that some type of adequate cave-in protection be provided when the trench is four (4) or more feet deep. OSHA REQUIREMENTS STATE THAT ADEQUATE PROTECTION IS ABSOLUTELY REQUIRED IF THE TRENCH IS FIVE (5) FEET OR MORE IN DEPTH. In addition, A PERSON DESIGNATED AS QUALIFIED AND COMPETENT TO RECOGNIZE AND EVALUATE HAZARDS MUST BE PRESENT. A COMPETENT PERSON



must inspect the equipment, be able to identify the hazards, and have the authority to stop work if conditions warrant. Methods of adequate protection include shoring, shielding, and sloping.

Shoring

Shoring is a complete framework of wood and/or metal that is designed to support the walls of the trench (*see Figure 12.1*). **Sheeting** is the solid material placed directly against the side of the trench. Either wooden sheets or metal plates might be used. Any space between the sheeting and the sides of the excavation should be filled in and compacted in order to prevent a cave-in from starting. **Uprights** are used to support the sheeting. They are usually placed vertically along the face of the trench wall. Spacing between the uprights varies depending upon the stability of the soil. **Stringers** are placed horizontally along the uprights. **Trench braces** are attached to the stringers and run across the excavation. The trench braces must be adequate to support the weight of the wall to prevent a cave-in. Examples of types of trench braces include solid wood or steel, screw jacks, or hydraulic jacks.

Shielding

Shielding is accomplished by using a two-sided, braced steel box that is open on the top, bottom, and ends. This “drag shield,” as it is sometimes called, is pulled through the excavation as the trench is dug out in front and filled in behind. Operators using a drag shield should always work only within the walls of the shield. If the trench is left open behind or in front of the shield, it could be tempting to wander outside of the shield’s protection sometime during the job. In addition, the heavy equipment operator must be very careful to dig trench walls that are straight and are the same width as the drag shield, so that there is no opportunity for a cave-in to start. There have been cases where this was not done and the shield was literally crushed by the weight of a collapsing trench wall.

Sloping

Sloping is a practice that simply removes the trench wall itself. The amount of soil needed to be removed will vary, depending on the stability of the soil. A good rule of thumb is to always slope at least one foot back for every one foot of depth on BOTH sides of the excavation. For deep trenches, sloping will usually require more space than is available.

Other Trenching Requirements

Certain soil conditions can contribute to the chances of a cave-in. These conditions include low cohesion, high moisture content, freezing conditions, or a recent excavation at the same site. Other factors to be considered are the depth of the trench, the soil weight, the weight of nearby equipment, and vibration from equipment or traffic. It is worth repeating that regardless of the presence or

absence of any or all of the above factors, the trench must still have proper cave-in protection if it is five or more feet deep. The **spoil** (dirt removed from the trench) must be placed at least two feet back from the trench and should be placed on one side of the trench only.

A LADDER IS REQUIRED FOR EACH WORKER IN THE TRENCH IF IT IS FOUR OR MORE FEET DEEP. THE LADDER MUST BE PLACED WITHIN 25 FEET OF THE WORKER AND MUST EXTEND AT LEAST THREE FEET ABOVE THE EXCAVATION WALL.

Confined Spaces

According to OSHA's Confined Space Entry Rule, a **confined space** is defined as an area large enough for entry with a limited ability to enter and exit and that is not intended for continuous occupancy. One easy way to identify a confined space is by whether or not you can enter it by simply walking while standing fully upright. If you must duck, crawl, climb, or squeeze into the space, it is probably considered a confined space.

A **permit-required confined space** is defined as a confined space that presents or has the potential for hazards related to atmospheric conditions or any other serious hazard. The potential for buildup of toxic or explosive gas mixtures and/or oxygen deficiency exists in many confined spaces found at water systems. Employees entering a permit required confined space must wear a harness and utilize emergency retrieval equipment. Employers must evaluate all workplaces and determine which confined spaces require an entry permit. One example of a confined space entry permit is shown on the following page (*see Figure 12.2*). An entry permit requiring different information might be used for some confined spaces if they are difficult to completely isolate and/or present special hazards.

Job Designations and Responsibilities

Before entering a permit-required confined space, an **entry supervisor** must prepare and sign an entry permit. The entry supervisor must know the potential hazards of confined spaces, verify that all atmospheric tests have been conducted and all procedures and equipment are in place before endorsing the entry permit. The entry supervisor also must determine that acceptable conditions continue until the work is completed. The entry permit is “canceled” after a significant break, work is completed or the approved duration of permit has passed, whichever comes first. All canceled entry permits must be kept for at least one year to allow for an annual review of the program.

The law also requires that an **attendant** be stationed outside confined spaces while the work is done (also known as the **buddy system**). The attendant must know the potential hazards of confined spaces, be aware of behavioral effects of potential exposures, and communicate with entrants as necessary to monitor their status. The attendant must remain outside the space until relieved. Attendants also must monitor activities inside and outside the permit space and order exit if required, summon rescuers if necessary, prevent unauthorized entry into confined space, and perform non-entry rescues. An attendant may not perform other duties that interfere with the primary duty of monitoring and protecting the safety of authorized entrants.

CONFINED SPACE ENTRY PERMIT

Date of Entry: _____ **Time:** _____ **Authorized Duration:** _____ hours (12 hours maximum)

Site Location & Description: _____

Potential Hazards of Space: _____ Atmospheric _____ Engulfment _____ Entrapment _____ Other _____

Comments: _____

Purpose of Entry: _____

Entry Supervisor: _____ (use separate roster to note replacement)

Authorized Attendant : _____ (use separate roster to note replacement)

Authorized Entrant(s): _____
(separate roster must be used to track all who are currently in the space)

Communication Procedures: _____

All requirements to be completed and reviewed prior to entry. (Enter N/A for items that do not apply)

Requirements Completed:	Date	Time	Requirements Completed:	Date	Time
Lock-out/De-energize/Try-out	_____	_____	Full Body Harness w/ "D" Ring	_____	_____
Line(s) Broken-Capped-Blanked	_____	_____	Lifelines	_____	_____
Purge-Flush and Vent	_____	_____	Non-Entry Retrieval Equipment	_____	_____
Ventilation	_____	_____	Fire Extinguishers	_____	_____
Secure Area (Post and Flag)	_____	_____	Lighting	_____	_____
Warning Signs, Barricades	_____	_____	Protective Clothing	_____	_____
MSDS Review	_____	_____	Hearing Protection	_____	_____

Continuous Monitoring	Permissible Entry Level	Record Monitoring Every Two Hours
Oxygen	19.5% to 23.5%	_____
Methane	Less than 0.5%	_____
Hydrogen Sulfide	Less than 10 ppm	_____
Carbon Dioxide	Less than 10,000 ppm	_____

Time Tests Were Performed _____
 Tester's Initials _____
 Testing Instrument _____ Model/Serial# _____ Date of Calibration _____

Rescue

All Emergencies (Fire, Rescue, Medical, Ambulance) - Call # _____

Safety Supervisor - Call # _____ Nearest Phone: _____

Rescue Personnel: _____
 Internal _____ Outside _____

Required Rescue Equipment: _____

Authorizing Entry Supervisor: _____ Date _____ Time _____

All required conditions satisfied? Yes _____ No _____ (Permit will remain at site until job completion)

Entry Supervisor Signature _____ Entry Concluded: Date _____ Time _____

Other Required Permits For Job: _____

Figure 12.2

Some of the Common Dangerous Gases Found in Water Treatment Plants and Distribution Systems

Name of Gas	Chemical Formula	Specific Gravity (Air=1.00)	Explosive Range (% in air)		Common Properties	Physical Effects
			LEL	UEL		
Methane	CH ₄	0.55	5.0%	15.0%	Colorless Tasteless Flammable Explosive	Asphyxiant Doesn't support life
Hydrogen Sulfide	H ₂ S	1.19	4.3%	46.0%	Rotten-egg odor Colorless Flammable Explosive Poisonous	Death in a few minutes at 0.2% Paralyzes respiratory center. Odor not detectable at high levels
Carbon Dioxide	CO ₂	1.53	Not flammable		Colorless Tasteless Odorless	10% can't be endured for more than 10 min. Acts on nerves of respiration
Chlorine	Cl ₂	2.5	Not flammable Not explosive		Greenish-yellow Strong odor Highly corrosive	30 ppm coughing 40-60 ppm dangerous 1000 ppm fatal in a few breaths

Figure 12.3

All authorized **entrants** (persons entering the confined space) must be trained in the hazards they may face, be able to recognize signs or symptoms of exposure and understand the consequences of exposure to hazards. They must also know how to use any needed equipment, communicate with attendants as necessary, alert attendants when a warning symptom or other hazardous condition exists. Entrants must exit as quickly as possible whenever ordered or alerted to do so. All **contractors** must be provided information by the system owner on permit spaces and likely hazards that the contractor might encounter. Joint entries must be coordinated.

Special training is necessary to provide all employees with the understanding, skills and knowledge to perform their individual duties. Training is required for all new employees and whenever duties change, the hazards in a space change or whenever an evaluation shows a need for additional training.

Rescue services (either on-site or off-site) must be readily available and able to be summoned quickly. On-site teams must be properly equipped. They must receive the same training as authorized entrants plus additional training on how to use personal protective and rescue equipment and first aid

training, including CPR. Simulated rescues must be performed at least once every 12 months. Outside rescue services must be made aware of hazards and receive access to comparable permit spaces to develop rescue plans and practice rescues.

Ventilation and Continuous Monitoring

CONFINED SPACES MUST BE PROPERLY VENTILATED USING SPECIALLY DESIGNED **FORCED-AIR VENTILATORS**. This crucial step must be taken even if gas detection and oxygen-deficiency detection instruments show the atmosphere to be safe. Because some of the gases likely to be found are explosive the blowers used must be specially designed to be **intrinsically safe**. This means that the blower itself will not create a spark and cause an explosion.

THE ATMOSPHERE MUST BE CONTINUOUSLY CHECKED WITH RELIABLE, CALIBRATED INSTRUMENTS. Several instruments are available that check for toxic gases, flammable gases and for oxygen deficiency. The oxygen concentration in normal breathing air is 20.9%. The atmosphere in the confined space must never fall below 19.5% oxygen.

THE SENSE OF SMELL IS ABSOLUTELY USELESS FOR EVALUATING THE PRESENCE OF GASES. Many dangerous gases have no odor at all. Furthermore, HYDROGEN SULFIDE PARALYZES THE SENSE OF SMELL. The higher the concentration, the faster the loss of smell.

The **upper explosive limit (UEL)** and **lower explosive limit (LEL)** indicate the range of concentrations at which combustible/explosive gases will explode upon ignition (*see Figure 12.3*). No explosion occurs when the concentration is outside of these ranges. The **specific gravity** of a gas indicates its weight as compared to air. Air has a specific gravity of exactly 1.0. Several gases (including hydrogen sulfide and chlorine) have a tendency to collect in low places because they have a specific gravity of greater than 1.0. This means that these gases are heavier than air. Methane will rise out of low places because it has a specific gravity of less than 1.0 and is lighter than air.

Only **non-sparking tools and lamps** should be used. Obviously, there should be no smoking anywhere near the entrance to a confined space.

Electrical and Mechanical Hazards

ELECTRICAL HAZARDS CAN CAUSE SERIOUS INJURY LEADING TO DEATH. UNDER NO CIRCUMSTANCES SHOULD PERSONS OPEN AN ELECTRICAL PANEL OR ATTEMPT ELECTRICAL REPAIRS UNLESS THEY ARE BOTH QUALIFIED AND AUTHORIZED.

Electrical energy of only 50 volts can be fatal if a good ground is made. Electricity is capable of paralyzing the nervous system and stopping the muscular action responsible for breathing and pumping blood.

In the event of electrical shock, the following steps should be taken.

1. Survey the scene and see if it is safe to enter.
2. If necessary, free the victim from a live power source by shutting power off at a nearby disconnect, or by using a dry stick or some other non-conducting object to move the victim.
3. Send for help, calling 911 or whatever the emergency number is in your community. Check for breathing and pulse. Begin CPR immediately if needed.

There are several things to keep in mind whenever working on electrical equipment.

1. Always lockout and tagout any electrical equipment being serviced. NEVER remove someone else's lock or tag.
2. Use only grounded power tools.
3. Do not use metal ladders when working on electrical equipment.
4. Only trained and legally licensed persons working in pairs should attempt electrical repairs.

Basic Lock-out/Tag-out Procedures

According to OSHA law, all equipment that could unexpectedly start-up or release stored energy must be locked out or tagged out to protect against accidental injury to personnel. Some of the most common forms of stored energy are electrical and hydraulic energy, among others.

Whenever major replacement, repair, renovation, or modification of equipment is performed, the energy isolating devices (switch, valve, etc.) for the equipment must be designed to accept a lockout device. A **lockout device** uses a positive means such as a lock, either key or combination type, to hold the switch in the safe position and prevent the equipment from becoming energized. A **tagout device** is a prominent warning, such as a tag, which can be securely fastened to the energy isolating device in accordance with an established procedure, to indicate that both it and the equipment being controlled may not be operated until the tagout device is removed. The basic procedures required for proper lock-out/tag-out are listed below.

1. Notify all affected employees that a lockout or tagout system is going to be utilized and the reason why. The authorized employee should know the type and magnitude of energy that the equipment utilizes and should understand the potential hazards.
2. If the equipment is operating, shut it down by the normal stopping procedure.

3. Operate the switch, valve, or other energy isolating device(s) so that the equipment is isolated from its energy source(s). Stored energy (such as that in springs, elevated machine members, rotating flywheels, hydraulic systems, and air, gas, steam , or water pressure, etc.) must be dissipated or restrained by methods such as repositioning, blocking, or bleeding down.
4. Lockout and/or tagout the energy isolating device with your assigned individual lock or tag.
5. After ensuring that no personnel are exposed, and as a check that the energy source is disconnected, operate the push button or other normal operating controls to make certain the equipment will not operate. **CAUTION! RETURN OPERATING CONTROLS TO THE NEUTRAL OR OFF POSITION AFTER THE TEST.**
6. The equipment is now locked out or tagged out and work on the equipment may begin.
7. After the work on the equipment is complete, all tools have been removed, guards have been reinstalled, and all personnel are in the clear, remove all lockout or tagout devices. Operate the energy isolating devices to restore energy to the equipment.

Hazardous Chemicals

Hazardous chemicals are present in many areas of the system. The plant laboratory uses a wide variety of acids, bases, and other potentially dangerous compounds. Water system operators will also likely come in contact with various forms of chlorine (see also Chapter 7 for specific information on chlorine safety). Each worker should be trained in safe chemical and handling procedures as required by the **Rules for Oklahoma Hazard Communication Standard**. These rules are based on a federal law designed to help minimize injuries among workers from chemical overexposure.

A MATERIAL SAFETY DATA SHEET (MSDS) FOR EACH AND EVERY CHEMICAL THAT IS PRESENT OR PRODUCED IN THE SYSTEM MUST BE READILY AVAILABLE TO ALL OPERATORS. The MSDS is a reliable reference (usually provided by the manufacturer) for the type of hazards the chemical presents and what to do in the case of an emergency. All operators should be familiar with the MSDS through training provided by the employer and personal study.

Safely handling chemicals used in daily water treatment is an operator's responsibility. However, if the situation ever gets out of hand, there are emergency teams that can respond with help anywhere there is an emergency. **Chemtrec** will provide immediate advice for those at the scene of an emergency and then quickly alert experts whose products are involved for more detailed assistance and appropriate follow-up. The toll-free Chemtrec number is 1-800-424-9300.

Noise

Noise is a hazard often overlooked. Prolonged exposure to high noise levels (85 decibels or greater) can lead to permanent hearing loss. Excessive noise can come from motor rooms, lawn mowers, and other tools and equipment. Noise levels should be checked using a noise dosimeter. In general, if you have to shout or cannot hear someone talking to you in a normal tone of voice, the noise level is excessive. Hearing protection such as ear plugs or muffs is required if the noise cannot be eliminated.

Physical Hazards

Physical hazards include falls and slips from stairs, ladders, rough ground, or slick surfaces. Other physical hazards are moving machinery, automatically operated equipment, and obstructing pipes or walkways. Some of these are called **built-in hazards** because they are built into the plant. Built-in hazards should be modified if possible, or clearly labeled and personnel made aware of the hazard. **Protective clothing** is needed by all operators. **Hardhats and steel-toed shoes** are often appropriate.

Other ways of avoiding injuries from physical hazards are to use the proper ladder or tool for the job, fill in holes, or post barricades, put additional tread on the steps, and paint slick areas with pumice paint. Emphasis should be put on good housekeeping as a way to eliminate accidents. Oil, water, polymer, or other debris left in walkways causes many slips and falls. Cleaning up spills as they occur and using oil soak or oil soak booms can eliminate much of this. Placing trash barrels in all areas of the facility will help stop clutter. Enforcing **good housekeeping habits** among all workers is a must.

Traffic

Traffic controls are absolutely essential for those working in the distribution system. This is important for line maintenance workers, meter readers, field samplers, and others. Some of the things you can do to eliminate injury from traffic are to:

1. DON'T WORK IN RUSH HOUR TRAFFIC.
2. PUT UP WARNINGS OR POST A FLAGMAN 500 FEET AHEAD OF ONCOMING TRAFFIC.
3. ALWAYS USE WARNINGS INCLUDING VESTS AND FLASHING LIGHTS.
4. PLACE A BARRIER BETWEEN THE WORKERS AND TRAFFIC such as a truck. The general rule is the bigger, the better.

Bloodborne Pathogens

Regulations governing exposure to bloodborne pathogens are mandated by OSHA. It is the employer's responsibility to develop an exposure control plan and provide training to those workers potentially exposed to bloodborne pathogens that may be present in body fluids. First aid procedures should outline the appropriate response for an employee to follow when rendering first aid. First aid kits should contain disposable gloves and biohazard bags to contain contaminated bandages or gauze.

Personal Protective Equipment

A Personal Protective Equipment (PPE) evaluation should be completed by the employer for each task performed by the employee and adequate protection should be provided. Hazards to be analyzed and protection provided for include: eye protection, fall protection, foot protection, hand protection, head protection, hearing conservation, and respiratory protection.

Process Safety Management Plan

The main objective of the process safety management of highly hazardous chemicals is to prevent unwanted release of hazardous chemicals especially into locations that could expose employees and others to serious hazards. With this objective in mind in 1992 OSHA issued one of its most comprehensive regulations -- Process Safety Management of Highly Hazardous Chemicals (29 CFR 1910.119).

The standard applies to water treatment facilities that process chemicals over threshold amounts: such as chlorine at 1500 pounds. Process Hazard Analysis (PHA) is the most essential part of a Process Safety Management Program. PHA is directed toward analyzing potential causes and consequences of fires, explosions, release of toxic or flammable chemicals and major spill of hazardous chemicals. PHA focus on instrumentation, equipment, utilities, human actions, and external factors that might impact the process. Operating Procedure is another important element. It describes tasks to be performed, data to be recorded, operating conditions to be maintained, samples to be collected, and safety and health precautions to be taken.

Chemical Hygiene Plan

This program describes various chemicals in use in the laboratory, PPE to be used in handling them, and precautions to be used by designated personnel in case of spills or release. A primary and secondary response person shall be designated in the plan to respond to spills.

Personal Responsibility for Safety

The final thing to remember about safety is that it is your life and health and that of your co-workers that is to be protected. **THE FINAL RESPONSIBILITY LIES WITHIN YOU.** The supervisor, manager, or mayor cannot be there at all times to make sure you do the safe thing. The safety gear provided should be used as it is intended to be used. Safety gear not already provided should be requested. **DENIAL OF REQUESTS FOR LEGALLY REQUIRED SAFETY GEAR OR OTHER UNRESOLVED SAFETY VIOLATIONS SHOULD BE REPORTED TO THE:**

Oklahoma State Department of Labor
Public Employees Health and Safety Division
(405) 528-1500 ext. 226

Most importantly, always approach each job with the question, “HOW CAN I DO THIS SAFELY?”

SUGGESTED REFERENCES FOR STUDY

California State University, Sacramento - **Water Treatment Plant Operation, Vol. 2**

Chapter 20 Safety

California State University, Sacramento - **Water Distribution System Operation & Maintenance**

Chapter 3 Distribution System Facilities (especially sections 3.653 and 3.659)

Chapter 6 Disinfection (especially sections 6.4 and 6.6)

Chapter 7 Safety

Rules for Oklahoma Hazard Communication Standard

Title 40 - Oklahoma Statutes for General Safety and Health

OSHA Confined Space Entry Rule

OTHER STUDY SUGGESTIONS

Study the guidelines from a current OSHA or Oklahoma State Department of Labor bulletin for excavation safety and confined space entry.

Be familiar with local rules for work site setup and traffic control in streets.

For the best information on chlorine handling and safety, obtain the Chlorine Manual from the Chlorine Institute.

SAMPLE QUESTIONS

Class D

The chemical information sheet that is supplied by manufacturers is called the

- A. plant operations and maintenance manual
- B. monthly operational report (MOR)
- C. material safety data sheet (MSDS)

Class C

Probably the two MOST dangerous gases that operators might encounter at a water system are

- A. Cl_2 and CO_2
- B. Cl_2 and H_2S
- C. CH_4 and CO_2

Class B

Which one of the following chemicals is considered most hazardous?

- A. CaO
- B. $\text{Ca}(\text{OH})_2$
- C. NaOH
- D. Na_2CO_3

Class A

When an ammonia gas cylinder has a serious leak and cannot be controlled, it should be

- A. submerged in water
- B. submerged in an acid solution
- C. submerged in strong alkaline solution
- D. submerged in a chlorine solution
- E. submerged in a sodium bicarbonate solution

Appendix A

Introduction to Basic Operator Math

This appendix offers some examples of how to work basic operator math problems. The “simplified” math formulas used in this Appendix will be provided with the test questions on the Class D exams. However, some of the conversion factors and abbreviations listed in this appendix must be memorized for the certification exam. To find out exactly what you need to know for your Class D exam, please refer to the *Suggested Study Guidelines* in each chapter of this study guide.

Also included in this Appendix are some practice problems. It is important to practice to improve your ability to work the problems while you are actually taking your exam. Some of the basic math practice problems in this appendix may require additional explanations not offered here. A more complete explanation concerning basic operator math skills can be found within the *Suggested References for Study* listed in Chapter 1 of this study guide. Many approved operator training classes also offer help in learning how to solve math problems. It is recommended that all new operators read this appendix and work the math problems before attending an approved standard entry level class.

Instructions for using APPENDIX A

1. Read completely.
2. Read each section again before working the practice problems for that section.
3. Compare your answers to answers on the last page of APPENDIX A. Don't be concerned if your answer is slightly different than the answer given.
4. Review before taking your certification exam.

*The #1 factor in how well you do in math can be summarized by the old saying;
“If you don't use it, you lose it.”*

VOLUME-TIME UNITS

Volume-time units measure the volume of flow over a specific period of time. There are many other volume-time units that are used for many different purposes. Two very commonly used volume-time units are MGD and gpd.

MGD (Million Gallons per day)
gpd (gallons per day)

It is important that all operators know how to convert between these two units. The real key to converting between MGD and gpd is to know how to move the decimal place exactly six places. This method of conversion works because the only difference between MGD and gpd is one million. One million is equal to six decimal places. If it's a little difficult at first, a little practice is all that's needed.

Basic Abbreviations

ac	acre
ac-ft	acre feet
amp	ampere
°C	degrees Celcius
cfm	cubic feet per minute
cfs	cubic feet per second
cm	centimeter
cu ft or ft ³	cubic feet
cu in or in ³	cubic inch
cu yd or yd ³	cubic yard
°F	degrees Fahrenheit
ft	feet or foot
gal	gallon
gm	gram
gpd	gallons per day
gpm	gallons per minute
HP	horsepower
hr	hour
in	inch
k	kilo
kg	kilogram
km	kilometer
kW	kilowatt
kWh	kilowatt-hour
L	liter
lb	pound
m	meter
M	million
mg	milligram
mg/L	milligram per liter
MGD	million gallons per day
ml	milliliter
min	minute
psf	pounds per square foot
psi	pounds per square inch
ppb	parts per billion
ppm	parts per million
sec	second
sq ft or ft ²	square feet
sq in or in ²	square inches
W	watt

Basic Conversion Factors

Length

12 in	1 ft	12 in / ft
3 ft	1 yd	3 ft / yd
5280 ft	1 mi	5280 ft / mi

Area

144 sq in	1 sq ft	144 sq in / sq ft
43,560 sq ft	1 acre	43,560 sq ft / acre

Volume

7.48 gal	1 cu ft	7.48 gal / cu ft
1000 ml	1 liter	1000 ml / liter
3.785 L	1 gal	3.785 L / gal
231 cu in	1 gal	231 cu in / gal
0.326 MG	1 ac-ft	0.326 MG / ac-ft

Weight

1000 mg	1 gm	1000 mg / gm
1000 gm	1 kg	1000 gm / kg
454 gm	1 lb	454 gm / lb
2.2 lbs	1 kg	2.2 lbs / kg

Power

.746 kW	1 HP	.746 kW / HP
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Density of Water

8.34 lbs	1 gal	8.34 lbs / gal
62.4 lbs	1 cu ft	62.4 lbs / cu ft

Dosage

1 mg/l	1 ppm	mg/l / ppm
17.1 mg/l	1 grain/gal	17.1 mg/l / grain/gal

Pressure

2.31 ft water	1 psi	2.31 ft water / psi
0.433 psi	1 ft water	0.433 psi / ft water

Flow

1,000,000 gpd	1 MGD	1,000,000 gpd / MGD
694 gpm	1 MGD	694 gpm / MGD
1.55 cfs	1 MGD	1.55 cfs / MGD

Time

60 secs	1 min	60 secs / min
60 min	1 hr	60 min / hr
1440 min	1 day	1440 min / day
24 hr	1 day	24 hr / day

PROBLEM

You have a flow of 17,000 gpd. What is the flow in MGD?

SOLUTION

First, start by writing down what you know. You know you have a flow of 17,000 gpd and you want to know what the flow is in MGD.

$$17,000 \text{ gpd} = ? \text{ MGD}$$

The decimal place is now just to the right of the last zero, at the end of the whole numbers.

$$17,000. \text{ gpd} = ? \text{ MGD}$$

Next, move the decimal place exactly six places to the left. You will see as you count out the six places to the left that you must add one zero to make room for the last decimal place. After this is done you can “drop off” the three zeroes that are “left over” on the right.

$$17,000. \text{ gpd} = .017 \text{ MGD}$$

PROBLEM

You have a flow of 2.3 MGD. What is the flow in gpd?

SOLUTION

Once again, start by writing down what you know. You know you have a flow of 2.3 MGD and you want to know what the flow is in gpd.

$$2.3 \text{ MGD} = ? \text{ gpd}$$

Next, move the decimal place exactly six places to the right. You will see as you do this that you must add five zeros on the right.

$$2.3 \text{ MGD} = 2,300,000 \text{ gpd}$$

VOLUME/TIME PRACTICE PROBLEMS

1. The flow is 100,000 gpd. What is the flow in MGD?
2. The flow is 1,200,000 gpd. What is the flow in MGD?
3. The flow is 120,000 gpd. What is the flow in MGD?
4. The flow is 56,000 gpd. What is the flow in MGD?
5. The flow is 8,200,000 gpd. What is the flow in MGD?
6. The flow is 5,300 gpd. What is the flow in MGD?
7. The flow is 11,000 gpd. What is the flow in MGD?
8. The flow is 4,336,000 gpd. What is the flow in MGD?
9. The flow is 1.60 MGD. What is the flow in gpd?

10. The flow is 2.36 MGD. What is the flow in gpd? _____
11. The flow is .08 MGD. What is the flow in gpd? _____
12. The flow is .004 MGD. What is the flow in gpd? _____
13. The flow is .876 MGD. What is the flow in gpd? _____
14. The flow is .054 MGD. What is the flow in gpd? _____
15. The flow is 1.76 MGD. What is the flow in gpd? _____

AREA AND VOLUME

Area and Volume of Squares and Rectangles

The formula for calculating the **surface area** of a square or rectangle is:

$$A = L \times W$$

A = Area

L = Length

W = Width

The formula for calculating the **volume** of a square or rectangle is:

$$V = L \times W \times H$$

V = Volume

L = Length

W = Width

H = Height or depth

Notice that the formula for area is the same as for the formula for volume except that one more “dimension” has been added (the height or depth).

PROBLEM

What is the surface area of a basin that is 40 feet long and 20 feet wide?

SOLUTION

The first thing to do when working with any math problem that requires the use of a formula is to write down the formula.

$$A = L \times W$$

Now place the numbers into the formula and multiply.

$$A = 40\text{ft} \times 20 \text{ ft}$$

And you are left with:

$$A = 800\text{ft} \times \text{ft}$$

A better way of saying “ft x ft” is “ft²” which is read as “square feet.”

$$A=800\text{ft}^2$$

PROBLEM

What is the volume of a basin that is 40 feet long, 20 feet wide, and 10 feet deep?

SOLUTION

First, write down the formula you are going to use.

$$V = L \times W \times H$$

Place the numbers into the formula and multiply.

$$V = 40\text{ft} \times 20\text{ft} \times 10\text{ft}$$

And you are left with:

$$V = 8,000\text{ft}$$

A better way of saying “ft x ft x ft “ is “ft³” which is read as “cubic feet.”

$$V= 8,000 \text{ ft}^3$$

Area and Volume of Cylinders

The formula for calculating the **surface area** of a round or cylindrical container is

$$A = \pi \times R^2$$

$$\pi = 3.1416$$

$$R^2 = R \times R = \text{radius} \times \text{radius}$$

The formula for calculating the **volume** of a round or cylindrical container is

$$V = \pi \times R^2 \times H$$

$$\pi = 3.1416$$

$$R^2 = R \times R = \text{radius} \times \text{radius}$$

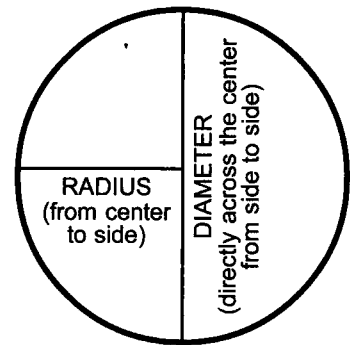
$$H = \text{height or depth}$$

The symbol “ π ” is the Greek letter pi (pronounced pie). π is a symbol used to represent the relationship of the diameter of a cylinder to its circumference. The circumference of a cylinder is always 3.1416 times greater than the diameter.

The letter “R” stands for radius.

The radius of a cylinder is exactly one-half of the diameter.

CIRCUMFERENCE
(all the way around)



PROBLEM

What is the surface area of a basin that has a diameter of 60 ft?

SOLUTION

First, write down the formula.

$$A = \pi \times R^2$$

As you work the formula from left to right, the first thing to do is replace π with the number 3.1416.

$$A = 3.1416 \times R^2$$

R^2 means “R squared” or “R x R.”

$$A = 3.1416 \times R \times R$$

*Remember that the R stands for **radius**. If the diameter is 60 feet, the radius is 30 feet because the radius is always exactly one-half of the diameter.*

$$A = 3.1416 \times 30\text{ft} \times 30\text{ft}$$

Now use your calculator to solve the problem.

$$A = 3.1416 \times 30\text{ft} \times 30\text{ft}$$

And you are left with

$$A = 2,827 \text{ ft} \times \text{ft}$$

$$A = 2,827 \text{ ft}^2$$

PROBLEM

What is the volume of a basin that is 60 ft in diameter and 15 feet deep?

SOLUTION

First, write down the formula.

$$V = \pi \times R^2 \times H$$

As you work the formula from left to right, the first thing to do is replace the symbol π with the number 3.1416.

$$V = 3.1416 \times R^2 \times H$$

Another way of saying R^2 is " $R \times R$."

$$V = 3.1416 \times R \times R \times H$$

If the diameter is 60 feet, the radius is 30 feet.

$$V = 3.1416 \times 30\text{ft} \times 30\text{ft} \times H$$

The H stands for the height or depth which is 15 feet.

$$V = 3.1416 \times 30\text{ft} \times 30\text{ft} \times 15\text{ft}$$

Now use your calculator to solve the problem.

$$V = 3.1416 \times 30\text{ft} \times 30\text{ft} \times 15\text{ft}$$

$$V = 42,412\text{ft} \times \text{ft} \times \text{ft}$$

$$V = 42,412\text{ft}^3$$

PROBLEM

What is the volume in **gallons** of a basin 60 feet in diameter and 15 feet deep?

SOLUTION

This is the same as the last problem except that the answer needs to be given in gallons instead of in cubic feet. Therefore, this problem will be worked exactly the same as the last problem except that one more step must be taken to convert from cubic feet to gallons.

There are 7.48 gallons in each cubic foot of water (see Common Conversion Factors in the Appendix).

In order to find out how many gallons are in the basin this conversion factor must be used.

$$V, \text{ gal} = 42,412 \text{ ft}^3 \times \frac{7.48 \text{ gal}}{\text{ft}^3}$$

And the correct answer is

$$V, \text{ gal} = 317,242 \text{ gal}$$

PROBLEM

What is the volume in **pounds** of a basin 60 feet in diameter and 15 feet deep?

SOLUTION

Now the question is how many pounds of water are in the basin. This is the same as the last problem except that the answer needs to be reported in pounds instead of in gallons. This type of information might be necessary in order to determine dosage rates, because dosages are often calculated in pounds of chemical added for every million pounds of water being treated.

A gallon of water weighs or has a "mass" of 8.34 lbs (see the Common Conversion Factors listed in this Appendix). In order to find out how many pounds of water are in the basin, this conversion factor must be used.

$$\text{Mass, lbs} = 317,424 \text{ gal} \times \frac{8.34 \text{ lbs}}{\text{gal}}$$

And the correct answer is

$$\text{Mass, lbs} = 2,645,796 \text{ lbs}$$

If the answer was "rounded off" and the decimal place was moved six places, it could also be correctly written as

$$\text{Mass, lbs} = 2.65 \text{ Mlbs}$$

AREA AND VOLUME PRACTICE PROBLEMS

1. A basin is 60 feet long and 30 feet wide. What is the surface area? _____
2. A basin is 35 feet long and 20 feet wide. What is the surface area? _____
3. A basin is 40 feet in diameter. What is the surface area? _____
4. A basin is 82 feet in diameter. What is the surface area? _____
5. A basin is 12 feet in diameter. What is the surface area? _____
6. What is the volume of a basin 20 feet long, 10 feet wide, and 5 feet deep? _____
7. What is the volume in gallons of the basin in question #6? _____
8. How many pounds of water are in the basin in question #6? _____
9. What is the volume of a basin 40 feet long, 15 feet wide, and 10 feet deep? _____
10. What is the volume in gallons of the basin in question #9? _____
11. How many pounds of water are in the basin in question #9? _____
12. What is the volume of a basin 30 feet in diameter and 10 feet deep? _____

13. What is the volume in gallons of the basin in question #12? _____
14. How many pounds of water are in the basin in question #12? _____
15. What is the volume of a basin 50 feet in diameter and 8 feet deep? _____
16. What is the volume in gallons of the basin in question #15? _____
17. How many pounds of water are in the basin in question #15? _____
18. What is the volume of a basin 45 feet in diameter and 15 feet deep? _____
19. What is the volume in gallons of the basin in question #18? _____
20. How many pounds of water are in the basin in question #18? _____

DETENTION TIME

The detention time is the amount of time the water or wastewater is retained in a tank or basin.

A formula used for measuring the detention time in days is

$$\text{Detention Time, days} = \frac{\text{Volume, gal}}{\text{Flow, gpd}}$$

A formula used for measuring the detention time in hours is

$$\text{Detention Time, hrs} = \frac{(\text{Volume, gal}) (24 \text{ hrs/day})}{\text{Flow, gpd}}$$

PROBLEM

A basin has a volume of 317,242 gallons and a flow of 2.3 MGD. What is the detention time in hours?

SOLUTION

First, write down the formula.

$$\text{Detention Time, hrs} = \frac{(\text{Volume, gal}) (24 \text{ hrs/day})}{\text{Flow, gpd}}$$

Next, place the needed numbers that are called for in the formula.

$$\text{Detention Time, hrs} = \frac{(317,242 \text{ gal}) (24 \text{ hrs/day})}{2,300,000 \text{ gpd}}$$

It was necessary to convert MGD to gpd because the formula required the flow to be entered as gpd.

Now use "cancellation" to eliminate some of the units of measurement

$$\text{Detention Time, hours} = \frac{317,242 \cancel{\text{ gallons}} (24 \text{ hrs/day})}{2,300,000 \cancel{\text{ gpd}}}$$

Next, solve the multiplication problem on the top

$$\text{And the answer is } \text{Detention Time, hrs} = \frac{7,613,808 \text{ hrs}}{2,300,000}$$

$$\text{Detention Time, hours} = 3.3 \text{ hrs}$$

PROBLEM

A basin is 70 ft in diameter and 15 ft in depth and has a flow of 4 MGD. What is the detention time in hours?

SOLUTION

First, write down the formula.

$$\text{Detention Time, hrs} = \frac{(\text{Volume, gal})(24 \text{ hrs/day})}{\text{Flow, gpd}}$$

In this problem, the volume in gallons is not provided. All that is given are the dimensions of the basin and the flow. Before you can use the formula you must first find the volume of the basin in gallons. It will also be necessary to convert MGD to gpd before using the formula.

To find the volume of the clarifier use the formula for the volume of a cylinder.

$$V = \pi \times R^2 \times V$$

Using the same steps used in the earlier example for this formula, the volume of this basin is

$$V = 57,727 \text{ ft}^3$$

Now it is necessary to convert the ft³ of water into gallons of water. This is done by multiplying the ft³ of water by 7.48 because each ft³ of water is equal to 7.48 gallons of water. (See the conversion factors listed at the beginning of this Appendix)

$$V = 57,727 \text{ ft}^3 \times \frac{7.48 \text{ gal}}{\text{ft}^3} = 431,798 \text{ gal}$$

After you convert the MGD to gpd, you will have all of the numbers necessary to proceed with the detention time formula.

$$\text{Detention Time, hrs} = \frac{(431,798 \text{ gal})(24 \text{ hrs/day})}{4,000,000 \text{ gpd}}$$

And the answer is

$$\text{Detention time, hours} = 2.6 \text{ hrs}$$

DETENTION TIME PRACTICE PROBLEMS

1. A basin holds 100,000 gallons. The flow is 600,000 gpd. What is the detention time in hours?

2. A basin holds 220,000 gallons. The flow is 1.3 MGD. What is the detention time in hours?

3. A basin is 40 ft long, 15 ft wide, and 6 ft deep and has a flow of .08 MGD. What is the detention time in hours?

4. A basin is 50 ft in diameter and 15 ft deep and has a flow of 1.5 MGD. What is the detention time in hours?

5. A pond holds 83 MG. The flow is 0.65 MGD. What is the detention time in days?

BASIC DOSAGE CALCULATIONS

A common way of expressing dosage levels in both water and wastewater treatment is in milligrams per liter, (mg/L)

A milligram per liter is one one-thousandth of a gram for every liter of water.

A mg/L is a unit of measurement often used for expressing a dosage of a substance in water or wastewater. **A mg/L is the same thing as a ppm.**

The ppm *or* mg/L are the pounds of the substance for every million pounds of water being treated. For example, 1 pound of chlorine in 1 million pounds of water would be 1 mg/L. Concentrations will always be expressed as mg/L.

There are two basic formulas that are used for dosage calculations. Which of the two formulas you use depends upon what you need to know.

If you need to know what the mg/L is, this formula can be used.

$$\text{Dose, mg/L} = \frac{\text{Chemical, lbs}}{\text{H}_2\text{O, Mlbs}}$$

If you need to know how many pounds of chemical you need to use for the dosage level you want, this formula can be used.

$$\text{Chemical, lbs} = (\text{Dose, mg/L}) (\text{H}_2\text{O, Mlbs})$$

PROBLEM

You have a flow of 2.3 MG that is being treated with 115 lbs of chlorine gas. What is the dosage in mg/L?

SOLUTION

First, choose the formula that will give you what you need to know and write it down

$$\text{Dose, mg/L} = \frac{\text{Chemical, lbs}}{\text{H}_2\text{O, Mlbs}}$$

This is the correct dosage calculation formula to use because mg/L is what you are looking for.

Next, make sure that you have all the information needed to work the problem. The formula needs the pounds of chemical being added each day and the million pounds of water being treated each day. You already know how many pounds of chemical are being used (115 lbs). However, the flow is listed in million gallons instead of in million pounds.

Therefore, you must convert the MG to Mlbs before you can work the dosage problem. This is done by multiplying the MG of water by 8.34 because each gallon of water weighs 8.34 lbs. (See the Common Conversion Factors listed in this Appendix)

$$2.3 \text{ MG} \times \frac{8.34 \text{ lbs}}{\text{gal}} = 19.2 \text{ Mlbs}$$

Now you know have all of the information needed for the formula in the proper units and you are ready to proceed.

Place the numbers in the proper places in the formula and finish the problem using division.

$$\text{Dose, mg/L} = \frac{115 \text{ lbs}}{19.2 \text{ Mlbs}}$$

$$\text{Dose} = 6 \text{ mg/L}$$

PROBLEM

Your plant has a flow of 3.8 MG and requires a chlorine dose of 8 mg/L. How many pounds of chlorine gas is needed to achieve this dosage?

SOLUTION

First, choose the formula that will give you what you need to know and write it down.

$$\text{Chemical, lbs} = (\text{Dose, mg/L}) (\text{H}_2\text{O, Mlbs})$$

This is the correct dosage calculation formula to use because pounds is what you need to know. Once again, you must make sure that you have all the information needed to work the problem. And once again you need to convert the MG to Mlbs before you can use the formula.

$$3.8 \text{ MG} \times \frac{8.34}{\text{gal}} = 31.7 \text{ Mlbs}$$

Now you are ready to proceed with the formula. Place the numbers into the formula and multiply.

$$\text{Chemical, lbs} = (8 \text{ mg/L}) (31.7 \text{ Mlbs})$$

And the answer is

$$\text{Chemical, lbs} = 254 \text{ lbs}$$

PROBLEM

Your plant has a flow of 3.8 MG and requires a chlorine dose of 8 mg/L. How many pounds of 65% HTH would be needed to achieve this dosage?

SOLUTION

This is the same as the previous problem except that 65% HTH is to be used instead of 100% chlorine gas. Probably the easiest way for most people to work this problem is to start by finding out how much chlorine gas would be needed, and then convert it to HTH.

First, work the problem in the same way it was done in the last problem.

$$\text{Chemical, lbs} = 254 \text{ lbs}$$

Because 65% HTH is being used, it will take more pounds than would be needed for chlorine gas. To get the correct answer, divide the number of pounds of chlorine gas that would be needed by 0.65 to find out how many pounds of 65% HTH would be needed.

$$\text{Chemical, lbs} = \frac{254 \text{ lbs}}{.65}$$

$$\text{HTH, lbs} = 391 \text{ lbs}$$

BASIC DOSAGE PRACTICE PROBLEMS

1. The flow is 2.4 MGD and the chlorine gas feed rate is 40 lbs/day. What is the dose in mg/L?
2. The flow is 1.2 MGD and the chlorine gas feed rate is 50 lbs/day. What is the dose in mg/L?
3. The flow is 0.60 MGD and the chlorine gas feed rate is 15 lbs/day. What is the dose in mg/L?
4. The flow is 0.30 MGD and the chlorine gas feed rate is 18 lbs/day. What is the dose in mg/L?

5. The flow is 2.4 MGD and a chlorine dose of 4 mg/L is required. How many pounds of chlorine gas must be used?

6. The flow is 1.8 MGD and a chlorine dose of 2 mg/L is required. How many pounds of chlorine gas must be used?

7. The flow is 3.0 MGD and a chlorine dose of 6 mg/L is required. How many pounds of chlorine gas must be used?

8. The flow is 0.3 MGD and a chlorine dose of 3 mg/L is required. How many pounds of chlorine gas must be used?

9. The flow is 0.5 MGD and a chlorine dose of 5 mg/L is required. How many pounds of 65% HTH must be used?

10. The flow is 0.018 MGD and a chlorine dose of 6 mg/L is required. How many pounds of 65% HTH must be used?

THE METRIC SYSTEM

The metric system is the main method of measurement in almost all of the industrialized countries in the world. Although many persons in the United States think that the metric system is confusing, it is probably even easier than the “English” system once you learn how to use it. Generally speaking, there are only three types of measurement; length, weight, and volume.

In the English system, length is measured in inches, feet, yards, miles, etc. In the metric system, length is measured in **meters**. In the English system, weight is measured in ounces, pounds, tons, etc. In the metric system, weight is measured in **grams**. In the English system, volume is measured in fluid ounces, pints, quarts, gallons, etc. In the metric system volume is measured in **liters**. The metric system is actually simpler than the English system because there is only one basic unit for length, one basic unit for weight, and one basic unit for volume.

Unit	Symbol	Measurement
Meter	m	Length
Gram	g or gm	Weight (or mass)
Liter	l or L	Volume

But how many or what part of a meter, gram, or liter? In the metric system, a prefix is used to tell you this. A prefix is something that is put in front of a word to modify it. In the metric system, a prefix is often used in front of one of the three basic units of measurement.

Prefix	Symbol	Meaning
Mega	M	one million (1,000,000)
Kilo	k	one thousand (1000)
Hecto	h	one hundred (100)
Deka	da	ten (10)
Deci	d	one tenth (0.1)
Centi	c	one one-hundredth (0.01)
Milli	m	one one-thousandth (0.001)
Micro	μ	one one-millionth (0.000001)

QUESTION

What is a ml?

ANSWER

The m is the prefix (it comes first). The prefix m is the symbol for milli which means one one-thousandth (1/1000). The l is a symbol for liter. A liter is the basic unit for measuring volume in the metric system.

ml is a symbol for **milliliter**, which is **one one-thousandth of a liter**.

QUESTION

What is a mg?

ANSWER

The m is the prefix (it comes first). The prefix m is the symbol for milli which means one one-thousandth (1/1000). The g is a symbol for gram. A gram is the basic unit for measuring weight in the metric system.

mg is a symbol for **milligram** which is **one one-thousandth of a gram**.

QUESTION

What is a mg/L?

ANSWER

A mg is a milligram which is one one-thousandth of a gram. L is the symbol for liter. The slash (/) means “per” or “in every”.

A mg/L is a symbol for a **milligram per liter**.

A **milligram per liter** is **one one-thousandth of a gram for every liter of water**.

Note: A mg/L is a unit of measurement often used for expressing a dosage of a substance in water or wastewater. A mg/L is the same thing as a ppm.

QUESTION

1 gram of chemical added to 1,000 ml of distilled water will make a stock solution containing how many mg/L?

$$1 \text{ gram} = 1,000\text{mg}$$

$$1,000 \text{ mL} = 1\text{L}$$

The solution strength is 1,000 mg/L

QUESTION

If 2 mL of a stock solution containing 1,000 mg/L is placed in a 1,000 mL of raw water the dosage is:

ANSWER

$$N_1 V_1 = N_2 V_2$$

N_1 is the strength of solution 1 (the stock solution)

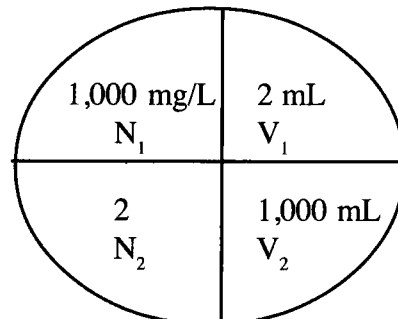
V_1 is the amount of solution 1

N_2 is the strength of solution 2 (the raw water)

V_2 is the amount of solution 2

$$1,000 \text{ mg/L} \times 2 \text{ ml} = \text{_____} \times 1,000 \text{ ml}$$

$$1,000 \times 2 = \frac{2,000}{1,000} = 2 \text{ mg/L}$$



ANSWERS TO APPENDIX A PRACTICE PROBLEMS

Volume/Time Units Practice Problems

1. 0.10 MGD
2. 1.2 MGD
3. 0.12 MGD
4. 0.056 MGD
5. 8.2 MGD
6. 0.0053 MGD
7. 0.011 MGD
8. 4.34 MGD
9. 1,600,000 gpd
10. 2,360,000 gpd
11. 80,000 gpd
12. 4000 gpd
13. 876,000 gpd
14. 54,000 gpd
15. 1,760,000 gpd

Area and Volume Practice Problems

1. 1800 ft²
2. 700 ft²
3. 1257 ft²
4. 5281 ft²
5. 113 ft²
6. 1000 ft³
7. 7480 gals
8. 62,383 lbs or 0.06 Mlbs
9. 6000 ft³
10. 44,880 gals

11. 374,299 lbs or 0.37 Mlbs
12. 7069 ft³
13. 52,873 gals
14. 440,962 lbs or 0.44 Mlbs
15. 15,708 ft³
16. 117,496 gals
17. 979,915 lbs or 0.98 Mlbs
18. 23,857 ft³
19. 178,447 gals
20. 1,488,246 lbs or 1.49 Mlbs

Detention Time Practice Problems

1. 4.0 hrs
2. 4.1 hrs
3. 8.1 hrs
4. 3.5 hrs
5. 128 days

Dosage Calculations Practice Problems

1. 2.0 mg/L
2. 5.0 mg/L
3. 3.0 mg/L
4. 7.2 mg/L
5. 80 lbs
6. 30 lbs
7. 150 lbs
8. 7.5 lbs
9. 32 lbs
10. 1.4 lbs

Appendix B

Certification Exam Formula Sheets

Listed in this appendix is the Class C exam formula sheet and the Class B and A exam formula sheet. Examinees must be familiar enough with the formula to be able to recognize it and use it properly if it is needed while taking the exam. Please see APPENDIX A for formulas provided on Class D exams.

Note: There are many mathematical calculations on the certification exams that do not involve specific formulas listed here. Also, there may be several calculations needed to convert the test question information into the form or units that the formulas require. Therefore, it's best to not limit your study of math to the use of these formulas only. To help prepare for other mathematical calculations that might be needed on an exam, operators are encouraged to follow the *Other Study Suggestions* related to math as well as practice the math problems found in the *Suggested References for Study* for each chapter.

Class C Water Operations Certification Exam Formula Sheet	
Dention Time, hr=	$\frac{(\text{Volume, gal})(24 \text{ hr/day})}{\text{Flow, gpd}}$
Dose, mg/L=	$\frac{\text{Chemical, lbs}}{\text{Flow, Mlbs}}$
Chemical Feed, lbs =	$(\text{Dose, mg/L})(\text{Flow, Mlbs})$
Weir Overflow, gpd/ft=	$\frac{\text{Flow, gpd}}{\text{Weir Length, ft}}$
Surface Loading, gpd/ft ² =	$\frac{\text{Flow, gpd}}{\text{Surface Area, ft}^2}$
Filtration Rate, gpm/ft ² =	$\frac{\text{Flow, gpm}}{\text{Surface Area, ft}^2}$
Velocity, ft/min=	$\frac{\text{Distance, ft}}{\text{Time, min}}$
Flow, ft ³ /min=	$(\text{Area, ft}^2)(\text{Velocity, ft/min})$

Class A & B Water Operations Certification Exam Formula Sheet

$$\text{Feed Rate, gpd} = \frac{(\text{Chemical Feed, lbs/day})(100\%)}{(\text{Chemical, lbs/gal})(\text{Purity of Chemical, \%})}$$

$$\text{Feeder Setting, gal/day} = \frac{(\text{Flow, MGD})(\text{Dosage, mg/L})(8.34 \text{ lbs/gal})}{\text{Chemical, lbs/gal}}$$

$$\text{Water HP} = \frac{(\text{Flow, gpm})(\text{TDH})}{3960}$$

$$\text{Motor HP} = \frac{(\text{Flow, gpm})(\text{Height, ft})}{(3960)(E_p)(E_m)}$$

$$\text{Brake HP} = \frac{(\text{Flow, gpm})(\text{Height, ft})}{(3960)(E_p)}$$

$$\text{Mixture Strength, \%} = \frac{(A, \text{ gal})(A\%) + (B, \text{ gal})(B\%)}{A, \text{ gal} + B, \text{ gal}}$$

$$\text{H}_2\text{O, gal} = \frac{(\text{Chemical, gal})(\text{Chemical \%}) - (\text{Chemical, gal})(\text{Desired \%})}{\text{Desired \%}}$$

$$\text{Dose, mg/L} = \frac{\text{Chemical, lbs}}{\text{Flow, Mlbs}}$$

$$\text{Chemical Feed, lbs} = (\text{Dose, mg/L})(\text{Flow, Mlbs})$$

$$\text{Detention Time, hr} = \frac{(\text{Volume, gal})(24 \text{ hr/day})}{\text{Flow, gpd}}$$

$$\text{Velocity, ft/min} = \frac{\text{Distance, ft}}{\text{Time, min}}$$

Flow, ft ³ /min = (Area, ft ²) (Velocity, ft/min)
Surface Loading, gpd/ft ² = $\frac{\text{Flow, gpd}}{\text{Surface Area, ft}^2}$
Weir Overflow, gpd/ft = $\frac{\text{Flow, gpd}}{\text{Weir Length, ft}}$
Filtration Rate, gpm/ft ² = $\frac{\text{Flow, gpm}}{\text{Surface Area, ft}^2}$

Appendix C

Introduction to Basic Chemistry

BASIC CHEMISTRY TERMS	
<i>Matter</i>	All substances in the universe.
<i>Chemistry</i>	The properties of matter and the changes in the composition of matter.
<i>Chemical Reaction</i>	When the basic chemical nature of matter is changed.
<i>Element</i>	A substance that cannot be separated into its constituent parts and still retain its chemical identity. For example sodium (Na) is an element.
<i>Atom</i>	The smallest unit of a element; composed of protons, neutrons, and electrons.
<i>Electron</i>	An extremely small negatively-charged particle; the part of an atom that determines its chemical properties.
<i>Compound</i>	A substance composed of two or more elements whose composition is constant. For example, table salt (sodium chloride — NaCl) is a compound.
<i>Molecule</i>	The smallest division of a compound that still retains or exhibits all the properties of the substance.
<i>Oxidizing Agent</i>	Any substance, such as oxygen (O ₂) or chloride (Cl ⁻) that will readily add (take on) electrons. The opposite is a reducing agent.
<i>Reducing Agent</i>	Any substance, such as a base metal that will readily donate (give-up) electrons. The opposite is an oxidizing agent.
<i>Ion</i>	An electrically charged atom or molecule formed by the loss or gain of one or more electrons. Positively-charged ions are often referred to as cations. Negatively-charged ions are often referred to as anions.
<i>Anode</i>	The positive pole or electrode of an electrolytic system, such as a battery. The anode attracts negatively-charged particles or ions (anions).
<i>Cathode</i>	The negative pole or electrode of an electrolytic system. The cathode attracts positively-charged particles or ions (cations).
<i>Valence</i>	The combining capacity of an element in a compound. The number of atoms of hydrogen that are equivalent to one atom of the element.
<i>Atomic Weight</i>	The quantity that tells how the weight of an average atom of that element compares with the weight of all other elements, with all relative weights based on the weight of Carbon (C), which has been set at 12.00.
Appendix C Table 1	

SOME COMMON CHEMICAL ELEMENTS				
Element	Symbol	Atomic Weight	Normal Valence	
			+	-
Aluminium	Al	26.97	3	
Bromine	Br	79.916		1
Calcium	Ca	40.08	2	
Carbon	C	12.00	4	
Chlorine	Cl	35.457		1
Copper	Cu	63.57	2	
Hydrogen	H	1.008	1	
Iron	Fe	55.84	2	
Lead	Pb	207.21	2	
Magnesium	Mg	24.32	2	
Manganese	Mn	54.93	2	
Nitrogen	N	14.008	5	
Oxygen	O	16.00		2
Phosphorous	P	31.02	5	
Potassium	K	39.096	1	
Sodium	Na	22.997	1	
Sulfur	S	32.066	6	

Appendix C Table 2

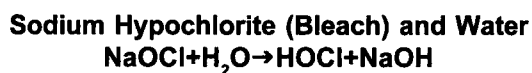
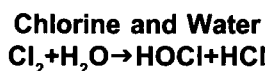
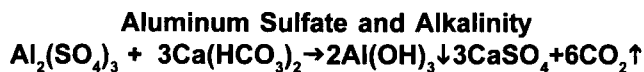
SOME COMMON CHEMICAL COMPOUNDS		
Chemical Name	Common Name(s)	Chemical Symbol
Aluminum sulfate	alum	$\text{Al}_2(\text{SO}_4)_3 \cdot 14\text{H}_2\text{O}$
Ammonia	ammonia	NH_3
Calcium carbonate	calcium carbonate	CaCO_3
Calcium oxide	lime	CaO
Calcium hydroxide	lime / slaked lime / hydrated lime	$\text{Ca}(\text{OH})_2$
Calcium hypochlorite	high-test hypochlorite / HTH	$\text{Ca}(\text{OCl})_2$
Carbon dioxide	carbon dioxide gas	CO_2
Chlorine	chlorine	Cl_2
Copper sulfate	blue vitriol / bluestone	$\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$
Hydrochloric Acid	muriatic acid	HCl
Hypochlorous Acid	hypochlorous acid	HOCl
Hydrogen sulfide	hydrogen sulfide gas	H_2S
Ferrous sulfate	copperas	$\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$
Fluorosilicic Acid	(also called hydrofluorosilicic acid)	H_2SiF_6
Methane	methane gas	CH_4
Potassium permanganate	permanganate	KMnO_4
Sodium carbonate	soda ash	Na_2CO_3
Sodium bicarbonate	baking soda	NaHCO_3
Sodium hydroxide	caustic / caustic soda / lye	NaOH
Sodium hypochlorite	bleach	NaOCl
Sodium fluoride	sodium fluoride	NaF
Sodium fluorosilicate	(also called sodium silicofluoride)	Na_2SiF_6

Appendix C Table 3

SOME COMMON CHEMICAL REACTIONS IN WATER TREATMENT

KEY

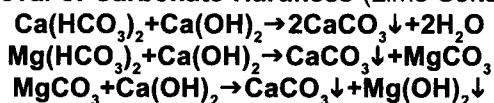
- yields or produces
 ↑ liberates as a gas
 ↓ precipitates as a solid



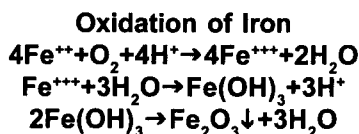
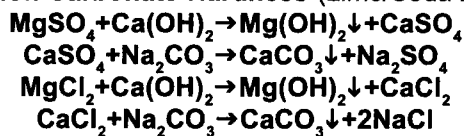
1. $\text{HOCl} + \text{NH}_3 \rightarrow \text{NH}_2\text{Cl} + \text{H}_2\text{O}$
2. $\text{HOCl} + \text{NH}_2\text{Cl} \rightarrow \text{NHCl}_2 + \text{H}_2\text{O}$
3. $\text{HOCl} + \text{NHCl}_2 \rightarrow \text{NCl}_3 + \text{H}_2\text{O}$



Removal of Carbonate Hardness (Lime Softening)



Removal of Non-Carbonate Hardness (Lime/Soda Ash Softening)



Appendix C Table 4

Answers to Sample Questions

CHAPTER 1

Class D C
Class C B
Class B B
Class A C

CHAPTER 2

Class D A
Class C C
Class B D
Class A C

CHAPTER 3

Class D C
Class C B
Class B A
Class A D

CHAPTER 4

Class D B
Class C A
Class B C
Class A C

CHAPTER 5

Class D C
Class C A
Class B B
Class A C

CHAPTER 6

Class D C
Class C A
Class B D
Class A D

CHAPTER 7

Class D B
Class C A
Class B C
Class A A

CHAPTER 8

Class D A
Class C B
Class B A
Class A C

CHAPTER 9

Class D C
Class C C
Class B B
Class A D

CHAPTER 10

Class D C
Class C C
Class B A
Class A B

CHAPTER 11

Class D C
Class C A
Class B C
Class A E

CHAPTER 12

Class D C
Class C B
Class B C
Class A A

COMPLETE SUGGESTED REFERENCES FOR STUDY

California State University, Sacramento - Water Treatment Plant Operation, Vol. 1

Chapter 1	The Water Treatment Plant Operator
Chapter 2	Water Sources and Treatment
Chapter 3	Reservoir Management and Intake Structures
Chapter 4	Coagulation and Flocculation
Chapter 5	Sedimentation
Chapter 6	Filtration
Chapter 7	Disinfection
Chapter 8	Corrosion Control
Chapter 9	Taste and Odor Control
Chapter 10	Plant Operation
Chapter 11	Laboratory Procedures
Appendix	How to Solve Water Treatment Plant Arithmetic Problems

California State University, Sacramento - Water Treatment Plant Operation, Vol. 2

Chapter 12	Iron and Manganese Control
Chapter 13	Fluoridation
Chapter 14	Softening
Chapter 15	Trihalomethanes
Chapter 16	Demineralization
Chapter 17	Handling and Disposal of Process Wastes
Chapter 18	Maintenance
Chapter 19	Instrumentation
Chapter 20	Safety
Chapter 21	Advanced Laboratory Procedures
Chapter 22	Drinking Water Regulations
Chapter 23	Administration

California State University, Sacramento - Small Water System Operation and Maintenance

Chapter 3	Wells
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California State University, Sacramento - Water Distribution System Operation and Maintenance

Chapter 1	The Water Distribution System Operator
Chapter 2	Storage Facilities
Chapter 3	Distribution System Facilities
Chapter 4	Water Quality Considerations in Distribution Systems
Chapter 5	Distribution System Operation
Chapter 6	Disinfection
Chapter 7	Safety

Oklahoma Operator Certification Rules (Chapter 710)

Public Water Supply Operations (Chapter 631)

Rules for Oklahoma Hazard Communication Standard

Title 40 - Oklahoma Statutes for General Safety and Health

OSHA Confined Space Entry Rule

*** AWWA Reference Handbook: Basic Science Concepts and Applications - Hydraulics Section**

** needed for certification purposes only by those persons preparing for a Class A examination.*

REFERENCE SOURCES

(for all references listed in the Suggested References for Study and Other Study Suggestions)

CSUS Water Treatment Plant Operation, Volume I
CSUS Water Treatment Plant Operation, Volume II
CSUS Water Distribution System Operation and Maintenance
CSUS Small Water System Operation and Maintenance

Kenneth D. Kerri, Office of Water Programs
6000 J Street
Sacramento, California 95819-6025
(916)278-6142 **Website:** www.owp.csus.edu

Water and Wastewater Works Operator Certification (Chapter 710)

Oklahoma Department of Environmental Quality
Customer Service
PO Box 1677
707 N. Robinson
Okla. City, OK 73101-1677
(405) 702-9100 **Website:** www.deq.state.ok.us

Public Water Supply Operations (Chapter 631)

Public Water Supply Constuction Standards (Chapter 625)

Oklahoma Department of Environmental Quality
Customer Assistance
PO Box 1677
707 N. Robinson
Okla. City, OK 73101-1677
(405) 702-9100 **Website:** www.deq.state.ok.us

Rules for Oklahoma Hazard Communication Standard

Title 40 - Oklahoma Statutes for General Safety and Health

OSHA Confined Space Entry Rule

Oklahoma State Department of Labor
Division of Public Employees Safety and Health
4001 N. Lincoln Blvd.
Okla. City, OK 73105
(405) 528-1500 ext. 266 **Website:** www.state.ok.us/~okdol

AWWA WSO Basic Science Textbook & Workbook

AWWA Standard for Disinfecting Water Mains (C651-99)

AWWA Standard for Disinfection of Water Storage Facilities (C652-92)

AWWA Standard for Disinfection of Water Treatment Plants (C653-97)

AWWA Standard Disinfection of Wells (C654-97)

American Water Works Association
6666 West Quincy Ave.
Denver, Colorado 80235
1-800-926-7337 **Website:** www.awwa.org

Chlorine Manual (Chlorine Institute Pamphlet #1 Edition 5, 1986)

Chlorine Institute
2001 L St. N.W. Suite 506
Washington D.C. 20036
(202) 775-2790

SOURCES OF ADDITIONAL STUDY MATERIAL

Operator Training Handbooks, References and Materials	American Water Works Association 6666 West Quincy Ave. Denver, Colorado 80235 1-800-926-7337 (catalog available) Website: www.awwa.org
Operator Training Publications and Materials	Water Environment Federation 601 Wythe Street Alexandria, Virginia 22314-1994 1-800-666-0206 (catalog available) Website: www.wef.org
Safety Publications and Materials	U.S. Dept. of Labor Occupational Sfty. & Hlth. Adm.(OSHA) (202) 219-4667 (catalog available)
Safety Publications and Materials	Oklahoma Safety Council 2725 E. Skelly Dr. Tulsa, OK 74105 1-800-324-6458 (catalog available) Website: www.oksafety@ionet.net
Operator Math Manuals and Workbooks	Technomic Publishing Company 851 New Holland Avenue, Box 3535 Lancaster, Pennsylvania 17604 1-800-233-9936 (catalog available) Website: techpub.com
EPA Technical Manuals and Materials	National Drinking Water Clearinghouse 1-800-624-8301 (catalog available)
Federal SDWA Amendments, Code of Federal Regulations	EPA Safe Drinking Water Act Hotline 1-800-426-4791
Operator Training Material Information	National Environmental Training Center 1-800-624-8301



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