VOLUME 2
INTERMEDIATE LEVEL

Spellman's Standard Handbook for Wastewater Operators

Frank R. Spellman

INTERMEDIATE LEVEL

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Frank R. Spellman, Ph.D.

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For Wastewater Operators Everywhere

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Preface

In *Volume 1: Fundamental Level* of *Spellman's Standard Handbook for Wastewater Operators,* the point was made that the three-volume set is more than just a study guide or a readily accessible source of information for review in preparing wastewater personnel for operator certification and licensure. Moreover, the point was made that this three-volume handbook is a resource manual and a troubleshooting guide that contains a compilation of wastewater treatment information, data, operational material, process control procedures and problem solving, safety and health information, new trends in wastewater treatment administration and technology, and numerous sample problem-solving practice sets. In short, the text's most important aspects were listed as three-fold:

(1) It gives today's wastewater operators instant information they need to expand their knowledge—which aids them in the efficient operation of a wastewater treatment plant.
(2) It provides the user with the basic information and sample problem-solving sets needed to prepare for state licensing/certification examinations.
(3) It provides user-friendly, straightforward, plain English fundamental reference material—a three-volume handbook of information and unit process troubleshooting guidance required on a daily basis, not only by the plant manager, plant superintendent, chief operator, lab technician, and maintenance operator, but more importantly by and for the plant operator.

In this volume, the ground rules have not changed, not a bit—not at all. Why would we want to change something that works, something that has proven its worth, that has been well received out there where it was intended to be received: In the wastewater industry? The only thing that has changed is the level of information provided. *Volume 2: Intermediate Level* focuses on stalking and illuminating, both literally and figuratively, information necessary to qualify you for service at a higher level of certification—at a higher level of responsibility.

In Volume 1, we set the groundwork, the foundation for advanced materials presented in this volume and in Volume 3. The handbook series' primary goal is to enhance the understanding, awareness, and abilities of practicing operators and those who aspire to be operators. For wastewater operators who are striving to attain professional achievement, to reach the top of their profession, can there be a more honorable goal? We think not.

The first volume (fundamental), second volume (intermediate), and third volume (advanced) are designed to build on one another, providing increasingly advanced information. This is an important point, because you will soon notice (i.e., if you have already used Volume 1—though it is not necessary) that Volume 2, after a brief refresher on wastewater mathematics, picks up where Volume 1 ended.

In Volume 1, it was stated that none of us are chained to the knowledge we already have. We

Spellman's Handbook series borrows from knowledge gained through doing, observing and making mistakes (and learning from them) and from new innovations that are constantly appearing on the scene; it is basically a vehicle designed to take you on a ride—a ride to the level you aspire to reach. However, don't be misguided; the journey ahead is not an easy one. Attaining certification as a professional wastewater operator is not easy—but the vehicle (this text) makes for a smoother, "easier," less painful trip.

In short, preparing for qualification as a wastewater treatment plant operator and providing a quick, ready reference for those who have already obtained licensure is what this handbook series is all about.

In Volume 1, we asked the question: Is this text needed? We answered: Absolutely. Why? Good question.

Remember, contrary to popular belief (and simply put), treating wastewater is not just an art but instead is both an art and a science. Treating wastewater successfully demands technical expertise and a broad range of available technologies, as well as an appreciation for and the understanding of the fundamental environmental and health reasons for the processes involved. It demands unique vision and capabilities. This is where *Spellman's Standard Handbook of Wastewater Treatment* comes in. From pumping influent and treating the wastestream through managing biosolids, this handbook series provides easy-to-understand, state-of-the-art information in a three-volume set that begins at the entry level for those preparing for the Class IV/Class III or Grade I/II operator examination, proceeds to the intermediate level for the Class III/Class II or Grade II/III operator examination, and finishes at the advanced level for Class I/Grade IV/V wastewater operator licensure examinations. Though formatted at three separate levels (introductory, intermediate, and advanced), overlap between each volume ensures continuity and a smooth read from volume to volume. In essence, each volume is a handheld reference text—one that enables the practitioner of the artful science of wastewater treatment operations to qualify for certifications and/or refresh his or her memory in an easy, precise, efficient, and effective manner.

This handbook was prepared to help operators obtain licensing and to operate wastewater treatment plants properly. Can it be used as a textbook in technical training courses in technical schools and at the junior college level? Absolutely. In fact, we highly recommend it.

Again, as stated in Volume 1, the handbook does not discuss the specific content of the examination. Instead, it reviews the wastewater operator's job-related knowledge identified by the examination developers as essential for a minimally competent Class IV through Class I or Grade I through Grade V wastewater treatment plant operator. Every attempt has been made to make the three-volume handbook as comprehensive as possible while maintaining the compact, practical format.

The bottom line: The handbook is not designed to simply "teach" the operator licensing exams, although it is immediately obvious to the users that the material presented will help them pass licensing exams. The material in each volume is intended for practical use and application. We present applied math and chemistry by way of real-world problems. Readers learn how to maintain equipment. We explain apparatus used in the laboratory and in the field (e.g., valves and pumps).

In the past, the effort required to obtain a wastewater operator's license has been likened to that of training an elephant to cross a tightwire above the Grand Canyon, and sifting through mountains of information and deciphering it can add further confusion and frustration.

Volume 2 of *Spellman's Standard Handbook for Wastewater Operators* presents a methodical, plain-English process for achieving the wastewater operator's goal, whether it be to increase level of knowledge or prepare for licensure—eliminating both confusion and frustration.

Have a smooth ride and an enlightening journey.

Acknowledgements

ALTHOUGH this three-volume set of handbooks bears my name, it should be pointed out that it is a compilation of many individuals' efforts put forth over the years. Modeled after the highly successful Wastewater Treatment Plant Operators Short Course presented annually by the Virginia Department of Environmental Quality at Virginia Polytechnic Institute and State University (Virginia Tech), this handbook series has benefited from many contributors, including students, too numerous in number to acknowledge here.

When one finds a model, a prototype, a paradigm—one that actually works, one that actually enables students to gain from the learning experience and to go on to have successful careers in the wastewater field—it seems only natural and quite fitting to bottle up such a program and make it available to wastewater practitioners worldwide. This is the purpose of this handbook series—to provide a model that works. We know this because it has been successfully tested, time and time again.

The format and material contained within this three-volume set has been continuously updated and used successfully for more than 20 years to train wastewater personnel for licensure and to equip them with the requisite knowledge required to operate wastewater treatment plants in the most efficient manner possible.

In short, though there are too many individuals to single out for recognition for their contributions to this text, there are always a few who stand out above the rest, and this is certainly the case with this publication. Thus, Dr. Gregory D. Boardman, an associate professor of environmental engineering at Virginia Tech, and Wayne Staples of Virginia's Department of Environmental Quality (DEQ) deserve much credit for the format and material contained within each of the three handbooks. In addition, Nancy E. Whiting (my able co-author of several other texts) provided some timely assistance with this work. I am indebted to Joanne Drinan who helped to craft many of the illustrations used in this volume. Without their efforts and expertise, this handbook series would not be possible.

CHAPTER 1

Introduction

1.1 SETTING THE STAGE

SPELLMAN'S *Standard Handbook for Wastewater Operators, Volume 2: Intermediate Level* begins where the first handbook left off—at a higher level, the intermediate level, building on the information base provided in Volume 1. Volume 2 covers four areas not previously covered in Volume 1: Troubleshooting guidelines, biosolids incineration, land application of biosolids, and fecal coliform testing. The math presented in Volume 2 is at a higher level than that presented in Volume 1—wastewater math you actually are required to use in real-world wastewater operations—and the type of math and math problems you will certainly see on licensure examinations. Volume 2 also provides more of the foundational information you'll need to understand the information presented in Volume 3 (advanced level). Simply put, this three-volume handbook series functions to provide a complete learning experience (see Figure 1.1) for wastewater operators and operations.

Volume 2 provides a readily accessible, user-friendly source of information for review in preparing for the Class III/II or Grade III state Wastewater Operator Licensure Examinations. Along with providing necessary information to successfully pass licensure examinations, Volume 2 also sets the stage (provides another level of knowledge to build on) for Volume 3, which is intended to prepare users to sit for Class II/I or Grade IV/V licensure.

We've made every attempt to format this presentation in ways that allow you to build upon the information we present, step-by-step, page-by-page, as you progress through the material. This handbook consolidates expert information available in many other sources (see Table 1.1 for a list of useful resources), giving you what you need to know for licensure. For additional information or more specific material on any of the topics presented, you should consult one or more of the references provided in Table 1.1.

Keep in mind that this intermediate-level handbook is intended for the user who is an operator-in-training—for those people currently preparing to sit for the Class III/II or Grade III operator licensure examination.

✓ *Note:* In this handbook, we refer to the "intermediate level" as the second major step in licensure, which is the case in many states.

✓ The symbol ✓("check mark") displayed in various locations throughout the handbook indicates an important point or note that the reader should read carefully. Moreover, in this volume and in Volume 3, the checkmark also highlights or flags information that you may see somewhere else, that may assist you in correctly answering many of the licensure questions or troubleshooting problems you may run across on future examinations and/or in process operations.

No one can guarantee you that you will pass a state licensure examination. However, we've made

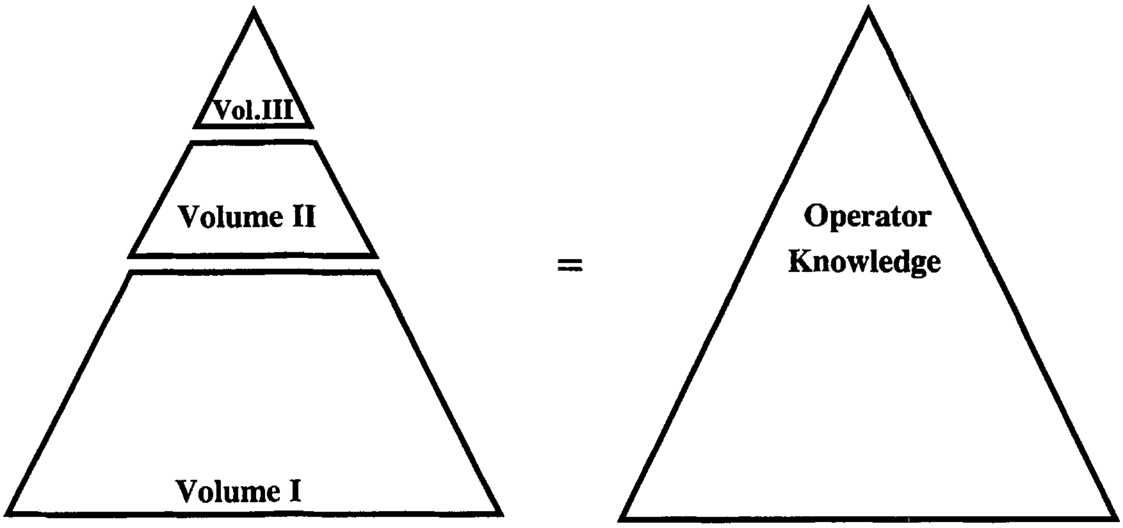


Figure 1.1 Successful completion of all three volumes of the *Handbook* will increase the operator's knowledge level.

every effort to include in this handbook series the type of information that will help you learn the information you need to know to pass these tests—to increase your knowledge of wastewater operations, your troubleshooting skills, and your sampling and sample testing knowledge and to prepare you for licensure. No single text can cover all the areas required, so you must augment the content of this handbook with other, more in-depth training materials. These materials include the various field study programs available from state water control boards, short courses presented by various universities (e.g., Virginia Tech) and/or technical schools, and correspondence studies from such sources as California State University, Sacramento (The "Sacramento Manuals").

Changes in technology and regulations occur frequently in the water pollution control industry. Because of this, it is important, as a licensure candidate, to stay abreast of these changes.

We divide Volume 2 into sections and chapters covering specific topic areas. As with the previous (and subsequent) volume, at the end of many chapters, we include a series of review questions. When you complete these chapters, answer the review questions and check your answers with those given in Appendix A. The final chapter of the handbook includes a comprehensive practice examination, to allow you to test the level of knowledge you've gained through study of this handbook, knowledge gained through on-the-job experience, and knowledge gained from other sources. We consider a score of 75% or above "good"—but more importantly, any questions you miss should signal to you the need to go back and re-read and re-study the applicable areas. By using the final examination as a measuring stick, you can gauge your level of knowledge in all pertinent areas and determine your strengths and weaknesses. In the real world, this is what testing is all about. Measuring your level of knowledge with the purposeful intent of directing study so that you can attain an even greater level of knowledge is a worthwhile objective. We provide the answers to the final review examination (in Chapter 20) in Appendix B. A standard formula sheet is provided in Appendix C and should be used for reference; it can and should be used when taking the final examination.

1.2 THE WASTEWATER TREATMENT PROCESS: THE MODEL

In Volume 1, we used a basic schematic—an example wastewater treatment process providing primary and secondary treatment using the activated sludge process (see Figure 1.2). We use this as the model, the prototype of wastewater processes in all three volumes of this handbook series. Though in secondary treatment (which provides BOD removal beyond what is achievable by simple sedimentation) three approaches (trickling filter, activated sludge, and oxidation ponds) are com-

TABLE 1.1. Recommended Reference Material.

1. *Advanced Waste Treatment, A Field Study Program,* 2nd ed., Kerri, K., et al. California State University, Sacramento, CA.
2. *Aerobic Biological Wastewater Treatment Facilities*, Environmental Protection Agency, EPA 430/9-77-006, Washington, D.C., 1977.
3. *Anaerobic Sludge Digestion*, Environmental Protection Agency, EPA 430/9-76-001, Washington, D.C., 1977.
4. *Annual Book of ASTM Standards, Section 11, "Water and Environmental Technology,"* American Society for Testing Materials (ASTM), Philadelphia, PA.
5. *Guidelines Establishing Test Procedures for the Analysis of Pollutants.* Federal Register (40 CFR 136), April 4, 1995, Volume 60, No. 64, Page 17160.
6. *Handbook of Water Analysis*, 2nd ed., HACH Chemical Company, P.O. Box 389, Loveland, CO, 1992.
7. *Industrial Waste Treatment, A Field Study Program, Volume I,* Kerri, K., et al. California State University, Sacramento, CA.
8. *Industrial Waste Treatment, A Field Study Program, Volume 2,* Kerri, K., et al. California State University, Sacramento, CA.
9. *Methods for Chemical Analysis of Water and Wastes,* U.S. Environmental Protection Agency, Environmental Monitoring Systems Laboratory-Cincinnati (EMSL-CL), EPA-6000/4-79-020, Revised March 1983 and 1979 (where applicable).
10. *O & M of Trickling Filters, RBC and Related Processes, Manual of Practice OM-10,* Water Pollution Control Federation (now called Water Environment Federation), Alexandria, VA, 1988.
11. *Operation of Wastewater Treatment Plants, A Field Study Program, Volume I,* 4th ed., Kerri, K., et al. California State University, Sacramento, CA.
12. *Operation of Wastewater Treatment Plants, A Field Study Program, Volume II,* 4th ed., Kerri, K., et al. California State University, Sacramento, CA.
13. *Standard Methods for the Examination of Water and Wastewater*, 18th ed., American Public Health Association, American Water Works Association-Water Environment Federation, Washington, D.C., 1992.
14. *Treatment of Metal Wastestreams*, Kerri, K., et al. California State University, Sacramento, CA.
15. *Basic Math Concepts: For Water and Wastewater Plant Operators.* Price, J. K. Lancaster, PA: Technomic Publishing Company, Inc., 1991.
16. *Simplified Wastewater Treatment Plant Operations*. Haller, E. J. Lancaster, PA: Technomic Publishing Company, Inc., 1995.
17. *Wastewater Treatment Plants: Planning, Design, and Operation,* 2nd ed. Qasim, S. R. Lancaster, PA: Technomic Publishing Company, Inc., 1999.
18. *Hands-On Water/Wastewater Equipment Maintenance.* Renner, D., Lancaster, PA: Technomic Publishing Company, Inc., 1999.
19. *Microbiology for Water/Wastewater Operators.* Spellman, F. R., Lancaster, PA: Technomic Publishing Company, Inc., 1997.
20. *Incinerating Biosolids.* Spellman, F. R., Lancaster, PA: Technomic Publishing Company, Inc., 1997.
21. *Dewatering Biosolids.* Spellman, F. R., Lancaster, PA: Technomic Publishing Company, Inc., 1997.

monly used, we focus on the activated sludge process throughout this handbook. We use the activated sludge process because the operation of an aeration system is complex and because a certain level of knowledge and understanding of the process is required to be able to properly operate the process. Figure 1.2 and its subsequent renditions enable you to follow the treatment process step-by-step as it is presented (and as it is actually configured in the real world) to help you understand how all the various unit processes sequentially follow and tie into each other. In Volume 2, we begin the chapters that discuss unit processes with variations of Figure 1.2—with the relevant subject area to be discussed included in the diagram along with previously presented processes. In essence, we start with a blank diagram and fill in the unit processes as we progress. Because wastewater treatment is

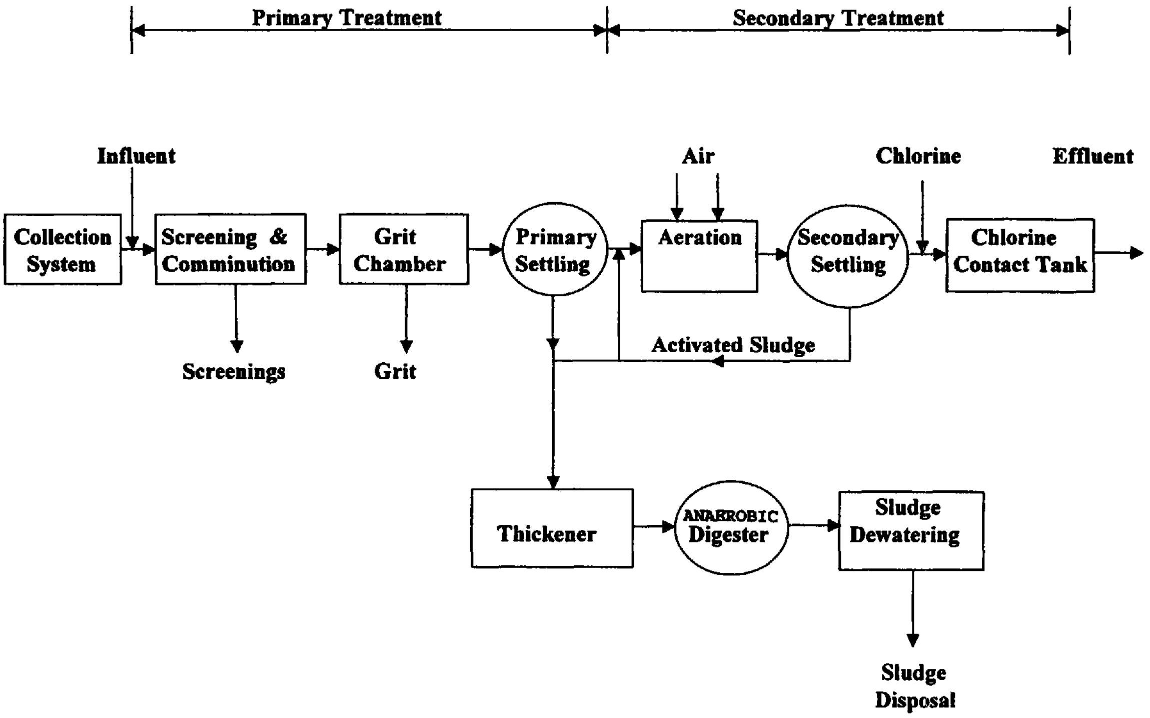


Figure 1.2 Schematic of a sample wastewater treatment process providing primary and secondary treatment using activated sludge process.

a series of individual steps (unit processes) that treat the wastestream as it makes its way through the entire process, seeing how the individual steps fit together visually can help you learn how the process functions as a whole. Even though the model shown in Figure 1.2 does not include all unit processes currently used in wastewater treatment, we do not ignore the other major processes. Trickling filters, rotating biological contactors (RBCs), oxidation ponds, and incineration and land application of biosolids are all presented and discussed in some detail.

1.3 THE BOTTOM LINE

We present the material in Volume 2 in a logical, step-by-step fashion, which works to help those studying for licensure and also can help those who use this handbook as a ready reference or as a troubleshooting guide—an answer book. Providing answers, solutions, and guidance is not only the bottom line but is what the handbook series is all about.

CHAPTER 2

Wastewater Teminology and Definitions

2.1 INTRODUCTION

WE pointed out in Volume 1 that every branch of science and technology has its own terms with their own definitions. This is certainly the case in wastewater treatment. For example, terms such as clarifiers, contact tanks, BOD, COD, DO, digesters, bar screens, comminution, grit removal, stabilization, composting, conditioning, dewatering, and others are typically associated with (and some are unique to) the wastewater profession; others combine words from many different professions. Wastewater treatment is a combination of engineering, biology, mathematics, hydrology, chemistry, physics, and other disciplines. Thus, many of the terms used in engineering, biology, mathematics, hydrology, chemistry, physics, and others are also used in wastewater treatment.

In this chapter, we identify and define many of the terms unique to wastewater treatment and other related terms. Those terms not listed or defined in the following section will be defined as they appear in the text.

You might ask, "Why not include these terms and their definitions in a glossary placed at the end of the text (the practice in most technical texts)?" The simple answer is that it is important to start out a learning activity on the right foot, using the correct terms and, more importantly, providing understanding early in the presentation for those terms that follow in subsequent chapters. The compound answer is actually a question: Do you really know anyone who actually uses a glossary?

2.2 TERMINOLOGY AND DEFINITIONS

- *Activated sludge* the solids formed when microorganisms are used to treat wastewater using the activated sludge treatment process. It includes organisms, accumulated food materials, and waste products from the aerobic decomposition process.
- *Advanced waste treatment* a treatment technology used to produce an extremely high-quality discharge.
- *Aerobic* conditions in which free, elemental oxygen is present. Also used to describe organisms, biological activity, or treatment processes that require free oxygen.
- *Afterburner* (incineration) a device that includes an auxiliary fuel burner and combustion chamber to incinerate combustible gas contaminants.
- *Air emission* for stationary sources, is the release or discharge of a pollutant by an owner or operator into the ambient air either by means of a stack or as a fugitive dust, mist, or vapor as a result inherent to the manufacturing or forming process.
- *Air pollutant* dust, fumes, smoke, and other particulate matter, vapor, gas odorous substances, or any combination thereof.

- *Anoxic* conditions in which no free, elemental oxygen is present. The only source of oxygen is combined oxygen, such as that found in nitrate compounds. Also used to describe biological activity or treatment processes that function only in the presence of combined oxygen.
- *Autogenous/autothermic combustion* (incinerator) the burning of a wet organic material where the moisture content is at such a level that the heat of combustion of the organic material is sufficient to vaporize the water and maintain combustion. No auxiliary fuel is required except for start-up.
- *Average monthly discharge limitation* the highest allowable discharge over a calendar month.
- *Average weekly discharge limitation* the highest allowable discharge over a calendar week.
- *Biochemical oxygen demand, BOD_5* the amount of organic matter that can be biologically oxidized under controlled conditions (five days @ 20°C in the dark).
- *Biosolids* from *Merriam-Webster's Collegiate Dictionary, Tenth Edition* (1998): biosolid *n* (1977)—solid organic matter recovered from a sewage treatment process and used especially as fertilizer (usually used in plural).

✓ *Note:* In this text and all other Spellman texts on wastewater topics, biosolids is used in many places (activated sludge being the exception) to replace the standard term sludge. The author (along with others in the field) views the term sludge as an ugly four-letter word that is inappropriate to use in describing biosolids. Biosolids can be reused; they have some value. Because biosolids have some value, they certainly should not be classified as a "waste" product—and in Volumes 2 and 3 of this handbook, when biosolids for beneficial reuse is addressed, it is made clear that biosolids is not a waste product.

- *Biosolids cake* the solid discharged from a dewatering apparatus.
- *Biosolids concentration* the weight of solids per unit weight of biosolids. It can be calculated in percent as follows:

$$\text{concentration} = \frac{\text{weight of dry biosolids solids}}{\text{weight of wet biosolids}} \times 100$$

- *Biosolids moisture content* the weight of water in a biosolids sample divided by the total weight of the sample. This is normally determined by drying a biosolids sample and weighing the remaining solids. Total weight of the biosolids sample equals the weight of water plus the weight of the dry solids. As an example, assume that 100 grams of biosolids is evaporated and produces 3 grams of residue.

$$\text{solids content} = \frac{3}{100} \times 100 = 3\%$$

$$\text{moisture content} = \frac{(100-3)}{100} \times 100 = 97\%$$

- *Biosolids quality parameters* three main EPA parameters used in gauging biosolids quality: (1) the relevant presence or absence of pathogenic organisms, (2) pollutants, and (3) the degree of attractiveness of the biosolids to vectors (i.e., insects and rodents).
- *Bottom ash* the solid material that remains on the hearth or falls off the grate after thermal

- *Burner* a device that positions a flame in the desired location by delivering fuel and air to that location in such a manner that continuous ignition is accomplished.
- *Burning rate* the volume of solid waste incinerated or the amount of heat released during incineration.
- *Cake solids discharge rate* the dry solids cake discharge from a centrifuge, which is expressed as follows:

$$\text{dry cake solids discharge rate} = (\text{dry solids feed rate}) \times (\text{solids recovery})$$

- *Carbonaceous biochemical oxygen demand,* $CBOD_5$ the amount of biochemical oxygen demand that can be attributed to carbonaceous material.
- *Centrate* the effluent or liquid portion of biosolids removed by or discharged from a centrifuge.
- *Chemical oxygen demand (COD)* the amount of chemically oxidizable materials present in the wastewater.
- *Clarifier* a device designed to permit solids to settle or rise and be separated from the flow. Also known as a settling tank or sedimentation basin.
- *Coliform* a type of bacteria used to indicate possible human or animal contamination of water.
- *Combined sewer* a collection system that carries both wastewater and stormwater flows.
- *Combustion air* the air used for burning a fuel.
- *Comminution* a process to shred solids into smaller, less harmful particles.
- *Composite sample* a combination of individual samples taken in proportion to flow.
- *Daily discharge* the discharge of a pollutant measured during a calendar day or any 24-hour period that reasonably represents a calendar day for the purposes of sampling. Limitations expressed as weight are total mass (weight) discharged over the day. Limitations expressed in other units are average measurements of the day.
- *Daily maximum discharge* the highest allowable values for a daily discharge.
- *Detention time* the theoretical time water remains in a tank at a given flow rate.
- *Dewatering* the removal or separation of a portion of water present in a sludge or slurry.
- *Discharge Monitoring Report (DMR)* the monthly report required by the treatment plant's NPDES discharge permit.
- *Dissolved oxygen (DO)* free or elemental oxygen that is dissolved in water.
- *Drying hearth* a solid surface in an incinerator upon which wet waste materials or waste matter that may turn to liquid before burning are placed to dry or to burn with the help of hot combustion gases.
- *Effluent* the flow leaving a tank, channel, or treatment process.
- *Effluent limitation* any restriction imposed by the regulatory agency on quantities, discharge rates, or concentrations of pollutants that are discharged from point sources into state waters.
- *Excess air* the amount of air required beyond the theoretical air requirements for complete combustion. This parameter is expressed as a percentage of the theoretical air required. Sample calculation for excess air:

$$\begin{aligned}\text{excess air} &= \frac{(\text{actual air rate} - \text{theoretical rate}) \times 100}{\text{theoretical air rate}}\\ &= \frac{(1{,}500 - 1{,}000) \times 100}{1{,}000}\\ &= 50\%\end{aligned}$$

- *Facultative* organisms that can survive and function in the presence or absence of free, elemental oxygen.
- *Fecal coliform* a type of bacteria found in the bodily discharges of warm-blooded animals. Used as an indicator organism.
- *Filtrate* the effluent or liquid portion of biosolids removed by or discharged from a centrifuge.
- *Flashpoint* the lowest temperature at which evaporation of a substance produces sufficient vapor to form an ignitable mixture with air, near the surface of the liquid.
- *Floc* solids that join together to form larger particles that will settle better.
- *Fluidized bed combustion* oxidation of combustible material within a bed of solid, inert particles that act as a fluid under the action of vertical hot airflow.
- *Flume* a flow rate measurement device.
- *Fly ash* airborne combustion residue from burning fuel.
- *Food-to-microorganism ratio (F/M)* an activated sludge process control calculation based upon the amount of food (BOD_5 or COD) available per pound of mixed liquor volatile suspended solids.
- *Forced draft* the positive pressure created by the action of a fan or blower that supplies the primary or secondary combustion air in an incinerator.
- *Furnace* a combustion chamber, an enclosed structure in which heat is produced.
- *Grab sample* an individual sample collected at a randomly selected time.
- *Grit* heavy inorganic solids, such as sand, gravel, egg shells, or metal filings.
- *Incineration* an engineered process using controlled flame combustion to thermally degrade waste material.
- *Induced draft* the negative pressure created by the action of a fan, blower, or other gas-moving device located between an incinerator and a stack.
- *Industrial wastewater* wastes associated with industrial manufacturing processes.
- *Infiltration/inflow* extraneous flows in sewers; defined by Metcalf & Eddy (1991), pp. 29–31 as follows:
  —*Infiltration* water entering the collection system through cracks, joints, or breaks.
  —*Steady inflow* water discharged from cellar and foundation drains, cooling water discharges, and drains from springs and swampy areas. This type of inflow is steady and is identified and measured along with infiltration.
  —*Direct flow* those types of inflow that have a direct stormwater runoff connection to the sanitary sewer and cause an almost immediate increase in wastewater flows. Possible sources are roof leaders, yard and areaway drains, manhole covers, cross connections from storm drains and catch basins, and combined sewers.
  —*Total inflow* the sum of the direct inflow at any point in the system plus any flow discharged from the system upstream through overflows, pumping station bypasses, and the like.
  —*Delayed inflow* stormwater that may require several days or more to drain through the sewer system. This category can include the discharge of sump pumps from cellar drainage as well as the slowed entry of surface water through manholes in ponded areas.
- *Influent* the wastewater entering a tank, channel, or treatment process.
- *Inorganic* mineral materials, such as salt, ferric chloride, iron, sand, gravel, etc.
- *License* a certificate issued by the State Board of Waterworks/Wastewater Works Operators authorizing the holder to perform the duties of a wastewater treatment plant operator.
- *Mean cell residence time (MCRT)* the average length of time a mixed liquor suspended solids particle remains in the activated sludge process. May also be known as sludge retention time.

- *mg/L* an expression of the weight of one substance contained within another. Commonly, it is used to express weight of a substance within a given weight of water and wastewater. It is sometimes expressed as parts per million (ppm), which is equal to mg/L. If there is one pound of a substance mixed in one million pounds of water, the resulting concentration is 1 mg/L.

$$\text{concentration, mg / L} = \frac{\text{weight of water / wastewater}}{\text{weight of substance} \times 10^6}$$

- *Mixed liquor* the combination of return activated sludge and wastewater in the aeration tank.
- *Mixed liquor suspended solids (MLSS)* the suspended solids concentration of the mixed liquor.
- *Mixed liquor volatile suspended solids (MLVSS)* the concentration of organic matter in the mixed liquor suspended solids.
- *Milligrams/Liter (mg/L)* a measure of concentration. It is equivalent to parts per million (ppm).
- *Moisture content* the amount of water per unit weight of biosolids. The moisture content is expressed as a percentage of the total weight of the wet biosolids. This parameter is equal to 100 minus the percent solids concentration or can be computed as follows:

$$\begin{aligned}\text{moisture content} &= \frac{(\text{weight of wet solids}) - (\text{weight of dry solids}) \times 100}{\text{weight of wet solids}}\\ &= \frac{(120-25)\times 100}{120}\\ &= 79.2\%\end{aligned}$$

- *Natural draft* the negative pressure created by the height of a stack or chimney and the difference in temperature between flue gases and the atmosphere.
- *Nitrogenous oxygen demand (NOD)* a measure of the amount of oxygen required to biologically oxidize nitrogen compounds under specified conditions of time and temperature.
- *NPDES permit* National Pollutant Discharge Elimination System permit, which authorizes the discharge of treated wastes and specifies the condition that must be met for discharge.
- *Nutrients* substances required to support living organisms. Usually refers to nitrogen, phosphorus, iron, and other trace metals.
- *Opacity* the degree of obstruction of light; e.g., a window has zero opacity, whereas a wall has 100% opacity.
- *Organic* materials that consist of carbon, hydrogen, oxygen, sulfur, and nitrogen. Many organics are biologically degradable. All organic compounds can be converted to carbon dioxide and water when subjected to high temperatures.
- *Particulate matter* any material, except water in uncombined form, that is or has been airborne and exists as a liquid or a solid at standard conditions.
- *Part per million* an alternative (but numerically equivalent) unit used in chemistry is milligrams per liter (mg/L). As an analogy, think of a ppm as being equivalent to a full shot glass in a swimming pool.
- *Pathogenic* disease causing. A pathogenic organism is capable of causing illness.
- *Point source* any discernible, defined, and discrete conveyance from which pollutants are or may be discharged.

- *Return activated sludge solids (RASS)* the concentration of suspended solids in the sludge flow being returned from the settling tank to the head of the aeration tank.
- *Sanitary wastewater* wastes discharged from residences and from commercial, institutional, and similar facilities that include both sewage and industrial wastes.
- *Scrubbing* the removal of impurities from a gas stream by spraying of a fluid.
- *Scum* the mixture of floatable solids and water that is removed from the surface of the settling tank.
- *Septic* a wastewater that has no dissolved oxygen present. Generally characterized by black color and rotten egg (hydrogen sulfide) odors.
- *Settleability* a process control test used to evaluate the settling characteristics of the activated sludge. Readings taken at 30 to 60 minutes are used to calculate the settled sludge volume (SSV) and the sludge volume index (SVI).
- *Settled sludge volume (SSV)* the volume in percent occupied by an activated sludge sample after 30 to 60 minutes of settling. Normally written as SSV with a subscript to indicate the time of the reading used for calculation (SSV_{60} or SSV_{30}).
- *Sewage* wastewater containing human wastes.
- *Slagging* the destructive chemical action that forms slag on refractory materials subjected to high temperatures; also molten or viscous coating produced on refractory materials by ash particles.
- *Sludge* the mixture of settleable solids and water that is removed from the bottom of the settling tank.
- *Sludge loading rate* the weight of wet biosolids fed to the reactor per square foot of reactor bed area per hour ($\text{lb/ft}^2\text{/h}$).
- *Sludge retention time (SRT)* *see* mean cell residence time.
- *Sludge volume index (SVI)* a process control calculation that is used to evaluate the settling quality of the activated sludge. Requires the SSV_{30} and mixed liquor suspended solids test results to calculate.
- *Solids concentration* the weight of solids per unit weight of sludge. It is calculated as follows:

$$\begin{aligned}\text{concentration} &= \frac{\text{weight of dry biosolids} \times 100}{\text{weight of wet biosolids}}\\ &= \frac{25 \times 100}{120}\\ &= 20.8\%\end{aligned}$$

- *Solids content* also called percent total solids, is the weight of total solids in biosolids per unit total weight of biosolids expressed in percent. Water content plus solids content equals 100%. This includes all chemicals and other solids added to the biosolids.
- *Solids feed rate* the dry solids fed to a centrifuge.
- *Solids loading (belt filter press)* the feed solids to the belt filter on a dry weight basis including chemicals per unit time.
- *Solids loading rate (drying beds)* the weight of solids on a dry weight basis applied annually per square foot of drying bed area.
- *Solids recovery (centrifuge)* the ratio of cake solids to feed solids for equal sampling times. It can be calculated with suspended solids and flow data or with only suspended solids data. The centrate solids must be corrected if chemicals are fed to the centrifuge.
- *Storm sewer* a collection system designed to carry only stormwater runoff.
- *Stormwater* runoff resulting from rainfall and snowmelt.

- *Supernatant* in a digester, it is the amber-colored liquid above the sludge.
- *Thermal efficiency* the ratio of heat used to total heat generated.
- *Turbulence* a state of high agitation. In turbulent fluid flow, the velocity of a given particle changes constantly both in magnitude and direction.
- *Volatile* used to describe any substance that evaporates at low temperature.
- *Volatility* the property of a substance to convert into vapor or gas without chemical change.
- *Wastewater* the water supply of the community after it has been soiled by use.
- *Waste activated sludge solids (WASS)* the concentration of suspended solids in the sludge that is being removed from the activated sludge process.
- *Weir* a device used to measure wastewater flow.
- *Zoogleal slime* the biological slime that forms on fixed film treatment devices. It contains a wide variety of organisms essential to the treatment process.

2.3 REFERENCE

Metcalf & Eddy. *Wastewater Engineering: Treatment, Disposal, Reuse,* 3rd. ed., New York: McGraw-Hill, Inc., 1991.

CHAPTER 3

Conversions

3.1 CONVERSION FACTORS

CONVERSION factors are used to change measurements or calculated values from one unit of measure to another. More importantly, they permit the plant operator to change measurements or calculated values from one unit of measure to another, making his or her job easier. Examples include hours to minutes, days to weeks, etc. The factors covered in this handbook are those used frequently within the wastewater treatment plant. Other common factors are provided for reference but are not discussed in the material.

✓ In making the conversion from one unit to another, you must know two things:

(1) The exact number that relates the two units
(2) Whether to multiply or divide by that number

For example, in converting from inches to feet, you must know that there are 12 in. in 1 ft, and you must know whether to multiply or divide the number of inches by 0.08333 (i.e., 1 in. = 0.08 ft).

When making conversions, there is often confusion about whether to multiply or divide; on the other hand, the number that relates the two units is usually known and, thus, is not a problem. Gaining understanding of the proper methodology—the "mechanics"—to use for various operations requires practice.

Along with using the proper "mechanics" and much practice in making conversions, probably the easiest and fastest method of converting units is to use a conversion table.

An example of the type of conversions the wastewater operator must be familiar with is provided in the following section on temperature conversions.

3.1.1 TEMPERATURE CONVERSIONS

Most wastewater operators are familiar with the formulas used for Fahrenheit and Celsius temperature conversions:

$$°C = 5/9\ (°F - 32) \tag{3.1}$$

$$°F = 9/5\ (°C) + 32 \tag{3.2}$$

The difficulty arises when required to recall these formulas from memory.

(1) Add 40°
(2) Multiply by the appropriate fraction (5/9 or 9/5)
(3) Subtract 40°

Obviously, the only variable in this method is the choice of 5/9 or 9/5 in the multiplication step. To make the proper choice, you must be familiar with two scales. On the Fahrenheit scale, the freezing point of water is 32°, whereas it is 0° on the Celsius scale. The boiling point of water is 212° on the Fahrenheit scale and 100° on the Celsius scale.

What does all this mean?

✓ Well, it is important to note, for example, that at the same temperature, higher numbers are associated with the Fahrenheit scale and lower numbers with the Celsius scale. This is an important relationship that helps you decide whether to multiply by 5/9 or 9/5. Let's look at a few conversion problems to see how the three-step process works.

Example 3.1

Problem:

Suppose that you wish to convert 210°F to Celsius. Using the three-step process we proceed as follows:

Solution:

(1) Step 1: add 40°

$$210° + 40° = 250°$$

(2) Step 2: 250° must be multiplied by either 5/9 or 9/5. Because the conversion is to the Celsius scale, you will be moving to a number *smaller* than 250. Through reason and observation, it is obvious that if 250 is multiplied by 9/5, it would almost be the same as multiplying by 2, which would double 250 rather than make it smaller. On the other hand, if you multiply by 5/9 it is about the same as multiplying by 1/2, which would cut 250 in half. Because in this problem you wish to move to a smaller number, you should multiply by 5/9:

$$(5/9)\,(250°) = 138.8°\mathrm{C}$$

(3) Step 3: now subtract 40°

$$138.8°\mathrm{C} - 40.0°\mathrm{C} = 98.8°\mathrm{C}$$

Therefore, 210°F = 98.8°C

Example 3.2

Problem:

Convert 25°C to Fahrenheit.

Solution:

Because you are converting from Celsius to Fahrenheit, you are moving from a smaller to a larger number, and 9/5 should be used in the multiplication:

(2) Step 2:

$$(9/5)\,(65°) = 117°$$

(3) Step 3: subtract 40°

$$117° - 40° = 77°$$

Thus, 25°C = 77°F

It is useful, of course, to know how to make these temperature conversion calculations. However, in practical *in situ* or non-*in situ* operations, you may wish to use a temperature conversion table.

3.2 THE CONVERSION TABLE

The conversion table (Table 3.1) provides many of the conversion factors used in wastewater treatment. Other conversions are presented in appropriate parts of the handbook.

TABLE 3.1. Conversion Table.

To Convert	Multiply By	To Get
Feet	12	Inches
Yards	3	Feet
Yards	36	Inches
Inches	2.54	Centimeters
Meters	3.3	Feet
Meters	100	Centimeters
Meters	1,000	Millimeters
Square Yards	9	Square Feet
Square Feet	144	Square Inches
Acres	43,560	Square Feet
Cubic Yards	27	Cubic Feet
Cubic Feet	1,728	Cubic Inches
Cubic Feet (Water)	7.48	Gallons
Cubic Feet (Water)	62.4	Pounds
Acre-Feet	43,560	Cubic Feet
Gallons (Water)	8.34	Pounds
Gallons (Water)	3.785	Liters
Gallons (Water)	3,785	Milliliters
Gallons (Water)	3,785	Cubic Centimeters
Gallons (Water)	3,785	Grams
Liters	1,000	Milliliters
Days	24	Hours
Days	1,440	Minutes
Days	86,400	Seconds
Million Gallons/Day	1,000,000	Gallons/Day
Million Gallons/Day	694.4	Gallons/Day
Million Gallons/Day	1.55	Cubic Feet/Second
Million Gallons/Day	3.069	Acre-Feet/Day
Million Gallons/Day	36.8	Acre-Inches/Day
Million Gallons/Day	3,785	Cubic Meters/Day
Gallons/Minute	1,440	Gallons/Day
Gallons/Minute	63.08	Liters/Minute
Pounds	454	Grams
Grams	1,000	Milligrams
Pressure, PSI	2.31	Head, ft (Water)
Horsepower	33,000	Foot-Pounds/Minute
Horsepower	0.746	Kilowatts
To Get	Divide By	To Convert

✓ To convert in the opposite direction (i.e., inches to feet) divide by the factor rather than multiply.

3.3 MAKING CONVERSIONS

In the sections that follow, several conversion problems common to wastewater treatment practice are presented.

3.3.1 CUBIC FEET TO GALLONS

$$\text{gallons} = \text{cubic feet, ft}^3 \times \text{gal}/\text{ft}^3 \tag{3.3}$$

Example 3.3

Problem:

How many gallons of sludge can be pumped to a digester that has 3,400 cubic feet of volume available?

Solution:

$$\text{gallons} = 3{,}400\ \text{ft}^3 \times 7.48\ \text{gal}/\text{ft}^3 = 25{,}432\ \text{gal}$$

3.3.2 GALLONS TO CUBIC FEET

$$\text{cubic feet} = \frac{\text{gallons}}{7.48\ \text{gal}/\text{ft}^3} \tag{3.4}$$

Example 3.4

Problem:

How many cubic feet of sludge are removed when 16,000 gal are withdrawn?

$$\text{cubic feet} = \frac{16{,}000\ \text{gal}}{7.48\ \text{gal}/\text{ft}^3} = 2{,}139\ \text{ft}^3$$

3.3.3 GALLONS TO POUNDS

$$\text{lb} = \text{gallons} \times 8.34\ \text{lb}/\text{gal} \tag{3.5}$$

Example 3.5

Problem:

If 1,400 gal of solids are removed from the primary settling tank, how many pounds of solids are removed?

Solution:

3.3.4 POUNDS TO GALLONS

$$\text{gallons} = \frac{\text{pounds}}{8.34\ \text{lb/gal}} \tag{3.6}$$

Example 3.6

Problem:

How many gallons of water are required to fill a tank that holds 6,500 lb of water?

Solution:

$$\text{gallons} = \frac{6{,}500\ \text{lb}}{8.34\ \text{lb/gal}} = 779.4\ \text{gal}$$

3.3.5 MILLIGRAMS PER LITER TO POUNDS

✓ For plant control operations, concentrations in milligrams per liter or parts per million determined by laboratory testing must be converted to quantities in pounds, kilograms, pounds per day or kilograms per day.

$$\text{lb} = \text{concentration, mg/L} \times \text{vol., MG} \times 8.34\ \text{lb/mg/L/MG} \tag{3.7}$$

Example 3.7

Problem:

The solids concentration in the aeration tank is 2,480 mg/L. The aeration tank volume is 0.95 MG. How many pounds of solids are in the tank?

Solution:

$$\text{lb} = 2{,}480\ \text{mg/L} \times 0.95\ \text{MG} \times 8.34\ \text{lb/mg/L/MG} = 19{,}649\ \text{lb}$$

3.3.6 MILLIGRAMS PER LITER TO POUNDS PER DAY

$$\text{lb/day} = \text{Conc., mg/L} \times \text{Flow, MGD} \times 8.34\ \text{lb/mg/L/MG} \tag{3.8}$$

Example 3.8

Problem:

How many pounds of solids are discharged per day when the plant effluent flow rate is 4.55 MGD and the effluent solids concentration is 26 mg/L?

Solution:

$$\text{lb/day} = 26\ \text{mg/L} \times 4.55\ \text{MGD} \times 8.34\ \text{lb/mg/L/MG} = 987\ \text{lb/day}$$

3.3.7 MILLIGRAMS PER LITER TO KILOGRAMS PER DAY

$$\text{kg/day} = \text{conc., mg/L} \times \text{vol., MG} \times 3.785\ \text{kg/mg/L/MG} \tag{3.9}$$

Example 3.9

Problem:

The effluent contains 35 mg/L of BOD_5. How many kilograms per day of BOD_5 are discharged when the effluent flow rate is 9.5 MGD?

Solution:

$$\text{kg/day} = 35\ \text{mg/L} \times 9.5\ \text{MGD} \times 3.785\ \text{kg/mg/L/MG} = 1{,}258.5\ \text{kg/day}$$

3.3.8 POUNDS TO MILLIGRAMS PER LITER

$$\text{concentration, mg/L} = \frac{\text{quantity, lb}}{\text{vol., MG} \times 8.34\ \text{lb/mg/L/MG}} \tag{3.10}$$

Example 3.10

Problem:

The aeration tank contains 79,990 lb of solids. The volume of the aeration tank is 4.25 MG. What is the concentration of solids in the aeration tank in mg/L?

Solution:

$$\text{concentration, mg/L} = \frac{79{,}990\ \text{lb}}{4.25\ \text{MG} \times 8.34\ \text{lb/MG/mg/L}} = 2{,}257\ \text{mg/L}$$

3.3.9 POUNDS PER DAY TO MILLIGRAMS PER LITER

$$\text{conc., mg/L} = \frac{\text{quantity, lb/day}}{\text{flow, MGD} \times 8.34\ \text{lb/mg/L/MG}} \tag{3.11}$$

Example 3.11

Problem:

The disinfection process uses 4,820 lb/day of chlorine to disinfect a flow of 22.2 MGD. What is the concentration of chlorine applied to the effluent?

Solution:

3.3.10 POUNDS TO FLOW IN MILLION GALLONS PER DAY

$$\text{flow} = \frac{\text{quantity, lb/day}}{\text{concentration, mg/L} \times 8.34\ \text{lb/mg/L/MG}} \tag{3.12}$$

Example 3.12

Problem:

You must remove 7,640 lb of solids from the activated sludge process per day. The waste activated sludge concentration is 5,899 mg/L. How many million gallons per day of waste activated sludge must be removed?

Solution:

$$\text{flow} = \frac{7{,}640\ \text{lb}}{5{,}899\ \text{mg/L} \times 8.34\ \text{lb/MG/mg/L}} = 0.16\ \text{MGD}$$

3.3.11 MILLION GALLONS PER DAY (MGD) TO GALLONS PER MINUTE (gpm)

$$\text{flow} = \frac{\text{flow, MGD} \times 1{,}000{,}000\ \text{gal/MG}}{1{,}440\ \text{minutes/day}} \tag{3.13}$$

Example 3.13

Problem:

The current flow rate is 4.55 MGD. What is the flow rate in gallons per minute?

Solution:

$$\text{flow} = \frac{4.55\ \text{MGD} \times 1{,}000{,}000\ \text{gal/MG}}{1{,}440\ \text{minutes/day}} = 3{,}160\ \text{gpm}$$

3.3.12 MILLION GALLONS PER DAY (MGD) TO GALLONS PER DAY (gpd)

$$\text{flow} = \text{flow, MGD} \times 1{,}000{,}000\ \text{gal/MG} \tag{3.14}$$

Example 3.14

Problem:

The influent meter reads 27.8 MGD. What is the current flow rate in gallons per day?

Solution:

$$\text{flow} = 27.8\ \text{MGD} \times 1{,}000{,}000\ \text{gal/MG} = 27{,}800{,}000\ \text{gpd}$$

3.3.13 MILLION GALLONS PER DAY (MGD) TO CUBIC FEET PER SECOND (cfs)

Example 3.15

Problem:

The flow rate entering the grit channel is 2.39 MGD. What is the flow rate in cubic feet per second?

Solution:

$$\text{flow} = 2.39\ \text{MGD} \times 1.55\ \text{cfs/MGD} = 3.7\ \text{cfs}$$

3.3.14 GALLONS PER MINUTE (gpm) TO MILLION GALLONS PER DAY (MGD)

$$\text{flow, MGD} = \frac{\text{flow, gpm} \times 1{,}440\ \text{minutes/day}}{1{,}000{,}000\ \text{gallons/MG}} \tag{3.16}$$

Example 3.16

Problem:

The flow meter indicates that the current flow rate is 1,469 gpm. What is the flow rate in MGD?

Solution:

$$\text{flow} = \frac{1{,}469\ \text{gpm} \times 1{,}440\ \text{minutes/day}}{1{,}000{,}000\ \text{gal/MG}} = 2.115360\ \text{MGD}$$

✓ Unless a higher degree of accuracy is required, this number would be rounded off to two decimal places (2.12).

3.3.15 GALLONS PER DAY (gpd) TO MILLION GALLONS PER DAY (MGD)

$$\text{flow, MGD} = \frac{\text{flow, gpd}}{1{,}000{,}000\ \text{gal/MG}} \tag{3.17}$$

Example 3.17

Problem:

The totalizing flow meter indicates that 30,669,969 gallons of wastewater have entered the plant in the past 24 hours. What is the flow rate in MGD?

Solution:

$$\text{flow} = \frac{30{,}669{,}969\ \text{gal/day}}{1{,}000{,}000\ \text{gal/MG}} = 30.669969\ \text{MGD}$$

✓ Unless a higher degree of accuracy is required, this number would be rounded to two decimal places (30.67).

3.3.16 FLOW IN CUBIC FEET PER SECOND (cfs) TO MILLION GALLONS PER DAY (MGD)

$$\text{flow, MGD} = \frac{\text{flow, cfs}}{1.55\,\text{cfs/MG}} \tag{3.18}$$

Example 3.18

Problem:

The flow in a channel is determined to be 3.96 cubic feet per second (cfs). What is the flow rate in million gallons per day (MGD)?

Solution:

$$\text{flow} = \frac{3.96\,\text{cfs}}{1.55\,\text{cfs/MGD}} = 2.5548387\,\text{MGD}$$

✓ Unless a higher degree of accuracy is required, this number would be rounded off to two decimal places (2.55 MGD).

3.4 CHAPTER REVIEW QUESTIONS

3-1 The depth of water in the grit channel is 52 inches. What is the depth in feet?

3-2 The operator withdraws 5,690 gal of solids from the digester. How many pounds of solids have been removed?

3-3 Sludge added to the digester causes a 2,996 cubic foot change in the volume of sludge in the digester. How many gallons of sludge have been added?

3-4 The plant effluent contains 45 mg/L solids. The effluent flow rate is 3.96 MGD. How many pounds per day of solids are discharged?

3-5 The plant effluent contains 36 mg/L of BOD_5. The effluent flow rate is 7.50 MGD. How many kilograms per day of BOD_5 are being discharged?

3-6 The operator wishes to remove 3,540 lb/day of solids from the activated sludge process. The waste activated sludge concentration is 3,450 mg/L. What is the required flow rate in million gallons per day?

3-7 500 lb of chlorine are added daily to the plant effluent. What is the concentration of the chlorine dose in mg/L when the effluent flow rate is 10 MGD?

CHAPTER 4

Intermediate Wastewater Treatment Math

4.1 INTRODUCTION

MATHEMATICAL operations are one of the main tools in the wastewater operator's bag of knowledge skills. Wastewater treatment and unit operations involve a large number of process control calculations. Most of these calculations are based upon the basic math principles that were covered in Volume 1 of the handbook series. In this chapter, we cover intermediate mathematical operations—practical operations that wastewater operators are required to use, many of them on a daily basis, in actual plant operating situations. Along with an explanation of each math operation, several sample problems are included. A practice test is included at the end of this chapter to determine your level of math skill. This is important because, without mastering math skills, the user of this text will find subsequent chapters (which include a lot of math) difficult to complete. More importantly, without a sound foundation in mathematical practical operation skills, the wastewater operator is at a serious disadvantage in his or her attempt to achieve licensure as a certified wastewater professional.

In Volume 1, we referred you to worthy advice given by J. K. Price (1991):

> Those who have difficulty in math often do not lack the ability for mathematical calculation, they merely have not learned, or have been taught, the "language of math." (Price, 1991, p. vii)

4.2 SETTING THE GROUND RULES

✓ *Note:* It is assumed that the reader has completed the basic math refresher in Volume 1 or already has a fundamental knowledge of basic mathematical operations. The purpose of the following sections is to provide a brief review of the mathematical operations and applications frequently employed in wastewater treatment plant operations.

Before attempting to solve any of the problems presented in this chapter and in subsequent chapters, it is important to point out a few basic details that will help you to decipher the math problems presented. Most of the math problems presented in the text are "word-type" problems. That is, most problems presented in this handbook and in licensure examinations present specific math problems in written form—instead of in simple numbers such as 18 + 23. Because this is the case—because the person attempting to solve the math problem is required to read each problem to determine what is being asked—there are certain steps that the problem solver should take and follow in solving such problems. These steps are listed and explained as follows:

being asked?" Pay particular attention to the terms (detention time, hydraulic loading, etc.). Also determine what units are being used or asked for (gpm, hours, gal/day/ft^3, etc.).
(3) Find out what is given (tank dimensions, tank flow, freeboard, etc.).
(4) Draw a rough diagram, and insert dimension values where required.
(5) Write out what you know (formulas, facts, etc.).
(6) Solve the problem, and check your calculations.
(7) Check to ensure that the units used are correct.
(8) When you have obtained an answer, it is always a good idea to ask yourself a few questions: "Is the answer reasonable? Does the answer make sense?"
(9) If unsure of the results obtained, work the problem again. Then, compare answers.

4.2.1 TABLE OF EQUIVALENTS, FORMULAE, AND SYMBOLS

To work mathematical operations (for practical application or for taking licensure examinations) to solve problems, it is essential to understand the language, equivalents, symbols, and terminology used.

✓ *Note:* For licensure examinations, the examination center normally provides a formula sheet that usually includes equivalents and symbols used to aid in solving questions provided in the examination.

Because this handbook is designed not only to be used in studying for licensure examinations but also for practical on-the-job applications, equivalents, formulae, and symbols are included, as a ready reference, in Table 4.1.

4.3 PRACTICAL WASTEWATER TREATMENT MATH OPERATIONS

In the following sections, several different types of intermediate-level wastewater treatment mathematical operations are provided, including several sample operations.

4.3.1 WASTEWATER VOLUME CALCULATIONS

Performing volume calculations goes hand-in-hand with wastewater operations. Why? All one needs do is to look around his or her plant site to understand why this is the case. In just about any direction you look, you will see tanks, channels, pipelines, pits, trenches, and/or ponds. Many of these vessels and structures are important parts of various treatment unit processes, and calculating their volumes is sometimes required.

✓ For many calculations, the volumes are expressed in gallons. To convert from cubic feet to gallons volume, a factor of 7.48 gal/cu ft is used. Refer to Chapter 3 for a more detailed discussion of conversions.

The general equation for most volume calculations is

$$\text{volume} = \text{area} \times \text{depth or height} \qquad (4.1)$$

4.3.1.1 Tank Volume Calculation

Rectangular or cylindrically shaped tanks are typically used in wastewater treatment unit processes (see Figure 4.1). The equation for volume calculations (rectangular tanks) is

TABLE 4.1. **Equivalents, Formulae, and Symbols.**

Equivalents

12 inches = 1 foot
36 inches = 1 yard
144 inches^2 = 1 foot^2
9 feet^2 = 1 yard^2
43,560 feet^2 = 1 acre
1 foot^3 = 1,728 inch^3
1 foot^3 of water = 7.48 gallons
1 foot^3 of water weighs = 62.4 lb
1 gallon of water weighs = 8.34 lb
1 liter = 1,000 milliliters
1 gram = 1,000 milligrams
1 million gal/day = 694 gal/min
= 1.545 ft^3/sec
average BOD/capita/day = .17 lb
average SS/capita/day = .20
average daily flow = assume 100 gal/capita/day

Symbols

A = area
V = velocity
t = time
SVI = sludge volume index
Vol = volume
# = pounds (lb)
eff = effluent
W = width
D = depth
L = length
Q = flow
r = radius
π = pi (3.14)
WAS = waste activated sludge
RAS = return activated sludge
MLSS = mixed liquor suspended solids
MLVSS = mixed liquor volatile suspended solids

Formulae

$$\text{SVI} = \frac{\text{volume}}{\text{concentration}} \times 100$$

$$\text{Q} = \text{A} \times \text{V}$$

$$\text{detention time} = \frac{\text{volume}}{Q}$$

$$\text{volume} = L \times W \times D$$

$$\text{area} = W \times L$$

$$\text{circular area} = \frac{\pi}{4} \times D^2 \ (= .785 \times D^2)$$

$$\text{circumference} = \pi D$$

$$\text{hydraulic loading rate} = \frac{Q}{A}$$

$$\text{sludge age} = \frac{\#\text{MLSS in aeration tank}}{\#\text{SS in primary eff / day}}$$

$$\text{MCRT} = \frac{\#\text{SS in secondary system (aeration tank + sec. clarifier)}}{\#\text{WAS / day} + \#\text{SS in eff / day}}$$

$$\text{organic loading rate} = \frac{\#\text{BOD / day}}{\text{volume}}$$

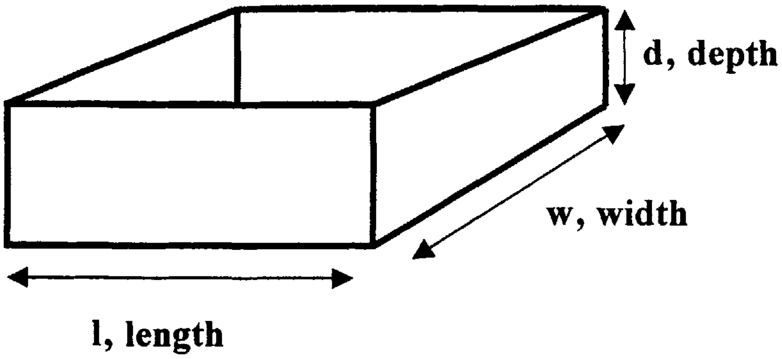


Figure 4.1

$$V = (lw)(d) \tag{4.2}$$

Figure 4.2 shows a cylindrical tank. The equation for volume calculation (circular or cylindrical tanks) is:

$$V = (0.785)(D^2) = (0.785)(D^2)(d) \tag{4.3}$$

Let's take a look at a couple of tank volume calculations.

Example 4.1

Problem:

Calculate the volume of the rectangular tank shown in Figure 4.3 in cubic feet.

✓ *Note:* If a drawing is not supplied with the problem, draw a rough picture or diagram. Make sure you label or identify the parts of the diagram from the information given in the question.

Solution:

$$\begin{aligned}\text{volume, cu ft} &= (lw)(d)\\ &= (50\text{ ft})(12\text{ ft})(8\text{ ft})\\ &= 4{,}800\text{ cu ft}\end{aligned}$$

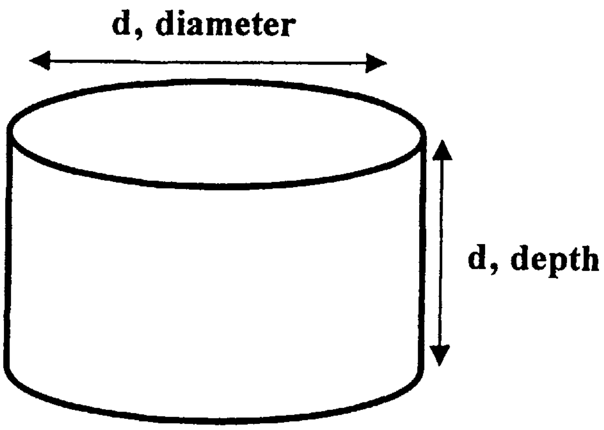


Figure 4.2

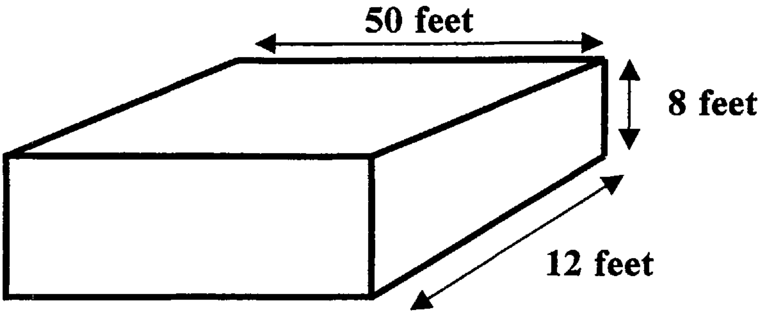


Figure 4.3

Example 4.2

Problem:

The diameter of a tank is 70 ft. When the water depth is 30 ft, what is the volume of wastewater in the tank, in gallons?

✓ Draw a diagram similar to that shown in Figure 4.4.

Solution:

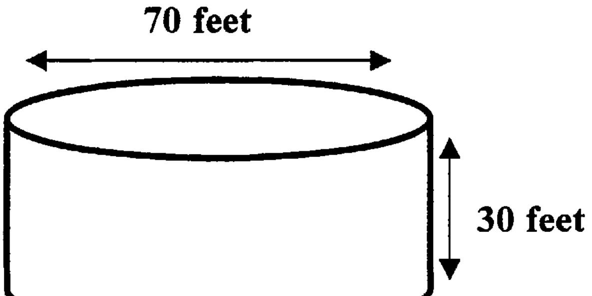
$$\text{volume, gal} = (0.785)\,(D^2)\,(d)\,(7.48\text{ gal/cu ft})$$

✓ Remember, the solution requires the result in gallons; thus, we must include 7.48 gal/cu ft in the operation to ensure the result is in gallons.

$$= (0.785)\,(70\text{ ft})\,(70\text{ ft})\,(30\text{ ft})\,(7.48\text{ gal/cu ft})$$

$$= 863{,}155\text{ gal}$$

Now, let's take a look at another cylindrical or circular tank problem, one with a different twist, so to speak.



Example 4.3

Problem:

A cylindrical tank is 12 ft in diameter and 24 ft in height. What is the approximate capacity in liters?

✓ Don't forget to draw a rough diagram of the tank and dimensions.

Solution:

Calculate the tank volume using the following formula:

$$V_{(\text{tank})} = \left(\frac{\pi D^2}{4}\right) H \tag{4.4}$$

$$= \frac{\pi(12\text{ ft})^2}{4}(24\text{ ft})$$

$$= 2{,}713\text{ cu ft}$$

✓ Remember, the problem asked for the tank capacity in "liters."

Convert 2,713 cu ft to liters:

$$= 2{,}713 \times 7.48\text{ gal/cu ft} \times 3.785\text{ L/gal}$$

$$= 76{,}810\text{ L}$$

4.3.1.2 Channel Volume Calculations

Channels are commonly used in wastewater treatment (e.g., contact tanks, etc.). Channels are typically rectangular- or trapezoid-shaped. For rectangular channels, use Equation (4.1).

$$V = (lw)(d)$$

Example 4.4

Problem:

Determine the volume of wastewater (in cu ft) in the section of rectangular channel shown in Figure 4.5 when the wastewater is 5 ft deep.

Solution:

$$\text{volume, cu ft} = (lw)(d)$$

$$= (600\text{ ft})(6\text{ ft})(5\text{ ft})$$

$$= 18{,}000\text{ cu ft}$$

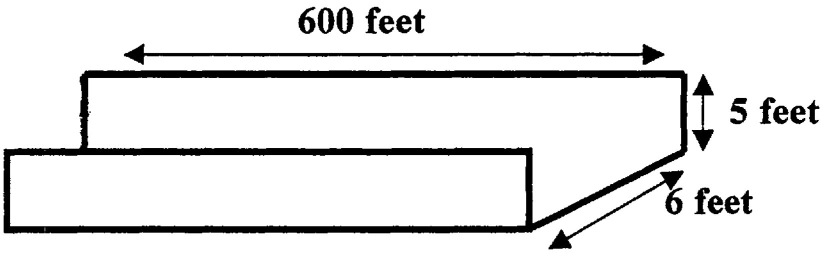


Figure 4.5

Example 4.5

$$\text{volume, cu ft} = \frac{(b_1 + b_2)}{2}(d)(l) \tag{4.5}$$

Problem:

Determine the volume of wastewater (in gallons) in a section of trapezoidal channel when the wastewater depth is 5 ft.

Solution:

$$\text{Given: } b_1 = 4' \text{ across bottom}$$

$$b_2 = 10' \text{ across water surface}$$

$$l = 1{,}000'$$

$$\text{volume, gal} = \frac{(b_1 + b_2)}{2}(d)(l)(7.48 \text{ gal/cu ft})$$

$$= \frac{(4 \text{ ft} + 10 \text{ ft})}{2}(5 \text{ ft})(1{,}000 \text{ ft})(7.48 \text{ gal/cu ft})$$

$$= (7)(5)(1{,}000)(7.48)$$

$$= 261{,}800 \text{ gal}$$

4.3.1.3 Volume of Circular Pipeline

$$\text{volume, cu ft} = (.0785)(D^2)(l) \tag{4.6}$$

Example 4.6

Problem:

What is the capacity in gallons of wastewater of a 10-inch diameter, 1,800 ft section of pipeline (see Figure 4.6)?

✓ Convert 10 inches to feet (10 in/12 in/ft = .833 ft).

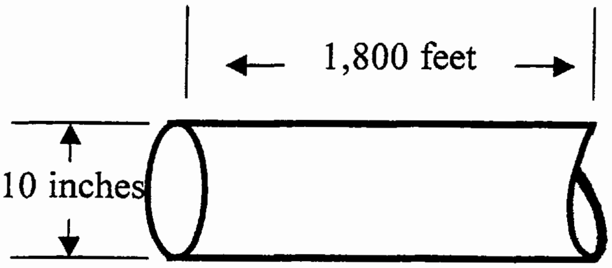


Figure 4.6

Solution:

$$\begin{aligned}\text{volume, gal} &= (0.785)\,(D^2)\,(l)\,(7.48\text{ gal/cu ft})\\ &= (0.785)\,(.833)\,(.833)\,(1{,}800\text{ ft})\,(7.48\text{ gal/cu ft})\\ &= 7{,}334\text{ gal}\end{aligned}$$

Now let's try another pipe volume problem.

Example 4.7

Problem:

Approximately how many gallons of wastewater would 800 ft of 8-inch pipe hold?

Solution:

$$\begin{aligned}\text{volume} &= \left(\frac{\pi D^2}{4}\right)(L)\\ &= \frac{\pi(0.67\text{ ft})^2}{4}(800\text{ ft})\\ &= 282\text{ cu ft}\end{aligned}$$

Convert: 282 cu ft to gallons

$$\begin{aligned}&= 282\text{ cu ft} \times 7.48\text{ gal/cu ft}\\ &= 2{,}110\text{ gal}\end{aligned}$$

4.3.1.4 Pit or Trench Volumes

Pits and trenches are often used in wastewater treatment plant operations for various unit processes. Thus, it is important to be able to determine their volumes. The calculations used in determining pit or trench volumes are similar to tank and channel volume calculations, with one difference—the volume is often expressed as cubic yards rather than cubic feet or gallons.

In calculating cubic yards, typically two approaches are used:

(1) Calculate the cubic feet volume, then convert to cubic yards volume.

$$\text{cu yds} = \frac{(\text{cu ft})}{27\ \text{cu ft}/\text{yd}} \tag{4.7}$$

(2) Express all dimensions in yards so that the resulting volume calculated will be cubic yards.

$$(\text{yds})\,(\text{yds})\,(\text{yds}) = \text{cu yds} \tag{4.8}$$

Now let's take a look at an example where we calculate the cubic feet volume, then convert to cubic yards volume.

Example 4.8

Problem:

A trench is to be excavated 3 feet wide, 5 feet deep, and 800 feet long. What is the cubic yards volume of the trench?

✓ Remember, draw a diagram similar to the one shown in Figure 4.7.

Solution:

$$\begin{aligned}\text{volume, cu ft} &= (lw)\,(d)\\ &= (800\ \text{ft})\,(3\ \text{ft})\,(5\ \text{ft})\\ &= 12{,}000\ \text{cu ft}\end{aligned}$$

Now convert cu ft volume to cu yds:

$$\begin{aligned}&= \frac{12{,}000\ \text{cu ft}}{27\ \text{cu ft}/\text{cu yds}}\\ &= 444\ \text{cu yds}\end{aligned}$$

Now let's take a look at an example where we express all dimensions in yards so we can calculate the volume in cubic yards.

Example 4.9

Problem:

What is the cubic yard volume of a trench 600 ft long, 2.5 ft wide, and 4 ft deep?

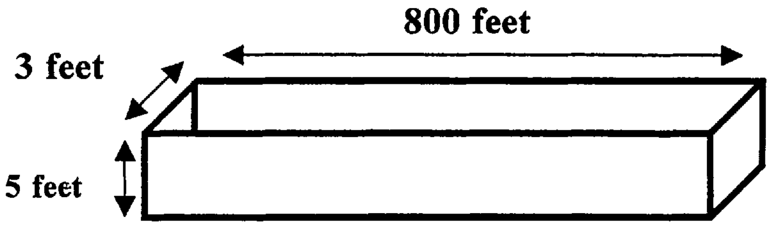


Figure 4.7

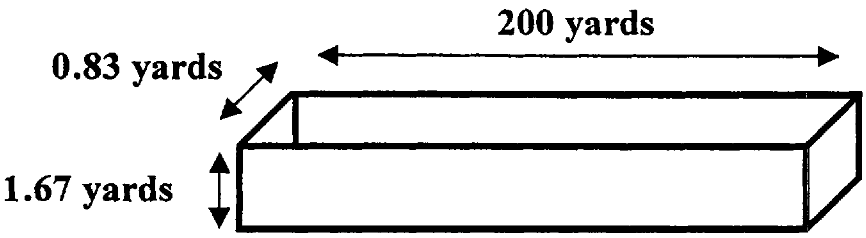


Figure 4.8

Solution:

The first thing you must do is to convert dimensions in feet to yards before beginning the volume calculation:

$$\text{length} = \frac{600\text{ ft}}{3\text{ ft/yds}} = 200\text{ yds}$$

$$\text{width} = \frac{2.5\text{ ft}}{3\text{ ft/yd}} = 0.83\text{ yds}$$

$$\text{depth} = \frac{5\text{ ft}}{3\text{ ft/yd}} = 1.67\text{ yds}$$

Now make a diagram and label dimensions as shown in Figure 4.8.

$$\begin{aligned}\text{volume, cu yds} &= (lw)(d)\\ &= (200\text{ yds})(0.83\text{ yds})(1.67\text{ yds})\\ &= 277\text{ cu yds}\end{aligned}$$

4.3.1.5 Pond Volumes

Ponds and/or oxidation ditches are commonly used in wastewater treatment operations. To determine the volume of a pond (or ditch), it is necessary to determine if all four sides slope or if just two sides slope. This is important because the means used to determine volume will vary depending on the number of sloping sides.

If only two of the sides slope and the ends are vertical, we calculate the volume using the equation:

$$V = \frac{(b_1 + b_2)}{2}(d)(l) \tag{4.9}$$

However, when all sides slope as shown in Figure 4.9, the equation we use must include average length and average width dimensions. Use the equation:

$$V = \frac{(l_1 + l_2)}{2}\frac{(w_1 + w_2)}{2}(\text{depth}) \tag{4.10}$$

Let's take a look at an example problem for determining the slope of a pond where all sides slope.

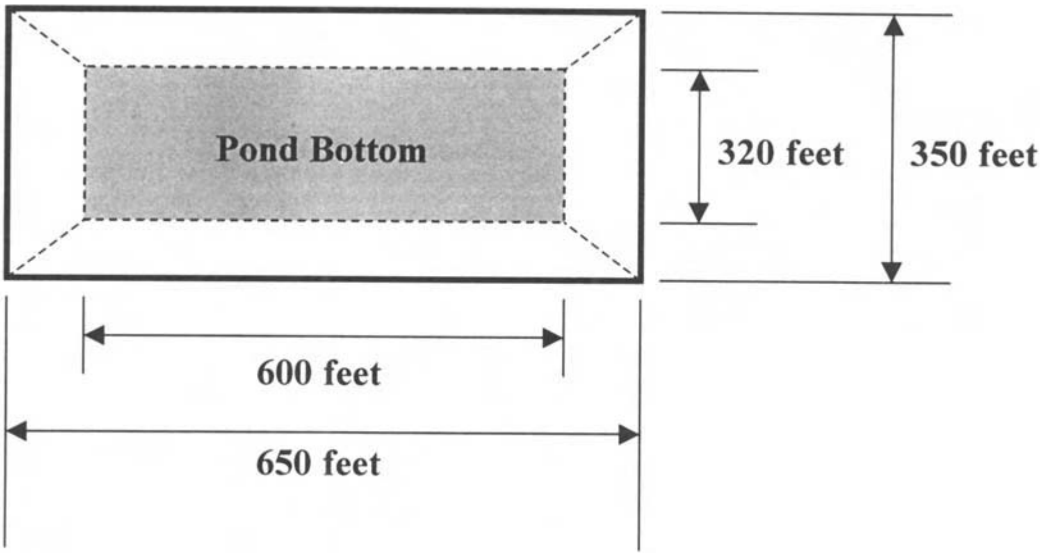


Figure 4.9

Example 4.10

Problem:

A pond is 6 ft deep with side slopes of 2:1 (2 ft horizontal: 1 ft vertical). Using the data supplied in Figure 4.9, calculate the volume of the pond in cubic feet.

$$V = \frac{(l_1 + l_2)}{2}\frac{(w_1 + w_2)}{2}(\text{depth})$$

$$= \frac{(600\text{ ft} + 650\text{ ft})}{2}\frac{(320\text{ ft} + 350\text{ ft})}{2}(6\text{ ft})$$

$$= (625\text{ ft})(335\text{ ft})(6\text{ ft})$$

$$= 1{,}256{,}250\text{ cu ft}$$

4.3.2 FLOW CALCULATIONS

In wastewater treatment, one of the major concerns of the operator is not only to maintain flow, but also to measure it. Normally, flow measurements are determined by metering devices. These devices measure wastewater flow at a particular moment (instantaneous flow) or over a specified time period (total flow). Instantaneous flow can also be determined mathematically. In this section, we discuss how to mathematically determine instantaneous and average flow rates and also how to make flow conversions.

4.3.2.1 Instantaneous Flow Rates

In determining instantaneous flows rates through channels, tanks, and pipelines, we can use the $Q = AV$ equation.

✓ It is important to remember that when using an equation such as $Q = AV$, the units on the left side of the equation must match those units on the right side of the equation (A and V) with respect to volume (cubic feet or gallons) and time (seconds, minutes, hours, or days).

Let's take a look at an example problem where we determine instantaneous flow rates (flow rate for any particular moment) by using the $Q = AV$ equation.

Example 4.11

Problem:

A channel 4 ft wide has water flowing to a depth of 2 ft. If the velocity through the channel is 2 feet per second (fps), what is the cubic feet per second (cfs) flow rate through the channel?

Solution:

$$Q, \text{cfs} = (A)(V, \text{fps})$$

$$= (4\text{ ft})(2\text{ ft})(2\text{ fps})$$

$$= 16\text{ cfs}$$

4.3.2.1.1 Instantaneous Flow Into and Out of a Rectangular Tank

One of the primary flow measurements the wastewater operator is commonly required to calculate is the flow through a tank. This measurement can be determined using the $Q = AV$ equation. For example, if the discharge valve to a tank were closed, the water level would begin to rise. If you time how fast the water rises, this would give you an indication of the velocity of flow into the tank. This information can be "plugged" into the $Q = AV$ equation to determine the flow rate through the tank. Let's take a look at an example.

Example 4.12

Problem:

A tank is 8 ft wide and 12 ft long. With the discharge valve closed, the influent to the tank causes the water level to rise 1.5 feet in one minute. What is the gpm flow into the tank?

Solution:

First, calculate the cfm flow rate:

$$Q, \text{cfm} = (A)(V, \text{fpm})$$

$$= (8\text{ ft})(12\text{ ft})(1.5\text{ fpm})$$

$$= 144\text{ cfm}$$

Then, convert cfm flow rate to gpm flow rate:

$$(144\text{ cfm})(7.48\text{ gal/cu ft}) = 1{,}077\text{ gpm}$$

Quite simply, actually. All one needs to do is time the rate of this drop in wastewater level so that the velocity of flow from the tank can be calculated. Then, we use the $Q = AV$ equation to determine the flow rate out of the tank, as illustrated in Example 4.13.

Example 4.13

Problem:

A tank is 9 ft wide and 11 ft long. The influent valve to the tank is closed, and the water level drops 2.5 ft in two minutes. What is the gpm flow from the tank?

$$\text{drop rate} = 2.5\ \text{ft}/2\ \text{min}$$

$$= 1.25\ \text{ft}/\text{min}$$

First, calculate the cfm flow rate:

$$Q,\ \text{cfm} = (A)\ (V,\ \text{fpm})$$

$$= (9\ \text{ft})\ (11\ \text{ft})\ (1.25\ \text{fpm})$$

$$= 124\ \text{cfm}$$

Then, convert cfm flow rate to gpm flow rate:

$$(124\ \text{cfm})\ (7.48\ \text{gal}/\text{cu ft}) = 928\ \text{gpm}$$

4.3.2.1.2 Flow Rate Into a Cylindrical Tank

We can use the same basic method to determine the flow rate when the tank is cylindrical in shape, as shown in Example 4.14.

Example 4.14

Problem:

The discharge valve to a 25-ft diameter cylindrical tank is closed. If the water rises at a rate of 12 inches in four minutes, what is the gpm flow into the tank?

Solution:

$$\text{rise} = 12\ \text{in} = 1\ \text{ft}$$

$$= 1\ \text{ft}/4\ \text{min}$$

$$= 0.25\ \text{ft}/\text{min}$$

First, calculate the cfm flow into the tank:

$$Q,\ \text{cfm} = (A)\ (V,\ \text{fpm})$$

Then, convert cfm flow rate to gpm flow rate:

$$(123\text{ cfm})\,(7.48\text{ gal/cu ft}) = 920\text{ gpm}$$

4.3.2.2 Flow Through a Full Pipeline

The flow through a pipeline is of considerable interest to wastewater collections workers and to operators. The flow rate can be calculated using the $Q = AV$ equation. The cross-sectional area of a round pipe is a circle, so the area, A, is represented by $(0.785)(D^2)$.

✓ To avoid errors in terms, it is prudent to express pipe diameters as feet.

Let's look at an example instantaneous flow calculation for a pipeline.

Example 4.15

Problem:

The flow through an 8-inch diameter pipeline is moving at a velocity of 4 ft/sec. What is the cfs flow rate through the full pipeline?

Convert 8 inches to feet:

$$8\text{ in}/12\text{ in/ft} = 0.67\text{ ft}$$

$$Q\text{, cfm} = (A)\,(V\text{, fps})$$

$$= (0.785)\,(0.67\text{ ft})\,(0.67\text{ ft})\,(4\text{ fps})$$

$$= 1.4\text{ cfs}$$

4.3.3 VELOCITY CALCULATIONS

To determine the velocity of flow in a channel or pipeline, we use the $Q = AV$ equation. However, to use the equation correctly, we must transpose the equation. We simply write into the equation the information given and then transpose for the unknown (V in this case), as illustrated in Example 4.16 for channels and 4.17 for pipelines.

Example 4.16

Problem:

A channel has a rectangular cross-section. The channel is 5 ft wide with wastewater flowing to a depth of 2 ft. If the flow rate through the channel is 8,500 gpm, what is the velocity of the wastewater in the channel (ft/sec)?

Convert gpm to cfs:

$$\frac{8{,}500\text{ gpm}}{(7.48\text{ gal/cu ft})\,(60\text{ sec/min})} = 18.9\text{ cu ft/sec (cfs)}$$

$$Q\text{, cfs} = (A)\,(V\text{, fps})$$

$$18.9\text{ cfs} = (5\text{ ft})\,(2\text{ ft})\,(\text{unknown, fps})$$

$$\text{velocity (the unknown, fps)} = \frac{18.9}{(5)\,(2)}$$

$$V = 1.89 \text{ fps}$$

Example 4.17

Problem:

A full 8-inch diameter pipe delivers 250 gpm. What is the velocity of flow in the pipeline (ft/sec)? Convert:

$$8 \text{ in} / 12 \text{ in to feet} = 0.67 \text{ ft}$$

Convert gpm to cfs flow:

$$\frac{250 \text{ gpm}}{(7.48 \text{ gal / cu ft})\,(60 \text{ sec / min})} = 0.56 \text{ cfs}$$

$$0.56 \text{ cfs} = (0.785)\,(0.67 \text{ ft})\,(0.67 \text{ ft})\,(\text{unknown}, V, \text{fps})$$

$$V = \frac{0.56 \text{ cfs}}{(0.785)\,(0.67)\,(0.67)}$$

$$V = 1.6 \text{ fps}$$

4.3.4 AVERAGE FLOW RATES CALCULATIONS

Flow rates in a wastewater treatment system vary considerably during the course of a day, week, month, or year. Therefore, when computing flow rates for trend analysis or for other purposes, an *average flow rate* is used to determine the typical flow rate. Example 4.18 illustrates one way to calculate an average flow rate.

Example 4.18

Problem:

The following flows were recorded for the week:

Monday	8.2 MGD
Tuesday	8.0 MGD
Wednesday	7.3 MGD
Thursday	7.6 MGD
Friday	8.2 MGD
Saturday	8.9 MGD
Sunday	7.7 MGD

What was the average daily flow rate for the week?

$$\text{average daily flow} = \frac{\text{total of all sample flows}}{\text{number of days}} \tag{4.11}$$

$$= \frac{55.9\,\text{MGD}}{7\,\text{Days}}$$

$$= 8.0\,\text{MGD}$$

4.3.5 FLOW CONVERSIONS CALCULATIONS

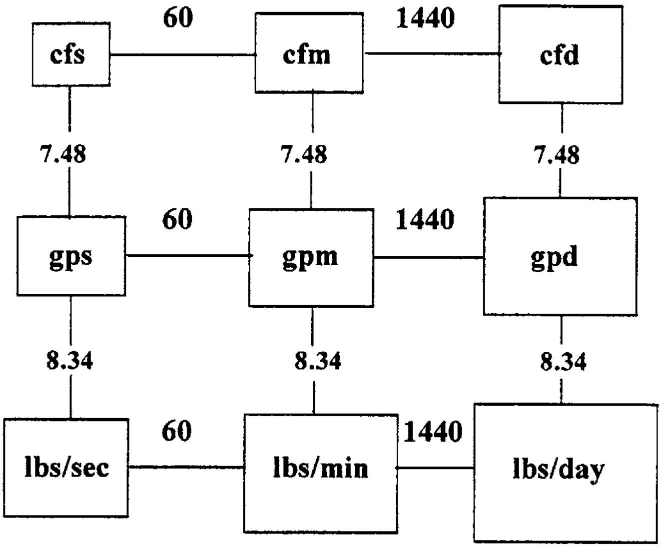
One of the tasks involving calculations that the wastewater operator is typically called on to perform involves converting one expression of flow to another. The ability to do this is also a necessity for those preparing for licensure examinations.

Probably the easiest way in which to accomplish flow conversions is to employ the box method illustrated in Figure 4.10. When using the box method, it is important to remember that moving from a smaller box to a larger box requires multiplication by the factor indicated. Moving from a larger box to a smaller box requires division by the factor indicated.

From Figure 4.10, it should be obvious that memorizing the nine boxes and the units in each box is not that difficult. The values of 60, 1,440, 7.48 and 8.34 are not that difficult to remember either—it is a matter of remembering the exact placement of the units and the values that is key to memorizing the box. Once this is accomplished, you have obtained a powerful tool that will enable you to make flow conversions in a relatively easy manner.

4.3.6 CHEMICAL DOSAGE CALCULATIONS

Chemicals are used extensively in wastewater treatment plant operations. Wastewater treatment plant operators add chemicals to various unit processes for slime-growth control, corrosion control,



cfs = cubic feet per second
cfm = cubic feet per minute
cfd = cubic feet per day

gps = gallons per second
gpm = gallons per minute
gpd = gallons per day

*The factors shown in the diagram have the following units associated with them:

odor control, grease removal, BOD reduction, pH control, sludge-bulking control, ammonia oxidation, bacterial reduction, and for other reasons.

In order to apply any chemical dose correctly, it is important to be able to make certain dosage calculations. One of the most frequently used calculations in wastewater mathematics is the conversion of milligrams per liter (mg/L) concentration to pounds per day (lb/day) or pounds (lb) dosage or loading. The general types of mg/L to lb/day or lb calculations are for chemical dosage, BOD, COD, SS loading/removal, pounds of solids under aeration, and WAS pumping rate. These calculations are usually made using either Equation (4.12) or (4.13).

$$(\text{mg}/\text{L})\,(\text{MGD flow})\,(8.34\ \text{lb}/\text{gal}) = \text{lb}/\text{day} \tag{4.12}$$

$$(\text{mg}/\text{L})\,(\text{MG volume})\,(8.34\ \text{lb}/\text{gal}) = \text{lb} \tag{4.13}$$

✓ *Note:* If mg/L concentration represents a concentration in a flow, then million gallons per day (MGD) flow is used as the second factor. However, if the concentration pertains to a tank or pipeline volume, then million gallons (MG) volume is used as the second factor.

4.3.6.1 Chlorine Dosage

Chlorine is a powerful oxidizer that is commonly used in wastewater treatment for disinfection, odor control, bulking control, and other applications. When chlorine is added to a unit process, we want to ensure that a measured amount is added, obviously.

In describing the amount of chemical added or required, two ways are used:

- milligrams per liter (mg/L)
- pounds per day (lb/day)

In the conversion from mg/L (or ppm) concentration to lb/day, we use Equation (4.14).

$$(\text{mg}/\text{L})\,(\text{MGD})\,(8.34) = \text{lb}/\text{day} \tag{4.14}$$

✓ *Note:* In previous years, it was normal practice to use the expression parts per million (ppm) as an expression of concentration, because 1 mg/L = 1 ppm. However, current practice is to use mg/L as the preferred expression of concentration.

Let's look at a couple of examples of how to calculate chlorine dosage.

Example 4.19

Problem:

Determine the chlorinator setting (lb/day) needed to treat a flow of 8 MGD with a chlorine dose of 6 mg/L.

Solution:

$$(\text{mg}/\text{L})\,(\text{MGD})\,(8.34) = \text{lb}/\text{day}$$

$$(6\ \text{mg}/\text{L})\,(8\ \text{MGD})\,(8.34\ \text{lb}/\text{gal}) = \text{lb}/\text{day}$$

$$= 400\ \text{lb}/\text{day}$$

Example 4.20

Problem:

What should the chlorinator setting be (lb/day) to treat a flow of 3 MGD if the chlorine demand is 12 mg/L and a chlorine residual of 2 mg/L is desired?

✓ The chlorine demand is the amount of chlorine used in reacting with various components of the wastewater, such as harmful organisms and other organic and inorganic substances. When the chlorine demand has been satisfied, these reactions stop.

$$(\text{mg/L})\,(\text{MGD})\,(8.34\ \text{lb/gal}) = \text{lb/day}$$

✓ In order to find the unknown value (lb/day), we must first determine chlorine dose. To do this, we must use Equation (4.15).

$$\text{chl. dose, mg/L} = \text{chl. demand, mg/L} + \text{chl. residual, mg/L} \tag{4.15}$$

$$= 12\ \text{mg/L} + 2\ \text{mg/L}$$

$$= 14\ \text{mg/L}$$

Then, we can make the mg/L to lbs/day calculation:

$$(14\ \text{mg/L})\,(3\ \text{MGD})\,(8.34\ \text{lb/gal}) = 350\ \text{lb/day}$$

4.3.6.2 Hypochlorite Dosage

At many wastewater facilities, sodium hypochlorite or calcium hypochlorite is used instead of chlorine. The reasons for substituting hypochlorite for chlorine vary. However, with the passage of stricter hazardous chemicals regulations under OSHA and the USEPA, many facilities are deciding to substitute the hazardous chemical chlorine with non-hazardous hypochlorite. Obviously, the potential liability involved with using deadly chlorine is also a factor involved in the decision to substitute it with a less toxic chemical substance.

For whatever reason the wastewater treatment plant decides to substitute chlorine with hypochlorite, there are differences between the two chemicals, of which the wastewater operator needs to be aware. Let's look at chlorine first.

Chlorine is a hazardous material. Chlorine gas is used in wastewater treatment applications at 100% available chlorine. This is an important consideration to keep in mind when making or setting chlorine feed rates. For example, if the chlorine demand and residual requires 100 lb/day chlorine, the chlorinator setting would be just that—100 lb/24 hr.

Hypochlorite is less hazardous than chlorine; it is similar to a strong bleach and comes in two forms: dry calcium hypochlorite (often referred to as HTH) and liquid sodium hypochlorite. Calcium hypochlorite contains about 65% available chlorine; sodium hypochlorite contains about 12% to 15% available chlorine (in industrial strengths).

✓ Because either type of hypochlorite is not 100% pure chlorine, more lb/day must be fed into the system to obtain the same amount of chlorine for disinfection. This is an important economical consideration for those facilities thinking about substituting hypochlorite for chlorine. Some

To calculate the lb/day hypochlorite required, a two-step calculation is required:

Step (1): mg/L (MGD (8.34)) = lb/day

Step (2):

$$\frac{\text{Chlorine, lb / day}}{\frac{\text{\% available}}{100}} = \text{hypochlorite, lb / day}$$

Let's put this two-step calculation procedure to work (see Examples 4.21 and 4.22).

Example 4.21

Problem:

A total chlorine dosage of 10 mg/L is required to treat a particular wastewater. If the flow is 1.4 MGD and the hypochlorite has 65% available chlorine, how many lb/day of hypochlorite will be required?

Solution:

Step 1: Calculate the lb/day chlorine required using the mg/L to lbs/day equation:

$$(\text{mg / L})\,(\text{MGD})\,(8.34) = \text{lb / day}$$

$$(10\ \text{mg / L})\,(1.4\ \text{MGD})\,(8.34\ \text{lb / gal}) = 117\ \text{lb / day}$$

Step 2: Calculate the lb/day hypochlorite required. Because only 65% of the hypochlorite is chlorine, more than 117 lb/day will be required:

$$\frac{117\ \text{lb / day chlorine}}{\frac{65\ \text{avail. chlorine}}{100}} = 180\ \text{lb / day hypochlorite}$$

Example 4.22

Problem:

A wastewater flow of 840,000 gpd requires a chlorine dose of 20 mg/L. If sodium hypochlorite (15% available chlorine) is to be used, how many lb/day of sodium hypochlorite are required? How many gal/day of sodium hypochlorite is this?

Solution:

(1) Calculate the lb/day chlorine required:

$$(\text{mg / L})\,(\text{MGD})\,(8.34) = \text{lb / day}$$

$$(20\ \text{mg / L})\,(0.84\ \text{MGD})\,(8.34\ \text{lb / gal}) = 140\ \text{lb / day chlorine}$$

(2) Calculate the lb/day sodium hypochlorite:

$$\frac{140\ \text{lb / day chlorine}}{\frac{15\ \text{avail. chlorine}}{100}} = 933\ \text{lb / day hypochlorite}$$

(3) Calculate the gal/day sodium hypochlorite:

$$\frac{933\text{ lb/day}}{8.34\text{ lb/gal}} = 112\text{ gal/day sodium hypochlorite}$$

Now, let's take a look at a chlorine dosage-type problem from a slightly different view—the type of dosage problem that is typically encountered in wastewater operations.

Example 4.23

Problem:

How many pounds of chlorine gas are necessary to treat 5,000,000 gallons of wastewater at a dosage of 2 mg/L?

Solution:

Step 1: Calculate the pounds of chlorine required.

$$V, 10^6\text{ gal} = \text{chlorine concentration (mg/L)} \times 8.34 = \text{lb chlorine}$$

Step 2: Substitute 5×10^6 gal × 2 mg/L × 8.34 = 83 lb chlorine

4.3.7 PRACTICAL PERCENTAGE CALCULATIONS

The words "per cent" mean "by the hundred." Percentage is often designated by the symbol %. Thus, 10% means 10 percent or 10/100 or 0.10. These equivalents may be written in the reverse order: 0.10 = 10/100 = 10%. In wastewater treatment, percent is frequently used to express plant performance and for control of sludge treatment processes.

✓ To determine percent, divide the quantity you wish to express as a percent by the total quantity; then, multiply by 100.

$$\text{percent} = \frac{\text{quantity} \times 100}{\text{total}} \tag{4.16}$$

Let's look at a couple of percent problems typically performed in wastewater treatment operations.

Example 4.24

Problem:

The plant operator removes 6,000 gallons of sludge from the settling tank. The sludge contains 320 gallons of solids. What is the percent solids in the sludge?

Solution:

$$\text{percent} = \frac{320\text{ gal}}{6{,}000\text{ gal}} \times 100$$

$$= 5.3\%$$

Example 4.25

Problem:

Sludge contains 5.3% solids. What is the concentration of solids in decimal percent?

Solution:

$$\text{decimal percent} = \frac{5.3\%}{100} = 0.053$$

✓ Unless otherwise noted, all calculations in the handbook using percent values require the percent be converted to a decimal before use.

✓ To determine what quantity a percent equals, first convert the percent to a decimal; then, multiply by the total quantity.

$$\text{quantity} = \text{total} \times \text{decimal percent} \tag{4.17}$$

Example 4.26

Problem:

Sludge drawn from the settling tank is 8% solids. If 2,400 gallons of sludge are withdrawn, how many gallons of solids are removed?

Solution:

$$\text{gallons} = \frac{8\%}{100} \times 2{,}400\ \text{gal} = 192\ \text{gal}$$

4.3.8 ARITHMETIC AVERAGE (OR ARITHMETIC MEAN)

During the day-to-day operation of a wastewater treatment plant, much data must be collected. The data, if properly evaluated, can provide useful information for trend analysis and can indicate how well the plant or unit process is operating. However, because there may be much variation in the data information, it is often difficult to determine trends in performance.

Arithmetic average refers to a statistical calculation used to describe a series of numbers, such as test results. By calculating an average, a group of data is represented by a single number. This number may be considered typical of the group. The *arithmetic mean* is the most commonly used measurement of average value.

✓ When evaluating information based on averages, remember that the "average" reflects the general nature of the group and does not necessarily reflect any one element of that group.

Arithmetic average is calculated by dividing the sum of all of the available data points (test results) by the number of test results.

$$\frac{\text{test 1} + \text{test 2} + \text{test 3} + \ldots + \text{test } N}{\text{number of tests performed } (N)} \tag{4.18}$$

Let's take a look at a couple of examples of how average is determined.

Example 4.27

Problem:

Effluent BOD test results for the treatment plant during the month of September are shown below.

Test 1	20 mg/L
Test 2	31 mg/L
Test 3	22 mg/L
Test 4	15 mg/L

What is the average effluent BOD for the month of September?

Solution:

$$\text{average} = \frac{20\text{ mg/L} + 31\text{ mg/L} + 22\text{ mg/L} + 15\text{ mg/L}}{4} = 22\text{ mg/L}$$

Example 4.28

Problem:

For the primary influent flow, the following composite-sampled solids concentrations were recorded for the week:

Monday	300 mg/L SS
Tuesday	312 mg/L SS
Wednesday	315 mg/L SS
Thursday	320 mg/L SS
Friday	311 mg/L SS
Saturday	320 mg/L SS
Sunday	310 mg/L SS
Total	2188 mg/L SS

What is the average?

Solution:

$$\text{average SS} = \frac{\text{sum of all measurements}}{\text{number of measurements used}}$$

$$= \frac{2{,}188\text{ mg/L SS}}{7}$$

$$= 312.6\text{ mg/L}$$

4.3.9 PERCENT REMOVAL

performance of the plant and individual treatment unit processes. The results can be used to determine if the plant is performing as expected or in troubleshooting unit operations by comparing the results with those listed in the plant's Operations and Maintenance Manual. It can be used with either concentration or quantities [see Equations (4.19) and (4.20)].

For concentrations, use

$$\%\text{ removal} = \frac{[\text{influent conc.} - \text{effluent conc.}] \times 100}{\text{influent conc.}} \tag{4.19}$$

For quantities, use

$$\%\text{ removal} = \frac{[\text{inf. quantity} - \text{eff. quantity}] \times 100}{\text{influent quantity}} \tag{4.20}$$

✓ Note that the calculation used for determining the performance (percent removal) for a digester is different from that used for performance (percent removal) for other processes, such as some process residuals or biosolids treatment processes. Ensure the right formula is selected.

Let's look at a typical percent removal calculation.

Example 4.29

Problem:

The plant influent contains 259 mg/L BOD_5, and the plant effluent contains 17 mg/L BOD_5. What is the % BOD_5 removal?

Solution:

$$\%\text{ removal} = \frac{[(259\text{ mg/L} - 17\text{ mg/L}) \times 100}{259\text{ mg/L}}$$

$$= 93.4\%$$

4.3.10 HYDRAULIC DETENTION TIME

The terms, *detention time* and *hydraulic detention time (HDT),* refer to the average length of time (theoretical time) a drop of water, wastewater, or suspended particle remains in a tank or channel. It is calculated by dividing the water/wastewater in the tank by the flow rate through the tank. The units of flow rate used in the calculation are dependent on whether the detention time is to be calculated in seconds, minutes, hours, or days. Detention time is used in conjunction with various treatment processes, including sedimentation and coagulation-flocculation.

Generally, in practice, detention time is associated with the amount of time required for a tank to empty. The range of detention time varies with the process. For example, in a tank used for sedimentation, detention time is commonly measured in minutes.

The calculation methods used to determine detention time are illustrated in the following sections.

4.3.10.1 Detention Time in Days

✓ The general hydraulic detention time calculation is

$$\text{HDT} = \frac{\text{tank volume}}{\text{flow rate}} \tag{4.21}$$

This general formula is then modified based upon the information provided/available and the "normal" range of detention times for the unit being evaluated. Equation (4.22) shows another form of the general equation.

$$\text{HDT, days} = \frac{\text{tank volume, ft}^3 \times 7.48\ \text{gal/ft}^3}{\text{flow, gal/day}} \tag{4.22}$$

Example 4.30

Problem:

An anaerobic digester has a volume of 2,200,000 gallons. What is the detention time in days when the influent flow rate is 0.06 MGD?

Solution:

$$\text{DT, days} = \frac{2{,}200{,}000\ \text{gal}}{0.06\ \text{MGD} \times 1{,}000{,}000\ \text{gal/MG}}$$

$$\text{DT, days} = 37\ \text{days}$$

4.3.10.2 Detention Time in Hours

$$\text{HDT, hours} = \frac{\text{tank volume, ft}^3 \times 7.48\ \text{gal/ft}^3 \times 24\ \text{hours/day}}{\text{flow, gal/day}} \tag{4.23}$$

Example 4.31

Problem:

A settling tank has a volume of 40,000 ft^3. What is the detention time in hours when the flow is 4.35 MGD?

Solution:

$$\text{DT, hours} = \frac{40{,}000\ \text{ft}^3 \times 7.48\ \text{gal/ft}^3 \times 24\ \text{hr/day}}{4.35\ \text{MGD} \times 1{,}000{,}000\ \text{gal/MG}}$$

$$\text{DT, hours} = 1.7\ \text{hours}$$

4.3.10.3 Detention Time in Minutes

$$\text{HDT, minutes} = \frac{\text{tank volume, ft}^3 \times 7.48\ \text{gal/ft}^3 \times 1{,}440\ \text{min/day}}{\text{flow, gal/day}} \tag{4.24}$$

Example 4.32

Problem:

Solution:

$$\text{DT, minutes} = \frac{1{,}240\ \text{ft}^3 \times 7.48\ \text{gal/ft}^3 \times 1{,}440\ \text{min/day}}{4{,}100{,}000\ \text{gal/day}}$$

$$= 3.26\ \text{minutes}$$

✓ The tank volume and the flow rate must be in the same dimensions before calculating the hydraulic detention time.

4.3.10.4 Population Equivalent (PE) or Unit Loading Factor

✓ When it is impossible to conduct a wastewater characterization study and other data are unavailable, population equivalent or unit per capita loading factors are used to estimate the total waste loadings to be treated. If the BOD contribution of a discharger is known, the loading placed upon the wastewater treatment system in terms of equivalent number of people can be determined. The BOD contribution of a person is normally assumed to be 0.17 lb BOD/day.

$$\text{PE, people} = \frac{\text{BOD}_5\ \text{contribution, lb/day}}{0.17\ \text{lb BOD}_5\text{/day/person}} \tag{4.25}$$

Example 4.33

Problem:

A new industry wishes to connect to the city's collection system. The industrial discharge will contain an average BOD concentration of 349 mg/L, and the average daily flow will be 50,000 gallons per day. What is the population equivalent of the industrial discharge?

Solution:

First, convert flow rate to million gallons per day:

$$\text{flow} = \frac{50{,}000\ \text{gpd}}{1{,}000{,}000\ \text{gal/MG}} = 0.050\ \text{MG}$$

Next, calculate the population equivalent:

$$\text{PE, people} = \frac{349\ \text{mg/L} \times 0.050\ \text{MGD} \times 8.34\ \text{lb/mg/L/MG}}{0.17\ \text{lb BOD/person/day}}$$

$$= 856\ \text{people/day}$$

4.3.10.5 Specific Gravity

✓ *Specific gravity* is the ratio of the density of a substance to that of a standard material under standard conditions of temperature and pressure. The standard material for gases is air, and the standard material for liquids and solids is water. Specific gravity can be used to calculate the weight of a gallon of liquid chemical.

$$\text{chemical, lb/gal} = \text{water, lb/gal} \times \text{chemical's specific gravity} \tag{4.26}$$

Problem:

The label of the chemical states that the contents of the bottle have a specific gravity of 1.4515. What is the weight of 1 gallon of solution?

Solution:

$$\text{weight, lb/gallon} = 1.4515 \times 8.34 \text{ lb/gallon}$$

$$= 12.1 \text{ lb}$$

4.3.10.6 Percent Volatile Matter Reduction in Sludge

The calculation used to determine *percent volatile matter reduction* is complicated because of the changes occurring during sludge digestion.

$$\%\,\text{VM reduction} = \frac{(\%\,\text{VM}_{\text{in}} - \%\,\text{VM}_{\text{out}}) \times 100}{[\%\,\text{VM}_{\text{in}} - (\%\,\text{VM}_{\text{in}} \times \%\,\text{VM}_{\text{out}})]} \tag{4.27}$$

✓ *Note:* VM = volatile matter

Example 4.34

Problem:

Using the digester data provided below, determine the % volatile matter reduction for the digester.

Data:

Raw Sludge Volatile Matter	72%
Digested Sludge Volatile Matter	51%

$$\%\,\text{volatile matter reduction} = \frac{(0.72 - 0.51) \times 100}{[0.72 - (0.72 \times 0.51)]} = 60\%$$

4.4 REFERENCE

Price, J. K., *Applied Math for Wastewater Plant Operators.* Lancaster, PA: Technomic Publishing Company, Inc., 1991.

4.5 CHAPTER REVIEW QUESTIONS

4-1 The sludge contains 6.55% solids. If 9,000 gallons of sludge are removed from the primary settling tank, how many pounds of solids are removed?

4-2 The operator wishes to remove 3,440 pounds per day of solids from the activated sludge process. The waste activated sludge concentration is 3,224 mg/L. What is the required flow rate in million gallons per day?

4-3 The plant influent includes an industrial flow that contains 240 mg/L BOD. The industrial flow is 0.90 MGD. What is the population equivalent for the industrial contribution in people per day?

4-4 Determine the per capita characteristics of BOD and suspended solids (SS), if garbage grinders are installed in a community. Assume that the average per capita flow is 120 gal/d and that the typical average per capita contributions for domestic wastewater with ground kitchen wastes are BOD: 0.29 lb/capita/d; SS: 0.22 lb/capita/d.

4-5 The label on hypochlorite solution states that the specific gravity of the solution is 1.1347. What is the weight of one gallon of the hypochlorite solution?

The following information is used for the chapter review questions 4-6 through 4-10.

Plant influent	Flow	8.25 MGD
	Suspended solids	350 mg/L
	BOD	225 mg/L
Primary effluent	Flow	8.35 MGD
	Suspended solids	144 mg/L
	BOD	175 mg/L
Activated sludge effluent (plant effluent)	Flow	8.35 MGD
	Suspended solids	17 mg/L
	BOD	24 mg/L
Anaerobic digester	Solids in	6.6%
	Solids out	13.4%
	Volatile matter in	66.3%
	Volatile matter out	49.1%

4-6 What is the plant percent removal for BOD_5?

4-7 What is the plant percent removal of TSS?

4-8 What is the primary treatment percent removal of BOD_5?

4-9 What is the primary treatment percent removal of TSS?

4-10 What is the percent volatile matter reduction in the anaerobic digestion process?

4-11 The influent flow rate to a primary settling tank is 1.30 MGD. The tank is 80 ft in length, 15 ft wide, and has a water depth of 12 ft. What is the detention time of the tank in hours?

The following information is used for the chapter review questions 4-12 through 4-14.

Plant influent	Flow	8.40 MGD
Grit channel	Number of channels	2
	Channel length	60 ft
	Channel width	4 ft
	Water depth	2.6 ft
Primary settling	Number	2
	Length	160 ft
	Width	110 ft
	Water depth	12 ft
Anaerobic digester	Flow	19,000 gpd
	Volume	110,000 ft^3

4-12 What is the hydraulic detention time in hours for primary settling when both tanks are in service?

4-13 What is the hydraulic detention time in the grit channel in minutes when both channels are in service?

4-14 What is the hydraulic detention time of the anaerobic digester in days?

4-15 The plant influent contains 348 mg/L of suspended solids. The plant effluent flow rate is 8.55 MGD. How many pounds per day of suspended solids entered the plant?

4-16 The digester has a diameter of 60 feet and is 26 feet deep. If the operator pumps 5,200 gallons of residuals (sludge) to the digester per day, what is the hydraulic detention time in the digester in days?

4-17 If 4,000 gallons of solids are removed from the primary settling tank, how many pounds of solids are removed?

4-18 The plant influent contains 240 mg/L BOD_5, the primary effluent contains 180 mg/L BOD_5 and the final effluent contains 22 mg/L BOD_5. What is the percent removal for the primary treatment process and for the entire plant?

4-19 The plant influent includes an industrial flow that contains 335 mg/L BOD_5. The industrial flow is 0.68 MGD. What is the population equivalent of the industrial discharge in people?

4-20 The label on the chemical container states that the specific gravity is 1.1435. What is the weight of one gallon of the chemical solution?

4-21 The influent flow rate is 5.0 MG, and the current return activated sludge flow rate is 2.0 MGD. If the SSV_{60} is 36%, what should be the return rate?

4-22 The operator determines that 12,000 lb of activated sludge must be removed from the process. The waste activated sludge solids concentration currently is 5,500 mg/L. What is the required waste activated sludge flow rate in MGD and gpm?

4-23 The plant effluent currently requires a chlorine dose of 7.0 mg/L to produce the required 1.1 mg/L chlorine residual in the chlorine contact tank. What is the chlorine demand in milligrams per liter?

4-24 The ferric chloride solution (stock solution) delivered to the plant contains 42.0% ferric chloride. Testing indicates that the optimum concentration for the working solution used in the treatment of the wastewater is 3.50%. How many gallons of stock ferric chloride solution must be used to prepare 6,000 gallons of working solution?

4-25 Sludge is added to a 560,000-gallon digester at the rate of 12,500 gallons per day. What is the sludge retention time?

CHAPTER 5

Troubleshooting Wastewater Treatment Systems

5.1 INTRODUCTION

FEW would argue that in order to paint a picture along the lines (or up to similar standards) of the great artists like Da Vinci, Raphael, and the other masters, a certain amount of artistic skill is not only involved but is also required. The same can be said for the bridge builder, the house builder, the car manufacturer, and many other types of builders; in a sense, they are all artisans.

Can we say the same for the troubleshooter? Yes, we can, absolutely. Why? Because troubleshooting is a skill, but it is also an art. The difference is, the ability to perform correct, accurate troubleshooting can be learned, taught, and mastered.

Having digested the material above, it may come as no surprise to the reader when we define troubleshooting as the "art" or science of problem solving. Some would go further and state that troubleshooting is a simple, systematic method to identify and correct problems. This may be the case; however, experience has shown that nothing is simple and/or systematic unless a certain amount of experience is thrown into the equation.

But there is more. The *Troubleshooting Expertise = Experience + Simplistic, Systematic Approach* does not complete the equation. A major factor is missing from this equation. The major factor missing? Common sense.

Absolutely. You may get by (to a degree) in troubleshooting with a lack of expertise, experience, and/or a simplistic, systematic approach, but you can't get by without a whole bunch of common sense.

Consider the student who spends several years in formal classroom training to become an electrician, for example. This student may have little difficulty in understanding Ohm's Law, AC/DC Theory, Inductance/Capacitance, Boolean Algebra, Logic Circuits, and other complex electrical theory. This same student may ace these subjects and the course itself. But does the ability to score high on theoretical concepts translate to a high degree of proficiency in troubleshooting an electronic/electrical circuit?

Maybe. Maybe not. It depends on experience for one thing. As the old adage says, "There simply is no substitute for experience."

"Well, with time," you say, "the brilliant electrical student will gain experience and, therefore, be able to troubleshoot any electrical/electronic problem."

Are you sure? Can you be sure, absolutely sure?

No, not really. How can you be? How can anyone be sure? We can't. One thing is certain, however. If you take this same brilliant student and expose him or her to real-life (on-the-job) situations (over time) where he or she has to troubleshoot complicated systems and solve problems, then he or she will learn. If you add the common sense factor into this learning experience, then he or she will learn easier and quicker and retain what has been learned.

simply say that we have said what we have learned from our own experience, and you can take it for what it is worth.

5.2 TROUBLESHOOTING: WHAT IS IT?

Troubleshooting is the "art" of problem solving (sound familiar?). Troubleshooting provides a mechanism to address problems and evaluate possible solutions. It is important to remember that no machine, electrical circuit, or wastewater treatment plant unit process runs at maximum efficiency at all times. In fact, in wastewater treatment, unit process problems are not that uncommon. Some of the problems are due to poor design or unusual influent characteristics. However, one thing is absolutely certain: the majority of treatment plant problems are avoidable with better operation, management, maintenance, and process control. To achieve optimum operation and control, the operator must be able to rapidly identify problems. More importantly, once identified, the problems must be corrected. Maintaining optimum performance of "any" system requires the ability to troubleshoot—the ability to troubleshoot correctly.

✓ It is important to recognize that, due to the complexity of treatment systems and unit processes and the number of variables involved, troubleshooting may not always identify one single "right" answer. The process requires experience, time, common sense, and usually a good deal of effort to solve performance problems. Probably the most important factor in troubleshooting, however, is system knowledge. Simply put, you can't determine what the solution to a problem is with most complex processes and/or systems unless you understand the operation of the process or system. To remedy difficulties experienced with any treatment unit process or system, the operator must know the characteristics of the wastestream, the design shortcomings of the process or system, and the indicators of operational problems (see Section 5.4).

5.3 GOALS OF TROUBLESHOOTING

There are many different reasons for troubleshooting a treatment plant or unit process. The reasons vary from developing procedures to prevent future problems, to improving overall plant performance, to reducing operation and maintenance costs. However, probably the most common reason (most important reason) for identifying and correcting a problem is when the problem causes the plant to violate permit. Remember, "making permit" each month is what wastewater treatment is all about (i.e., in the view of the regulators).

5.4 THE TROUBLESHOOTING PROCESS

✓ *Note:* There is no one "perfect" method for troubleshooting treatment process problems; each situation can (and probably will) vary. However, there are certain steps or elements in the process of troubleshooting that should be followed each time—these are listed in this section.

The common elements in successful troubleshooting approaches include the following:

- *Observe/gather information*—to begin the correct troubleshooting process or approach, there is a need to understand "what is or is not happening" with the process. It doesn't work. Okay, what does that mean? What doesn't work or what doesn't work correctly? These questions must be asked first, before any corrective action is attempted. Follow the old adage: "Don't leap before you look."
- *Identify additional data needed*—many wastewater treatment systems and/or unit processes are quite complex. Simply because one element of the process has been identified as

non-functional doesn't necessarily mean that it is the causal factor of the overall malfunction. Many times, failure to one component is caused by failure of some other device or system downstream or upstream of the component not functioning as designed. Collect "all" the information, not just patchwork details.

- *Evaluate available information*—once all the data and information are collected, the next step is to evaluate what it is that you know.
- *Identify potential problems, causes, and corrective actions*—with the proper information in hand, the next step is to look at each potential causal factor and, then, through process of elimination, narrow down the causes and corrective actions.
- *Prioritize problems, causes, and corrective actions*—with the potential causes and corrective actions narrowed down to a "small" list, prioritize them.
- *Select the actions to be taken*—a short list of actions to be taken should be made to determine if any of them are the corrective action(s) required.
- *Implement*—starting with the most likely corrective action, implement it first and then proceed down the list until the problem is remedied. (*Note:* If the problem is not remedied from the corrective actions listed, then the process needs to start again from the beginning.)
- *Observe the results*—once the selected remedial action is effected, observing the impact of the action is important, obviously.
- *Documenting (recordkeeping) for future use*—one thing is certain: If a system or unit process fails once, it is quite likely that it will fail again. If this is the case (and it is), then why would anyone want to spend an inordinate amount of time and effort finally determining the causal factor without taking the time to document it? Local knowledge is important in maintaining the smooth, uninterrupted operation of a wastewater treatment plant; local troubleshooting knowledge is more than important, it is critical.

A basic summary of the elements listed above is shown in Figure 5.1. Figure 5.2 shows a more detailed step-by-step troubleshooting process, a model or paradigm that has one huge advantage over many others: it has been tested.

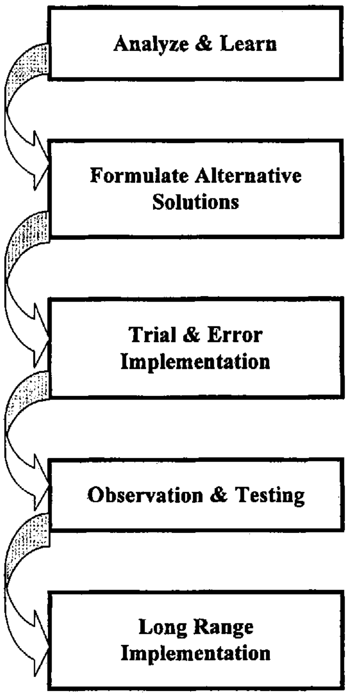


Figure 5.1 Simplified troubleshooting steps.

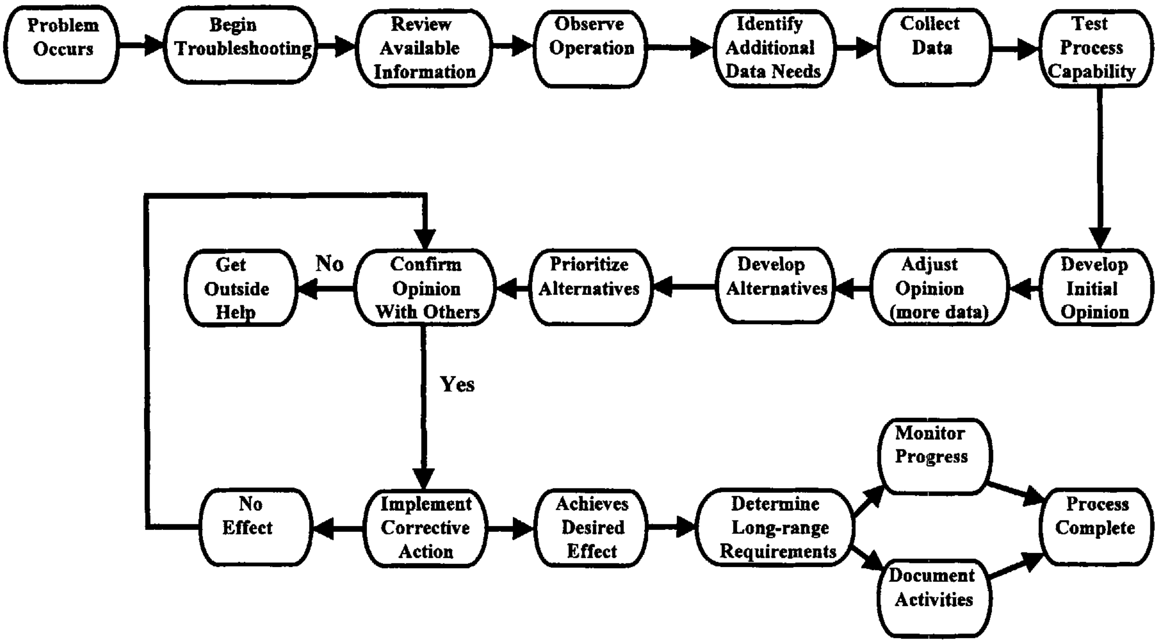


Figure 5.2 Troubleshooting sequence.

Along with the common troubleshooting elements listed above and those depicted in Figures 5.1 and 5.2, charts (or other illustrative devices) showing common problems, causes, and possible corrective actions are provided to assist you in developing a troubleshooting approach (Tables 5.1 and 5.2).

5.5 KNOWING THE SYSTEM OR PROCESS

We stated earlier that anyone attempting to troubleshoot a system or a process without first knowing the basic operation of the system or process is performing a foolhardy exercise at best. Moreover, we also pointed out that the operator (the troubleshooter) must know the characteristics, the design shortcomings, and the indicators of operational problems for the particular system or process he or she is attempting to troubleshoot. The best way in which to illustrate this process (and what we mean) is to provide an example.

The example used here draws on the expertise of USEPA. Specifically, we use guidance provided by USEPA in two of its somewhat dated but still practical guides: *Operation of Wastewater Treatment Plants, A Field Study Training Program* (1971) and *Procedural Manual for Evaluating the Performance of Wastewater Treatment Plants* (1973).

The unit process described below is used to demonstrate the three main aspects of wastewater treatment unit process troubleshooting (i.e., knowing the characteristics of affected wastestream, the design shortcomings of equipment, and the indicators of operational problems). Keep in mind that the steps discussed can be used to troubleshoot any wastewater treatment unit process.

5.5.1 KNOWING THE CHARACTERISTICS (PRIMARY SETTLING)

For primary sedimentation, the operator must know the quality of the sludge. We are talking about knowing the characteristics and variations in sludge composition. More importantly, the operator must know what causes variations and what they depend on. For example, the operator needs to know that sludge variations depend on composition, freshness, strength, constituents, and settleabil-

TABLE 5.1. Common Design Shortcomings (Sedimentation Basins and Associated Equipment).

Shortcoming	Solution
Poor flotation of grease	Preaeration of wastewater to increase buoyancy.
Scum overflow	Move scum collection system away from outlet weir.
Sludge hard to remove from hopper because of excessive grit	Install grit chamber or eliminate sources of grit entering the system.
Heavy wear and frequent breakage of scrapers and shear pins because of grit	Install grit chamber.
Inadequate removal of heavy grease loading	Divert or provide alternate disposal for other plant process wastes (i.e., centrates and supernates that are typically recirculated into the sedimentation basin).
Excessive corrosion because of septic wastewater	Coat all surfaces with proper paint or other coating.
Consistent problems with thermal currents in clarifier	Install flow equalization and mixing basin ahead of the clarifier.
Poor scum removal because of wind	Install a wind barrier to protect tank from wind effects. Modify scum collection system to compensate for wind.
Septic wastewater	Improve hydraulics of collector system to reduce accumulation of solids.

Source: USEPA, 1973.

ity of the wastewater entering the process. The operator must know the characteristics and adequacy of the sedimentation tanks. Lastly, the operator must know how to operate the sedimentation system and how to manage it, including the methods of sludge removal.

5.5.2 KNOWING DESIGN SHORTCOMINGS (PRIMARY SETTLING)

Along with knowing the characteristics of the wastestream they are treating, operators also must recognize design shortcomings that affect settling performance and the possible remedies. Table 5.1 presents the USEPA list of design shortcomings observed for sedimentation basins and associated equipment and the possible solutions or remedies of those shortcomings.

5.5.3 KNOWING OPERATION PROBLEMS AND SOLUTIONS

The USEPA provides a troubleshooting guide (see Table 5.2) to assist the operator in identifying problems with primary sedimentation and determining their solutions.

✓ Keep in mind that the nature of an operational problem and its severity may be temperature dependent. For example, in colder weather, sludge will be more difficult to pump, sludgelines will collect grease more quickly, and there will be a noticeable increase in skimmings; on the other hand, septicity and odor will likely lessen.

5.5.4 OTHER SOURCES OF ASSISTANCE

There are times when even the most skillful troubleshooter needs assistance in remedying treatment process problems. Fortunately, there are many sources of assistance. These include regulatory agencies (e.g., USEPA, State Department of Environmental Quality, and State Department of Health), Professional Associations (e.g., Water Environment Federation), and colleges and universities. A valuable source of assistance that is sometimes overlooked is other professional wastewater treatment plant operators at your site or at other treatment facilities within your area.

TABLE 5.2. **Troubleshooting Guide for Primary Sedimentation Problems.**

Indicators	Probable Cause	Solutions
Floating sludge	Excessive sludge accumulating in the tank	Remove sludge more frequently or at a higher rate.
	Scrapers worn or damaged	Repair or replace as necessary.
	Return of well-nitrified waste activated sludge	Vary age of returned sludge or move point of waste sludge recycle.
	Sludge withdrawal line plugged	Flush or clean line.
	Damaged or missing inlet baffles	Repair or replace as necessary.
Black and odorous septic wastewater or sludge	Sludge collectors worn or damaged	Repair or replace as necessary.
	Improper sludge removal pumping cycles	Increase frequency and duration of pumping cycles until sludge density decreases.
	Inadequate pretreatment of organic industrial waste	Preaerate waste. Have pretreated by industry.
	Wastewater decomposing in collection system	Add chemicals or aerate in collector system.
	Recycle of excessively strong digester supernatant	Improve sludge digestion to obtain better quality supernatant. Reduce or delay withdrawal until quality improves. Select better quality supernatant from another digester zone. Discharge supernatant to lagoon, aeration tank, or sludge drying bed.
	Sludge withdrawal line plugged	Clean line.
	Septic dumpers	Regulate or curtail dumping.
	Insufficient run time for sludge collectors	Increase run time or run continuously.
Scum overflow	Frequency of removal inadequate	Remove scum more frequently.
	Heavy industrial waste contributions	Limit industrial waste contributions.
	Worn or damaged scum wiper blades	Clean or replace wiper blades.
	Improper alignment of skimmer	Adjust alignment.
	Inadequate depth of scum baffle	Increase baffle depth.
Sludge hard to remove from hopper	Excessive grit, clay, and other easily compacted material	Improve operation of grit removal unit.
	Low velocity in withdrawal lines	Increase velocity in sludge withdrawal lines. Check pump capacity.
	Pipe or pump clogged	Backflush clogged pipe lines and pump sludge more frequently.
Undesirably low solids contents	Hydraulic overload	Provide more even flow distribution in all tanks, if multiple tanks.
	Short circuiting of flow through tanks	See short circuiting of flow through tanks.
	Overpumping of sludge	Reduce frequency and duration of pumping cycles.
Short circuiting of flow through tanks	Uneven weir settings	Change weir settings.
	Damaged or missing inlet line baffles	Repair or replace baffles.
Surging flow	Poor influent pump programming	Modify pumping cycle.
Excessive sedimentation in inlet channel	Velocity too low	Increase velocity or agitate with air or water to prevent decomposition.
Poor suspended solids removal	Hydraulic overloading	Use available tankage, shave peak flow, chemical addition.
	Septic influent	Intensify and resolve upstream causes. Pretreat with chlorine or other oxidizing chemical until problem is resolved.
	Short circuiting	See short circuiting of flow through tanks.
	Poor sludge removal	Frequent and consistent pumping.
	Industrial waste	Eliminate industrial wastes that hinder settling.
	Density currents wind temperature related	Eliminate storm flows from sewer system. Install wind barrier.
Excessive growth on surfaces of weirs	Accumulation of wastewater solids and resultant growth	Frequent and thorough cleaning of surfaces.

Source: USEPA, 1971; 1973.

5.6 REFERENCES

USEPA, *Operation of Wastewater Treatment Plants, A Field Study Training Program.* Office Water Programs, Washington, D.C., 1971.

USEPA, *Procedural Manual for Evaluating the Performance of Wastewater Treatment Plants.* Office Water Programs, Washington, D.C., 1973.

CHAPTER 6

Preliminary Treatment

6.1 INTRODUCTION

THE initial stage of treatment in the wastewater treatment process (following collection and influent pumping) is preliminary treatment. Raw influent entering the treatment plant may contain many kinds of materials: rags, rocks, sand, metal, and other inorganics and disposables. The purpose of preliminary treatment is to protect plant equipment downstream by removing these materials that could cause clogs, jams, equipment breakdowns, or excessive wear to plant machinery. In addition to protecting downstream equipment, the removal of various materials at the beginning of the treatment process saves valuable space within the treatment plant.

Preliminary treatment may include many different processes, each designed to remove a specific type of material that is a potential problem for the treatment process. Processes include wastewater collections, influent pumping, screening, shredding, grit removal, flow measurement, preaeration, chemical addition, and flow equalization. The major processes are shown in Figure 6.1. In this chapter, we describe and discuss each of these processes and their importance in the treatment process.

✓ Not all treatment plants include all of the processes shown in Figure 6.1. Specific processes have been included to facilitate discussion of major potential problems with each process and its operation; this is information that may be important to the wastewater operator.

6.2 SCREENING

The purpose of screening is to remove large solids, such as rags, cans, rocks, branches, leaves, roots, etc., from the flow before the flow moves on to downstream processes.

✓ Typically, a treatment plant will remove anywhere from 0.5 to 12 ft^3 of screenings for each million gallons of influent received.

A *bar screen* traps debris as wastewater influent passes through. Typically, a bar screen consists of a series of parallel, evenly spaced bars or a perforated screen placed in a channel. The wastestream passes through the screen and the large solids (*screenings*) are trapped on the bars for removal.

✓ The screenings must be removed frequently enough to prevent accumulation, which will block the screen and cause the water level in front of the screen to build up.

The bar screen may be coarse (2- to 4-inch openings) or fine (0.75- to 2.0-inch openings).

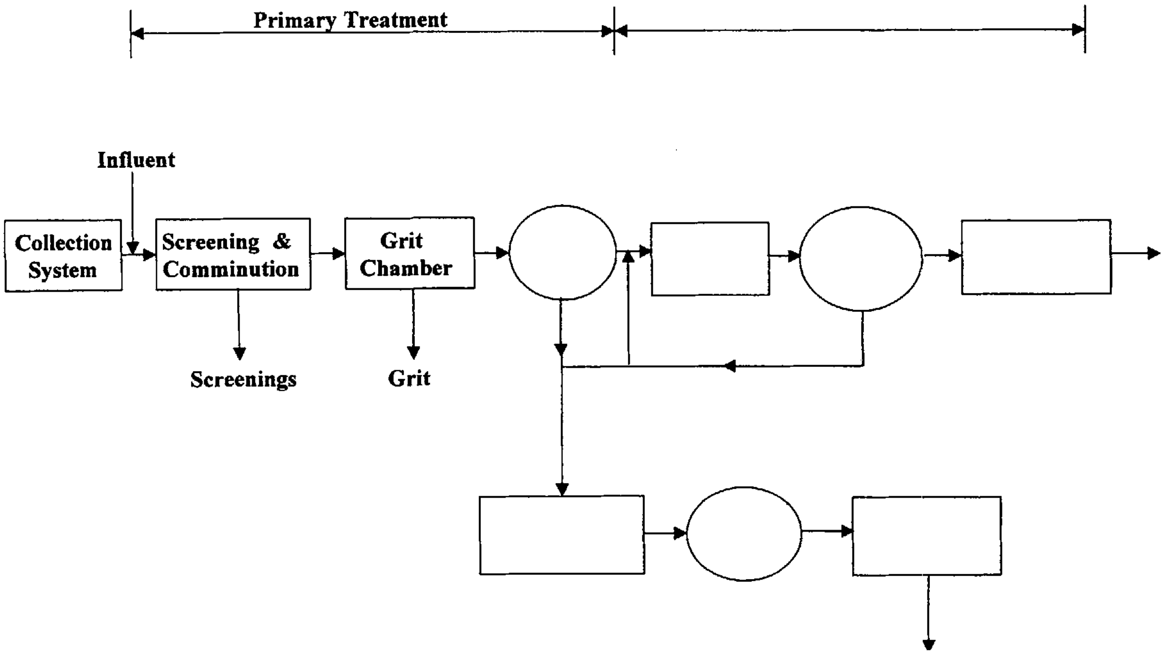


Figure 6.1 Preliminary treatment.

One of the new developments in screening employs the use of a traveling screen. The traveling screen consists of a series of interlocked sections that are combined to form a continuous belt. This belt is suspended in the channel and is mechanically driven. Wastewater flows through the openings, and the solids are trapped on the surface. As the belt rotates out of the water, the solids collected on the surface are mechanically removed. Because the screen is continuously cleaned, it is designed with smaller openings and removes finer solids. This results in significantly larger volumes of solids for disposal.

✓ Keep in mind that the screening method employed depends on the design of the plant, the amount of solids expected, and whether the screen is for constant or emergency use only.

6.2.1 MANUALLY CLEANED SCREENS

Manually cleaned screens are cleaned at least once per shift (or often enough to prevent buildup, which may cause reduced flow into the plant) using a long tooth rake. Solids are manually pulled to the drain platform and allowed to drain before storage in a covered container.

✓ A manually cleaned bar screen should be cleaned at least once per day.

The area around the screen should be cleaned frequently to prevent a buildup of grease, or other materials, which can cause odors, slippery conditions, and insect and rodent problems.

Because screenings may contain organic matter as well as large amounts of grease they should be stored in a covered container. Screenings can be disposed of by burial in approved landfills or by incineration. Some treatment facilities grind the screenings into small particles that are then returned to the wastewater flow for further processing and removal later in the process.

6.2.1.1 Operational Problems

Manually cleaned screens require a certain amount of operator attention to maintain optimum operation. Failure to clean the screen frequently can lead to septic wastes entering the primary, surge flows after cleaning, and/or low flows before cleaning. On occasion, when such operational problems occur, it becomes necessary to increase the frequency of the cleaning cycle. Another operational problem is excessive grit in the bar screen channel. This problem may be caused by improper design or construction or insufficient cleaning. The corrective action required is either to correct the design problem or increase cleaning frequency and flush the channel regularly. Another common problem with manually cleaned bar screens is their tendency to clog frequently. This may be caused by excessive debris in the wastewater or the screen is too fine for its current application. The operator should locate the source of the excessive debris and eliminate it. If the screen is the problem, a coarser screen may need to be installed. If the bar screen area is filled with obnoxious odors and flies and other insects, it may be necessary to dispose of screening more frequently.

6.2.2 MECHANICALLY CLEANED/TRAVELING SCREENS

Mechanically cleaned screens use a mechanized rake assembly to collect the solids and move them (carry them) out of the wastewater flow for discharge to a storage hopper. The screen may be continuously cleaned or cleaned on a time- or flow-controlled cycle. As with the manually cleaned screen, the area surrounding the mechanically operated screen must be cleaned frequently to prevent buildup of materials, which can cause unsafe conditions.

As with all mechanical equipment, operator vigilance is required to ensure proper operation and that proper maintenance is performed. Maintenance includes lubricating equipment and maintaining it in accordance with manufacturer's recommendations or the plant's Operations and Maintenance Manual.

Screenings from mechanically operated bar screens are disposed of in the same manner as screenings from manually operated screens: landfill disposal, incineration, or ground for return to the wastewater flow.

6.2.2.1 Operational Problems

✓ Typically, mechanically operated screens have operational problems that fall into four categories:

- Unusual operational conditions (sudden loads of debris that clog or jam the screening equipment).
- Equipment breakdown (component failure).
- Control failure.
- Screens without level sensing systems receiving sudden large loads of debris that jam their raking mechanisms.

Along with those problems listed above, mechanically operated bar screens have the same types of problems as manual screens: septic wastes entering the primary, surge flows after cleaning, excessive grit in the bar screen channel, and/or the screen clogs frequently. Basically, the same corrective actions employed for manually operated screens would be applied for these problems in mechanically operated screens. In addition to these problems, however, mechanically operated screens also have other problems, including the cleaner not operating at all and the rake not operating but the motor operates. Obviously, these are mechanical problems that could be caused by a jammed cleaning mechanism, broken chain, broken cable, or broken shear pin. Authorized and fully trained maintenance operators should be called in to handle these problems.

6.2.3 SCREENING: OPERATING GUIDELINES

Screening equipment must be checked several times during a shift to ensure that it functions as designed. While in operation, the operator should check for unusual noises, scraping of the screen, jerking of the drive mechanisms, the need to properly dispose of screenings, and lubricating the drive mechanism.

Screenings are a major source of odors. Thus, the operator should avoid any overflows in the screening storage areas to prevent possible decay of organic matter and the production of odors. Screenings must be disposed of frequently.

Debris collected on either manually or mechanically cleaned bar screens should be removed at least daily, depending on weather conditions. The standard rule of thumb on bar screen cleaning: Screenings are to be removed as often as necessary to ensure free flow of wastewater.

✓ During rainy conditions, a greater number of objects may be washed into the plant from combined sewers, requiring more frequent removal from the screens.

✓ Proper disposal of screenings and grit requires burial in an approved landfill.

6.2.4 SAFETY CONSIDERATIONS

The screening area is the first location where the operator is exposed to wastewater flow. Any toxic, flammable, or explosive gases present in the wastewater can be released at this point. Operators who frequent enclosed bar screen areas should be equipped with personal air monitors. Good safety practice demands continuous monitoring of hydrogen sulfide (rotten egg odor) and methane levels in these areas, and smoking must be strictly prohibited. Adequate ventilation must be provided.

✓ Note that whenever working on any piece of mechanized or electrical equipment (before beginning the work), power must be shut off to the equipment, and the system must be completely locked out/tagged out to prevent injury to workers.

Operators must follow good housekeeping procedures in the preliminary treatment area. Because of grease attached to the screenings, this area of the plant can be extremely slippery. Thus, routine cleaning is required to minimize this problem.

Another safety concern related to screenings (and to grit) is the presence of pathogenic organisms. There is nothing unusual about pathogenic microorganisms in wastewater, but the problem with handling screenings (and grit) is that they contain sharp objects that can result in injuries. Thus, it is important that all protective guards be left in place, where they belong. Moreover, all associated safety devices must be in good operating order. Plant operators must use the appropriate personal protective equipment (PPE) when working near screenings (and grit) and must wash their hands with an antibacterial soap before eating, drinking, or smoking.

✓ Never override safety devices on mechanical equipment. Overrides can result in dangerous conditions, injuries, and major mechanical failure.

6.3 SHREDDING/GRINDING

Shredding or grinding can be used to reduce solids to a size that can enter the plant without causing mechanical problems or clogging. Shredding/grinding processes include comminution (comminute means "cut up") and barminution devices. These devices, normally preceded by a bar screen, do not remove the chopped, cut up, shredded, or ground solids from the wastewater flow and rely on their removal by subsequent treatment unit processes. However, at some small plants, shredding/grinding devices are used in place of bar screens.

✓ *Note:* Because shredded rags can adversely affect the operation and maintenance of primary clarifiers, thickening units, and dewatering units, they are being replaced at many plants.

6.3.1 COMMINUTION

The comminutor is the most common shredding device used in wastewater treatment. In this device, all the wastewater flow passes through the grinder assembly. The grinder consists of a screen or slotted basket, a rotating or oscillating cutter, and a stationary cutter. Solids pass through the screen and are chopped or shredded between the two cutters. The comminutor will not remove solids that are too large to fit through the slots, and it will not remove floating objects. These materials must be removed manually.

Maintenance requirements for comminutors include aligning, sharpening, and replacing cutters and routine corrective and preventive maintenance performed in accordance with plant Operations and Maintenance Manual.

✓ Cutter bar adjustment is critical to proper operation of the comminutor.

6.3.1.1 Operational Problems

A common operational problem associated with comminutors is the output containing coarse solids. When this occurs, it is usually a sign that the cutters are dull or misaligned. If the system does not operate at all, the unit is either clogged or jammed, a shear pin or coupling is broken, or electrical power is shut off. If the unit stalls or jams frequently, this usually indicates cutter misalignment, excessive debris in influent, or dull cutters.

✓ Only qualified maintenance operators should perform maintenance on shredding equipment.

6.3.2 BARMINUTION

In barminution, the barminutor uses a bar screen to collect solids that are then shredded and passed through the bar screen for removal at a later process. In operation, cutter alignment and sharpness are critical factors in effective operation. Cutters must be sharpened or replaced, and alignment must be checked in accordance with manufacturer's recommendations. Solids that are not shredded must be removed daily, stored in closed containers, and disposed of by burial or incineration.

Barminutor operational problems are similar to those listed in Section 6.3.1.1. Preventive and corrective maintenance as well as lubrication must be performed by qualified personnel and in accordance with the plant's Operations and Maintenance Manual. Because of higher maintenance requirements, barminutors are not widely used.

6.4 GRIT REMOVAL

According to Peavy et al. (1985), wastewater grit materials consist of discrete particles, are generally nonputrescible, and have a settling velocity greater than that of organic putrescible solids. Such materials include sand, cinders, rocks, coffee grounds, cigarette filter tips, and other large, relatively nonputrescible organic and inorganic substances.

The purpose of grit removal is to remove the heavy inorganic solids that could cause clogging in pipes, excessive mechanical wear to mechanical equipment and pumps, and accumulations of materials in aeration tanks and digesters or other solids-handling processes that result in loss of usable volume and could reduce accumulations at the base of screens. Grit is heavier than inorganic solids.

Several processes or devices are used for grit removal. All of the processes are based on the fact that grit is heavier than the organic solids that should be kept in suspension for treatment in following processes. Grit removal may be accomplished in grit chambers or by the centrifugal separation of sludge. Processes use gravity/velocity, aeration, or centrifugal force to separate the solids from the wastewater.

6.4.1 GRAVITY/VELOCITY CONTROLLED GRIT REMOVAL

Gravity/velocity controlled grit removal is normally accomplished in a channel or tank where the speed or the velocity of the wastewater is controlled to about 0.3 m/s or one foot per second (ideal), so that grit will settle while organic matter remains suspended. As long as the velocity is controlled in the range of 0.7 to 1.4 feet per second (fps), the grit removal will remain effective. Velocity is controlled by the amount of water flowing through the channel, the depth of the water in the channel, the width of the channel, or the cumulative width of channels in service.

6.4.1.1 Process Control Calculations

Because velocity is a controlling factor, calculations focus on velocity to determine the operational status of the process. Velocity of the flow in a channel can be calculated either by the float and stopwatch method or by channel dimensions.

6.4.1.1.1 Velocity by Float and Stopwatch

$$\text{velocity, fps} = \frac{\text{distance traveled, ft}}{\text{time required, seconds}} \tag{6.1}$$

Example 6.1

Problem:

A float takes 28 seconds to travel 32 feet in a grit channel. What is the velocity of the flow in the channel?

Solution:

$$\text{velocity, fps} = \frac{32\ \text{feet}}{28\ \text{seconds}} = 1.1\ \text{fps}$$

6.4.1.1.2 Velocity by Flow and Channel Dimensions

This calculation can be used for a single channel or tank or multiple channels or tanks with the same dimensions and equal flow. If the flow through each unit of the unit dimensions is unequal, the velocity for each channel or tank must be computed individually.

Example 6.2

Problem:

The plant is currently using two grit channels. Each channel is 2 feet wide and has a water depth of 1.4 feet. What is the velocity when the influent flow rate is 4.0 MGD?

Solution:

$$\text{velocity, fps} = \frac{4.0\ \text{MGD} \times 1.55\ \text{cfs/MGD}}{2\ \text{channels} \times 2\ \text{ft} \times 1.4\ \text{ft}}$$

$$\text{velocity, fps} = \frac{6.2\ \text{cfs}}{5.6\ \text{ft}^2} = 1.1\ \text{fps}$$

✓ Channel dimensions must always be in feet. Convert inches to feet by dividing by 12 inches per foot.

6.4.1.1.3 Required Settling Time

✓ This calculation can be used to determine the time required for a particle to travel from the surface of the liquid to the bottom at a given settling velocity. In order to compute the settling time, the settling velocity in fps must be provided or determined experimentally in a laboratory.

$$\text{settling time, seconds} = \frac{\text{liquid depth in feet}}{\text{settling, vel., fps}} \tag{6.3}$$

Example 6.3

Problem:

The plant's grit channel is designed to remove sand, which has a settling velocity of 0.075 fps. The channel is currently operating at a depth of 2.1 feet. How many seconds will it take for a sand particle to reach the channel bottom?

Solution:

$$\text{settling time, seconds} = \frac{2.1\ \text{feet}}{0.075,\ \text{fps}} = 28\ \text{seconds}$$

6.4.1.1.4 Required Channel Length

This calculation can be used to determine the length of channel required to remove an object with a specified settling velocity.

$$\text{required channel length} = \frac{\text{channel depth, ft} \times \text{flow vel., fps}}{\text{settling, vel., fps}} \tag{6.4}$$

Example 6.4

Problem:

The plant's grit channel is designed to remove sand, which has a settling velocity of 0.072 fps. The channel is currently operating at a depth of 3 ft. The calculated velocity of flow through the channel is 0.90 fps. The channel is 32 feet long. Is the channel long enough to remove the desired sand particle size?

Solution:

$$\text{required channel length, ft} = \frac{3\text{ ft} \times 0.90\text{ fps}}{0.072\text{ fps}} = 37.5\text{ feet}$$

No, the channel is not long enough to ensure all of the sand will be removed.

6.4.1.2 Cleaning

Gravity-type systems are rectangular, circular, or square tanks that may be manually or mechanically cleaned. Most of the rectangular grit tanks have velocity-control devices and a chain-and-flight mechanism or air lift pump to move the grit to a sump. Square or circular tanks contain deflector baffles at the inlets to equally distribute the flow and a weir at the effluent end. These units include a circular collector mechanism that scrapes the grit to a central collection hopper where it is removed by a grit bucket arrangement or screw conveyor system. Manual cleaning normally requires the channel be taken out of service, drained, and manually cleaned. Mechanical cleaning systems are operated continuously or on a time cycle. Removal should be frequent enough to prevent grit carry-over into the rest of the plant.

✓ Before and during cleaning activities, always ventilate the area thoroughly.

6.4.2 AERATED SYSTEMS

Aerated grit removal systems use aeration to keep the lighter organic solids in suspension while allowing the heavier grit particles to settle out. Aerated grit removal may be manually or mechanically cleaned; however, the majority of the systems are mechanically cleaned.

In normal operation, the aeration rate is adjusted to produce the desired separation, which requires observation of mixing and aeration and sampling of fixed suspended solids. Actual grit removal is controlled by the rate of aeration. If the rate is too high, all of the solids remain in suspension. If the rate is too low, both the grit and the organics will settle out.

6.4.3 CYCLONE DEGRITTER

The cyclone degritter uses a rapid spinning motion (centrifugal force) in a cone-shaped unit to separate the heavy inorganic solids or grit from the light organic solids. This unit process is normally used on primary sludge rather than the entire wastewater flow. The critical control factor for the process is the inlet pressure. If the pressure exceeds the recommendations of the manufacturer, the unit will flood, and grit will carry through with the flow. Grit is separated from the flow and discharged directly to a storage container. Grit removal performance is determined by calculating the percent removal for inorganic (fixed) suspended solids. *Note:* As much water as possible should be removed after cyclone degritting.

6.4.4 GRIT WASHING

Grit washers are used to remove organics from grit. To produce a product low in organics, screw and rake-type grit washers are typically used. During operation, it is important to ensure a low volatile content by using ample dilution water.

6.4.5 GRIT REMOVAL OPERATION

A high level of grit removal from the wastestream early in the treatment process is the primary objective of grit removal. However, removal of grit from the system depends on a number of factors. For example, if too much grit is removed, then excessive organic material will be removed with the grit. (*Note:* The more organic material contained in the grit, the more likely the grit will produce an increase in undesirable odors.) In addition, operating the grit removal equipment excessively will increase maintenance costs. Thus, the exact frequency and exact amount of grit removed from a particular facility is site specific and can only be determined by the facility.

6.4.6 TROUBLESHOOTING GRIT SYSTEMS

The more moving parts a particular installed grit removal system has, the more likely it is to malfunction and break down. This is what you are trying to prevent, of course. Malfunctions and breakdowns can adversely affect the operation and efficiency of the system. As with all other wastewater equipment, the operator must know the equipment and how to assess problems that occur. The most commonly encountered problems with grit systems are listed below. In troubleshooting these problems, the operator should always follow the guidelines provided in the manufacturer's Operations and Maintenance Manual.

Common indicators of problems in grit systems include the following:

- grit packed on collectors
- too much vibration of cyclone degritter
- rotten-egg odor in grit chamber
- corrosion of metal and concrete
- low recovery rate of grit
- surface turbulence in aerated grit chamber is reduced
- overflowing grit chamber
- removed grit is gray in color, smells, and feels greasy
- accumulated grit in the chamber

6.5 FLOW MEASUREMENT

Flow measurement is used throughout the treatment process to ensure the efficient operation of treatment processes and to provide information (hydraulic and organic loading) needed to prepare required compliance reports for regulatory agencies. In addition, flow measurement records are invaluable for future reference, particularly when plant expansion is needed. Flow measurement records may also indicate population growth, infiltration, or industrial waste discharge into the sewers, and an increase in flow during wet weather is a measure of infiltration/inflow

Many different methods are available for measuring flows. The methodology used is generally based upon making a physical measurement that can then be related to the quantity of liquid moving past a given point in a specified length of time.

✓ The best type of combination wastewater flow and sludge flow measuring device is the magnetic flow meter.

6.5.1 FILL AND DRAW

In the fill and draw method of flow measurement, liquid flows into a container of known volume. The time required is measured. Dividing the liquid volume by time results in a flow rate.

The actual methodology used is explained as follows:

(1) Measure the dimensions of the container.
(2) Calculate the volume of the container.
(3) Determine the time required to collect the desired volume.
(4) Calculate the flow.

Let's take a look at exactly how the fill and draw method is used in practice.

Example 6.5

Problem:

The aerobic digester is 60 ft long and 26 ft wide. The waste sludge pump operates for 45 minutes, and the level of the liquid in the digester increases 2.7 ft. What is the flow rate in gallons per minute?

Solution:

$$\text{volume pumped, ft}^3 = 60\text{ ft} \times 26\text{ ft} \times 2.7\text{ ft}$$

$$= 4{,}212\text{ ft}^3$$

$$\text{volume pumped, gal} = 4{,}212\text{ ft}^3 \times 7.48\text{ gal/ft}^3$$

$$= 31{,}506\text{ gal}$$

$$\text{flow rate, gpm} = \frac{31{,}506\text{ gal}}{45\text{ min}}$$

$$= 700\text{ gpm}$$

6.5.2 WEIRS

Weirs are used to measure the flow in open channels. They are easy to install in partially filled pipes, channels, or streams, and they act as a dam or obstruction. They are accurate and relatively inexpensive. Their main disadvantages include large amounts of head loss and settling of solids upstream of the weir (Qasim, p. 227, 1994).

The principle involved with the operation of a weir used for measurement is quite simple: When a constriction or barrier is placed in an open channel, the amount of water that passes over or through the constriction is directly proportional to the head (height) of the water behind the constriction and the area of the opening in the constriction. Because the area of the opening in the constriction remains constant, the only required measurement is the head behind the constriction. With this information, the flow rate can be calculated.

Configured in many different forms, the basic design of the weir, in all cases, is a constriction or a dam placed across a channel. The most common type of weir used in wastewater treatment is the V-notch weir. This weir consists of a solid vertical plate with a sharp crest and a V-notch (or triangular) cut in the top edge. The V-notch may have a 22.5°, 30°, 45°, 60°, or 90° angle.

Normal operation of the V-notch weir requires measurement of the head (distance from the surface of the water to the bottom of the V-notch at a point that is at least four times the maximum head of the weir behind the weir). The head over the weir must be measured accurately by a float, hook gauge, or level sensor. The head measurement is then converted to flow rate by reading a chart or calculation. Due to the complexity of the calculation, the use of a chart or instrumentation that automatically converts the head reading is recommended.

$$\text{Flow } (Q), \text{CFS} = K \times H^{2.5} \tag{6.5}$$

where

H = head in feet

K = constant related to weir angle

45° = 1.035

90° = 2.500

Weirs require periodic cleaning to ensure that the head area relationship is not changed by growth or buildup of debris in the notch. Weirs that use devices to sense, display, and record flow rates must be checked periodically (annually) by a qualified technician.

✓ Weir loading rate is determined by dividing flow (Q) by weir length.

6.5.3 FLUMES

Flumes use the same basic hydraulic principle as the weir. The major difference is in the construction of the unit. The flume design includes a very narrow section known as the throat of the flume and a section that gradually changes from the width of the channel to the width of the throat. This section is known as the converging section. The throat of the flume produces a head in the converging section that can be measured and converted to flow rate. Critical depth is measured at the flume.

There are several types of flumes. Probably the most common flume in wastewater treatment is the *Parshall Flume*. Normal operation of the Parshall Flume is the measurement of the head upstream of the throat at a point that is approximately two-thirds the length of the converging section. Head can be measured manually or by mechanical means (floats, sonic units, etc.). Flow rates can then be determined from a chart, by calculation, or automatically using mechanical or electronic methods. Due to the complexity of the calculation, flows are normally determined using a chart provided with the flume or by plant instrumentation.

✓ All plant instrumentation, including flow measurement devices, must be serviced periodically by

6.6 PREAERATION

In the preaeration process, wastewater is aerated to achieve and maintain an aerobic state (to freshen septic wastes), strip off hydrogen sulfide (to reduce odors and corrosion), and agitate solids to release trapped gases (improve solids separation and settling). All of this can be accomplished by aerating the wastewater for 10 to 30 minutes. To reduce BOD_5, preaeration must be conducted for 45 to 60 minutes.

6.7 CHEMICAL ADDITION

Chemical addition is made to the wastestream in order to reduce odors, neutralize acids or bases, reduce corrosion, reduce BOD_5, improve solids and grease removal, reduce loading on the plant, and aid subsequent processes. Actual chemical use depends on the desired result. Chemicals must be added at a point where sufficient mixing will occur to obtain maximum benefit. Chemicals typically used in wastewater treatment include chlorine, peroxide, acids and bases, mineral salts (ferric chloride, alum, etc.), and bioadditives and enzymes.

✓ When primary sedimentation basins are being operated at flows greater than their design flow, flow equalization basins should be installed ahead of the primary tanks.

6.8 FLOW EQUALIZATION

The purpose of flow equalization is to reduce or remove the wide swings in flow rates (diurnal and storm) normally associated with wastewater treatment plant loadings. Plant flows through parallel units, such as screens and grit chambers, need balancing to aid optimum performance of each unit.

The flow equalization process can be designed to prevent flows above maximum plant design hydraulic capacity, to reduce the magnitude of diurnal flow variations, and to eliminate flow variations. Flow equalization is accomplished using mixing or aeration equipment, pumps, and flow measurement. Normal operation depends on the purpose of the flow equalization system. Equalized flows allow the plant to perform at optimum levels by providing a stable hydraulic and organic loading. The downside to flow equalization is in the additional costs associated with construction and operation of the flow equalization facilities.

6.9 REFERENCES

Peavy, H. S., Rowe, D. R. and Tchobanoglous, G., *Environmental Engineering.* New York: McGraw-Hill, p. 221, 1985.

Qasim, S. R., *Wastewater Treatment Plants: Planning, Design, and Operation.* Lancaster, PA: Technomic Publishing Co. Inc., 1994.

6.10 CHAPTER REVIEW QUESTIONS

6-1 While making rounds of the bar screens, you detect the smell of rotten eggs. What does this indicate?

6-2 What is the purpose of preliminary treatment?

6-3 What is the purpose of the bar screen?

6-4 What two methods are available for cleaning a bar screen?

6-5 Name two ways to dispose of screenings.

6-6 What is a Parshall Flume used for?

6-7 What must be done to the cutters in a comminutor to ensure proper operation?

6-8 What controls the velocity in a gravity-type grit channel?

6-9 The plant has three channels in service. Each channel is 3 feet wide and has a water depth of 2.5 feet. What is the velocity in the channel when the flow rate is 9.0 MGD?

6-10 A section of sprocket chain is broken on the mechanically cleaned screen. To ensure your safety while replacing the chain, you should first secure all energy sources to the machine. What should you do next?

6-11 List three reasons why you might wish to include preaeration in the preliminary treatment portion of your plant.

6-12 Name two reasons why we would want to remove grit.

6-13 How slow should the flow of wastewater be in order to settle the grit?

6-14 Below what velocity will grit settle in the screening channel?

6-15 An empty screenings hopper 4 ft by 6 ft is filled to an even depth of 24 in over the course of 64 hr. If the average plant flow rate was 4.0 MGD during this period, how many cubic feet of screenings were removed per million gallons of wastewater received?

6-16 The decomposition process that results in the production of methane gas is known as ______________ decomposition.

6-17 A V-notch weir is normally used to measure ______________.

6-18 If untreated organic wastes are discharged to a stream, the dissolved oxygen level of the stream will ______________.

6-19 The main purpose of the grit chamber is to ______________.

6-20 The main purpose of primary treatment is to ______________.

6-21 List four applications for chemical addition as a preliminary treatment process.

6-22 Calculate the weir loading for a sedimentation tank that has an outlet weir 500 ft long and a flow of 4.5 MGD. Your answer should be in gpd/ft.

CHAPTER 7

Sedimentation

7.1 INTRODUCTION

THE purpose of sedimentation (or clarification) is to remove settleable organic and flotable solids. In primary treatment, normally, each primary clarification unit can be expected to remove 90 to 95% settleable solids, 40 to 60% total suspended solids, and 25 to 35% BOD_5.

✓ *Note:* Performance expectations for settling devices used in other areas of plant operation are normally expressed as overall unit performance rather than settling unit performance.

✓ *Note:* There are many different terms used to describe the sedimentation process. The terms *clarification, settling, sedimentation,* and *thickening* can be used.

Sedimentation may be used throughout the plant to remove settleable and flotable solids. It is used in primary treatment, secondary treatment, and advanced wastewater treatment processes. In primary treatment, settleable and floatable solids are removed using septic tanks, two-story tanks (Imhoff tanks), or plain settling tanks. In secondary treatment, sedimentation occurs in plain settling tanks and is used to remove solids produced by the biological processes used for secondary treatment.

✓ *Note:* When sludge depth in a secondary sedimentation tank is too high, sludge may become septic.

In advanced (tertiary) treatment, sedimentation occurs in plain settling tanks used to remove solids produced by biological or chemical processes.

In this chapter, we discuss primary treatment or primary clarification and also include a discussion on the operation of secondary clarifiers.

Primary sedimentation or treatment using large basins in primary settling is achieved under relatively quiescent conditions (see Figure 7.1). Within these basins, the primary settled solids are collected by mechanical scrapers into a hopper, from which they are pumped to a sludge-processing area. Oil, grease, and other floating materials (scum) are skimmed from the surface. The effluent is discharged over weirs into a collection trough.

✓ *Note:* The primary or secondary sedimentation basis drains must be higher than the receiving sump to allow for gravity flow out of the basin.

✓ In the daily operation of the primary sedimentation or settling process, the operator normally collects influent and effluent settleable solids samples, removes scum and sludge, and monitors the operation of mechanical equipment.

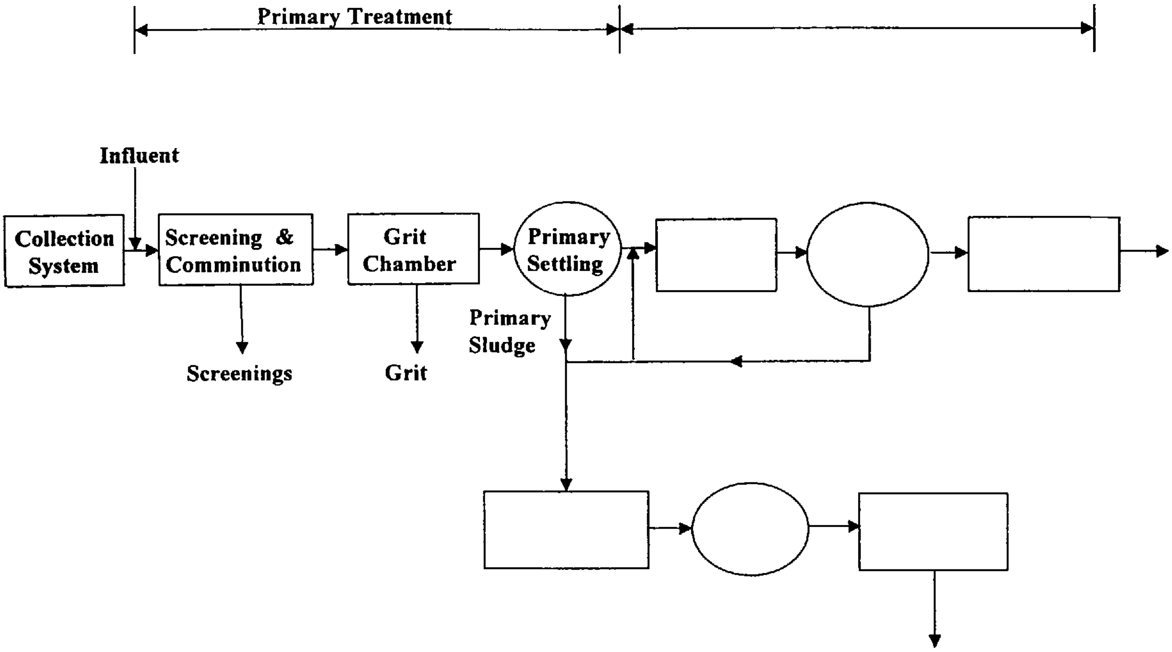


Figure 7.1 Sedimentation.

7.2 PRIMARY SEDIMENTATION: PROCESS DESCRIPTION

In primary sedimentation, wastewater enters a settling tank or basin. Velocity is reduced to approximately one foot per minute.

✓ Notice that the velocity is based on minutes instead of seconds as was the case in the grit channels. A grit channel velocity of 1 ft/s would be 60 ft/min.

Solids that are heavier than water settle to the bottom while solids that are lighter than water float to the top. Settled solids are removed as sludge, and floating solids are removed as scum. Wastewater leaves the sedimentation tank over an effluent weir and on to the next step in treatment. The efficiency of the process is controlled by detention time, temperature, tank design, and condition of the equipment.

✓ A device called a "collector" is sometimes installed on the surface of circular primary settling tanks to remove floatable solids.

7.2.1 EQUIPMENT: PLAIN SETTLING TANKS (CLARIFIERS)

The plain settling tank or clarifier optimizes the settling process. The tanks can be rectangular, square, or circular. Rectangular tanks normally have the flow entering on one end and leaving at the opposite end. Circular units may have the flow entering at the center (center feed) and leaving along the outer edge or entering along the outer edge (peripheral feed) and leaving near the center.

Sludge is removed from the tank for processing in other downstream treatment units. Flow enters the tank, is slowed and distributed evenly across the width and depth of the unit, passes through the to three hours (two hour average) and two to four hours (three hour average) for secondary settling tanks.

Sludge removal is accomplished frequently on either a continuous or intermittent basis. Continuous removal requires additional sludge treatment processes to remove the excess water resulting from removal of sludge that contains less than 2 to 3% solids. Intermittent sludge removal requires the sludge be pumped from the tank on a schedule frequent enough to prevent large clumps of solids from rising to the surface but infrequent enough to obtain 4 to 8% solids in the sludge withdrawn.

✓ To determine when enough sludge has been withdrawn from the primary clarifier is to note the consistency of the sludge by sampling from the pump discharge line.

Scum must be removed from the surface of the settling tank frequently. This is normally a mechanical process but may require manual start-up. The system should be operated frequently enough to prevent excessive buildup and scum carryover but not so frequent as to cause hydraulic overloading of the scum removal system.

Settling tanks require housekeeping and maintenance. Baffles (prevent flotable solids, scum, from leaving the tank), scum troughs, scum collectors, effluent troughs, and effluent weirs require frequent cleaning to prevent heavy biological growths and solids accumulations. Mechanical equipment must be lubricated and maintained as specified by manufacturer's recommendations or in accordance with procedures listed in the plant Operations and Maintenance Manual.

Process control sampling and testing is used to evaluate the performance of the settling process. Settleable solids, dissolved oxygen, pH, temperature, total suspended solids and BOD_5, as well as sludge solids and volatile matter testing are routinely accomplished.

7.2.2 PROCESS CONTROL CALCULATIONS

As with many other wastewater treatment plant unit processes, process control calculations aid in determining the performance of the sedimentation process. Process control calculations are used in the sedimentation process to determine

- percent removal
- hydraulic detention time
- surface loading rate (surface settling rate)
- weir overflow rate (weir loading rate)
- sludge pumping
- percent total solids (% TS)

In the following sections, we look at a few of the process control calculations used in primary sedimentation processes.

7.2.2.1 Surface Loading Rate (Surface Settling Rate)

Surface loading rate is the number of gallons of wastewater passing over one square foot of tank per day. This can be used to compare actual conditions with design. Normal range is 300 to 1,200 gallons/day/ft^2.

flow, gal / day

Example 7.1

Problem:

The settling tank is 110 feet in diameter, and the flow to the unit is 4.0 MGD. What is the surface loading rate in gallons/day/ft^2?

Solution:

$$\text{surface loading rate} = \frac{4.0\,\text{MGD} \times 1{,}000{,}000\,\text{gal/MGD}}{0.785 \times 110\,\text{ft} \times 110\,\text{ft}} = 421\,\text{gpd/ft}^2$$

7.2.2.2 Weir Overflow Rate (Weir Loading Rate)

Weir overflow rate (weir loading rate) is the amount of water leaving the settling tank per linear foot of weir. The result of this calculation can be compared with design. Normally, weir overflow rates of 10,000 to 20,000 gallon/day/foot are used in the design of a settling tank.

$$\text{weir overflow rate, gpd/ft} = \frac{\text{flow, gal/day}}{\text{weir length, ft}} \tag{7.2}$$

Example 7.2

Problem:

The circular settling tank is 80 feet in diameter and has a weir along its circumference. The effluent flow rate is 2.65 MGD. What is the weir overflow rate in gallons per day per foot?

Solution:

$$\text{weir overflow, gpd/ft} = \frac{2.65\,\text{MGD} \times 1{,}000{,}000\,\text{gal/MGD}}{3.14 \times 80\,\text{feet}}$$

$$= 10{,}549\,\text{gallons/day/foot}$$

7.2.2.3 Sludge Pumping

Determination of underflow sludge pumping (the quantity of solids and volatile solids removed from the sedimentation tank) provides accurate information needed to evaluate the performance of the operation and to control process residual treatment units.

$$\text{Solids pumped, lb/day} = \text{pump rate, gpm} \times \text{pump time, min/day} \times 8.34\,\text{lbs/gal} \times \%\,\text{solids} \tag{7.3}$$

$$\text{Volatile solids, lb/day} = \text{pump rate} \times \text{pump time} \times 8.34 \times \%\,\text{solids} \times \%\,\text{volatile matter} \tag{7.4}$$

Example 7.3

Problem:

The sludge pump operates 20 minutes per hour. The pump delivers 25 gallons/minute of sludge. Laboratory tests indicate that the sludge is 5.0% solids and 64% volatile matter. How many pounds of volatile matter are transferred from the settling tank to the digester each day?

Solution:

pump time = 20 minutes/hour
pump rate = 25 gpm
% solids = 5.0%
% VM = 64%

$$\begin{aligned}\text{volatile solids, lb/day} &= 25\text{ gpm} \times (20\text{ min/hr} \times 24\text{ hr/day}) \times 8.34\text{ lb/gal} \times 0.050 \times 0.64\\ &= 3{,}202.6\text{ lb/day}\end{aligned}$$

7.2.2.4 Percent Total Solids (% TS)

Example 7.4

Problem:

A settling tank sludge sample is tested for solids. The sample and dish weigh 72.69 g. The dish alone weighs 20.20 g. After drying, the dish with dry solids weighs 22.50 g.

What is the percent total solids (% TS) of the sample?

Solution:

sample + dish	72.69 g	dish + dry solids	22.5 g
dish alone	−20.2 g	dish alone	−20.2 g
sample weight	52.49 g	dry solids weight	2.3 g

$$\frac{2.3\text{ g}}{52.49\text{ g}} \times 100\% = 4.4\%$$

7.2.2.5 Solids Mass Balance

The quantity of solids entering any settling tank must equal the quantity of solids removed from the unit (either as underflow solids or effluent solids). If there is a significant difference between these two numbers (>10–15%) it usually indicates a process control problem or a sampling and testing problem.

7.2.2.5.1 Solids In

$$\text{solids}_{\text{in}}\text{, lb/day} = \text{TSS}_{\text{in}}\text{, mg/L} \times \text{flow}_{\text{in}}\text{, MGD} \times 8.34\text{ lb/mg/L/MG} \tag{7.5}$$

Example 7.5

Problem:

Using the following data, how many pounds of solids enter the settling tank each day?

Solution:

$$\text{solids}_{\text{in}} = 268\ \text{mg/L} \times 2.57\ \text{MGD} \times 8.34\ \text{lb/mg/L/MG}$$

$$= 5{,}744\ \text{lb/day}$$

7.2.2.5.2 Solids Out

$$\text{solids}_{\text{out}}, \text{lb/day} = \text{TSS}_{\text{out}}, \text{mg/L} \times \text{flow}_{\text{out}}, \text{MGD} \times 8.34\ \text{lb/mg/L/MG} \tag{7.6}$$

Example 7.6

Problem:

Using the following data, how many pounds of solids leave with the settling tank effluent each day?

flow = 2.57 MGD
TSS = 175 mg/L

Solution:

$$\text{solids}_{\text{in}} = 175\ \text{mg/L} \times 2.57\ \text{MGD} \times 8.34\ \text{lb/mg/L/MG} = 3{,}751\ \text{lb/day}$$

7.2.2.5.3 Underflow Solids

$$\text{solids, lb} = \text{gpm} \times \text{minutes} \times \text{cycles/day} \times 8.34\ \text{lb/gal} \times 0.045 \tag{7.7}$$

Example 7.7

Problem:

Using the data provided, how many pounds of underflow solids are removed each day?

Pump rate	85 gpm
Pump cycle time	20 minutes/cycle
Frequency	3 cycles/day
% Solids	4.0%

Solution:

$$\text{solids, lbs} = 85\ \text{gpm} \times 20\ \text{min} \times 3\ \text{cycles/day} \times 8.34\ \text{lb/gal} \times 0.04 = 1{,}701\ \text{lb/day}$$

7.2.2.5.4 Solids Balance

$$\text{solids, lb} = \frac{[\text{solids}_{\text{in}}, \text{lb/day} - (\text{solids}_{\text{out}}, \text{lb/day} + \text{underflow solids})] \times 100}{\text{solids}_{\text{in}}, \text{lb/day}} \tag{7.8}$$

Example 7.8

Problem:

Using the following data, determine the solids balance for the primary settling tank.

$\text{Solids}_{\text{in}}$	6,290 lb/day

$\text{Solids}_{\text{out}}$	3,785 lb/day
Underflow solids	1,811 lb/day

Solution:

$$\text{solids balance} = \frac{[6{,}290\ \text{lb/day} - (3{,}785\ \text{lb/day} + 1{,}811\ \text{lb/day})] \times 100}{6{,}290\ \text{lb/day}} = 11\%$$

7.2.2.6 Expected Performance

Primary settling will normally remove:

Settleable solids	90–95%
Total suspended solids	40–60%
BOD_5	25–35%

7.3 SECONDARY SEDIMENTATION

As stated earlier, sedimentation occurs in both primary and secondary clarifiers. The sedimentation process that occurs in the secondary clarifier is somewhat similar to what occurs in the primary. In this section, we discuss the factors that affect secondary clarifier performance.

✓ The main difference between the operation of a primary and secondary clarifier is the density of the sludge removed from each clarifier.

7.3.1 FACTORS AFFECTING SECONDARY CLARIFIER PERFORMANCE

Secondary clarifier performance is affected by five factors:

- hydraulic loading rate (a.k.a. overflow rate)
- solids loading rate
- settled sludge volume (SSV)
- sludge volume index (SVI)
- return sludge rate

7.3.1.1 Hydraulic Loading Rate

Hydraulic loading rate calculates the upward velocity of the water in the clarifier. The upward velocity is important because the sludge settling rate must be faster than this upward velocity in order for the sludge to settle rather than be carried over the weir.

Hydraulic loading rate is calculated by dividing the clarifier effluent flow by the clarifier surface area. (*Note:* The clarifier effluent flow is assumed to be equal to the aeration influent flow.) Making this calculation is similar to calculating the velocity in a pipe; we can say that it is just a large diameter pipe with the flow going upward. Units used are gal/day/ft^2.

✓ *Note:* 100 gal/day/ft^2 is equal to .009 ft/min or .11 in/min.

Example 7.9

Problem:

Using the data below, calculate hydraulic loading rate.

Aeration influent flow = 25 MGD
Aeration tank MLTSS = 2,300 mg/L
Four clarifiers: 125 ft diameter, 12 ft in depth

Solution:

$$\text{hydraulic loading rate} = \frac{25{,}000{,}000}{(125)^2\,(3.14/4)\,4}$$

$$= 510\ \text{gal/day/ft}^2$$

✓ Typical hydraulic loading rates for clarifier design are 450 to 600 gal/day/ft^2.

✓ Hydraulic load at peak sustained daytime flow should not exceed 750 gal/day/ft^2.

7.3.1.2 Solids Loading Rate

The solids loading rate calculates the downward flow of solids needed in the clarifier. This is important because there is a maximum rate at which solids will move to the bottom of the clarifier.

$$\text{solids loading rate} = \frac{(\text{aeration influent flow} + \text{return sludge flow}) \times 8.34}{\left[\#\,\text{clarifiers} \times (\text{diameter})^2 \times \dfrac{(3.14)}{4}\right]} \tag{7.9}$$

Example 7.10

Problem:

Using the data below, calculate the solids loading rate.

Aeration influent flow = 25 MGD
Aeration tank MLTSS = 2,300 mg/L
Return sludge, flow = 18 MGD
RTSS = 5,500 mg/L
Four clarifiers: 125 ft diameter, 12 ft depth

Solution:

$$\text{solids loading rate} = \frac{(25+18)\,(2{,}300)\,(8.34)}{\left[4\,(125)^2 \times \dfrac{(3.14)}{4}\right]} = 16.8\ \text{lb/day/ft}^2$$

✓ Most clarifiers will not work correctly if the solids loading rate exceeds 24 lb/day/ft^2; however, some deep clarifiers have recently been reported to work correctly at solids loadings of 30 lb/day/ft^2.

7.3.1.3 Settled Sludge Volume (SSV)

five minutes and 30 minutes, respectively. The units are mL/L. Originally, the test was run in 1,000 milliliter graduated cylinders but did not accurately represent the clarifier because the friction of the sludge against the wall slowed down the rate of settling.

To solve this problem, the Mallory settleometer was developed. The Mallory is run in a two-liter beaker that is marked as if it was a one-liter beaker. It is about three times the diameter of a graduated cylinder and about one third as tall. The Mallory accurately predicts clarifier performance as long as the 30-minute SSVs are less than 500 mL/L. At values above this, the Mallory is also interfered with by the beaker walls.

To eliminate all the wall effects, the stirred settleometer is used. It is run in a graduated cylinder with a slow 12 RPH stirrer to prevent the sludge from clinging to the walls and to simulate the effect of the clarifier rake.

7.3.1.4 Sludge Volume Index (SVI)

The sludge volume index (SVI) indicates the ability of sludge to compact. It is determined by dividing the SSV_{30} by the MLTSS concentration and multiplying this value by 1,000.

Example 7.11

Problem:

Using the data below, calculate the sludge volume index.

Aeration influent flow = 25 MGD
Aeration tank MLTSS = 2,300 mg/L
Return sludge flow = 18 MGD
RTSS = 5,500 mg/L
SSV_{30} = 325 mL/L
Four clarifiers: 125 ft diameter, 12 ft depth

Solution:

$$\text{SVI} = (325/2{,}300)\,(1{,}000) = 141\ \text{mL/g}$$

✓ The SVI of a properly operated activated sludge process should be between 75 and 125 mL/g.

7.3.1.5 Return Sludge Rate

The return sludge rate is the one physical parameter the operator can easily adjust to control operation of the secondary clarifier. The other physical parameters an operator can change are the number of clarifiers in service or chemical (polymer) addition. Return sludge flow rate is normally expressed as a percent of the aeration influent flow rate.

Example 7.12

Problem:

Using the data below, determine the return sludge rate.

Aeration tank MLTSS = 2,300 mg/L
Return sludge, flow = 18 MGD
RTSS = 5,500 mg/L
Four clarifiers: 125 ft diameter, 12 ft depth

Solution:

$$(18/25)(100) = 72\%$$

7.4 PRIMARY SEDIMENTATION: COMMON OPERATIONAL PROBLEMS

Wastewater treatment plant operators must become familiar with and recognize the probable causes and solutions of operational problems in primary sedimentation. Two of the most common operational problems are presented in Table 7.1 along with the probable causes and solutions.

7.5 EFFLUENT FROM SETTLING TANKS

Upon completion of screening, degritting, and settling in sedimentation basins, large debris, grit, and many settleable materials have been removed from the wastestream. What is left is referred to as *primary effluent.* Usually cloudy and frequently grey in color, primary effluent still contains large amounts of dissolved food and other chemicals (nutrients). These nutrients are treated in the next step in the treatment process (Secondary Treatment Unit Processes).

✓ *Note:* Four processes occur in the primary treatment sedimentation unit processes: (1) flotation, (2) settling and compaction of solids, (3) clarification, and (4) solids thickening.

7.6 CHAPTER REVIEW QUESTIONS

7-1 What is the purpose of sedimentation?

TABLE 7.1. Primary Sedimentation: Operational Problems.

Observations	Probable Cause	Solutions
Floating sludge	Solids decomposing in tank.	Remove solids (underflow) more often or at a higher rate.
	Scrapers damaged or worn.	Repair or replace scrapers as necessary.
	Solids withdrawal line clogged.	Clear line.
	Damaged or missing inlet baffles.	Repair or replace baffles.
Black and odorous septic wastewater	Solids collectors worn or damaged.	Repair or replace collectors as necessary.
	Improper underflow (solids) pumping rates.	Increase frequency and duration of pumping cycles until solids density decreases to desirably low value.
	Inadequate pretreatment of organic industrial wastes.	Pre-aerate wastewater.
	Sewage decomposing in collection system. Recycle of excessively strong digester supernatant.	Chlorinate in collection system. Provide treatment before cycling, or reduce rate of return.
	Underflow (solids) withdrawal line plugged.	Reverse flow to clean line.

7-2 The sludge pump operates 20 minutes every three hours. The pump delivers 70 gpm. If the sludge is 5.0% solids and has a volatile matter content of 64%, how many pounds of volatile solids are removed from the settling tank each day?

7-3 The circular settling tank is 90 ft in diameter and has a depth of 10 ft. The flow rate is 2.5 MGD. What is the detention time in hours, surface loading rate in gallons/day/ft^2, and weir overflow rate in gallons/day/foot?

7-4 What is the recommended procedure to follow when removing sludge intermittently from a primary settling tank?

7-5 Why is there normally a baffle at the effluent end of the primary settling tank?

7-6 How much of the settleable solids are removed by primary settling?

7-7 What is an average detention time in a primary clarifier?

7-8 A settling tank is 90 ft long, 25 ft wide, 10 ft deep, and receives a flow rate of 1.6 MGD. What is the surface overflow rate in gpd/ft^2?

7-9 A settling tank with a total weir length of 90 ft receives a flow rate of 1.35 MGD. What is the weir overflow rate in gpd/ft?

7-10 A wastewater treatment plant has six primary tanks. Each tank is 90 ft long and 15 ft wide with a side water depth of 10 ft and has a total weir length of 80 ft. The flow rate to the plant is 6 MGD. There are three tanks currently in service. Calculate the detention time in minutes, the surface overflow rate in gpd/ft^2, and the weir overflow rate in gpd/ft.

7-11 A primary settling tank is 80 feet in diameter and 10 feet deep. What is the detention time when the flow rate is 3.25 MGD? Your answer should be in hours.

7-12 What is the purpose of the settling tank in the secondary or biological treatment process?

7-13 The circular settling tank is 90 ft in diameter and has a depth of 10 ft. The effluent weir extends around the circumference of the tank. The flow rate is 3.70 MGD. What is the detention time in hours, surface loading rate in gallons/day/ft^2, and weir overflow rate in gallons/day/foot?

7-14 An underflow pump operates 30 minutes every three hours. The pump delivers 80 gpm. If the underflow is 5.0% solids and has a volatile matter content of 66%, how many pounds of volatile solids are removed from the settling tank each day?

7-15 A circular setting tank is 80 ft in diameter and has a depth of 9 ft. The effluent weir extends around the circumference of the tank. The flow rate is 2.60 MGD. What is the detention time in hours, surface loading rate in gallons/day/ft^2, and weir overflow rate in gallons/day/foot?

7-16 There are several large clumps of black, odorous solids floating on the surface of the primary clarifier. The total solids concentration of the underflow from the clarifier at the beginning of the 20-minute pumping cycle is 10%. After 10 minutes of pumping, the solids concentration drops to 1.0%. What is happening, and what should the operator do to correct the problem?

7-17 The effluent from a primary clarifier contains an excessive amount of suspended solids. The theoretical detention time based on flow rates and clarifier volume are well within the design range for the clarifier. A dye introduced into the clarifier influent appears in the clarifier effluent in 12 minutes and can no longer be seen in the clarifier after 25 minutes. What is the most likely problem? What are the possible causes and the appropriate solutions to the problem?

7-18 The primary settling tank is 150 feet long, 90 feet wide, and 12 feet deep. The average daily flow is 13.4 MGD. What is the hydraulic detention time in hours?

CHAPTER 8

Wastewater Treatment Ponds

8.1 INTRODUCTION

THE pond is one of the most widely used devices for treatment of municipal and industrial wastes. Oxidation ponds or lagoons can provide equivalent treatment results even without preliminary treatment. Ponds have low operation and maintenance requirements and, when land costs are relatively low, low initial construction costs.

Ponds, along with trickling filters (see Chapter 9) and rotating biological contactors (RBCs) (see Chapter 10), are considered secondary treatment unit processes. Secondary treatment refers to those treatment processes that use biological processes to convert dissolved suspended and colloidal organic wastes to more stable solids that can either be removed by settling or discharged to the environment without causing harm.

Exactly what is secondary treatment? As defined by the Clean Water Act (CWA), secondary treatment produces an effluent with no more than 30 mg/L BOD_5 and 30 mg/L total suspended solids.

✓ The CWA also states that ponds and trickling filters will be included in the definition of secondary treatment even if they do not meet the effluent quality requirements continuously.

Most secondary treatment processes decompose solids aerobically, producing carbon dioxide, stable solids, and more organisms. Because solids are produced, all of the biological processes must include some form of solids removal (settling tank, filter, etc.).

Secondary treatment processes can be separated into two large categories: fixed film systems and suspended growth systems.

Fixed film systems are processes that use a biological growth (biomass or slime) that is attached to some form of medium. Wastewater passes over or around the medium and the slime. When the wastewater and slime are in contact, the organisms remove and oxidize the organic solids. The medium may be stone, redwood, synthetic materials, or any other substance that is durable (capable of withstanding weather conditions for many years), provides a large area for slime growth while providing open space for ventilation, and is not toxic to the organisms in the biomass. Fixed film devices include trickling filters and RBCs.

Suspended growth systems are processes that use a biological growth that is mixed with the wastewater. The most typical suspended growth systems are the various modifications of the activated sludge process (see Chapter 11).

8.2 TREATMENT PONDS

much lower cost. It is the cost (the economics) that drives many managers to decide on the pond option. Unfortunately, it is the ease of operation of ponds that often leads to the opinion that ponds do not need operator attention or control. Nothing could be further from the truth—ponds, to perform as designed, do require operator attention and control.

The actual degree of treatment provided depends on the type and number of ponds used. Ponds can be used as the sole type of treatment, or they can be used in conjunction with other forms of wastewater treatment—that is, other treatment processes followed by a pond or a pond followed by other treatment processes.

✓ *Note:* Algae is necessary for the proper functioning of a stabilization or oxidation pond.

8.2.1 TYPES OF PONDS

Ponds can be classified (named) based upon their location in the system, by the type of wastes they receive, and by the main biological process occurring in the pond. First, we look at the types of ponds according to their location and the type of wastes they receive: raw sewage stabilization ponds, oxidation ponds, and polishing ponds. Then, in the following section, we look at ponds classified by the type of processes occurring within the pond: aerobic ponds, anaerobic ponds, facultative ponds, and aerated ponds.

✓ *Note:* Cattails growing in a lagoon or pond will cause short circuiting in the affected lagoon or pond.

8.2.1.1 Raw Sewage Stabilization Pond

The raw sewage stabilization pond is the most common type of pond. With the exception of screening and shredding, this type of pond receives no prior treatment. Generally, raw sewage stabilization ponds are designed to provide a minimum of 45 days detention time and to receive no more than 30 pounds of BOD_5 per day per acre. The quality of the discharge is dependent on the time of the year. Summer months produce high BOD_5 removal and excellent suspended solids removals.

The pond consists of an influent structure, pond berm or walls, and an effluent structure designed to permit selection of the best quality effluent. Normal operating depth of the pond is three to five feet.

The process occurring in the pond involves bacteria decomposing the organics in the wastewater (aerobically and anaerobically) and algae using the products of the bacterial action to produce oxygen (photosynthesis). Because this type of pond is the most commonly used in wastewater treatment, the process that occurs within the pond is described in greater detail in the following.

When wastewater enters the stabilization pond, several processes begin to occur. These include settling, aerobic decomposition, anaerobic decomposition, and photosynthesis. Solids in the wastewater will settle to the bottom of the pond. In addition to the wastewater solids entering the pond, solids that are produced by the biological activity will also settle to the bottom. Eventually, this will reduce the detention time and the performance of the pond. When this occurs (20 to 30 years is normal), the pond will have to be replaced or cleaned.

Bacteria and other microorganisms use the organic matter as a food source. They use oxygen (aerobic decomposition), organic matter and nutrients to produce carbon dioxide, water, stable solids (which may settle out), and more organisms. The carbon dioxide is an essential component of the photosynthesis process occurring near the surface of the pond.

Organisms also use the solids that settled out as food material; however, the oxygen levels at the bottom of the pond are extremely low, so the process used is anaerobic decomposition. The organisms use the organic matter to produce gases (hydrogen sulfide, methane, etc.) that are dissolved in the water, stable solids, and more organisms.

Near the surface of the pond, a population of green algae will develop, which can use the carbon dioxide produced by the bacterial population, nutrients, and sunlight to produce more algae and oxygen, which is dissolved into the water. The dissolved oxygen is then used by organisms in the aerobic decomposition process.

When compared with other wastewater treatment systems involving biological treatment, a stabilization pond treatment system is the simplest to operate and maintain. Operation and maintenance activities include collecting and testing samples for dissolved oxygen (DO) and pH, removing weeds and other debris (scum) from the pond, mowing the berms, repairing erosion, and removing burrowing animals.

✓ *Note:* Dissolved oxygen and pH levels in the pond will vary throughout the day. Normal operation will result in very high DO and pH levels due to the natural processes occurring.

✓ *Note:* When operating properly, the stabilization pond will exhibit a wide variation in both dissolved oxygen and pH. This is due to photosynthesis occurring in the system.

8.2.1.2 Oxidation Pond

An oxidation pond, which is normally designed using the same criteria as the stabilization pond, receives flows that have passed through a stabilization pond or primary settling tank. This type of pond provides biological treatment, additional settling, and some reduction in the number of fecal coliform present.

✓ *Note:* In order to effectively produce algae in an oxidation pond, the essential elements carbon, nitrogen, and phosphorous must be present.

8.2.1.3 Polishing Pond

A polishing pond, which uses the same equipment as a stabilization pond, receives flow from an oxidation pond or from other secondary treatment systems. Polishing ponds remove additional BOD_5, solids and fecal coliform, and some nutrients. They are designed to provide one to three days detention time and normally operate at a depth of five to 10 feet. Excessive detention time or too shallow a depth will result in algae growth, which increases influent suspended solids concentrations.

8.2.1.4 Ponds Based on the Type of Processes Occurring Within

Ponds may also be classified by the type of processes occurring within the pond. These include the aerobic, anaerobic, facultative, and aerated processes.

8.2.1.4.1 Aerobic Ponds

In aerobic ponds (which are not widely used), oxygen is present throughout the pond. All biological activity is aerobic decomposition.

8.2.1.4.2 Anaerobic Ponds

Anaerobic ponds are normally used to treat high strength industrial wastes. No oxygen is present in the pond, and all biological activity is anaerobic decomposition.

8.2.1.4.3 Facultative Pond

The facultative pond is the most common type of pond (based on processes occurring). Oxygen is present in the upper portions of the pond, and aerobic processes are occurring. No oxygen is present in the lower levels of the pond where processes occurring are anoxic and anaerobic.

✓ *Note:* DO and pH tests should be run on a daily basis in the operation of a facultative pond. DO content is highest at 3 P.M.

✓ *Note:* The greatest bacterial activity and the highest BOD_5 removal in a facultative pond will occur when there is good sunlight, warm temperature, and moderate breeze.

✓ *Note:* If no corrective actions are taken, the color of an organically overloaded facultative stabilization pond will eventually change to black.

8.2.1.4.4 Aerated Pond

In the aerated pond, oxygen is provided through the use of mechanical or diffused air systems. When aeration is used, the depth of the pond and/or the acceptable loading levels may increase. Mechanical or diffused aeration is often used to supplement natural oxygen production or to replace it.

8.3 NORMAL OPERATION

Although the pond or lagoon is a relatively low-cost, low-maintenance process where treatment is a combination of natural physical (settling) and biological (aerobic and anaerobic) processes, it requires some attention to operate properly.

During operation, the operator is required to monitor pond operation. To the uninitiated, this may seem silly or ridiculous. A pond is a pond. It just sits there. What is it that an operator can do to a pond?

The statement, "It just sits there," is partially correct, because it does in fact just sit there. However, the operator must make certain observations to ensure that the pond is operating correctly, as per design. For example, when operating properly, the pond gives certain indications of this state of operation. Let's take a look at a few of the typical observations the treatment pond operator would make.

When operating properly, the treatment pond operator will notice that

(1) The pond or lagoon has a green color, a light musty odor, no accumulation of solids on the surface, and no evidence of short-circuiting.
(2) There will be no high weeds, eroded berms (banks), or weed growth within the pond itself.
(3) There will be no evidence of operational problems (i.e., insects or burrowing animals, duck weed, etc.).
(4) The effluent from the pond will normally be clear with a green tint.

The treatment pond operator is also required to take samples from the pond and perform process control tests on the samples. Of primary concern to the operator are the pH and dissolved oxygen (DO) tests. In addition, performance testing on total suspended solids (TSS) and BOD_5 may be required.

✓ *Note:* Control test results will vary considerably during the course of a single day. This is especially true for the pH and dissolved oxygen.

The treatment pond operator not only needs to know what to look for in the operation of the pond but also how to take samples and how to test and evaluate them—and there is more. The operator must understand pond operation. He or she must understand the factors that cause process control text variations, for example, such as sunlight (intensity and duration), temperature, wind, and ice.

We listed the main observations the operator should make when he or she is monitoring pond operation. These indicators pointed to proper operation of the pond. The operator must also know when these indicators identify problems. Let's look at a few.

(1) Color—if the operator notices rapid or gradual changes in the color of the pond contents, this could be an indication of operational problems.

✓ *Note:* When a pond turns dull green, grey, or colorless, generally the pH and DO have dropped too low.

(2) Flow—the amount of flow the pond or lagoon receives as well as the visible patterns of flow through the pond can indicate problems.
(3) Water depth—the depth of the liquid in the pond or lagoon can indicate increased flow or increased evaporation and/or leaks into the groundwater.
(4) Aerator performance—in aerated ponds or lagoons the performance of the aeration system can be not only a cause of poor performance but also an indicator of performance problems.

✓ *Note:* The widest variation in DO, pH, and temperature in a typical wastewater pond occurs at a depth of about six inches.

8.4 TROUBLESHOOTING POND PROBLEMS

It is important to recognize that most pond problems can be solved through visual observations, simple testing, and application of common sense actions. Table 8.1 lists common operational problems associated with pond or lagoon operations.

8.4.1 TROUBLESHOOTING APPROACH

Obviously, the information contained in Table 8.1 can be used to assist the operator in troubleshooting most pond problems. In the troubleshooting effort, it is helpful if the troubleshooter follows the guidelines presented in Chapter 5. In addition, most troubleshooting procedures can be organized into a simple systematic outline approach, such as the one presented below. This outline approach can be used to troubleshoot any unit process in wastewater treatment:

(1) Description of problem
(2) "Operator" information
(3) Identified problem(s)
(4) Possible causes
(5) Additional information required
(6) Possible short-term corrections
(7) Potential long-term corrections

8.5 PROCESS CONTROL CALCULATIONS: PONDS

✓ *Note:* There are no recommended process control calculations for the pond. However, there are

TABLE 8.1. Common Operational Problems: Pond/Lagoons.

Observations	Probable Cause	Solutions
Poor effluent quality	Organic overloading	Add sodium nitrate to pond. Increase/install aeration equipment in the pond. Recirculate pond effluent.
	Low temperature	Operate multiple ponds in series.
	Toxic influent flows	Identify source and eliminate.
	Lowered hydraulic detention time due to solids accumulation	Remove the solids accumulation from the pond.
	Aeration equipment malfunction	Repair/replace broken parts.
	Mixing equipment malfunction	Repair/replace worn equipment.
	Excessive turbidity from algae and scum	Break up scum mats. Operate transfer pipes at less than 50%.
	Light is blocked by excessive growth in pond	Remove any growth at regular intervals.
Cannot maintain minimum required operating level	Pond leakage	Add bentonite clay to pond effluent.
	Excessive evaporation/percolation	Add additional water to pond influent.
Foaming and sprays in aerated pond	Windy conditions	No action required unless neighbors are close to pond. Build wind screen.
Ground water contamination	Leakage through sides and bottom	Apply bentonite clay to pond influent.
Odors	Anaerobic conditions throughout pond	Breakup/resuspend anaerobic solids and scum. Divert flow to another cell, take cell off line to rest. Add sodium nitrate to pond. Chlorinate pond influent. Recirculate pond effluent.
	Algal blooms	Add algicide. Add copper sulfate monthly at appropriate dosage during problem period—ensure you have regulatory permission.
Insect generation	Scum layer and/or excessive plant growth providing place for insect growth	Improve weed and scum removal. Apply insecticide—ensure regulatory permission.
	Shallow standing pools of water on edges of pond	Remove vegetation around pond. Fill in low spots/potholes where water collects.
Animals burrowing into berms (dikes)		Vary depth of ponds several times in rapid succession.
		Obtain assistance to trap/relocate animals.
Excessive weed and operating tulle growth	Pond operating depth too shallow	Increase depth to at least 3 feet.
	Poor vegetation control program	Establish housekeeping program. Line pond.
Low dissolved oxygen in pond	Low algal growth	Remove floating weeds, scum, and debris to improve light penetration.
	High sulfide concentration in pond influent	Chlorinate pond influent. Eliminate septic flows into pond.
	Inadequate detention time	Increase pond detention time.

several calculations that may be helpful in evaluating process performance or identifying causes of poor performance. These include hydraulic detention time and loading and organic loading. In this section, a few calculations that might be helpful in the pond performance evaluation and identification of causes of poor performance process have been included along with other calculations that may be helpful.

✓ *Note:* Process control calculations are an important part of wastewater treatment operations, including pond operations. More significantly, process control calculations are an important part of state wastewater licensing examinations—you simply cannot master the licensing examinations without being able to perform the required calculations. Thus, as with previous chapters (and with chapters to follow), whenever possible, example process control problems are provided to enhance your knowledge and skill.

✓ *Note:* Waste loading of oxidation ponds can be expressed in pounds of BOD per day per acre, inches of depth added per day, or per capita served per acre.

8.5.1 DETERMINING POND AREA IN ACRES

$$\text{area, acres} = \frac{\text{area, ft}^2}{43{,}560\ \text{ft}^2/\text{acre}} \tag{8.1}$$

8.5.2 DETERMINING POND VOLUME IN ACRE-FEET

$$\text{volume, acre-feet} = \frac{\text{volume, ft}^3}{43{,}560\ \text{ft}^2/\text{acre-foot}} \tag{8.2}$$

8.5.3 DETERMINING FLOW RATE IN ACRE-FEET/DAY

$$\text{flow, acre-feet/day} = \text{flow, MGD} \times 3.069\ \text{acre-feet/MG} \tag{8.3}$$

✓ *Note:* Acre-feet (ac-ft) is a unit that can cause confusion, especially for those not familiar with pond or lagoon operations. One acre-foot is the volume of a box with a 1-acre top and 1 ft of depth—but the top doesn't have to be an even number of acres in size to use acre-feet.

8.5.4 DETERMINING FLOW RATE IN ACRE-INCHES/DAY

$$\text{flow, acre-inches/day} = \text{flow, MGD} \times 36.8\ \text{acre-inches/MG} \tag{8.4}$$

8.5.5 HYDRAULIC DETENTION TIME, DAYS

$$\text{hydraulic detention time, days} = \frac{\text{pond volume, acre-feet}}{\text{influent flow, acre-feet/day}} \tag{8.5}$$

✓ *Note:* Normally, hydraulic detention time ranges from 30 to 120 days for stabilization ponds.

Let's take a look at an example of how to determine detention time in days for a stabilization pond.

Example 8.1

Problem:

A stabilization pond has a volume of 54.5 acre-feet. What is the detention time in days when the flow is 0.35 MGD?

Solution:

$$\begin{aligned}\text{flow, ac-ft/day} &= 0.35\ \text{MGD} \times 3.069\ \text{ac-ft/MG}\\ &= 1.07\ \text{ac-ft/day}\end{aligned}$$

$$\text{DT days} = \frac{54.5\ \text{acre}/\text{ft}}{0.92\ \text{ac-ft/day}} = 50.7\ \text{days}$$

8.5.6 HYDRAULIC LOADING, INCHES/DAY (OVERFLOW RATE)

$$\text{Hydraulic Loading, inches}/\text{day} = \frac{\text{influent flow, acre-inches/day}}{\text{pond area, acres}} \qquad (8.6)$$

8.5.7 POPULATION LOADING

$$\text{population loading, people}/\text{acre}/\text{day} = \frac{\text{pop. served by system, people}}{\text{pond area, acres}} \qquad (8.7)$$

✓ *Note:* Population loading normally ranges from 50 to 500 people per acre.

8.5.8 ORGANIC LOADING

Organic loading can be expressed as pounds of BOD_5 per acre per day (most common), pounds of BOD_5 per acre-foot per day or, people per acre per day.

$$\text{organic L, lb BOD}_5/\text{acre}/\text{day} = \frac{\text{BOD}_5\text{, mg}/\text{L Infl. flow, MGD} \times 8.34}{\text{pond area, acres}} \qquad (8.8)$$

✓ *Note:* Normal range is 10 to 50 lb BOD_5 per day per acre.

Example 8.2

Problem:

A wastewater treatment pond has an average width of 370 ft and an average length of 730 ft. The influent flow rate to the pond is 0.10 MGD with a BOD concentration of 165 mg/L. What is the organic loading rate to the pond in pounds per day per acre (lb/d/ac)?

Solution:

$$730\ \text{ft} \times 370\ \text{ft} \times \frac{1\ \text{ac}}{43{,}560\ \text{ft}^2} = 6.2\ \text{acre}$$

$$0.10\ \text{MGD} \times 165\ \text{mg}/\text{L} \times 8.34\ \text{lb}/\text{gal} = 138\ \text{lb}/\text{d}$$

$$\frac{138\ \text{lb}/\text{d}}{6.2\ \text{ac}} = 22.2\ \text{lb}/\text{d}/\text{ac}$$

8.6 CHAPTER REVIEW QUESTIONS

8-1 A wastewater treatment pond has an average length of 680 ft with an average width of 420 ft. If the flow rate to the pond is 310,000 gal each day and is operated at a depth of 6 ft, what is the hydraulic detention time in days?

8-2 A pond 740 ft long and 400 ft wide receives an influent flow rate of 0.65 ac-ft/d. What is the hydraulic loading rate on the pond in inches per day?

8-3 The pond is 440 ft long and 270 ft wide and is operating at a depth of 3.5 ft. The current influent flow rate is 0.08 MGD. What is the hydraulic detention time in days?

8-4 Over a period of seven days, the color of the facultative stabilization pond changes from green to dark grey. The operator determines the cause was a temporary increase in organic loading caused by a local industry's preparation for its annual two-week vacation shut down. What actions should be taken to minimize the impact of this?

8-5 A pond has a surface area of 1,089,000 ft^2 and an operating depth of three feet. The average daily influent flow rate is 9.54 MGD. What is the hydraulic detention time in days?

CHAPTER 9

Trickling Filters

9.1 INTRODUCTION

WHERE used in wastewater treatment systems, the trickling filter follows primary treatment (primary settling), and must include a secondary settling tank or clarifier (as shown in Figure 9.1) to remove solids generated by the biological activity. Trickling filters are widely used for the treatment of domestic and industrial wastes or combinations of the two. The process is a fixed film or attached growth biological treatment method designed to remove BOD_5 and suspended solids (through biological oxidation and settling) but can also be designed to remove nitrogen. Although the term *filter* is the accepted designation for this unit, no physical filtration occurs; contaminants are removed by biological action. The medium placed in a tank under the wastewater distributor can be crushed rock (see Figures 9.2 and 9.3), plastic-sheet packing formed into modules, or random plastic packing of various shapes.

9.2 THE TRICKLING FILTER

A trickling filter consists of a rotating distribution arm that sprays and evenly distributes liquid wastewater over a circular bed of fist-sized rocks, other coarse materials, or synthetic media [see Figure 9.2(a) and (b)].

✓ *Note:* The rock in most trickling filters is placed on system tile underdrains.

The spaces between the media allow air to circulate easily so that aerobic conditions can be maintained.

✓ *Note:* Air flow through a trickling filter when the influent is warmer than the air temperature is upward through the filter.

The spaces also allow wastewater to trickle down through, around, and over the medium. The medium material is covered by a layer of biological slime (see Figure 9.3) that absorbs and consumes the wastes trickling through the bed. The organisms aerobically decompose the solids, producing more organisms and stable wastes that either become part of the slime or are discharged back into the wastewater flowing over the medium. This slime consists mainly of bacteria, but it may also include algae, protozoa, worms, snails, fungi, and insect larvae. The accumulating slime occasionally sloughs off (sloughings) individual media materials and is collected at the bottom of the filter, along with treated wastewater, and is passed on to the secondary settling tank where it is removed.

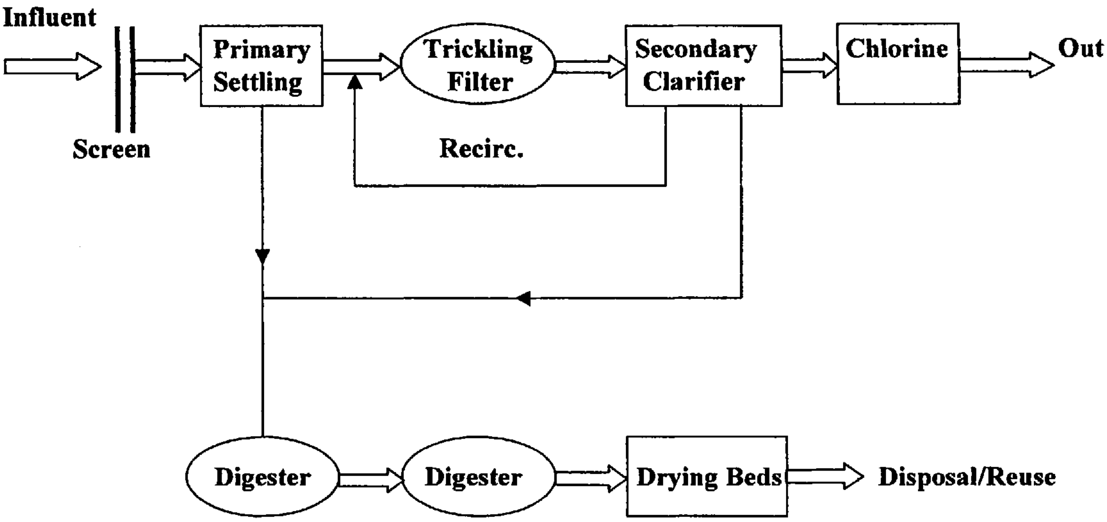


Figure 9.1 Typical trickling filter arrangement.

The overall performance of the trickling filter is dependent on hydraulic and organic loading, temperature, and recirculation.

Let's take a closer look at the equipment that makes up a trickling filter.

9.2.1 TRICKLING FILTER EQUIPMENT

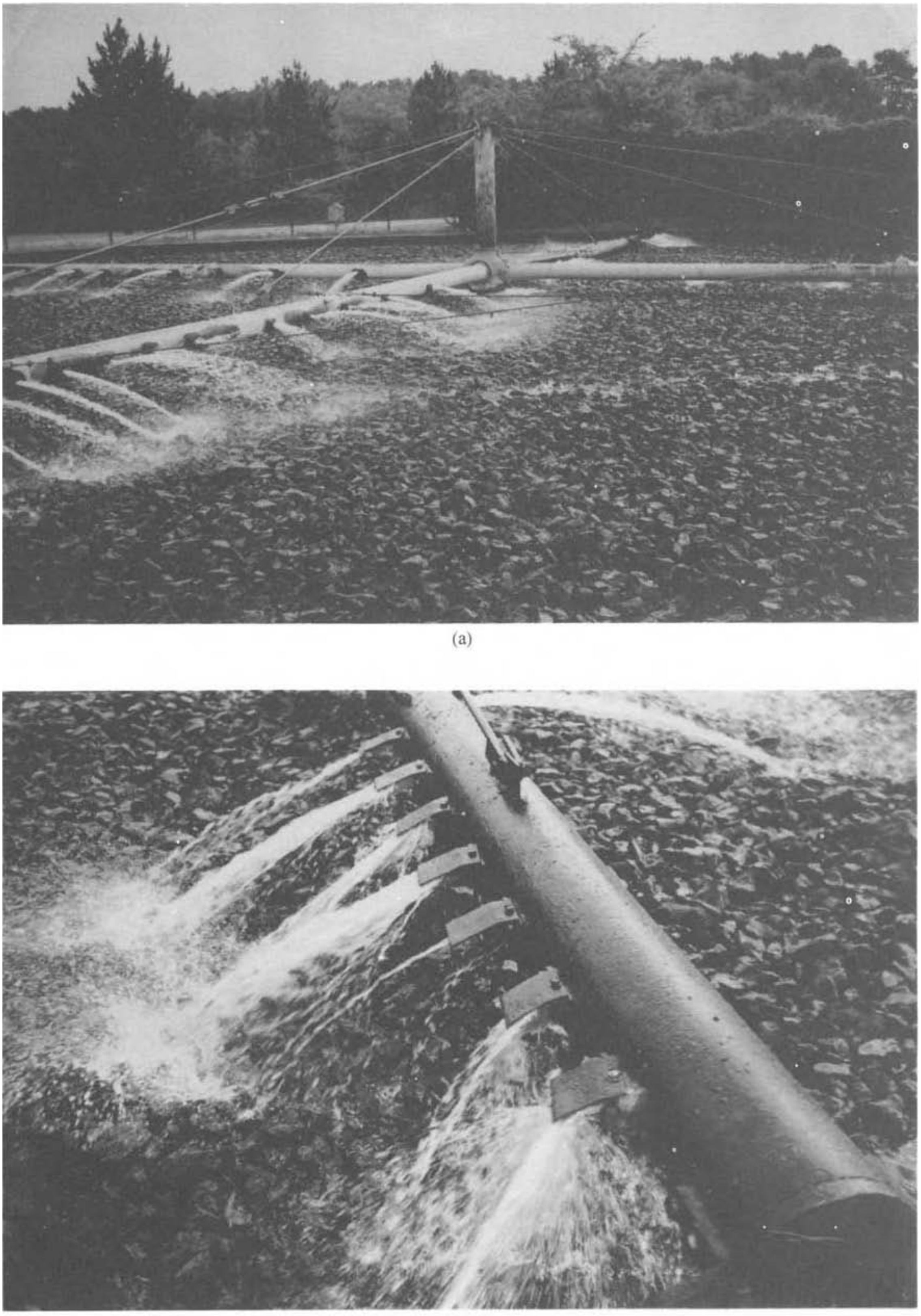
The distribution system is designed to spread wastewater evenly over the surface of the entire medium. The most common system is the rotary distributor, which moves above the surface of the medium and sprays the wastewater on the surface [see Figure 9.2(a)]. The rotary system is driven by the force of the water leaving the orifices. The distributor arms usually have small plates below each orifice to spread the wastewater into a fan-shaped distribution system [see Figure 9.2(b)]. The second type of distributor is the fixed nozzle system. In this system, the nozzles are fixed in place above the medium and are designed to spray the wastewater over a fixed portion of the medium. This system is used frequently with deep bed synthetic media filters.

✓ *Note:* The level of the distribution arms should be checked and adjusted seasonally.

✓ *Note:* The slow, smooth movement of the rotary distributor on a trickling filter hides the force (momentum) the distributor possesses.

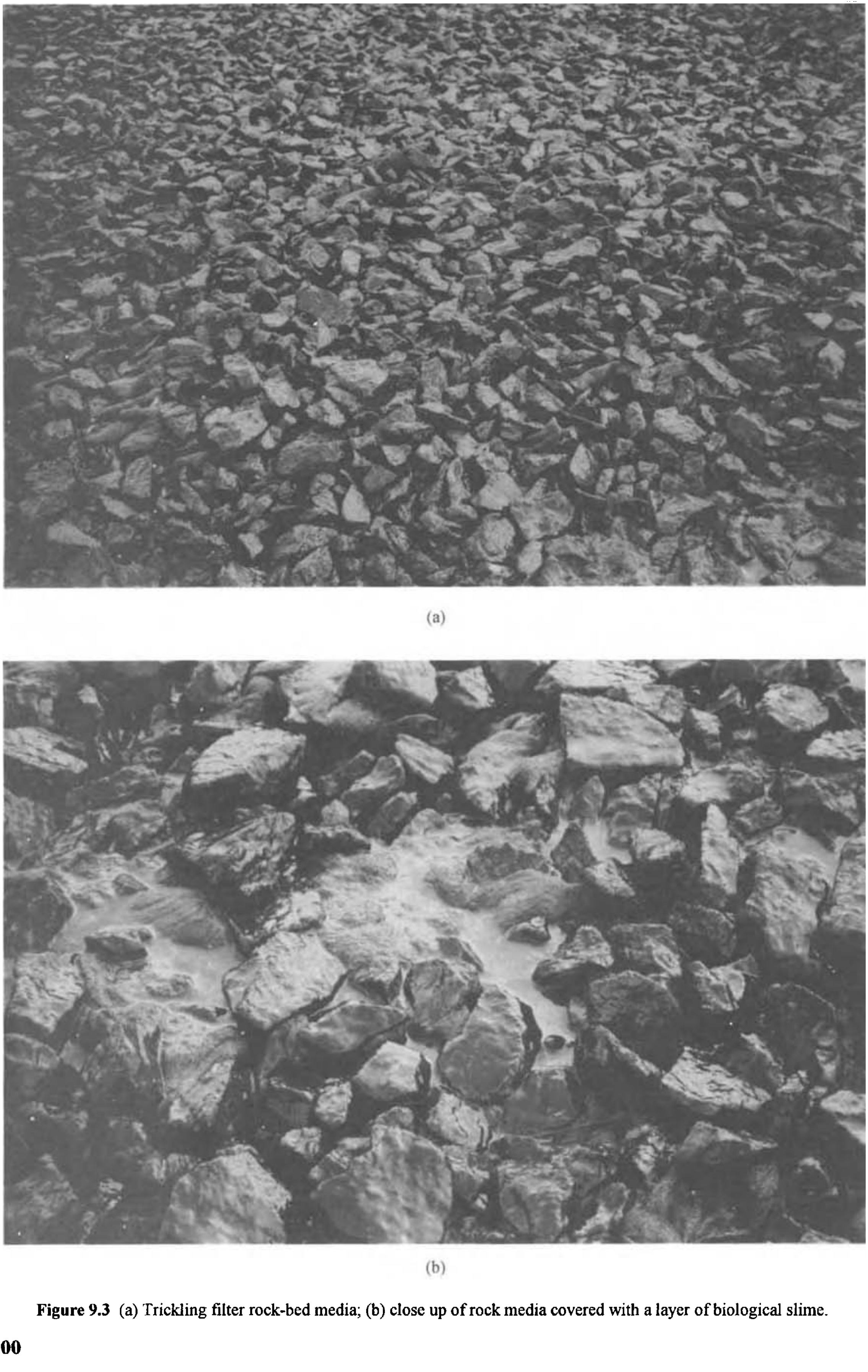
No matter which type of medium is selected, the primary consideration is that it must be capable of providing the desired film location for the development of the biomass. Depending on the type of medium used and the filter classification, the medium may be three to 20 or more feet in depth.

✓ *Note:* Trickling filters that use ordinary rock are normally only about three meters in depth because of structural problems caused by the weight of rocks, which also requires the construction of beds that are quite wide, in many applications, up to 60 feet in diameter. When synthetic media are used, the bed can be much deeper.


(a)

(b)

Figure 9.2 (a) Trickling filter; (b) close up of distribution arm spraying rock media.



(a)

(b)

Figure 9.3 (a) Trickling filter rock-bed media; (b) close up of rock media covered with a layer of biological slime.

✓ To ensure sufficient air flow to the filter, the underdrains should never be allowed to flow more than 50% full of wastewater.

The effluent channel is designed to carry the flow from the trickling filter to the secondary settling tank.

The secondary settling tank provides two to four hours of detention time to separate the sloughing materials from the treated wastewater. Design, construction, and operation are similar to that of the primary settling tank. Longer detention times are provided because the sloughing materials are lighter and settle more slowly.

Recirculation pumps and piping are designed to recirculate (and thus improve the performance of the trickling filter or settling tank) a portion of the effluent back to be mixed with the filter influent. When recirculation is used, obviously, pumps and metering devices must be provided.

9.2.2 FILTER CLASSIFICATIONS

Trickling filters are classified based on hydraulic and organic loading. Moreover, the expected performance and the construction of the trickling filter are determined by the filter classification. Filter classifications include standard rate, intermediate rate, high rate, super high rate (plastic media), and roughing rate types. *Note:* The standard-rate and high-rate types are arguably the two most popular types used.

9.2.2.1 Standard-Rate Trickling Filter

The standard-rate filter has a hydraulic loading (gpd/ft^3) of 25 to 90 and organic loading (BOD$_5$/1,000 ft^3) of 5 to 25; has a seasonal sloughing frequency; does not employ recirculation; and typically has an 80 to 85% BOD$_5$ removal rate and an 80 to 85% TSS removal rate.

9.2.2.2 Intermediate-Rate Trickling Filter

The intermediate-rate filter has a hydraulic loading (gpd/ft^3) of 90 to 230 and an organic loading (BOD$_5$/1,000 ft^3) of 15 to 30%; has a variable sloughing frequency; usually employs recirculation; and typically has a 50 to 70% BOD$_5$ removal rate and a 50 to 70% TSS removal rate.

9.2.2.3 High-Rate Trickling Filter

The high-rate filter has a hydraulic loading (gpd/ft^3) of 230 to 900 and an organic loading (BOD$_5$/1,000 ft^3) of 65 to 80%; has a continuous sloughing frequency; always employs recirculation; and typically has a 65 to 80% BOD$_5$ removal rate and a 65 to 80% TSS removal rate.

✓ *Note:* The temperature of the wastewater to a trickling filter affects its operation, and the effect is more evident in high-rate filters than in standard-rate filters.

9.2.2.4 Super High-Rate Trickling Filter

The super high-rate trickling filter (plastic media) has a hydraulic loading (gpd/ft^3) of 350 to 2,100 and an organic loading (BOD$_5$/1,000 ft^3) up to 300; has a continuous sloughing frequency; employs continuous recirculation; and typically has a 65 to 85% BOD$_5$ removal rate and a 65 to 85% TSS removal rate.

9.2.2.5 Roughing Trickling Filter

The roughing filter has a hydraulic loading (gpd/ft^3) of >900 and an organic loading (BOD$_5$/1,000 ft^3) of >300; has a continuous sloughing frequency; does not normally include recirculation; and typically has a 40 to 65% removal rate and a 40 to 65% TSS removal rate.

✓ *Note:* A roughing filter is commonly used to pretreat high-strength wastewaters (industrial wastes) for BOD reduction before the wastes are applied to an activated sludge unit.

9.3 STANDARD OPERATING PROCEDURES

✓ *Note:* Trickling filters should be operated in series whenever a primary clarifier is out of service.

Standard operating procedures for trickling filters include sampling and testing, observation, recirculation, maintenance, and expectations of performance.

Collection of influent and process effluent samples to determine performance and monitor process condition of trickling filters is required. Dissolved oxygen, pH, and settleable solids testing should be done daily. BOD$_5$ and suspended solids testing should be done as often as practical to determine the percent removal.

The operation and condition of the filter should be observed daily. Items to observe include the distributor movement, uniformity of distribution, evidence of operation or mechanical problems, and the presence of objectionable odors. In addition to the items above, the normal observation for a settling tank should also be performed.

Recirculation is used to reduce the organic loading, improve sloughing, reduce odors, and reduce or eliminate filter fly or ponding problems. The amount of recirculation is dependent on the design of the treatment plant and the operational requirements of the process. Recirculation flow may be expressed as a specific flow rate (i.e., 2.0 MGD). In most cases, it is expressed as a ratio (3:1, 0.5:1.0, etc). Recirculation is always listed as the first number, and influent flow is listed as the second number.

✓ Because the second number in the ratio is always 1.0 the ratio is sometimes written as a single number (dropping the :1.0)

Flows can be recirculated from various points following the filter to various points before the filter. The most common form of recirculation removes flow from the filter effluent or settling tank and returns it to the influent of the trickling filter as shown in Figure 9.4.

Maintenance requirements include lubrication of mechanical equipment, removal of debris from the surface and orifices, as well as adjustment of flow patterns and maintenance associated with the settling tank.

Expected performance varies for each classification of trickling filter. Moreover, the levels of BOD$_5$ and suspended solids removal are dependent on the type of filter.

9.4 TROUBLESHOOTING TRICKLING FILTER PROBLEMS

As with other wastewater treatment unit processes, trickling filters have common operational problems. Table 9.1 lists many of the common trickling filter operational problems, symptoms, and corrective actions.

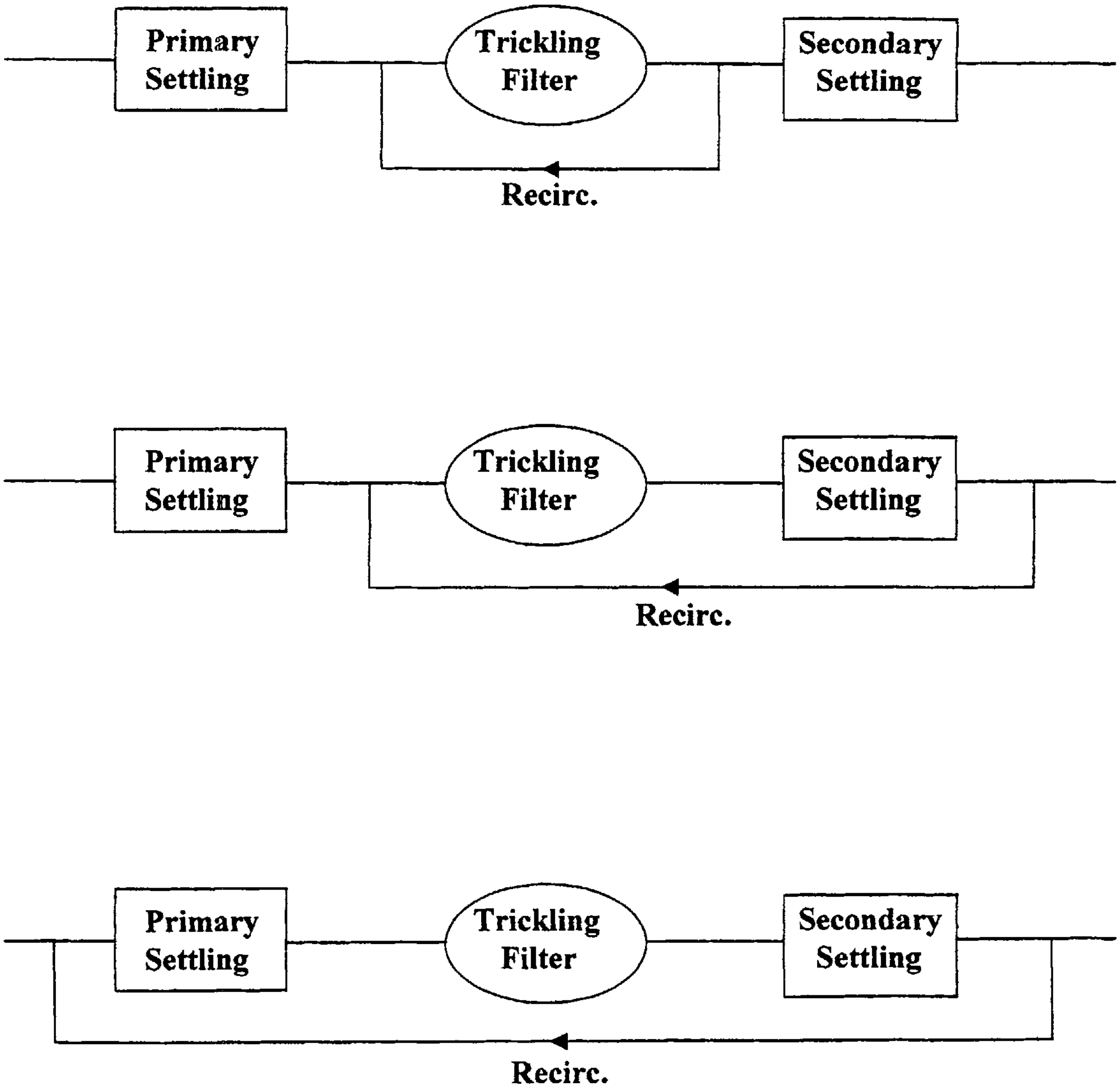


Figure 9.4 Various trickling filter recirculation schemes.

9.5 PROCESS CALCULATIONS

Several calculations are useful in the operation of a trickling filter. These include total flow, hydraulic loading, and organic loading.

9.5.1 TOTAL FLOW

Whenever recirculation is used, its volume must be taken into account when computing the total flow or hydraulic loading applied to the unit. Because recirculation can be expressed as a specific flow rate (i.e., 30 MGD) or as a ratio based upon influent flow, there are two methods for calculating total flow.

If the recirculated flow rate is given, total flow is

$$\text{total flow, MGD} = \text{influent flow, MGD} + \text{recirculation flow, MGD} \tag{9.1}$$

✓ total flow, gpd = total flow, MGD × 1,000,000 gallons/MG

TABLE 9.1. **Troubleshooting Chart: Trickling Filters.**

Observations	Cause	Solutions
Ponding (small pool of water on the surface of media)	Organic overloading	Increase or add recirculation. Reduce organic loading.
	Debris on media, excessive slime growth, snail and larvae growth	Increase or add recirculation. Spray surface w/high pressure hose. Rake or fork media surface. Chlorinate w/high chlorine residual (5 mg/L). Dry filter for several hours. Flood filter for 24 hours (if structure can handle weight of water).
	Media breakdown	Replace media.
Overgrowth of small insects	Natural phenomenon	Remove shrubs and trees near filter. Increase or add recirculation. Chlorinate with <1.0 mg/L chlorine residual. Dry filter for several hours. Flood filter for 24 hours (if structure can handle weight of water). Apply insecticide (with approval).
	Poor housekeeping, warm weather, intermittent wet-dry conditions	Improve housekeeping.
Foul odors originating in trickling filter	Poor ventilation	Increase recirculation. Aerate influent. Add forced ventilation.
	Septic influent	Aerate influent. Increase ventilation. Add forced ventilation.
	Clogged vents and underdrains	Flush underdrains and vents. Increase recirculation.
	Excessive activity/limited sloughing	Maintain aerobic influent. Add masking agent to filter influent.
Reduced performance due to ice formation on media	Prolonged cold weather	Decrease recirculation. Run series filters in parallel. Add wind screens. Cover filter (need forced ventilation). Cover all areas where heat loss occurs. Remove splash plates. Leave dump gates slightly open.
Uneven distribution of flow on the filter surface	Clogging of distributor orifices	Remove and clean distributor nozzles. Flush distributor piping.
	Inadequate hydraulic load on filter	Maintain adequate hydraulic loading.
	Seal leaks	Maintain adequate hydraulic loading. Replace seal.
Snails, moss, and/or roaches clogging filter media	Natural phenomena that occurs based upon climatic conditions and geographical location	Chlorinate to produce <1.0 chlorine residual.
Increase in clarifier effluent suspended solids	Excessive sloughing from filter due to seasonal change	Add polymer to clarifier influent.
	Excessive sloughing due to organic loading	Increase clarifier underflow rate.
	Excessive sloughing due to pH or toxic conditions	Maintain pH between 5.5 and 9.5.
	Denitrification in clarifier	Increase clarifier underflow rate.
	Final clarifier hydraulically overloaded	If due to recirculation, reduce recirculation rate during peak flow periods.
	Final settling equipment malfunction	Repair or replace broken equipment.
	Install baffles	Temperature currents in final settling tank.

Example 9.1

Problem:

Influent = 3.0 MGD
Recirculation flow = 3.0 MGD

Solution:

$$\text{total flow, MGD} = 3.0\,\text{MGD} + 3.0\,\text{MGD}$$
$$= 6.0\,\text{MGD}$$

✓ The total flow to the tricking filter includes the influent flow and the recirculated flow. This can be determined using the recirculation ratio.

$$\text{total flow, MGD} = \text{influent flow} \times (\text{recirc. rate} + 1.0) \tag{9.2}$$

Example 9.2

Problem:

The trickling filter is currently operating with a recirculation rate of 1.6. What is the total flow applied to the filter when the influent flow rate is 3.85 MGD?

Solution:

$$\text{total flow, MGD} = 3.85\,\text{MGD} \times (1.6 + 1.0)$$
$$= 10\,\text{MGD}$$

9.5.2 HYDRAULIC LOADING

Calculating the hydraulic loading rate is important in accounting for both the primary effluent as well as the recirculated trickling filter effluent. Both of these are combined before being applied to the surface of the filter. The hydraulic loading rate is calculated based on the surface area of the filter.

$$\text{hydraulic loading, gpd/ft}^2 = \frac{\text{total flow to filter, gpd}}{\text{filter area, ft}^2} \tag{9.3}$$

✓ *Note:* It is important to remember that the recirculation flow must be included when calculating hydraulic loading.

Example 9.3

Problem:

A trickling filter 85 ft in diameter is operated with a primary effluent of 1.48 MGD and a recirculated effluent flow rate of 0.56 MGD. Calculate the hydraulic loading rate on the filter in units gpd/ft^2.

Solution:

The primary effluent and recirculated trickling filter effluent are applied together across the surface of the filter, therefore

$$1.48\ \text{MGD} + 0.56\ \text{MGD} = 2.04\ \text{MGD} = 2{,}040{,}000\ \text{gpd}$$

$$\begin{aligned}\text{circular surface area} &= 0.785 \times (\text{diameter})^2\\ &= 0.785 \times (85\ \text{ft})^2\\ &= 5{,}672\ \text{ft}^2\end{aligned}$$

$$\frac{2{,}040{,}000\ \text{gpd}}{5{,}672\ \text{ft}^2} = 359.7\ \text{gpd/ft}^2$$

9.5.3 ORGANIC LOADING RATE

As mentioned earlier, trickling filters are sometimes classified by the organic loading rate applied. The organic loading rate is expressed as a certain amount of BOD applied to a certain volume of media.

✓ *Note:* Organic loading is the pounds of BOD_5 per day applied per 1,000 cubic feet of filter media. This calculation provides information that can be compared with the filter design when evaluating the operation to determine possible causes for operational problems.

$$\text{OL, lb/day/1,000 ft}^3 = \frac{\text{BOD}_5\ \text{in, mg/L} \times \text{flow}_{\text{PEF}}\ \text{MGD} \times 8.34\ \text{lb/mg/L/MG} \times 1{,}000}{\text{filter volume, ft}^3} \quad (9.4)$$

Example 9.4

Problem:

Given the data below, what is the organic loading in pounds of BOD_5 per day per 1,000 cubic feet?

Filter diameter	90 ft
Medium depth	6 ft
Recirculation rate	0.5
Primary effluent flow	1.44 MGD
Primary effluent BOD	120 mg/L

Solution:

$$\begin{aligned}\text{OL, lb/day/1,000 ft}^3 &= \frac{120\ \text{mg/L} \times 1.44\ \text{MGD} \times 8.34\ \text{lb/MG/mg/L} \times 1{,}000}{0.785 \times 90\ \text{ft} \times 90\ \text{ft} \times 6\ \text{ft}}\\ &= 37.8\ \text{lb/day/1,000 ft}^3\end{aligned}$$

✓ *Note:* Primary effluent = Trickling filter influent

Let's try another example, which is slightly different from Example 9.4.

Example 9.5

Problem:

A trickling filter, 60 ft in diameter, receives a primary effluent flow rate of 0.450 MGD. Calculate the organic loading rate in units of pounds of BOD applied per day per 950 ft^3 of medium volume. The primary effluent BOD concentration is 75 mg/L. The medium depth is 8 ft.

Solution:

$$0.450\,\text{MGD} \times 75\,\text{mg/L} \times 8.34\,\text{lb/gal} = 281.5\,\text{BOD applied/d}$$

$$\text{surface area} = 0.785 \times (60)^2$$

$$= 2{,}826\,\text{ft}^2$$

$$\text{area} \times \text{depth} = \text{volume}$$

$$2{,}826\,\text{ft}^2 \times 8\,\text{ft} = 22{,}608\,\text{(TF Volume)}$$

✓ *Note:* To determine the pounds of BOD per 950 ft^3 in a volume of thousands of cubic feet, we must set up the equation as shown below.

$$\frac{281.5\,\text{lb BOD/d}}{22{,}608} \times \frac{950}{950}$$

Regrouping the numbers and the units together:

$$= \frac{281.5 \times 950}{22{,}608} \, \frac{\text{lb BOD/d}}{950\,\text{ft}^3}$$

$$= 11.8 \frac{\text{lb BOD/d}}{950\,\text{ft}^3}$$

9.6 SETTLING TANK

It is important to note that in the operation of settling tanks that follow trickling filters, various calculations are routinely made to determine detention time, surface settling rate, hydraulic loading, and sludge pumping.

✓ *Note:* Sludge removed from a secondary clarifier following a trickling filter grey in color is indicative of excellent operation.

9.7 CHAPTER REVIEW QUESTIONS

9-1 Name three factors that can affect the operation of a trickling filter.

9-2 Name three main parts of a trickling filter, and give the purpose or purposes of each part.

9-3 What is the main difference between the standard-rate trickling filter and the high-rate filter?

9-4 How often should the operation of a trickling filter be checked?

9-5 Recirculation for a trickling filter can cause______________

9-6 Calculate the pounds of BOD per day entering the trickling filter. Data: raw wastewater flow = 1.6 MGD, raw wastewater BOD = 140 mg/L. There is a 25% reduction in BOD through primary treatment.

9-7 Name three classifications of trickling filter based on their organic loading rate.

9-8 What is the purpose of recirculation?

9-9 The recirculation rate is 0.85. The influent flow rate is 2.2 MGD. What is the total flow being applied to the filter in MGD?

9-10 Why is a settling tank required following the trickling filter?

9-11 A treatment plant receives a flow rate of 3.5 MGD. If the trickling filter effluent is recirculated at a rate of 4.20 MGD, what is the recirculation ratio?

9-12 List three things that should be checked as part of the normal operations and maintenance procedures for a trickling filter.

9-13 The recirculation rate is 0.85. The influent flow rate is 2.4 MGD. What is the total flow being applied to the filter in MGD?

9-14 A trickling filter has a diameter of 80 feet. The filter receives 1.40 MGD of primary effluent. The filter is currently operating with a recirculation ratio of 0.5:1.0. What is the hydraulic loading in gallons per square foot per day?

9-15 If the filter in the previous question has six feet of media, and the primary effluent BOD$_5$ is 140 mg/L, what is the organic loading in pounds of BOD$_5$ per 1,000 cubic feet of media?

Use the data contained in the chart below to solve problems 9-16 through 9-20.

Primary effluent	Flow	2.40 MGD
	Suspended solids	205 mg/L
	BOD$_5$	196 mg/L
Trickling filters	Number	2
	Diameter	90 ft
	Media depth	8 ft
Recirculation	Ratio	1.5:1.0

9-16 What is the total flow to each filter in million gallons per day (assume the flow is equally split)?

9-17 What will the total flow to each filter be in million gallons per day if the operator changes the recirculation rate to 0.75:1.0 (assume the flow is equally split between the two filters)?

9-18 What is the hydraulic loading in gallons per day per square foot for each filter at a 1.5:1.0 recirculation rate (assume the flow is equally split between the two filters)?

9-19 What is the hydraulic loading in gallons per day per square foot for each filter at a 0.75:1.0 recirculation (assume the flow is equally split between the two filters)?

9-20 What is the organic loading in pounds of BOD per 1,000-ft^3 for each filter at a 0.75:1.0 recirculation rate (assume the flow is equally split between the filters)?

9-21 Briefly describe the trickling filter process.

9-22 What happens when the slime growth on the media becomes too thick?

9-23 What is the most common method for moving the distribution arm?

9-24 Why is the size of the media so important?

9-25 What are the two types of ventilation used in the trickling filter? Which is the most widely used?

CHAPTER 10

Rotating Biological Contactors (RBCs)

10.1 INTRODUCTION

THE rotating biological contactor (RBC) is a biological treatment system and is a variation of the attached growth idea provided by the trickling filter. Moreover, the arrangement for secondary treatment of municipal wastewater by the RBC process, as shown in Figure 10.1, is similar to the flow diagram of a trickling-filter plant.

✓ *Note:* Unlike trickling filter operation, return flow via recirculation is not normally employed in the operation of RBCs because recirculation does not improve performance.

Still relying on microorganisms that grow on the surface of a medium, the RBC is instead a fixed film biological treatment device. The basic biological process, however, is similar to that occurring in the trickling filter. The biological process is preceded by primary clarifiers and followed by secondary clarifiers.

An RBC consists of a shaft of circular plastic disks closely spaced (mounted side by side) that are typically about 12 ft in diameter revolving at 40% submergence in a contour-bottom tank and attached to a rotating horizontal shaft. The nominal spacing between disks is 0.50 to 0.75 inches so that during submergence the wastewater can enter between the surfaces. As the RBC rotates, the attached biomass film (zoogleal slime) that grows on the surface of the disks moves into and out of the wastewater. While submerged in the wastewater, the microorganisms absorb organics; while they are rotated out of the wastewater, they are supplied with needed oxygen for aerobic decomposition. As the zoogleal slime reenters the wastewater, excess solids and waste products are stripped off the media as sloughings. These sloughings are transported with the wastewater flow to a settling tank for removal.

Modular RBC units are placed in series, simply because a single contactor is not sufficient to achieve the desired level of treatment; however, the resulting treatment achieved using RBC units placed in series exceeds conventional secondary treatment. Each individual contactor is called a stage and the group is known as a train. Most RBC systems consist of two or more trains with three or more stages in each. In processing domestic wastewater, a series of four stages is usually employed to ensure adequate BOD reduction. When designed for this purpose, the RBC system can be configured to obtain organic (BOD) removal in the early stages (i.e., stages 1 through 3) and nitrogen removal in the later stages. When configured in this manner, the initial stages will have the characteristic slime for BOD removal (gray color and shaggy appearance) while the slime on the later stages of the unit will have the characteristics of a nitrification slime (reddish brown to golden color and shaggy appearance). The key advantage in using RBCs instead of trickling filters is that RBCs are easier to operate under varying load conditions, because it is easier to keep the solid medium wet at all times. Moreover, as stated above, the level of nitrification that can be achieved by an RBC system is significant—especially when multiple stages are employed.

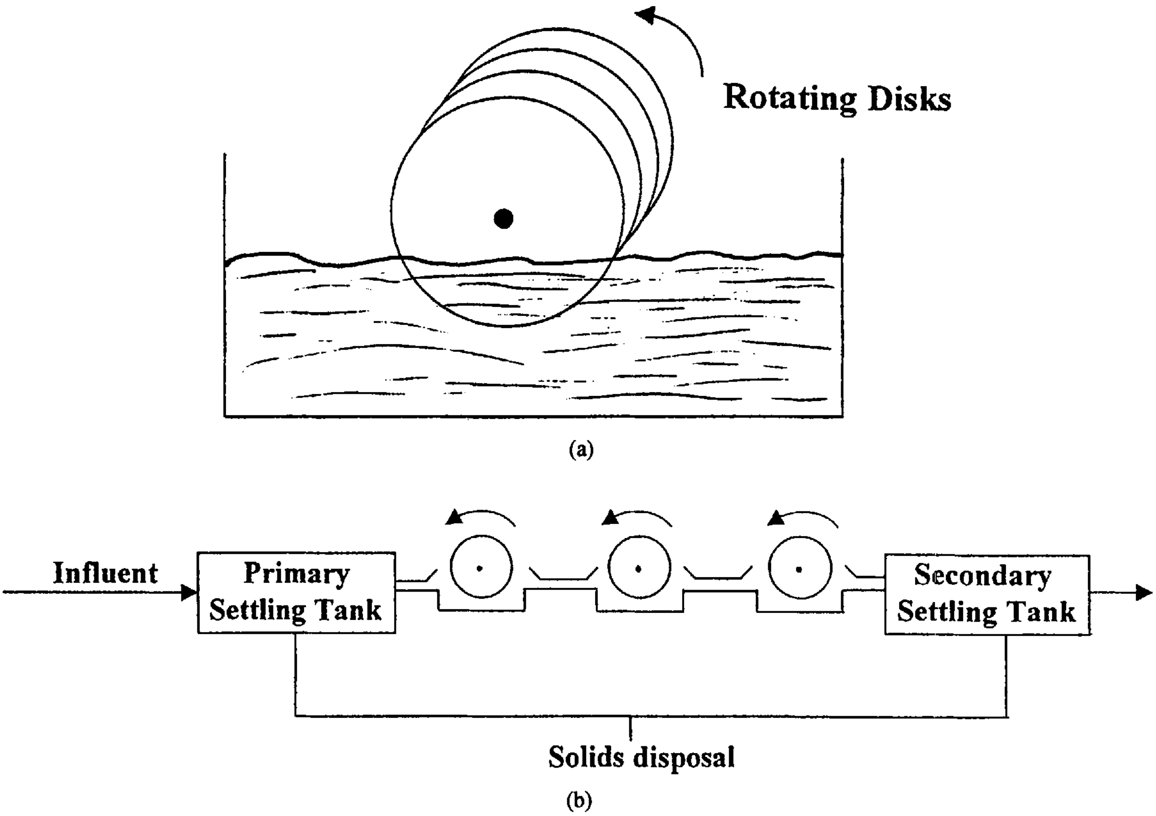


Figure 10.1 Rotating biological contactor (RBC): (a) RBC cross section; (b) RBC treatment system.

✓ *Note:* The RBC can withstand intermittent hydraulic overloading.

10.2 RBC EQUIPMENT

The equipment that makes up an RBC system includes the rotating biological contactor (the media: either standard or high density), a center shaft, drive system, tank, baffles, housing or cover, and a settling tank.

The rotating biological contactor consists of circular sheets of synthetic material (usually plastic) that are mounted side by side on a shaft. The sheets (media) contain large amounts of surface area for growth of the biomass.

The center shaft provides the support for the disks of media and must be strong enough to support the weight of the media and the biomass. Experience has indicated that a major problem has been the collapse of the support shaft.

The drive system provides the motive force to rotate the disks and shaft. The drive system may be mechanical or air driven or a combination of each. When the drive system does not provide uniform movement of the RBC, major operational problems can arise.

The tank holds the wastewater in which the RBC rotates. It should be large enough to permit variation of the liquid depth and detention time.

Baffles are required to permit proper adjustment of the loading applied to each stage of the RBC process. Adjustment can be made to increase or decrease the submergence of the RBC.

RBC stages are sensitive to cold and must be protected from normal outdoor weather condienclose individual stages in some type of protective structure (cover housing—in many instances, this housing greatly restricts access to the RBC) or to house a series of units in a suitable building with adequate ventilation.

The settling tank is provided to remove the sloughing material created by the biological activity and is similar in design to the primary settling tank. The settling tank provides two- to four-hour detention time to permit settling of lighter biological solids.

10.3 RBC OPERATION

It is important to note that manufacturers typically recommend RBC design criteria suited for secondary treatment of domestic wastewater designed to yield an effluent of less than 30 mg/L of BOD and 30 mg/L of suspended solids to meet regulatory requirements. Viessman and Hammer (1998, p. 564) point out that, in order to meet this yield (in larger installations), RBCs must be designed and operated to meet the following criteria:

(1) Average loading based on total RBC surface area should be 1.5 lb/1,000 ft^2/day of soluble BOD or 3.0 lb/1,000 ft^2/day of total BOD.
(2) Maximum loading on the first stage should be 6 lb/1,000 ft^2/day of soluble BOD or 12 lb/1,000 ft^2/day of total BOD.
(3) A temperature correction for additional RBC surface area of 15% should be made for each 5°F below a design wastewater temperature of 55°F.

During normal operation, operator vigilance is required to observe RBC movement, slime color, and appearance. However, if the unit is covered, observations may be limited to that portion of the media that can be viewed through the access door. Slime color and appearance can indicate process condition:

- Gray, shaggy, translucent slime growth indicates normal operation.
- Reddish brown to golden shaggy growth indicates nitrification is occurring.
- White, dull chalky appearance indicates high sulfur waste concentrations.
- No visible slime indicates severe temperature or pH changes.

Sampling and testing should be conducted daily for dissolved oxygen content and pH. BOD_5 and suspended solids testing should also be accomplished to aid in assessing performance.

In summary, the main operational duties for an RBC operator include inspecting the equipment, testing influent and effluent, observing the media, and correcting or reporting any equipment or operational problems.

✓ The highest organic loading in a rotating biological contactor train usually occurs on the first stage.

10.3.1 RBC: EXPECTED PERFORMANCE

The RBC normally produces a high-quality effluent:

BOD_5	85–95%
Suspended solids removal	85–95%

The RBC treatment process may also significantly reduce (if designed for this purpose) the levels of organic nitrogen and ammonia nitrogen.

TABLE 10.1. **RBC Troubleshooting Procedures.**

Observations	Cause	Solutions
White slime on most of the disc area	High hydrogen sulfide in influent	Aerate RBC or plant influent. Add sodium nitrate or hydrogen peroxide to influent. Reduce amount of septage accepted by plant.
	Septic influent	Aerate RBC influent. Add sodium nitrate or hydrogen peroxide to influent.
	First stage overloaded	Adjust baffles between stages 1 and 2 to increase fraction of total surface area in first stage.
Excessive sloughing (loss of slime)	Excessive pH variation	Implement/enforce pretreatment program. Install pH control equipment.
	Toxic influent	Implement/enforce pretreatment program. Equalize flow to acclimate organisms.
RBC rotation is uneven	Mechanical problem	Repair mechanical problem.
	Uneven growth	Increase rotational speed. Adjust baffles to decrease loading. Increase sloughing.
Solids accumulating in reactors	Inadequate pretreatment	Identify and correct grit removal problem. Identify and correct primary settling problem.
Shaft bearings running hot or failing	Inadequate maintenance	Follow manufacturer's recommendations.
Drive motor running hot	Inadequate maintenance	Follow manufacturer's recommendations.
	Improper chain drive alignment	Adjust alignment.

10.4 RBC: TROUBLESHOOTING PROCEDURES

Table 10.1 lists common operational problems, causes, and corrective actions for various RBC process problems.

✓ *Note:* Remember, a white filamentous growth in an RBC system, which results in poor BOD removal efficiency, is caused by septic wastewater.

10.5 RBC: PROCESS CONTROL CALCULATIONS

The following calculations are used primarily for RBC design but may be useful to monitor current operational conditions and for comparison with unit design.

10.5.1 SOLUBLE BOD

Due to the physical and biological processes occurring in the RBC process, it is sometimes helpful to determine what the influent soluble (dissolved) BOD_5 is. This can be determined in the laboratory by performing BOD_5 tests on a series of filtered RBC influent samples. It can also be estimated based upon the RBC influent suspended solids concentration and a k factor. This k factor is the result of research using either the plant influent BOD_5 or information found in wastewater treatment plant design references. It represents the approximate portion of the BOD_5 that comes from the degradation of organic solids in the suspended solids. The k factor must be provided as part of the given information, be determined experimentally in the laboratory, or be estimated based upon information found in design references. Typical k factors for domestic wastes are in the range of 0.5 to 0.7.

$$\text{soluble, BOD, mg/L} = \text{total BOD}_5 - (k \text{ factor} \times \text{inf TSS, mg/L}) \tag{10.1}$$

Example 10.1

Problem:

The influent BOD_5 is 150 mg/L, and the influent TSS is 182 mg/L. Using a *k* factor of 0.6, what is the influent soluble BOD_5?

Solution:

$$\begin{aligned} BOD_{soluble} &= 150\ \text{mg/L} - (0.6 \times 182\ \text{mg/L}) \\ &= 150\ \text{mg/L} - 109\ \text{mg/L} \\ &= 41\ \text{mg/L} \end{aligned}$$

10.5.2 RBC: HYDRAULIC LOADING RATE

The RBC media surface area is normally specified by the manufacturer, and the hydraulic loading rate is based on the media surface area, usually in square feet (ft^2). Simply put, hydraulic loading on an RBC is the amount of water being applied per square foot of media surface area. It is computed using the total flow being applied to the RBC (influent and recirculation). Hydraulic loading on an RBC can range from 1 to 3 gpd/ft^2.

$$\text{hydraulic loading, gpd/ft}^2 = \frac{\text{influent flow} \times 1{,}000{,}000\ \text{gal/MG}}{\text{total media area, ft}^2} \tag{10.2}$$

Example 10.2

Problem:

An RBC treats a primary effluent flow rate of 0.230 MGD. What is the hydraulic loading rate in gpd/ft^2 if the media surface area is 96,000 ft^2?

Solution:

$$\frac{230{,}000\ \text{gpd}}{96{,}000\ \text{ft}^2} = 2.40\ \text{gpd/ft}^2$$

10.5.3 RBC: TOTAL ORGANIC LOADING RATE

Organic loading can be expressed as total BOD loading in pounds per day per 1,000 square feet of media. This expression is normally abbreviated TOL. The actual values can then be compared with plant design specifications to determine the current operating condition of the system.

$$\text{TOL, lb BOD}_5\text{/day/1,000 ft}^2 =$$

$$\frac{\text{RBC influent total BOD}_5\text{, mg/L} \times \text{flow, MGD} \times 8.34\ \text{lb/mg/L/MG} \times 1{,}000}{\text{total RBC media area, ft}^2} \tag{10.3}$$

Example 10.3

Problem:

The RBC influent flow rate is 1.70 MGD and has a BOD_5 of 160 mg/L. The total media area for the RBC is 450,000 ft^2.

What is the TOL?

Solution:

$$\text{TOL} = \frac{160\ \text{mg/L} \times 1.70\ \text{MGD} \times 8.34\ \text{lb/mg/L/MG} \times 1{,}000}{450{,}000\ \text{ft}^2}$$

$$= 5.04\ \text{lb}/\text{BOD}_5/\text{day}/1{,}000\ \text{ft}^2$$

10.5.4 SOLUBLE ORGANIC LOADING (SOL)

The soluble organic loading (SOL) is defined as the pounds of soluble BOD_5 per 1,000 square feet of media per day.

$$\text{SOL, lb}/1{,}000\ \text{ft}^2 = \frac{\text{inf. soluble BOD, mg/L} \times \text{flow, MGD} \times 8.34\ \text{lb/mg/L/MG} \times 1{,}000}{\text{total media area, ft}^2} \quad (10.4)$$

Example 10.4

Problem:

Using the data provided, what is the soluble organic loading (SOL) in pounds of soluble BOD per day per 1,000 ft^2?

Solution:

Flow = 3.50 MGD
BOD_5, in = 190 mg/L
TSS, in = 160 mg/L
Total media area = 750,000 ft^2
k Factor = 0.7

$$\text{soluble BOD}_5 = 190\ \text{mg/L} - (160\ \text{mg/L} \times 0.7)$$

$$= 78\ \text{mg/L}$$

$$\text{SOL} = \frac{78\ \text{mg/L} \times 3.50\ \text{MGD} \times 8.34\ \text{lb/mg/L/MG} \times 1{,}000}{750{,}000\ \text{ft}^2}$$

$$= 3.04\ \text{lb SBOD}_5/\text{day}/1{,}000\ \text{ft}^2$$

10.5.5 TOTAL MEDIA AREA

The total media area in ft^2 is normally provided in the plant design specifications or Operations and Maintenance Manual. However, there are occasions when some of the information is provided but the total media area in ft^2 is not. When this is the case, to calculate the total media area provided by the RBCs, you must make this determination yourself by determining the total media area per stage.

$$\text{total media train, ft}^2 = \text{stage}_1 + \text{stage}_2 + \ldots + \text{stage}_n \text{ ft}^2 \tag{10.5}$$

If all stages have the same area, simplify to

$$\text{total media, ft}^2 = \text{number of stages} \times \text{media / stage, ft}^2 \tag{10.6}$$

Once the available media area per train is calculated, the total available media area is calculated by using Equation (10.5) or (10.6).

Example 10.5

Problem:

The RBC consists of two trains with six stages per train. Each stage has a media area of 110,000 ft^2. What is the total media area in the RBC system?

Solution:

$$\text{total media train} = 6 \text{ stages} \times 110{,}000 \text{ ft}^2\text{/stage}$$

$$= 660{,}000 \text{ ft}^2$$

$$\text{total media area, ft}^2 = 2 \text{ trains} \times 660{,}000 \text{ ft}^2\text{/train}$$

$$= 1{,}320{,}000 \text{ ft}^2$$

10.6 REFERENCE

Viessman, W. and Hammer, M. J., *Water Supply and Pollution Control,* 6th ed. Menlo Park, CA: Addison-Wesley, 1998.

10.7 CHAPTER REVIEW QUESTIONS

10-1 Why does the RBC perform at approximately the same performance levels throughout the year?

10-2 Describe the RBC.

10-3 Describe the process occurring in the RBC process.

10-4 Describe the appearance of the slime when the RBC is operating correctly.

10-5 Can an RBC be operated without primary settling?

10-6 The slime in the first stage of the RBC is gray and shaggy. The slime on the last two stages of the train is reddish brown. What does this indicate?

10-7 What does chalky white biomass indicate?

10-8 A rotating biological contactor (RBC) receives 2.70 MGD of primary effluent. The RBC has a total surface area of 500,000 square feet. What is the hydraulic loading in gallons per square foot per day?

10-9 Name two types of RBC media.

10-10 What makes the RBC similar to the trickling filter?

10-11 The RBC influent flow rate is 2.35 MGD and has a BOD_5 of 170 mg/L. The total media area for the RBC is 430,000 ft^2. What is the total organic loading in pounds of BOD_5 per day per 1,000 square feet of media?

10-12 The RBC influent flow rate is 2.90 MGD. The influent contains 205 mg/L BOD_5 and 176 mg/L suspended solids. The *k* factor for this waste was determined to be 0.65. The total media area for the RBC is 650,000 ft^2. What is the soluble organic loading in pounds of soluble BOD_5 per day per 1,000 square feet of media?

10-13 An RBC unit treats a flow rate of 0.40 MGD. The two shafts used provide a total surface area of 210,000 ft^2. What is the hydraulic loading on the unit in gpd/ft^2?

CHAPTER 11

Activated Sludge

11.1 INTRODUCTION

IN wastewater treatment, activated-sludge processes are used for both secondary treatment and complete aerobic treatment without primary sedimentation. Activated sludge refers to biological treatment systems that use a suspended growth of organisms to remove BOD_5 and suspended solids. The process requires aeration equipment, aeration and settling tanks, and return and waste activated sludge support equipment, such as pumps and flow measurement. Wastewater is fed continuously into an aerated tank, where the microorganisms metabolize and biologically flocculate the organics (see Figure 11.1). Microorganisms (activated sludge) are settled from the aerated mixed liquor under quiescent conditions in the final clarifier and are returned to the aeration tank. Clear supernatant from the final settling tank is the plant effluent.

✓ *Note:* Although trickling filters and other systems cost more to build than activated sludge systems, it is important to point out that activated sludge systems cost more to operate because of the need for energy to run pumps and blowers.

To better understand the explanation of the activated sludge process presented in the following sections, it is important to understand the terms associated with the process. These terms are identified and defined below:

- *Activated sludge* a floc or solid formed by the microorganisms. It includes organisms, accumulated food materials, and waste products from the aerobic decomposition process.
- *Food to microorganism ratio* a process control calculation used to evaluate the amount of food (BOD_5 or COD) available per pound of mixed liquor volatile suspended solids. This may be written as F/M ratio.
- *Mean cell residence time (MCRT)* the average length of time a mixed liquor suspended solids particle remains in the activated sludge process. This is usually written as MCRT. This may also be known as sludge retention rate (SRT).
- *Mixed liquor* the combination of return activated sludge and wastewater (either influent or primary effluent) that flows into the aeration tank.
- *Mixed liquor suspended solids* the suspended solids concentration of the mixed liquor. Many references use this concentration to represent the amount of organisms in the activated sludge process. This is usually written as MLSS.
- *Mixed liquor volatile suspended solids* the organic matter in the mixed liquor suspended solids. This can also be used to represent the amount of organisms in the process. This is

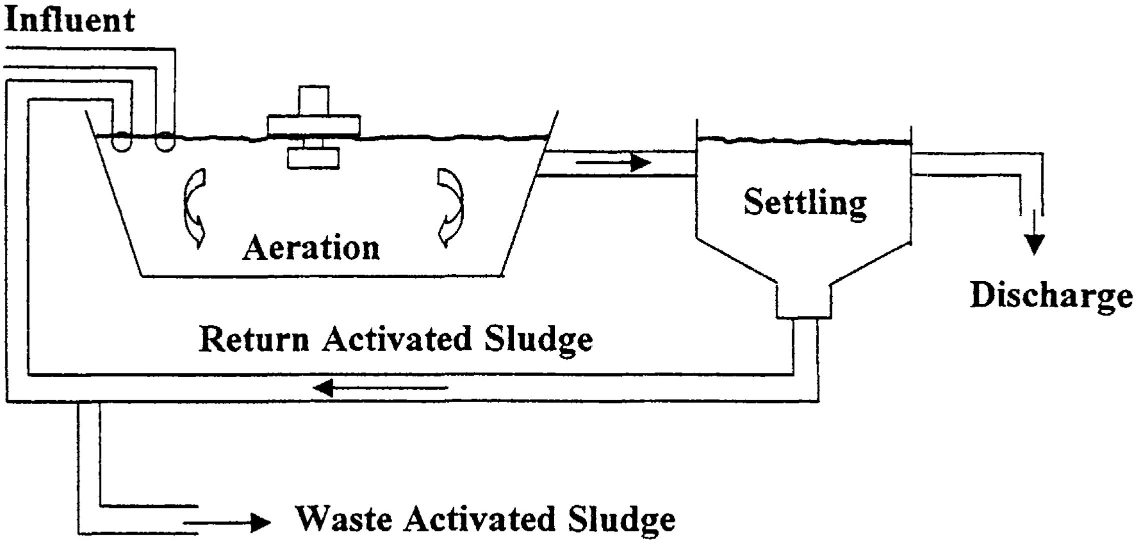


Figure 11.1 Activated sludge process (simplified).

- *Settleability* a process control test used to evaluate the settling characteristics of the activated sludge. Readings taken at 30 to 60 minutes are used to calculate the settled sludge volume (SSV) and the sludge volume index (SVI).
- *Settled sludge volume* the volume of mL/L (or percent) occupied by an activated sludge sample after 30 or 60 minutes of settling. Normally written as SSV with a subscript to indicate the time of the reading used for calculation (SSV_{30} or SSV_{60}).
- *Sludge volume index* a process control calculation that is used to evaluate the settling quality of the activated sludge. Requires the SSV_{30} and mixed liquor suspended solids test results to calculate.
- *Waste activated sludge* the solids being removed from the activated sludge process. This is normally written as WAS.

11.2 ACTIVATED SLUDGE PROCESS: PURPOSE

The activated sludge process is designed to remove BOD_5 and suspended matter through aerobic decomposition. Nitrogen and phosphorus may also be removed if process controls are properly adjusted.

✓ Removal of nutrients may require inclusion of anaerobic and/or anoxic stages.

11.3 ACTIVATED SLUDGE PROCESS: DESCRIPTION OF OPERATION

As stated previously, activated sludge processes may or may not follow primary treatment. The need for primary treatment is determined by the process modification selected for use. However, all activated sludge systems include a settling tank following the aeration basin. For our purposes, we use Figures 11.1 and 11.2 to assist in explaining the process. As indicated in Figure 11.2, the key biological unit in the process is the aeration tank, which receives effluent from the primary clarifier. It also receives a mass of recycled biological organisms from the secondary settling tank; this is known as *activated sludge.* To maintain aerobic conditions, air or oxygen is pumped into the tank via blowers, and the mixture is kept thoroughly agitated by mixers. After about six to eight hours of agitation, the wastewater (*mixed liquor*) flows into the secondary settling tank where the solids, mostly bacterial masses, are separated from the liquid by subsidence. A portion of those solids is returned to the aeration tank to maintain the proper bacterial population there, while the remainder must be processed and disposed of.

Let's take a look at the activated sludge process presented in a more straightforward, simplified manner.

In the activated sludge process, wastewater (primary effluent or plant influent) is mixed with return activated sludge (RAS). The mixture is known as mixed liquor. The mixed liquor is aerated for a specified length of time. Activated sludge organisms feed on the available organic matter (primary feeders are bacteria; secondary feeders are holozoic protozoans—see Figure 11.3). The process produces stable solids and more organisms. The quantity of solids and organisms (activated sludge) in the system increases. Activated sludge is separated from the wastewater by settling. Settled activated sludge solids are returned to the head of the process. Excess activated sludge solids are removed from the system (waste activated sludge—see Figure 11.1).

There are a number of factors that affect the performance of an activated sludge system. These are listed as follows:

- temperature
- return rates
- amount of oxygen available
- amount of organic matter available
- pH
- waste rates
- aeration time
- wastewater toxicity

To obtain the desired level of performance in an activated sludge system, a proper balance must be maintained between the amount of food (organic matter), organisms (activated sludge), and oxygen (dissolved oxygen, DO). The majority of problems with the activated sludge process result from an imbalance between these three items.

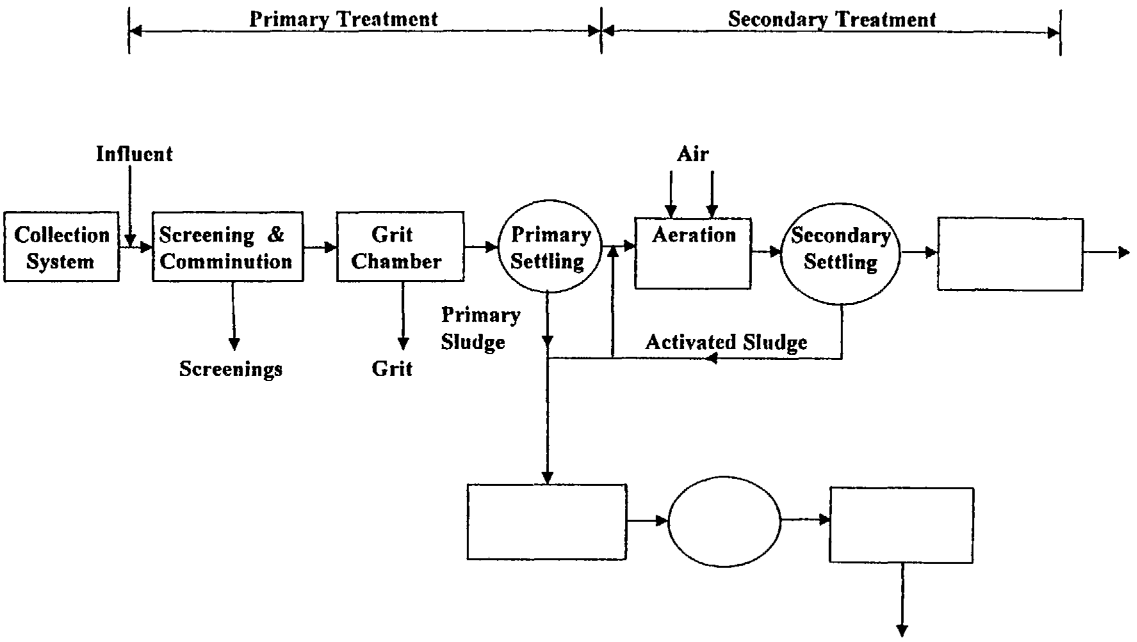


Figure 11.2 Activated sludge process.

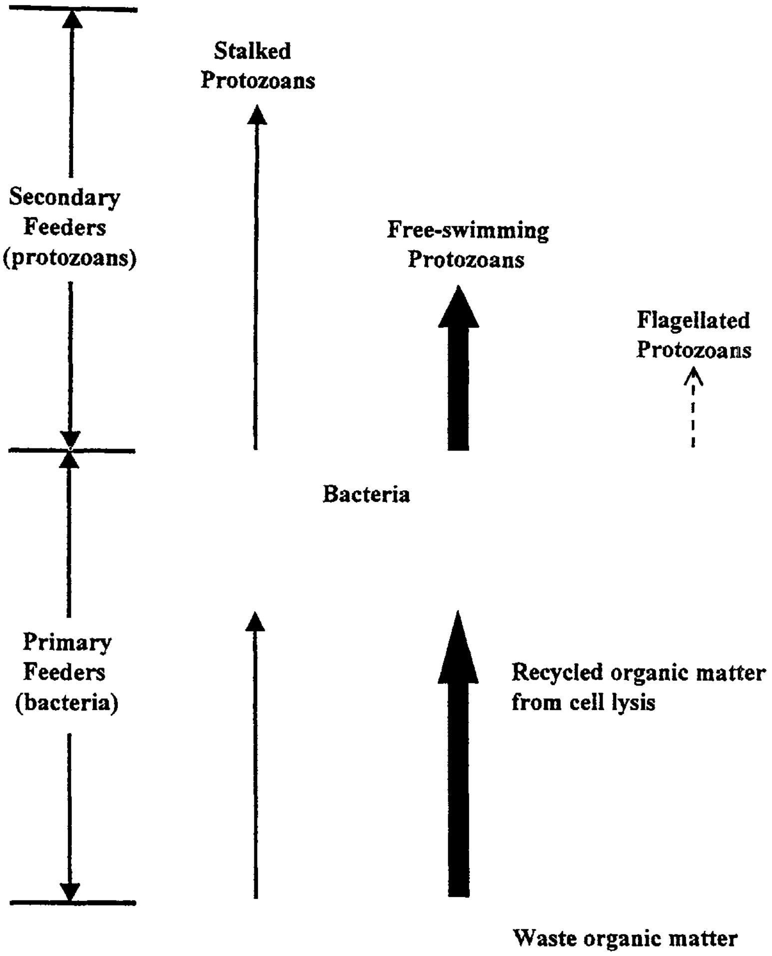


Figure 11.3 Schematic diagram of the population dynamics in activated sludge. *Source:* Adapted from Viessman and Hammer, 1998, p. 532.

The actual operation of an activated-sludge system is regulated by three factors: (1) the quantity of air supplied to the aeration tank; (2) the rate of activated-sludge recirculation; and (3) the amount of excess sludge withdrawn from the system. Sludge wasting is an important operational practice because it allows the operator to establish the desired concentration of MLSS, food/microorganism ratio, and sludge age.

✓ *Note:* Activated sludge is truly an aerobic treatment process because the biological floc particles are suspended in a liquid medium containing dissolved oxygen.

✓ *Note:* Air requirements in an activated sludge basin are governed by (1) BOD loading and the desired removal effluent; (2) volatile suspended solids concentration in the aerator; and (3) suspended solids concentration of the primary effluent.

11.4 ACTIVATED SLUDGE PROCESS: EQUIPMENT

The equipment requirements for the activated sludge process are more complex than the other processes discussed. Equipment includes an aeration tank, aeration, system settling tank, return sludge, and waste sludge.

11.4.1 AERATION TANK

The aeration tank is designed to provide the required detention time (depends on the specific modification) and to ensure that the activated sludge and the influent wastewater are thoroughly mixed. Tank design normally attempts to ensure no dead spots are created.

11.4.2 AERATION

The aeration system provides oxygen and energy for mixing; it can be mechanical or diffused. Mechanical aeration systems use agitators or mixers to mix air and mixed liquor. Some systems use sparge ring to release air directly into the mixer.

Diffused aeration systems use pressurized air released through diffusers near the bottom of the tank. Efficiency is directly related to the size of the air bubbles produced. Fine bubble systems have a higher efficiency. The diffused air system has a blower to produce large volumes of low pressure air (5 to 10 psi), air lines to carry the air to the aeration tank, and headers to distribute the air to the diffusers, which release the air into the wastewater.

11.4.3 SETTLING TANK

Activated sludge systems are equipped with plain settling tanks designed to provide two to four hours of hydraulic detention time.

11.4.4 RETURN SLUDGE

The return sludge system includes pumps, a timer or variable speed drive to regulate pump delivery, and a flow measurement device to determine actual flow rates.

11.4.5 WASTE SLUDGE

In some cases, the waste activated sludge withdrawal is accomplished by adjusting valves on the return system. When a separate system is used, it includes pump(s), a timer or variable speed drive, and a flow measurement device.

11.5 ACTIVATED SLUDGE PROCESS: MODIFICATIONS

Many activated sludge process modifications exist. Each modification is designed to address specific conditions or problems. The modifications discussed in this handbook are

- conventional activated sludge
- step aeration
- complete mix
- pure oxygen
- contact stabilization activated sludge
- extended aeration activated sludge
- oxidation ditch activated sludge

11.5.1 CONVENTIONAL ACTIVATED SLUDGE

- When the conventional activated sludge modification is employed, primary treatment is required.

- Excellent treatment is provided; however, large aeration tank capacity is required, and construction costs are high.
- In operation, initial oxygen demand is high. Moreover, the process is very sensitive to operational problems (e.g., bulking).

11.5.2 STEP AERATION

- requires primary treatment
- provides excellent treatment
- operates on similar characteristics as conventional
- distributes organic loading by splitting influent flow
- reduces oxygen demand at the head of the system
- reduces solids loading on settling tank

11.5.3 COMPLETE MIX

- may or may not include primary treatment
- distributes waste, return, and oxygen evenly throughout tank
- aeration may be more efficient
- maximizes tank use
- permits a higher organic loading

11.5.4 PURE OXYGEN

- requires primary treatment
- permits higher organic loading
- uses higher solids levels
- operates at higher F:M ratios
- uses covered tanks
- potential safety hazards (pure oxygen)
- oxygen production is expensive

11.5.5 CONTACT STABILIZATION

- Contact stabilization does not require primary treatment.
- During operation, organisms collect organic matter (during contact).
- Solids and activated sludge are separated from flow via settling.
- Activated sludge and solids are aerated for three to six hours (stabilization).

✓ *Note:* Return sludge is aerated before it is mixed with influent flow.

- The activated sludge oxidizes available organic matter.
- While the process is complicated to control, it requires less tank volume than other modifications and can be prefabricated as a package unit for flows of 0.05 to 1.0 MGD.
- A disadvantage is that common process control calculations do not provide usable information.

11.5.6 EXTENDED AERATION

- does not require primary treatment

- used frequently for small flows, such as schools and subdivisions
- uses 24-hour aeration
- produces low BOD_5 effluent
- produces the least amount of waste activated sludge
- process is capable of achieving 95% or more removals of BOD_5
- can produce effluent low in organic and ammonia nitrogen

11.5.7 OXIDATION DITCH

- does not require primary treatment
- is similar to the extended aeration process

11.6 AERATION TANK OBSERVATIONS

Wastewater operators are required to monitor or to observe the performance of treatment unit processes to ensure optimum performance and to make adjustments when required. In monitoring the operation of an aeration tank, there are three physical parameters that the operator should look for (turbulence, surface foam and scum, and sludge color and odor) that aid in determining how the process is operating and indicate if any operational adjustments need to be made. Let's take a look at a few of these parameters.

11.6.1 TURBULENCE

Normal operation of an aeration basin includes a certain amount of turbulence. This turbulent action is, of course, required to ensure a consistent mixing pattern. However, whenever excessive, deficient, or non-uniform mixing occurs, adjustments may be necessary to air flow, or diffusers may need cleaning or replacement.

11.6.2 SURFACE FOAM AND SCUM

The type, color, and amount of foam or scum present may indicate the required wasting strategy to be employed. Types of foam include

- *Fresh, crisp, white foam*—a moderate amount of a crisp, white foam is usually associated with activated sludge processes that are producing an excellent final effluent. Adjustment: None, normal operation.
- *Thick, greasy, dark tan foam*—a thick greasy dark tan or brown foam or scum normally indicates an old sludge that is over-oxidized. Adjustment: Indicates old sludge, more wasting required.
- *White billowing foam*—large amounts of a white, soap suds-like foam, indicate a very young under-oxidized sludge. Adjustment: Young sludge, less wasting required.

11.6.3 SLUDGE COLOR AND ODOR

Though not as reliable an indicator of process operations as foam, sludge color and odor are useful indicators. Colors and odors that are important include

(1) *Chocolate brown, earthy odor* indicates normal operation.
(2) *Light tan or brown/no odor* indicates sand and clay from infiltration/inflow. Adjustment: extremely young sludge, decrease wasting.

(3) *Dark brown/earthy odor* indicates old sludge, high solids. Adjustment: increase wasting.
(4) *Black color/rotten egg odor* indicates septic conditions. Adjustment: increase aeration.

11.7 FINAL SETTLING TANK (CLARIFIER) OBSERVATIONS

Settling tank observations include flow pattern (normally uniform distribution), settling, amount and type of solids leaving with the process effluent (normally very low), and the clarity or turbidity of the process effluent (normally very clear).

Observations should include the following conditions:

(1) *Sludge bulking*—occurs when solids are evenly distributed throughout the tank and leaving over the weir in large quantities.
(2) *Sludge solids washout*—sludge blanket is down, but solids are flowing over the effluent weir in large quantities. Control tests indicate a good quality sludge.
(3) *Clumping*—large "clumps" or masses of sludge (several inches or more) rise to the top of the settling tank.
(4) *Ashing*—fine particles of gray to white material flowing over the effluent weir in large quantities.
(5) *Straggler floc*—small, almost transparent, very fluffy, buoyant solids particles (1/8″ to 1/4″ diameter rising to the surface). Usually is accompanied by a very clean effluent. Usually new growth, most noted in the early morning hours. Sludge age is slightly below optimum.
(6) *Pin floc*—very fine solids particles (usually less than 1/32″ in diameter) suspended throughout lightly turbid liquid. Usually the result of an over-oxidized sludge.

✓ *Note:* Settled activated sludge is generally thinner than raw sludge.

11.8 PROCESS CONTROL TESTING AND SAMPLING

Process control testing may include settleability testing to determine the settled sludge volume; suspended solids testing to determine influent and mixed liquor suspended solids; return activated sludge solids and waste activated sludge concentrations; determination of the volatile content of the mixed liquor suspended solids; dissolved oxygen and pH of the aeration tank; BOD_5 and/or COD of the aeration tank influent and process effluent; and microscopic evaluation of the activated sludge to determine the predominant organism.

The following sections describe most of the common process control tests.

11.8.1 pH

pH is tested daily with a sample taken from the aeration tank influent and process effluent. pH is normally close to 7.0 (normal) with the best pH range from 6.5 to 8.5 (however, a pH range of 6.5 to 9.0 is satisfactory). Keep in mind that the effluent pH may be lower because of nitrification.

11.8.2 TEMPERATURE

Temperature is important because it forecasts the following:

- temperature increases: organism activity increases, aeration efficiency decreases, and oxygen solubility decreases

- temperature decreases: organism activity decreases, aeration efficiency increases, and oxygen solubility increases

11.8.3 DISSOLVED OXYGEN

Content of dissolved oxygen (DO) in the aeration process is critical to performance. DO should be tested at least daily (peak demand). Optimum is determined for individual plants, but normal is from 1 to 3 mg/L. If the system contains too little DO, the process will become septic. If it contains too much DO, energy and money are wasted.

11.8.4 SETTLED SLUDGE VOLUME (SETTLEABILITY)

Settled sludge volume (SSV) is determined at specified times during sample testing. Thirty- and 60-minute observations are used for control. Subscripts (SSV_{30} and SSV_{60}) indicate settling time. The test is performed on aeration tank effluent samples.

$$\mathrm{SSV} = \frac{\text{milliliters of settled sludge } 1{,}000 \text{ mL/L}}{\text{milliliters of sample}} \tag{11.1}$$

$$\%\,\mathrm{SSV} = \frac{\text{milliliters of settled sludge} \times 100}{\text{milliliters of sample}} \tag{11.2}$$

11.8.4.1 Interpretation

- "Normal" operation—When the process is operating properly, the solids will settle as a "blanket" (a mass) and there will be a crisp or sharp edge between the solids and the liquor above. The liquid over the solids will be clear with little or no visible solids remaining in suspension. Settled sludge volume at the end of 30 to 60 minutes will be in the range of 400 to 700 mL.
- "Old" or over-oxidized activated sludge—When the activated sludge is over-oxidized, the solids will settle as discrete particles. The edge between the solids and liquid will be fuzzy, and there will be a large number of visible solids (pin floc, ash floc, etc.) in the liquid. The settled sludge volume at the end of 30 or 60 minutes will be greater than 700 mL.
- "Young" or under-oxidized activated sludge—When the activated sludge is under-oxidized, the solids will settle as discrete particles, and the boundary between the solids and the liquid will be poorly defined. There will be large amounts of small visible solids suspended in the liquid. The settled sludge volume after 30 or 60 minutes will usually be less than 400 mL.
- Bulking activated sludge—When the activated sludge is experiencing a bulking condition, there will be very little or no settling observed.

✓ Running the settleability test with a diluted sample can assist in determining if the activated sludge is old (too many solids) or bulking (not settling). Old sludge will settle to a more compact level when diluted.

11.8.5 CENTRIFUGE TESTING

The centrifuge test provides a quick, relatively easy control test for the solids level in the aerator, but does not usually correlate with MLSS results. Results are directly affected by variations in sludge quality.

11.8.5.1 Sampling

Mixed liquor, return, and/or waste activated sludge samples can be tested. Use grab samples, and test as quickly as possible. The test uses a clinical centrifuge and 12.5 mL API centrifuge tubes (graduated in milliliters).

11.8.5.2 Procedure

(1) Fill the centrifuge tube to the line with well-mixed sample.
(2) Place the filled tubes in the centrifuge.
(3) Centrifuge at maximum speed for 15 minutes.
(4) Remove the tube, and read the solids content.
(5) Calculate the % solids volume.

$$\%\ \text{solids volume} = \frac{\text{solids, mL} \times 100}{\text{sample volume, mL}} \tag{11.3}$$

11.8.6 MICROSCOPIC EXAMINATION

The activated sludge process can't operate as designed without the presence of microorganisms. Thus, microscopic examination of an aeration basin sample, to determine the presence and the type of microorganisms, is important. Different species prefer different conditions; therefore, the presence of different species can indicate process condition.

✓ *Note:* It is important to point out that, during microscopic examination, identifying all organisms present is not required, but identification of the predominant species is required.

Table 11.1 lists process conditions indicated by the presence and population of certain microorganisms.

TABLE 11.1. Process Condition versus Organisms Present/Population.

Process Condition	Organism Population
Poor BOD_5, and TSS Removal Mainly dispersed bacteria No floc formation Very cloudy effluent	Predominance of amoeba and flagellates A few ciliates present
Poor Quality Effluent Dispersed bacteria Some floc formation Cloudy effluent	Predominance of amoeba and flagellates Some free-swimming ciliates
Satisfactory Effluent Good floc formation Good settleability Good clarity	Predominance of free-swimming ciliates Few amoeba and flagellates
High Quality Effluent Excellent floc formation Excellent settleability High effluent clarity	Predominance of stalked ciliates Some free-swimming ciliates A few rotifers A few flagellates
Effluent High TSS and Low BOD_5 High settled sludge volume Cloudy effluent	Predominance of rotifers Large numbers of stalked ciliates A few free-swimming ciliates No flagellates

11.8.6.1 Sampling

A grab sample of aeration tank mixed liquor should be used. The sample should be tested as quickly as possible.

11.8.6.2 Microscopic Examination Equipment and Procedure

To perform microscopic examination of the contents of the grab sample taken from the aeration basin, the following equipment is recommended:

Micro scope 10× (or higher) eye piece; 45× and 100× objective
Microscopic slides
Cover slips
Beakers: 50, 100 mL
Eyedroppers

Using the equipment listed above, the following procedure should be followed in examining the aeration basin sample.

(1) Using an eyedropper, transfer a small drop of well-mixed sample to the microscope slide.
(2) Carefully place a cover slip over the drop.
(3) Place the slide on the microscope.
(4) Adjust the lighting and rough and fine focus until the picture is clear.
(5) Slowly move the slide, and observe the microorganisms.
(6) Record all the organisms observed in each major category.
(7) Continue until the entire slide has been observed.
(8) Repeat for two additional slides.
(9) Count the number of organisms in each major category on each slide.
(10) Determine the average number of each organism identified.
(11) Determine the order of predominance.

11.8.6.2.1 Interpretation

Routine process control identification can be limited to the general category of organisms present. For troubleshooting more difficult problems, a more detailed study of organism distribution may be required. (The knowledge required to perform this type of detailed study is beyond the scope of this handbook.) The major categories of organisms found in activated sludge are

- protozoa
- rotifers
- filamentous organisms

✓ *Note:* Bacteria are the most important of the microorganisms in the activated sludge. They perform most of the stabilization/oxidization of the organic matter and are normally present in extremely large numbers. They are, however, not normally visible with a conventional microscope operating at the recommended magnification and are not included in the list of indicator organisms.

✓ *Note:* The presence of free-swimming and stalked ciliates, some flagellates, and rotifers found in mixed liquor indicate a balanced, good settling environment.

11.8.6.2.1.1 PROTOZOA

We stated earlier that protozoans are secondary feeders in the activated sludge process (secondary as feeders, but definitely, nonetheless, important to the activated sludge process). Their principal function is to remove (eat or crop) dispersed bacteria and help to produce a clear process effluent.

To help gain an appreciation for the role of protozoans in the activating sludge process, consider the following explanation.[1]

The activated sludge process is typified by the successive development of protozoa and mature floc particles. This succession can be indicated by the presence of the type of dominant protozoa. At the start of the activated process (or recovery from an upset condition), the amoebas dominate.

✓ *Note:* Amoebas have very flexible cell walls and move by shifting fluids within the cell wall. Amoebas predominate during process start-up or during recovery from severe plant upsets.

As the process continues, uninterrupted or without upset, small populations of bacteria begin to grow in logarithmic fashion, which, as the population increases, develop into mixed liquor. When this occurs, the flagellates dominate.

✓ *Note:* Flagellated protozoa typically have a single hair-like flagella or "tail," which is used for movement. The flagellate predominates when the MLSS and bacterial populations are low and organic load is high. As the activated sludge gets older and more dense, the flagellates will decrease until they are seldom noted.

When the sludge attains an age of about three days, lightly dispersed floc particles (flocculation: "grows" fine solids into larger, more settleable solids) begin to form, and there is an increase in bacteria. At this point, the free-swimming ciliates dominate.

✓ *Note:* The free-swimming ciliated protozoa have hair-like projections (cilia) that cover all or part of the cell. The cilia are used for motion and create currents that carry food to the organism. The free-swimming ciliates are sometimes divided into two sub-categories: free swimmers and crawlers. The free swimmers are usually seen moving through the fluid portion of the activated sludge, while the crawlers appear to be "walking" or "grazing" on the activated sludge solids. The free-swimming ciliated protozoa usually predominate when there is a large number of dispersed bacteria that can be used as food. Their predominance indicates a process that is nearing optimum conditions and effluent quality.

The process goes on with floc particles beginning to stabilize, taking on irregular shapes, and starting to show filamentous growth. At this stage, the crawling ciliates dominate. Eventually, mature floc particles develop and increase in size, and large numbers of crawling and stalked ciliates are present. When this occurs, the succession process has reached its terminal point.

The succession of protozoan and mature floc particle development just described details the occurrence of phases of development in a step-by-step progression. This is also the case when protozoan succession is based on other factors, such as dissolved oxygen and food availability.

Probably the best way in which to understand protozoan succession based on dissolved oxygen and food availability is to view the wastewater treatment plant's aeration basin as a "stream within a container." Using the *saprobity system* to classify the various phases of the activated sludge process

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[1] From F. R. Spellman, pp. 70–75.

in relation to the self-purification process that takes place in a stream, one is able to see a clear relationship between the two processes based on available dissolved oxygen and food supply.

Any change in the relative numbers of bacteria in the activated sludge process has a corresponding change to microorganisms population. Decreases in bacteria increase competition between protozoa and result in secession of dominant groups of protozoa.

The degree of success or failure of protozoa to capture bacteria depends on several factors. For example, those with more advanced locomotion capability are able to capture more bacteria. Individual protozoan feeding mechanisms are also important in the competition for bacteria. At the beginning of the activated sludge process, amoebas and flagellates are the first protozoan groups to appear in large numbers. They can survive on smaller quantities of bacteria because their energy requirements are lower than other protozoan types. Because few bacteria are present, competition for dissolved substrates is low. However, as the bacteria population increases, these protozoa are not able to compete for available food. This is when the next group of protozoa, the free-swimming protozoa, enter the scene.

The free-swimming protozoa take advantage of the large populations of bacteria because they are better equipped with food-gathering mechanisms than the amoebas and flagellates. The free swimmers are important not only because of their insatiable appetites for bacteria but also in floc formation. Secreting polysaccharides and mucoproteins that are absorbed by bacteria—which make the bacteria "sticky" through biological agglutination (biological gluing together)—allows them to stick together and, more important, to stick to floc. Thus, large quantities of floc are prepared for removal from secondary effluent and are either returned to aeration basins or wasted.

The crawlers and stalked ciliates succeed the free swimmers.

✓ *Note:* Stalked ciliated protozoa are attached directly to the activated sludge solids by a stalk. In some cases, the stalk is rigid and fixed in place, while in others the organism can move (contract or expand the stalk) to change its position. The stalked ciliated protozoa normally has several cilia, which are used to create currents that carry bacteria and organic matter to it. The stalked ciliated protozoa predominates when the dispersed bacteria population decreases and does not provide sufficient food for the free swimmers. Their predominance indicates a stable process that is operating at optimum conditions.

The free swimmers are replaced, in part because the increasing level of mature floc retards their movement. Additionally, the type of environment that is provided by the presence of mature floc is more suited to the needs of the crawlers and stalked ciliates. The crawlers and stalked ciliates also aid in floc formation by adding weight to floc particles, thus enabling removal.

11.8.6.2.1.2 ROTIFERS

Rotifers are a higher life form that is normally associated with clean, unpolluted waters. Rotifers are significantly larger than most of the other organisms observed in activated sludge and can use other organisms, as well as organic matter, as their food source. Rotifers are usually the predominant organisms when the activated sludge is over-oxidized. When the rotifer is the predominant organism, the effluent will usually be cloudy (pin or ash floc) and will have very low BOD_5.

11.8.6.2.1.3 FILAMENTOUS ORGANISMS

Filamentous organisms (bacteria, fungi, etc.) occur whenever the environment of the activated sludge favors their predominance. They are normally present in small amounts and provide the basic framework for floc formation. When the environmental conditions (i.e., pH, nutrient levels, DO, etc.) favor their development, they become the predominant organisms. When this occurs, they restrict settling, and the condition known as "bulking" occurs.

✓ *Note:* Microscopic examination of activated sludge is a useful control tool. In attempting to identify the microscopic contents of a sample, the operator should try to identify the predominant groups of organisms.

✓ *Note:* During microscopic examination of the activated sludge, the operator notices a predominance of amoebas. This indicates that the activated sludge is very young.

11.8.7 SLUDGE BLANKET DEPTH

Sludge blanket depth refers to the distance from the surface of the liquid to the solids-liquid interface or the thickness of the sludge blanket as measured from the bottom of the tank to the solids-liquid interface. An important part of the operator's sampling routine, this measurement is taken directly in the final clarifier. Sludge blanket depth is dependent upon hydraulic load, return rate, clarifier design, waste rate, sludge characteristics, and temperature. If all other factors remain constant, the blanket depth will vary with amount of solids in the system and the return rate; thus, it will vary throughout the day.

In checking the sludge blanket, a sludge blanket indicator is used. An important point to keep in mind when measuring sludge blanket depth is that there are many factors that can change the sludge blanket depth that are not indicators of process condition. It is best to establish a standard procedure for determining sludge blanket that eliminates as many of these factors as possible (i.e., perform the sludge blanket depth test at the same time each day and at the same point in the tank).

The optimum sludge blanket depth must be determined on a case-by-case basis. It is normally dependent on hydraulic loading, clarifier design, sludge quality, and temperature. When these factors remain constant, any blanket depth variation would be directly related to the amount of activated sludge in the system and the current return/waste rate. One benefit of using the sludge blanket depth as a control technique is its direct relationship to the potential for solids loss over the effluent weir.

11.8.8 SUSPENDED SOLIDS AND VOLATILE SUSPENDED SOLIDS

Suspended solids and volatile suspended solids concentrations of the mixed liquor (mixed liquor suspended solids—MLSS), the return activated sludge (RAS), and the waste activated sludge (WAS) are routinely sampled (using either grab or composite samples) and tested because they are critical to process control.

The results of the suspended and volatile suspended tests can be used directly or to calculate such process control figures as mean cell residence time (MCRT) or food to mass ratio (F:M). In most situations, increasing the MLSS will produce an older, more dense sludge, while decreasing MLSS, will produce a younger, less dense sludge.

✓ *Note:* Control of sludge wasting rate by constant MLVSS concentration involves maintaining a certain concentration of volatile suspended solids in the aeration tank.

✓ *Note:* The activated sludge aeration tank should be observed daily. Included in this daily observation should be a determination of the type and amount of foam, mixing uniformity, and color.

11.9 PROCESS CONTROLS

In the routine performance of their duties, wastewater operators make process control adjustments to various unit processes, including the activated sludge process. In the following, a summary is provided of the process controls routinely made to the activated sludge process and the result(s) that will occur from adjustment of each.

11.9.1 PROCESS CONTROL: RETURN RATE

(1) Condition: *Return rate too high*
   Result:
   - hydraulic overloading of aeration and settling tanks
   - reduced aeration time
   - reduced settling time
   - loss of solids over time

(2) Condition: *Return rate too low*
   Result:
   - septic return
   - solids buildup in settling tank
   - reduced MLSS in aeration tank
   - loss of solids over weir

11.9.2 PROCESS CONTROL: WASTE RATE

(1) Condition: *Waste rate too high*
   Result:
   - reduced MLSS
   - decreased sludge density
   - increased SVI
   - decreased MCRT
   - increased F:M ratio

(2) Condition: *Waste rate too low*
   Result:
   - increased MLSS
   - increased sludge density
   - decreased SVI
   - increased MCRT
   - decreased F:M ratio

✓ *Note:* When a high organic waste load reaches an activated sludge plant, the operator's first indicator is a decrease in DO residual in the aeration tank.

11.9.3 PROCESS CONTROL: AERATION RATE

(1) Condition: *Aeration rate too high*
   Result:
   - wasted energy

  - increased operating cost
  - rising solids
  - breakup of activated sludge

(2) Condition: *Aeration rate too low*

Result:

  - septic aeration tank
  - poor performance
  - loss of nitrification

✓ *Note:* Not supplying enough air to the aeration tank will cause turbidity of final effluent to increase.

11.10 TROUBLESHOOTING OPERATIONAL PROBLEMS

Without a doubt, the most important dual function performed by the wastewater operator is the identification of process control problems and the implementation of the appropriate actions to correct the problem(s). Field observations for monitoring an aeration system are the rates of wastewater influent, excess sludge wasting, and sludge recirculation; the dissolved-oxygen concentration in the mixed liquor; and the depth of the sludge blanket in the final clarifier. Laboratory tests are used to determine influent and effluent BOD, concentration of suspended solids in the return sludge, and the concentration of MLSS in the aeration tank. From these data, the operator should be able to determine whether or not the process is performing up to expectations. If not, then the operator should be able to utilize troubleshooting procedures to determine the causal factors and corrective action(s). In this section, typical aeration system operational problems are listed with their symptoms, causes, and the appropriate corrective actions required to restore the unit process to a normal or optimal performance level.

11.10.1 SYMPTOM 1

The solids blanket is flowing over the effluent weir (classic bulking). Settleability test shows no settling.

(1) *Cause:* Organic overloading

Corrective action: Reduce organic loading.

(2) *Cause:* Low pH

Corrective action: Add alkalinity.

(3) *Cause:* Filamentous growth

Corrective action: Add nutrients; add chlorine or peroxide to return.

(4) *Cause:* Nutrient deficiency

Corrective action: Add nutrients.

(5) *Cause:* Toxicity

Corrective action: Identify source; implement pretreatment.

(6) *Cause:* Overaeration

Corrective action: Reduce aeration during low flow periods.

11.10.2 SYMPTOM 2

(1) *Cause:* Billowing solids due to short circuiting
Corrective action: Identify short-circuiting cause and eliminate if possible.

11.10.3 SYMPTOM 3

Large amounts of small pin-head sized solids leaving settling tank.

(1) *Cause:* Old sludge
Corrective action: Reduce sludge age (gradual change is best); increase waste rate.
(2) *Cause:* Excessive turbulence
Corrective action: Decrease turbulence (adjust aeration during low flows).

11.10.4 SYMPTOM 4

Large amount of light floc (low BOD_5 and high solids) leaving settling tank.

(1) *Cause:* Extremely old sludge
Corrective action: Reduce age; increase waste.

11.10.5 SYMPTOM 5

Large amount of small translucent particles (1/16–1/8″) are leaving the settling tank.

(1) *Cause:* Rapid solids growth
Corrective action: Increase sludge age.
(2) *Cause:* Slightly young activated sludge
Corrective action: Decrease waste.

11.10.6 SYMPTOM 6

Solids settling properly but rise to surface within a short time. Many small (1/4″) to large (several feet) clumps of solids on surface of settling tank.

(1) *Cause:* Denitrification
Corrective action: Increase rate of return; adjust sludge age to eliminate nitrification.
(2) *Cause:* Overaeration
Corrective action: Reduce aeration.

11.10.7 SYMPTOM 7

Return activated sludge has a rotten egg odor.

(1) *Cause:* Return is septic
Corrective action: Increase aeration rate.
(2) *Cause:* Return rate is too low
Corrective action: Increase rate of return.

11.10.8 SYMPTOM 8

Activated sludge organisms die during a short time.

(1) *Cause:* Influent contained toxic material
Corrective action: Isolate activated sludge (if possible); return all available solids; stop wasting; increase return rate; implement pretreatment program.

11.10.9 SYMPTOM 9

Surface of aeration tank covered with thick, greasy foam.

(1) *Cause:* Extremely old activated sludge
Corrective action: Reduce activated sludge age; increase wasting; use foam control sprays.
(2) *Cause:* Excessive grease and oil in system
Corrective action: Improve grease removal; use foam control sprays; implement pretreatment program.
(3) *Cause:* Froth-forming bacteria
Corrective action: Remove froth-forming bacteria.

11.10.10 SYMPTOM 10

Large "clouds" of billowing white foam on the surface of the aeration tank.

(1) *Cause:* Young activated sludge
Corrective action: Increase sludge age; decrease wasting; use foam-control sprays.
(2) *Cause:* Low solids in aeration tank
Corrective action: Increase sludge age; decrease wasting; use foam-control sprays.
(3) *Cause:* Surfactants (detergents)
Corrective action: Eliminate surfactants; use foam-control sprays; add antifoam.

✓ In conducting troubleshooting, the operator should list the symptoms he or she observes. From this data list, it should become obvious to the operator not only what the probable cause is but also what the probable cause *is not*. Troubleshooting, then, is really nothing more than a process of elimination. For example, if the data list consists of the following observations and/or indications, the operator should be able, via process of elimination, to determine what the problem is.

- DO in aerator high
- sludge blanket in clarifier high
- return sludge flow low
- air lift control valve open
- blower normal

The problem? In this instance, the most likely cause is that the return sludge air lift is clogged.

Let's look at another situation—a typical low DO level problem in an activated sludge aeration tank with a diffused aeration system problem.

We list the observed data as follows:

- blower air rate output high
- organic load normal
- hydraulic load normal
- low turbulence throughout aeration tank

Two of these indicators should stick out like sore thumbs. First, the blower is running at too high an output rate. Why? Second, we are producing a lot of air, but have low turbulence. Obviously, we have a lot of air being generated, but it is not reaching the aeration tank. Thus, the aeration system piping must be leaking.

Let's look at an extended aeration facility problem. The data:

- dead spot on surface around one drop pipe
- blower normal
- flow normal for dry weather
- DO level normal
- drop pipe air control valves half open
- dead spot remains when drop pipe air control valve fully open

The problem: more than likely, the drop pipe is clogged.

✓ A final word on troubleshooting activated sludge systems. Before the troubleshooter (the operator) can expect to pursue a logical troubleshooting scheme in attempting to determine process problems, he or she must be well-versed in the factors that can adversely affect settleability of activated sludge. These factors include biological, chemical, as well as physical factors.

11.11 PROCESS CONTROL CALCULATIONS

As with other wastewater treatment unit processes, process control calculations are important tools used by the operator to optimize and control process operations. In this section, we review the most frequently used activated sludge calculations.

11.11.1 SETTLED SLUDGE VOLUME (SSV)

Settled sludge volume (SSV) is the volume that a settled activated sludge occupies after a specified time. The settling time may be shown as a subscript (i.e., SSV_{60} indicates the reported value was determined at 60 minutes). The settled sludge volume can be determined for any time interval; however, the most common values are the 30-minute reading (SSV_{30}) and 60-minute reading (SSV_{60}). The settled sludge volume can be reported as milliliters of sludge per liter of sample (mL/L) or as a percent settled sludge volume.

$$\text{settled sludge volume, mL/L} = \frac{\text{settled sludge volume, mL}}{\text{sample volume, L}} \tag{11.4}$$

✓ 1,000 mL = 1 L

$$\text{sample volume, L} = \frac{\text{sample volume in mL}}{\text{1,000 mL/L}} \tag{11.5}$$

$$\text{\% settled sludge volume} = \frac{\text{settled sludge volume, mL} \times 100}{\text{sample volume, mL}} \tag{11.6}$$

Example 11.1

Problem:

Using the information provided in the table, calculate the SSV_{30} and the % SSV_{60}.

Time	Millileters
Start	2,400
15 minutes	2,200
30 minutes	1,700
45 minutes	1,500
60 minutes	1,100

Solution:

$$\text{settled sludge volume } (SSV_{30}) = \frac{1{,}700\text{ mL}}{2.4\text{ L}} = 708\text{ mL/L}$$

$$\%\text{ settled sludge volume } (SSV_{60}) = \frac{1{,}100\text{ mL} \times 100}{2{,}400\text{ mL}} = 46\%$$

11.11.2 ESTIMATED RETURN RATE

There are many different methods available for estimation of the proper return sludge rate. A simple method described in the *Operation of Wastewater Treatment Plants: Field Study Training Program* (1986)—developed by the California State University, Sacramento—uses the 60-minute percent settled sludge volume. The % SSV_{60} can provide an approximation of the appropriate return activated sludge rate. The results of this calculation can then be adjusted based upon sampling and visual observations to develop the optimum return sludge rate.

✓ The % SSV_{60} must be converted to a decimal percent and total flow rate (wastewater flow and current return rate in million gallons per day must be used).

$$\text{estimated return rate, MGD} = (\text{influent flow, MGD} + \text{current return flow, MGD}) \times \%\ SSV_{60} \quad (11.7)$$

Assumes % SSV_{60} is representative.
Assumes return rate, in percent, equals % SSV_{60}.
Actual return rate is normally set slightly higher.

Example 11.2

Problem:

The influent flow rate is 4.0 MGD, and the current return activated sludge flow rate is 1.7 MGD. The SSV_{60} is 36%. Based upon this information, what should be the return sludge rate in million gallons per day (MGD)?

Solution:

$$\text{return, MGD} = (4.0\text{ MGD} + 1.7\text{ MGD}) \times 0.36 = 2.1\text{ MGD}$$

11.11.3 SLUDGE VOLUME INDEX

result in an increase in effluent suspended solids. As the SVI decreases, the sludge becomes more dense, settling is more rapid, and the sludge is becoming older. SVI is the volume in milliliters occupied by 1 g of activated sludge. The settled sludge volume, mL/L and the mixed liquor suspended solids (MLSS), mg/L are required for this calculation.

$$\text{sludge volume index (SVI)} = \frac{\text{SSV, mL/L} \times 1{,}000}{\text{MLSS mg/L}} \tag{11.8}$$

Example 11.3

Problem:

The SSV_{30} is 360 mL/L, and the MLSS is 2,325 mg/L. What is the SVI?

Solution:

$$\text{sludge volume index} = \frac{360\ \text{mL/L} \times 1{,}000}{2{,}325\ \text{mg/L}} = 155$$

SVI equals 155—what does this mean? It means that the system is operating normally with good settling and low effluent turbidity.

How do we know this? We know this because we compare the 155 result with the parameters listed below to obtain the expected condition (the result).

SVI Value	Expected Condition (indicates)
Less than 100	Old sludge—possible pin floc Effluent turbidity increasing
100–200	Normal operation—good settling Low effluent turbidity
Greater than 250	Bulking sludge—poor settling High effluent turbidity

11.11.4 WASTE ACTIVATED SLUDGE

The quantity of solids removed from the process as waste activated sludge is an important process control parameter with which operators need to be familiar and, more importantly, know how to calculate.

$$\text{waste, lb/day} = \text{WAS conc., mg/L} \times \text{WAS flow, MGD} \times 8.34\ \text{lb/MG/mg/L} \tag{11.9}$$

Example 11.4

Problem:

The operator wastes 0.40 MGD of activated sludge. The waste activated sludge has a solids concentration of 5,500 mg/L. How many pounds of waste activated sludge are removed from the process?

Solution:

$$\text{waste, lb/day} = 5{,}500\ \text{mg/L} \times 0.40\ \text{MGD} \times 8.34 = 18{,}348\ \text{lb/day}$$

11.11.5 FOOD TO MICROORGANISM RATIO (F/M RATIO)

The Food to Microorganism Ratio (F/M ratio) is a process control calculation used in many activated sludge facilities to control the balance between available food materials (BOD or COD) and available organisms (mixed liquor volatile suspended solids, MLVSS).

$$\text{F/M ratio} = \frac{\text{primary eff. COD/BOD mg/L} \times \text{flow MGD} \times 8.34\ \text{lb/mg/L/MG}}{\text{MLVSS mg/L} \times \text{aerator volume, MG} \times 8.34\ \text{lb/mg/L/MG}} \tag{11.10}$$

Typical F:M ratio for activated sludge processes is shown in the following:

Typical F:M Ratio (Activated Sludge Processes)

Process	$\frac{\text{lb BOD}_5}{\text{lb MLVSS}}$	$\frac{\text{lb COD}}{\text{lb MLVSS}}$
Conventional	0.2–0.4	0.5–1.0
Contact stabilization	0.2–0.6	0.5–1.0
Extended aeration	0.05–0.15	0.2–0.5
Oxidation ditch	0.05–0.15	0.2–0.5

Example 11.5

Problem:

Given the following data, what is the F:M ratio?

Primary effluent flow	2.0 MGD
Primary effluent BOD	140 mg/L
Primary effluent TSS	175 mg/L
Effluent flow	2.1 MGD
Effluent BOD	21 mg/L
Effluent TSS	14 mg/L
Aeration volume	0.60 MG
Settling volume	0.35 MG
MLSS	3,640 mg/L
MLVSS	2,750 mg/L
% Waste volatile	72%
Desired F/M	0.2

Solution:

$$\text{F/M ratio} = \frac{140\ \text{mg/L} \times 2.0\ \text{MGD} \times 8.34\ \text{lb/mg/L/MG}}{2{,}750\ \text{mg/L} \times 0.60\ \text{MG} \times 8.34\ \text{lb/mg/L/MG}}$$

$$= 0.17\ \text{lb BOD/lb MLVSS}$$

✓ If the MLVSS concentration is not available, it can be calculated if % volatile matter (% VM) of the mixed liquor suspended solids (MLSS) is known [see Equation (11.8)].

✓ *Note:* The "F" value in the F/M ratio for computing loading to an activated sludge process can be either BOD or COD.

Example 11.6

Problem:

The aeration tank contains 2,785 mg/L of MLSS. Laboratory tests indicate the MLSS is 64% volatile matter. What is the MLVSS concentration in the aeration tank?

Solution:

$$\text{MLVSS, mg/L} = 2{,}785\ \text{mg/L} \times 0.64 = 1{,}782\ \text{mg/L}$$

11.11.6 MEAN CELL RESIDENCE TIME (MCRT)

Mean cell residence time (MCRT) (sometimes called sludge retention time) is a process control calculation used for activated sludge systems. The MCRT calculation illustrated in Example 11.7 uses the entire volume of the activated sludge system (aeration and settling).

mean cell residence time, days =

$$\frac{[\text{MLSS mg/L} \times (\text{aeration vol., MG} + \text{clarifier vol., MG}) \times 8.34]}{[\text{WAS, mg/L} \times \text{WAS flow, MGD} \times 8.34) + (\text{TSS out, mg/L} \times \text{Flow} \times 8.34)]} \quad (11.12)$$

✓ Due to the length of the MCRT equation, the units for the conversion factor 8.34 have not been included. The dimensions for the 8.34 conversion factor are lb/mg/L/MG.

✓ *Note:* MCRT can be calculated using only the aeration tank solids inventory. When comparing plant operational levels to reference materials, it is important to determine which calculation the reference manual uses to obtain its example values.

Example 11.7

Problem:

Given the following data, what is the MCRT?

Influent flow	4.2 MGD
Influent BOD	135 mg/L
Influent TSS	150 mg/L
Effluent flow	4.2 MGD
Effluent BOD	22 mg/L
Effluent TSS	11 mg/L
Aeration volume	1.25 MG
Settling volume	0.65 MG
MLSS	3,300 mg/L
Waste rate	0.080 MGD
Waste conc.	6,000 mg/L
Desired MCRT	8.5 days

Solution:

$$\text{MCRT} = \frac{[3{,}300\text{ mg/L} \times (1.25\text{ MG} + 0.65) \times 8.34]}{[(6{,}000\text{ mg/L} \times 0.08\text{ MGD} \times 8.340) + (11\text{ mg/L} \times 4.2\text{ MGD} \times 8.34)]}$$

$$\text{MCRT} = 11.9\text{ days}$$

11.11.7 WASTE QUANTITIES (lb/day) USING MEAN CELL RESIDENCE TIME

The use of MCRT for process control requires the determination of the optimum range for MCRT values. This is accomplished by comparison of the effluent quality with MCRT values. When the optimum MCRT is established, the following calculation is used to determine the quantity of solids to be removed from the process.

$$\text{waste qty., lb/day} = \frac{\text{MLSS} \times (\text{aer., MG} + \text{clarifier, MG}) \times 8.34}{\text{desired MCRT}} - [\text{TSS}_{\text{out}}, \times \text{flow} \times 8.34] \quad (11.13)$$

Example 11.8

$$\text{waste qty., lb/day} = \frac{3{,}300\text{ mg/L} \times (1.5\text{ MG} + 0.50\text{ MG}) \times 8.34}{8.8\text{ days}} - [10\text{ mg/L} \times 4.0\text{ MGD} \times 8.34]$$

$$\text{waste qty., lb/day} = 5{,}921\text{ lb}$$

11.11.8 WASTE RATE IN MILLION GALLONS/DAY

When the quantity of solids to be removed from the system is known, the desired waste rate in million gallons or gallons per day can be determined. The unit used to express the rate (MGD, gpd, gpm) is a function of the volume of waste to be removed and the design of the equipment.

$$\text{waste, MGD} = \frac{\text{waste solids, pounds}}{\text{waste activated sludge concentration, mg/L} \times 8.34} \quad (11.14)$$

Example 11.9

Problem:

Based upon the calculation in Section 11.11.7, the operator must waste 5,921 lb of solids. What is the required waste rate in MGD?

Solution:

$$\text{waste, MGD} = \frac{5{,}921\text{ lb}}{6{,}000\text{ mg/L} \times 8.34}$$

$$= 0.118\text{ gal/MG}$$

11.11.9 WASTE RATE IN GALLONS PER DAY

$$\text{waste, gpd} = \text{waste rate, MGD} \times 1{,}000{,}000\ \text{gal/MG} \tag{11.15}$$

Example 11.10

Problem:

What is the required waste rate in gallons per day when the waste rate in million gallons per day is 0.088 MGD?

Solution:

$$\text{waste gpd} = 0.088\ \text{MGD} \times 1{,}000{,}000\ \text{gal/MG} = 88{,}000\ \text{gpd}$$

11.11.10 WASTE RATE IN GALLONS PER MINUTE

$$\text{waste, gpm} = \frac{\text{waste rate, MGD} \times 1{,}000{,}000\ \text{gal/MG}}{1{,}440\ \text{min/day}} \tag{11.16}$$

Example 11.11

Problem:

What is the waste rate in gallons per minute if the waste rate in million gallons per day is 0.088 MGD?

Solution:

$$\text{waste, gpm} = \frac{0.088\ \text{MGD} \times 1{,}000{,}000\ \text{gal/MG}}{1{,}440\ \text{min/day}} = 61\ \text{gpm}$$

11.12 SOLIDS CONCENTRATION: SECONDARY CLARIFIER

Solids concentration in the secondary clarifier can be assumed to be equal to the solids concentration in the aeration tank effluent. It may also be determined in the laboratory using a core sample taken from the secondary clarifier. The secondary clarifier solids concentration can be calculated as an average of the secondary effluent suspended solids and the return activated sludge suspended solids concentration.

11.13 ACTIVATED SLUDGE PROCESS RECORDKEEPING REQUIREMENTS

Wastewater operators soon learn that recordkeeping is a major requirement and responsibility of their jobs. Records are important (essential) for process control, for providing information on the cause of problems, for providing information for making seasonal changes, and for compliance with regulatory agencies. Records should include sampling and testing data, process control calculations, meter readings, process adjustments, operational problems and corrective action taken, and process observations.

11.14 REFERENCES

Kerri, K. et al., *Operation of Wastewater Treatment Plants: A Field Study Training Program,* vol. 2, 3rd ed. Sacramento, CA: California State University, 1986.

Spellman, F. R., *Microbiology for Water/Wastewater Operators.* Lancaster, PA: Technomic Publishing Co. Inc., 1997.

Viessman, W. and Hammer, M. J., *Water Supply and Pollution Control,* 6th ed. Menlo Park, CA: Addison-Wesley, 1998.

11.15 CHAPTER REVIEW QUESTIONS

11-1 Increasing the wasting rate will ____________ the MLSS concentration, ____________ the return concentration, ___________ the MCRT, the F/M ratio, and ___________ the SVI.

11-2 What two purposes does the air supplied to the aeration basin serve?

Use the following data table for review questions 11-3 through 11-7.

Plant influent	Flow	2.10 MGD
	BOD	230 mg/L
	TSS	370 mg/L
Primary effluent	Flow	2.10 MGD
Aeration tank influent	BOD	175 mg/L
	TSS	133 mg/L
Activated sludge process effluent (sec. process eff.)	Flow	2.10 MGD
	BOD	22 mg/L
	TSS	18 mg/L
Aeration tank	Volume	1,265,000 gal
	MLSS	2,780 mg/L
	MLVSS	1,860 mg/L
SSV test (settleability test)	Sample	2,000 mL
	30 Minutes	1,750 mL
	60 Minutes	1,050 mL
Waste activated sludge	Flow	0.090 MGD
	Solids	6,125 mg/L
	Volatile solids	4,105 mg/L
Return activated sludge	Flow	0.50 MGD
	Solids	5,785 mg/L
	Volatile solids	4,165 mg/L
Settling tank volume		882,000 gal
Desired F/M ratio		0.25 lb/lb
Desired MCRT		6.5 days

11-3 What is the mean cell residence time (MCRT) in days?

11-4 What is the food-to-microorganism (F/M) ratio?

11-5 What is the SSV_{60} mL/L?

11-6 Using the SSV_{60} in mL/L, what is the sludge volume index?

11-7 What must be done to decrease the SVI?

11-8 What is the liquid mixture of microorganisms and solids removed from the bottom of the settling tank called?

11-9 What is the mixture of primary effluent and return sludge called?

11-10 What are the three things that must be balanced to make the activated sludge process perform properly?

11-11 What is the major purpose of an activated sludge process?

11-12 Name two types of aeration devices used in the activated sludge process.

11-13 List three observations the operator should make as part of the daily operation of the activated sludge process.

11-14 A 2,100 mL sample of activated sludge is allowed to settle for 60 minutes. At the end of the 60 minutes, the sludge has settled 1,200 mL. What is the SSV_{60} of the sample?

11-15 An activated sludge sample has an MLSS concentration of 2,240 mg/L. The SSV_{30} of the sample is 425 mL/L. What is the sludge volume index of the sample?

11-16 The operator wastes 0.067 MGD of activated sludge. The WAS concentration is 8,180 mg/L. How many pounds of activated sludge solids have been removed from the process?

11-17 Which activated sludge process aerates the return sludge before mixing it with the influent flow?

11-18 A microscopic examination of the activated sludge reveals a predominance of rotifers. What process adjustment does this indicate is required?

11-19 Given the following data, calculate the desired pounds of mixed liquor suspended solids (MLSS) in the aeration tank. Data:

Primary effluent suspended solids = 125 mg/L
Influent flow = 2.2 MGD
Desired sludge age = 5.0 days
Aeration tank = 100 ft × 40 ft × 12 ft
Influent BOD = 230 mg/L
Effluent suspended solids = 14 mg/L

11-20 List three observations that would indicate the activated sludge was becoming old.

11-21 What are the major differences between the conditions known as bulking, rising, and ashing sludge?

11-22 Why is color a less reliable process indicator?

11-23 List the conditions you would expect to observe when the activated sludge system is operating normally.

11-24 Why is it important to select the same sample time and location each day?

11-25 What can cause the sludge blanket to increase?

11-26 Describe a device used to measure sludge blanket depth.

CHAPTER 12

Chemical Treatment

12.1 INTRODUCTION

IN the past, chemical addition (to effect chemical precipitation) was used to enhance the degree of suspended solids and BOD removal (1) where there were seasonal variations in the concentration of the wastewater, (2) where an intermediate degree of treatment was required, and (3) as an aid to the sedimentation process (Metcalf & Eddy, 1991, p. 303). Currently, the need to provide more complete removal of the organic compounds and nutrients (phosphorous and nitrogen) contained in wastewater has brought about renewed interest in chemical addition. Chemical organic compounds and nutrients are also used in wastewater treatment for disinfection (see Chapter 13) and odor control.

Chemical addition for disinfection is nothing new in water/wastewater treatment. We have been disinfecting water and wastewater (in some form or fashion) since the early 1900s. However, chemical odor control is a relatively new phenomenon in wastewater treatment.

New phenomenon? Why? Hasn't odor control always been a problem in treating wastewater?

Maybe. Maybe not. It depends. Remember, odor normally is not a problem until the neighbors complain.

Seems like a simplistic statement, doesn't it? Maybe even a bit ridiculous to some. But if you work in wastewater treatment, you know that this simplistic, ridiculous statement is very real indeed. In years past (mostly during the 1940s and 1950s and even more recently), wastewater treatment plants were built in outlying areas, away from towns and neighborhoods. Odor was not a problem in the early days because, in many locations, there were few neighbors living close to wastewater treatment plants. Thus, odor events were not a problem; few lived close to the plant to register complaints.

This is not the case today, of course. Urban sprawl has literally surrounded, if not engulfed, many of the older wastewater treatment plants—many that were once surrounded only by forest or wide open spaces. Encroachment of settlements close to the plant site precipitated complaints. Today, odor control in wastewater treatment is a growing industry. In fact, performing wastewater treatment operations without employing some type of odor control is rather difficult to do.

Though chemical addition is important for disinfection and/or odor control, this chapter is not about these two important topics. Instead, it is about chemical treatment for other purposes. Specifically, because chemical treatment is used most often for removal of phosphorous, most of the material contained in this chapter deals with chemical addition for phosphorous removal.

✓ *Note:* When handling any chemical substance, care and caution is advised. Consult the Material Safety Data Sheet (MSDS) for each chemical handled. Ensure guidelines for proper chemical handling and personal protective equipment (PPE) are followed closely.

12.2 PHOSPHORUS REMOVAL

Phosphorus can be removed from wastewater by the addition of certain mineral compounds that chemically react with the soluble phosphorus, converting it to an insoluble solid that is then removed by physical methods, such as sedimentation or filtration. Excellent removal of phosphorus can be obtained by these methods. Chemical removal can be used as a supplement—as an advanced waste treatment process following conventional treatment to enhance phosphorus, BOD, COD, and TSS removal to meet stringent regulatory effluent requirements. It can also be used in place of biological treatment.

12.3 CHEMICALS USED FOR PHOSPHORUS REMOVAL

Many different chemicals are used for wastewater treatment. The chemicals normally associated with phosphorus removal include many of the aluminum salts (aluminum sulfate, sodium aluminate, or aluminum chloride); iron salts (ferric chloride, ferric sulfate, ferrous sulfate, ferrous chloride); and lime (hydrated or quicklime).

✓ *Note:* Chemical treatment can occur as a separate treatment step following secondary (biological) treatment, or it can be combined with primary or secondary treatment processes. Keep in mind that, because biological treatment requires phosphorus, extra care must be taken to control chemical additions for phosphorus removal prior to biological treatment units.

The chemicals most commonly used for phosphorus removal and their chemical characteristics are shown in Table 12.1.

✓ *Note:* The precipitate in coagulation with alum is aluminum hydroxide.

When chemicals are added to wastewater to remove phosphorus, specific chemical reactions occur. These reactions change the phosphorus to a solid (precipitate), which then can be physically separated from the wastewater by settling and/or filtration.

In addition to using chemicals for phosphorus removal, many facilities use flocculent aids to improve solids separation. Flocculent aids can be chemical salts, like those already discussed, or organic compounds known as polymers. Polymers aid the flocculation of wastewater solids and improve settling. The dosage of these chemicals must be carefully controlled because they are expensive.

Polymers are cationic, anionic, or non-ionic. Cationic polymers have a positive charge and attract negatively charged solids. Anionic polymers have a negative charge and attract positively charged particles. Non-ionic polymers have no surface charge and attract particles by physical or chemical structure.

The theoretical dosage and reactions presented in this section must be considered a starting point for the investigation of various alternatives available for chemical removal of phosphorus. It is essential that this theoretical information be supplemented by extensive testing to determine

TABLE 12.1.

	Alum	Ferric Chloride	Lime
Formula	$Al_2(SO_4)_3 \cdot 14H_2O$	$FeCl_3$	CaO (Quicklime)
Molecular weight	594	162	56
Color	White	Dark brown	White
pH (1%)	3.5	2.0	12.4
Form	Dry crystals	Liquid	Dry solid
% Active ingredient	17%	35–45%	70–96%
Density	38 lb/ft^3	11.2 lb/gal	55 lb/ft^3

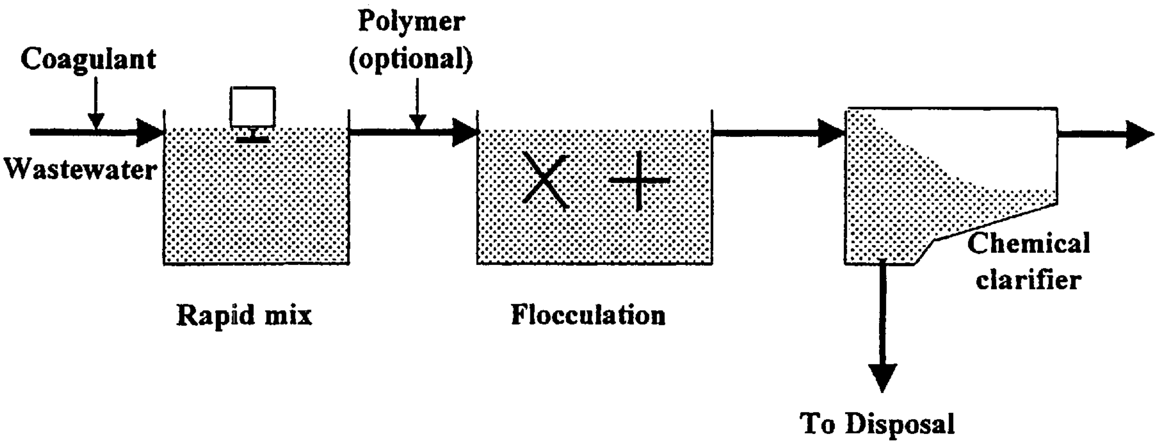

Figure 12.1 Schematic of rapid mix, flocculation and sedimentation system using separate basins.

- the best chemical for the specific waste being treated
- the optimum dosage of chemical
- the optimum conditions (pH, mixing, etc.)
- flocculation additives that may be necessary (polymer, acid, or base addition)

The most effective method for determination of this information is to perform jar tests using the wastes to be treated and the various chemicals under consideration. The procedure for performing a jar test is included in Section 12.7.

12.4 CHEMICAL TREATMENT PROCESS

Chemicals can be added at many different points throughout a treatment plant. For best results, however, chemical treatment should be a separate treatment step. When used as a separate step (or process), chemical treatment has three components or phases: rapid mix (coagulation), flocculation, and separation (see Figure 12.1).

12.4.1 RAPID MIX

In the rapid mix step, chemicals are added to the wastewater at the desired dose. Sufficient energy is supplied by means of mechanical mixers to distribute the chemical throughout the flow. During the rapid mix step, chemical reactions neutralize electrical charges on the solids particles of the wastewater. Prior to this neutralization, the solids particles would repel each other, keeping the solids in suspension and preventing formation of larger, more settleable solids. The neutralization of these charges allows the formation of small solids that form larger, more settleable solids when they collide. This chemical reaction is called precipitation or coagulation. Controlling factors in the rapid mix step are (1) maintaining the desired chemical dose and (2) providing the required mixing energy. The rapid mix step will usually have a very short hydraulic detention time (10 to 60 seconds) and be designed to avoid vortexing (drawing air into the mixture of chemical and wastewater).

12.4.2 FLOCCULATION

In the flocculation step, the solids formed during the rapid mix step are gently agitated. The slow, gentle mixing allows the solids to collide and form larger, more settleable solids. Flocculation normally requires a hydraulic detention time of approximately 20 minutes and mechanical mixers capable of providing gentle, continuous mixing of the entire contents of the flocculation unit. This is important because, if the solids particles are provided sufficient agitation, they will undergo multiple collisions and will grow the fine colloidal-sized particles formed in the rapid mix to large visible solids that can be easily removed by plain sedimentation.

12.4.3 SOLIDS SEPARATION

After flocculation, the solids must be removed from the flow. This can be accomplished using conventional settling tanks, tube settlers, gravity or pressure filtration systems, or microstrainers. In most instances, plant design will include settling to remove most of the solids, followed by filtration or microstraining to remove any remaining fine chemical solids.

12.5 CHEMICAL TREATMENT EQUIPMENT

Whether used as part of some other treatment process or as an individual treatment process, chemical addition requires special storage equipment, makeup tanks, mixers, metering devices, pumps, and appropriate personal protective equipment (PPE)—refer to the appropriate MSDS.

12.6 OPERATION PROCEDURES FOR CHEMICAL TREATMENT

Operation of chemical treatment equipment should be made in accordance with recognized operating procedures, manufacturers' recommendations, and/or plant standard operating procedures (SOP). Moreover, ensure all chemical addition operations are also in accordance with the plant's safe work practices.

The first step in normal operation of a chemical treatment process consists of chemical makeup. In some cases, the chemicals are supplied to the user in a ready-to-use mixture—the operator is only required to add the appropriate amount of this "ready mix" to the equipment. In other cases, chemical makeup may involve the mixing of ingredients before addition or after addition.

✓ *Note:* Care and caution are always advised whenever mixing chemicals.

Once the chemical makeup procedure is completed, the equipment can be put into operation. When this occurs, the operator's function shifts to the observation, adjustment, and maintenance mode. These duties should be performed on chemical feed, solids removal, and solids processing systems.

✓ *Note:* It is important to remember that maintenance of chemical inventories and control and maintenance of chemical storage areas are also often important operator responsibilities.

12.7 PROCESS CONTROL TESTING

Routine control testing provides the plant operator with a means to make process adjustments. The tests described in this section, combined with effluent testing and visual observations, should provide the operator with sufficient information to operate the facility at or near optimum values.

12.7.1 pH

Because all of the precipitation mechanisms have optimum pH ranges for their operation, there should be routine testing of the pH of the wastewater leaving the rapid mix basin.

pH should be determined using a pH meter and the appropriate electrode (high lime processes may require the use of a high pH electrode). The procedure should include standardization of the meter using the appropriate buffer prior to determining the pH of the wastes.

TABLE 12.2. Optimum Operating pH Range.

Chemical	Optimum pH Range
Alum	5.5–6.5
Iron salt (ferrous)	4.5–5.0
Iron salt (ferric)	8.0
Lime	>9.0

In many cases, the pH of the chemical treatment process must be maintained within a narrow range for optimum performance. The optimum pH range for alum, ferric iron salts, ferrous iron salts, and lime are shown in Table 12.2. In some cases pH adjustment may be required to achieve optimum performance.

12.7.2 JAR TESTING

The jar test has been used for many years by the water treatment industry. The test conditions are intended to reflect the normal operation of a chemical treatment facility. In this way, the type and quantity of sludge, as well as the physical properties of the floc, can be evaluated.

The test can be used to

- select the most effective chemical
- select the optimum dosage
- determine the value of a flocculant aid and the proper dose

The testing procedure requires a series of samples to be placed in testing jars (see Figure 12.2) and mixed at 100 rpm. Varying amounts of the process chemical or specified amounts of several flocculants are added (one volume/sample container). The mix is continued for one minute. Next, the mixing is slowed to 30 rpms to provide gentle agitation. Following gentle agitation, the floc is allowed to settle. The flocculation period and settling process are observed carefully to determine the floc strength, settleability, and clarity of the supernatant liquor. Additionally, the supernatant can be tested to determine the efficiency of the chemical addition for removal of TSS, BOD_5, and phosphorus.

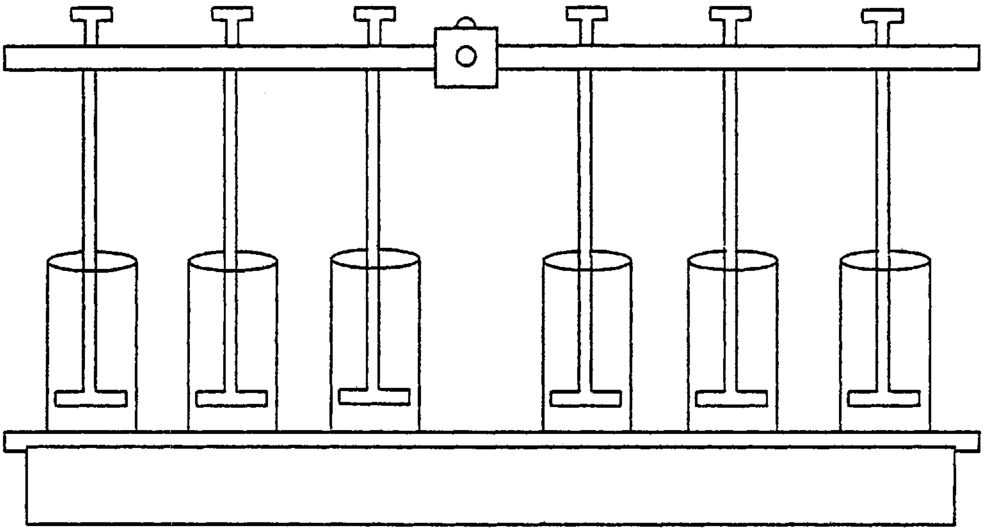

Figure 12.2 Jar test—variable speed paddle mixer.

The equipment required for the jar test includes a six-position variable speed paddle mixer (see Figure 12.2), six two-quart wide-mouth jars, an interval timer, and assorted glassware, pipets, graduates, and so forth.

12.7.2.1 Jar Testing Procedure

(1) Place an appropriate volume of wastewater sample in each of the jars (250 to 1,000 mL samples may be used depending upon the size of the equipment being used). Start mixers, and set for 100 rpms.
(2) Add previously selected amounts of the chemical being evaluated. (Initial tests may use wide variations in chemical volumes to determine the approximate range. This is then narrowed in subsequent tests.)
(3) Continue mixing for one minute.
(4) The mixer speed is then reduced to a gentle agitation (30 rpm), and the mixing is continued for 20 minutes. Again, time and mixer speed may be varied to reflect the facility.

- ✓ During this time, observe the floc formation, that is, how well the floc particles hold together during the agitation (floc strength).

(5) Turn off the mixer, and allow solids to settle for 20 to 30 minutes. Observe the settling characteristics, the clarity of supernatant, the settleability of the solids, the flocculation of the solids, and compactability of the solids.
(6) Perform phosphate tests to determine removals.
(7) Select the dose that provided the best treatment based upon the observations made during the analysis.

- ✓ After initial ranges and/or chemical selections are completed, repeat the test using a smaller range of doses to optimize performance.

12.8 TROUBLESHOOTING: RAPID MIXING AND FLOCCULATION

In chemical treatment for phosphorus removal, generally, it is the rapid mixing and flocculations steps where the operator must observe how well the entire process is performing. As with other treatment processes, chemical treatment systems can develop conditions where less than optimum performance is obtained. When this occurs, the operator needs to be able to determine through observation and testing where the problem lies. To assist the operator in troubleshooting chemical treatment systems, a basic troubleshooting chart is presented in Table 12.3. For further guidance in troubleshooting site-specific chemical treatment systems, consult the plant's Operations and Maintenance Manual or the manufacturer's technical manual.

12.9 PROCESS CONTROL CALCULATIONS

In most instances, the exact amount of pure chemical required to obtain the desired results is determined through laboratory jar tests. The following calculations are provided to convert the results of laboratory testing into application rates or feed rates.

12.9.1 DRY CHEMICAL FEED SYSTEM

TABLE 12.3. Troubleshooting: Rapid Mixing and Flocculation Systems.

Observations	Probable Cause	Solutions
Poor floc formation and settling characteristics	Chemicals not sufficiently dispersed during rapid mixing	Increase speed of rapid mixing device.
	Prolonged rapid mixing	Reduce rapid mixing time.
	Improper coagulant dosage	Correct coagulant dosage as per jar test results.
	Flocculator agitators operating at excessive speeds	Reduce flocculator agitator speed.
Good floc formation in flocculation basin but poor settleability in clarifier tank	Excessive velocity between flocculation unit and clarifier unit	Reduce velocity.
Clarifier sludge turning anaerobic	Sludge blanket present in clarifier	Increase sludge removal rate to remove sludge blanket and prevent its formation.
	Excessive carryover of organic solids from secondary process to chemical clarifier	Correct problems in secondary process.

of pure chemical required to achieve the desired results. The actual feed rate (pounds per day) of process chemical must be calculated using the current flow rate and the purity of the process chemical.

(1) Required feed, pounds per day (pure chemical)

$$\text{feed rate} = \text{dose, mg/L} \times \text{daily flow, MGD} \times 8.34\ \text{lb/mg/L/MG} \tag{12.1}$$

(2) Feed rate, pounds per day (process chemical)

$$\text{feed rate} = \frac{\text{dose, mg/L} \times \text{daily flow, MGD} \times 8.34\ \text{lb/mg/L/MG}}{\text{\% (decimal) active ingredient in process chemical}} \tag{12.2}$$

✓ This figure is then converted to the appropriate dry chemical feed rate (pounds/hour, pounds/minute, etc.) based upon the requirements of the plant's chemical feed system.

(3) Feed rate (pounds per hour) of process chemical

$$\text{feed rate} = \frac{\text{required chemical feed rate, lb/day}}{24\ \text{hr/day}} \tag{12.3}$$

(4) Feed rate (grams per minute) of process chemical

$$\text{feed rate} = \frac{\text{required chemical feed rate, lb/min}}{1{,}440\ \text{min/day}} \tag{12.4}$$

(5) Feed rate (grams per minute) of process chemical

$$\text{feed rate} = \frac{\text{required chemical feed rate, lb/day} \times 454\ \text{g/lb}}{1{,}440\ \text{min/day}} \tag{12.5}$$

12.9.2 SOLUTION FEED SYSTEMS

The calculation of the required feed rate of pure chemical is the same as that described for dry chemicals.

(1) Required feed, pounds per day (pure chemical)

$$\text{feed rate} = \text{dose, mg/L} \times \text{daily flow, MGD} \times 8.34\ \text{lb/mg/L/MG} \tag{12.6}$$

(2) Required feed, gallons per day (process chemical)

The required feed rate of liquid chemicals must take two factors into account:

- % active ingredient
- the weight of the chemical solution per gallon

$$\text{feed rate} = \frac{\text{dose, mg/L} \times \text{daily flow, MGD} \times 8.34\ \text{lb/mg/L/MG}}{\text{\% active ingredient in sol. chemical wt, lb/gal}} \tag{12.7}$$

✓ *Note:* If the weight per gallon is not available, it can be calculated using the specific gravity of the solution. Either the weight per gallon or specific gravity or both are normally provided in the manufacturer's literature or on the MSDS.

$$\text{weight, lb/gal} = \text{specific gravity} \times 8.34\ \text{lb/gal} \tag{12.8}$$

(3) Feed rate, gallons per hour

$$\text{feed rate} = \frac{\text{dose, mg/L} \times \text{daily flow, MGD} \times 8.34\ \text{lb/mg/L/MG}}{\text{\% active ingredient in sol.} \times \text{chemical wt, lb/gal} \times 24\ \text{hr/day}} \tag{12.9}$$

(4) Feed rate, gallons per minute

$$\text{feed rate} = \frac{\text{dose, mg/L} \times \text{daily flow, MGD} \times 8.34\ \text{lb/mg/L/MG}}{\text{\% act. ingred. in sol.} \times \text{chem. wt, lb/gal} \times 1{,}440\ \text{min day}} \tag{12.10}$$

(5) Feed rate (milliliters per minute)

$$\text{feed rate, mL/min} = \frac{\text{dose, mg/L} \times \text{flow, MGD} \times 8.34\ \text{lb/mg/L/MG} \times 3{,}785\ \text{mL/gal}}{\text{\% act. ingred. in sol.} \times \text{chemical wt, lb/gal} \times 1{,}440\ \text{min/day}} \tag{12.11}$$

12.9.3 SOLUTION MAKEUP

In many instances, chemicals are not received in ready-to-add form or in the proper concentration required for use. These chemicals must be properly prepared for use.

To determine the amount of chemical required to prepare a solution, the desired concentration of the final solution, the concentration of the chemical used for makeup, and the volume of chemical solution to be prepared must be known.

$$\text{volume}_{\text{makeup}} = \frac{\text{concentration}_{\text{working}} \times \text{volume}_{\text{working}}}{\text{concentration}_{\text{makeup}}} \tag{12.12}$$

12.9.4 SOLUTION MAKEUP FROM DRY CHEMICAL

To prepare chemical solutions from dry chemicals, you must know the

- volume of working solution being prepared
- % active ingredient in the working solution
- % active ingredient in the dry chemical

$$\text{required} = \frac{\%\text{ act. chem}_{\text{working}} \times \text{vol.}_{\text{working}}\text{ gal} \times 8.34\text{ lb/gal}}{\%\text{ act. chemical}_{\text{supply}}} \tag{12.13}$$

✓ All percents must be in decimal form.

12.10 REFERENCE

Metcalf & Eddy. *Wastewater Engineering: Treatment, Disposal, and Reuse,* 3rd ed. New York: McGraw-Hill, 1991.

12.11 CHAPTER REVIEW QUESTIONS

12-1 What are some of the reasons chemical addition might be used in a treatment plant?

12-2 List the three steps of a chemical treatment process.

12-3 List three chemicals used for phosphorus removal.

12-4 A jar test indicates that the optimum dose for ferric chloride is 19.0 mg/L. The average flow is 4.0 MGD, and the ferric chloride working solution contains 3.0 lb/gal of ferric chloride. What is the required feed rate of ferric chloride in gallons per minute?

12-5 Alum is added to the wastewater for chemical removal of phosphorus. The alum arrives at the plant in 100-lb bags and is 16% aluminum sulfate. The alum is dissolved to make up 1,000 gallons of a working solution containing 6% aluminum sulfate by weight. How many pounds of alum must be added to the working solution tank each day? The calculation is to be based on a single 1,000 gallon tank full of chemical.

12-6 Jar testing shows that phosphorus removal will require a 7.6 mg/L alum dose. The industrial grade chemical the plant uses is 36% alum. How many pounds per day of chemical are required to treat an average flow of 5.57 MGD?

12-7 Chemical treatment with ferric chloride is normally used to remove_______________.

12-8 Improper handling, storing, or preparing solutions of chemicals can cause_______________.

12-9 Required chemical coagulation doses are commonly determined by_______________.

Disinfection

13.1 INTRODUCTION

SEVERAL years ago, G. C. White^2 (arguably the guru of chlorination) stated, “Just as water is close to being a universal solvent, so chlorine is nearly a universal water treatment chemical” (p. 256).

We can take White’s statement a step further: “Just as water is close to being a universal solvent, so chlorine is nearly a universal water [and wastewater] treatment chemical.” This modified statement reflects chlorine’s actual use in water and wastewater treatment; it states the case more precisely and accurately—simply stated, chlorine has been the workhorse used in disinfecting both water and wastewater since the early 1900s. Because chlorine is used primarily in disinfecting water and wastewater, we commonly (as a matter of speaking on the topic) speak of water/wastewater disinfection, as “chlorination”—a substitute term used for the term disinfection.

The primary objectives of wastewater disinfection are to prevent the spread of disease and to protect potable water supplies, bathing beaches, receiving waters used for recreational sports, and shellfish growing areas. The importance of chlorination disinfection also includes an important useful feature that, according to G. C. White, is often overlooked: Wastewater disinfection has the useful feature or ability to serve as a monitor for the combined wastewater treatment processes. “If all the unit processes are not performing properly, the chlorination system will not be able to deliver an effluent that meets the NPDES discharge requirement” (p. 476).

Although chlorine is the workhorse used in disinfecting water and wastewater, there are alternatives to chlorine use. These alternatives include chlorine dioxide, ozonation, potassium permanganate, ultraviolet (UV) radiation systems, membrane processes, air stripping, and activated carbon adsorption. In this chapter, we focus on those disinfection processes that are most commonly used (at present) for disinfection: chlorination and dechlorination, ultraviolet (UV) irradiation, ozonation, and disinfection by bromine chloride.

13.2 CHLORINE DISINFECTION

Chlorination for disinfection, as shown in Figure 13.1, follows all other steps of treatment. The purpose of chlorination is to reduce the population of organisms in the wastewater to levels low enough to ensure that pathogenic organisms will not be present in sufficient quantities to cause disease when discharged.

✓ *Note:* Chlorine gas is heavier than air. Therefore, exhaust from a chlorinator room should be taken from floor level.

✓ The safest action to take in the event of a major chlorine container leak is to call the fire department.

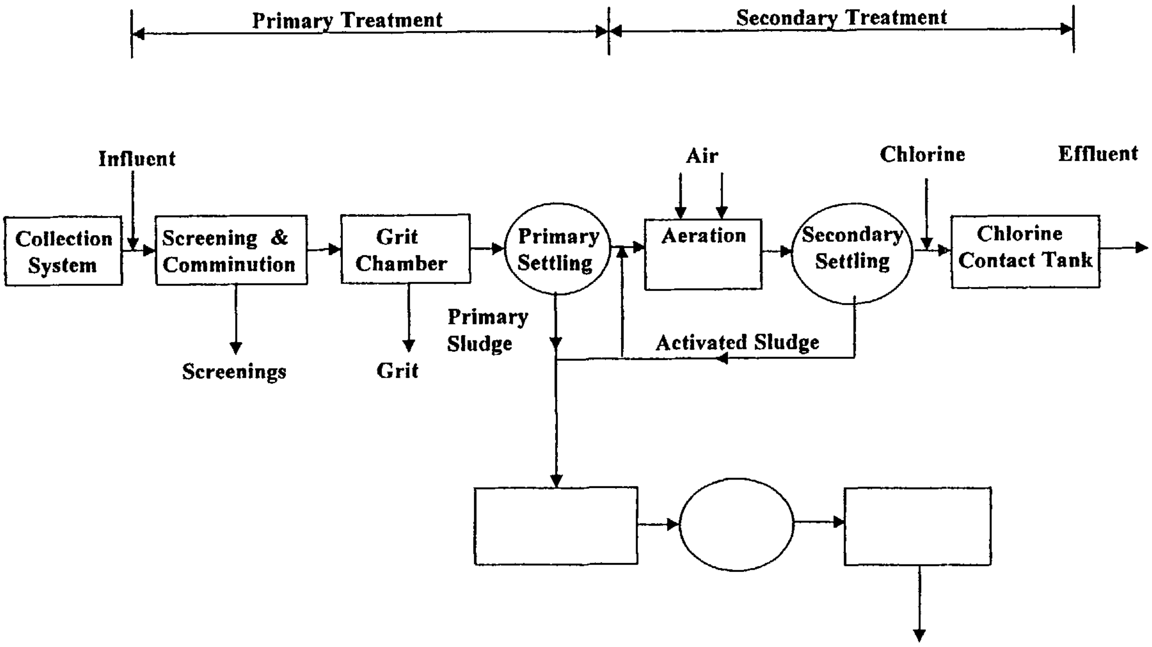

Figure 13.1 Disinfection.

13.2.1 CHLORINATION TERMINOLOGY

There are several terms used in discussion of disinfection by chlorination. It is important for the operator to be familiar with these terms.

- *Chlorine*—a strong oxidizing agent that has strong disinfecting capability. A yellow-green gas that is extremely corrosive and is toxic to humans in extremely low concentrations in air.
- *Contact time*—the length of time the disinfecting agent and the wastewater remain in contact.
- *Demand*—the chemical reactions that must be satisfied before a residual or excess chemical will appear.
- *Disinfection*—refers to the selective destruction of disease-causing organisms. All the organisms are not destroyed during the process. This differentiates disinfection from sterilization, which is the destruction of all organisms.
- *Dose*—the amount of chemical being added in milligrams/liter.
- *Feed rate*—the amount of chemical being added in pounds per day.
- *Residual*—the amount of disinfecting chemical remaining after the demand has been satisfied.

✓ *Note:* Chlorine residual may be determined using the reagent Diethyl-*p*-phenylene diamine (DPD).

- *Sterilization*—the removal of all living organisms.

✓ *Note:* Acids should never be added to chlorine solutions because they cause chlorine gas to be released.

13.2.2 CHLORINATION: PROCESS DESCRIPTION

Chlorine is a very reactive substance. It is added to wastewater to satisfy all chemical demands, that is, to react with certain chemicals (such as sulfide, sulfite, ferrous iron, etc.). The chlorine used by these reactions is chemically changed (reduced) and is no longer available for disinfection purposes. The chlorine used up in these reactions is known as chemical demand. Chlorine will also react with ammonia to produce chloramines (chemicals consisting of chlorine, nitrogen, and hydrogen). The chloramines have some disinfecting capability and show up in combined residual when performing a chlorine residual test. After all of the chemical demands are met, chlorine will react with water to form hypochlorous (HOCl) and hydrochloric (HCl) acids. The hypochlorous acid is the most effective form of chlorine for disinfection and is known as free residual. In most wastewater treatment plants, the chemicals present in the wastes make it impractical to try to achieve a free residual. For this reason, wastewater disinfection is usually accomplished using the combined residual. The process is controlled by monitoring the total residual chlorine (TRC). For most domestic wastes, disinfection requires a total residual chlorine concentration of ≥1.0 mg/L for at least 30 minutes at design flow. To ensure actual detention time is close to the calculated hydraulic detention time, most chlorine contact tanks are usually designed with baffling to prevent short-circuiting.

✓ *Note:* When the velocity of flow varies in different areas of a tank, short-circuiting may occur.

✓ *Note:* As water temperatures decrease, the disinfecting action of chlorine decreases.

Contact tanks normally are designed to provide a tank length to width ratio of ≥20:1 and depth to width ratio of 1:1 (see Figure 13.2).

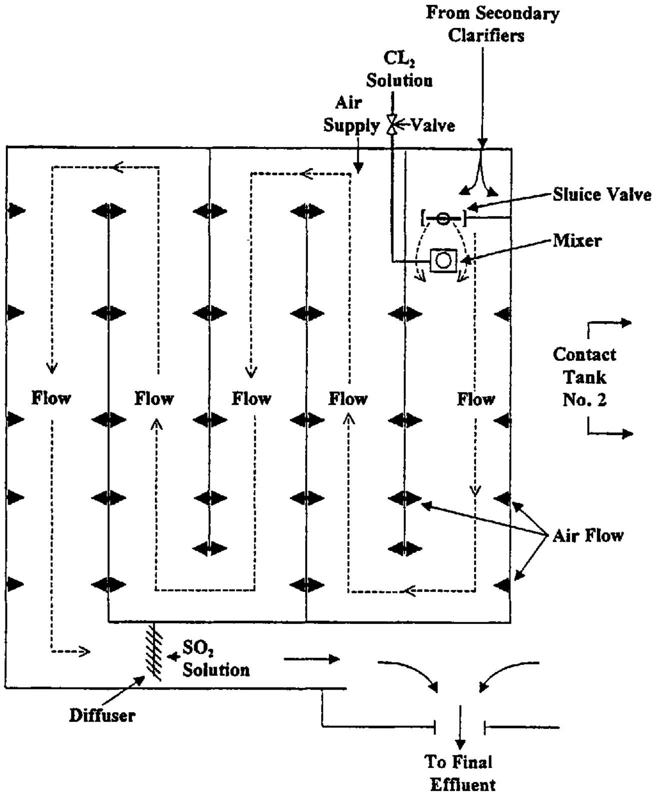

Figure 13.2 Disinfection contact basin.

✓ *Note:* Disinfection is affected by residual level, contact time, and effluent quality. Failure to maintain the desired residual levels for the required contact time will result in lower efficiency and increased probability that disease organisms will be discharged.

✓ *Note:* High solids in the effluent will require increased residual and/or detention time to achieve the desired level of organism destruction.

✓ *Note:* Failure of the chlorine solution pumps would result in higher effluent fecal coliform count (see Chapter 18).

13.2.3 CHLORINE DISINFECTION: ADVANTAGES/DISADVANTAGES

Chlorine disinfection has several advantages: cost, dependability, and predictable performance. Although increased safety and regulatory requirements have increased operational and liability costs, chlorine remains relatively inexpensive when compared with other disinfection methods.

Chlorination equipment has been used for years, and, as a result, designs are dependable. This reduces breakdowns and helps to ensure that, when problems do occur, minimal time will be required to identify and correct the problem.

The performance of the chlorine disinfection process is well documented and has an easy-to-use control mechanism (residual and contact time).

Chlorine disinfection also has disadvantages: environmental impact and potential in-plant hazards. Chlorine produces chloramines and other substances that are toxic to fish and aquatic organisms even when present in very low concentrations. Many of these compounds remain active in the receiving stream for very long periods. For this reason, many State Water Control Boards established chlorine water quality standards of total residual chlorine ≤ 0.011 mg/L in fresh waters and ≤ 0.0075 mg/L for chlorine-produced oxidants in saline waters.

✓ *Note:* Chloramines are combined chlorine.

Chlorine also produces by-products that are harmful to humans (trihalomethanes) and require additional treatment steps before the water can be re-used.

Because chlorine is an extremely toxic material, extra safety precautions, personal protective equipment, emergency response plans, considerable training time, and additional regulatory monitoring and reporting are required.

✓ *Note:* While chlorine is suitable as an inactivating agent and a primary disinfectant, its efficacy decreases with increasing pH; it is also affected by ammonia or organic nitrogen.

✓ *Note:* With the recent implementation of OSHA's Process Safety Management (PSM) Standard (29 CFR 1910.119) and USEPA's Risk Management Program (RMP—40 CFR Part 68) (which are quite rigorous and demanding), many water and wastewater facilities presently using chlorine, sulfur dioxide, ammonia, and other hazardous materials for treatment are either substituting these chemicals with non-hazardous materials or are contemplating substitution.[3]

✓ *Note:* Chlorine used in the disinfection process normally is in the form of hypochlorite (similar to that used for home swimming pools) or free chlorine gas.

✓ *Note:* An increase in organic matter increases chlorine demand.

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[3] From F. R. Spellman, 1997.

13.2.3.1 Chlorine Safe Work Practices

(1) Plant personnel *must* be trained and instructed on the use and handling of chlorine, chlorine equipment, chlorine emergency repair kits, and other chlorine emergency procedures.
(2) Use extreme care and caution when handling chlorine.
(3) Lift chlorine cylinders only with an approved and load-tested device.
(4) Secure chlorine cylinders into position immediately. *Never* leave a cylinder suspended.
(5) Avoid dropping chlorine cylinders.
(6) Avoid banging chlorine cylinders into other objects.
(7) Store chlorine one-ton cylinders in a cool dry place away from direct sunlight or heating units. Railroad tank cars are direct-sunlight compensated.
(8) Store chlorine one-ton cylinders on their sides only (horizontally).
(9) Do not stack unused or used chlorine cylinders.
(10) Provide positive ventilation to the chlorine storage area and chlorinator room.
(11) *Always* keep chlorine cylinders at ambient temperature. *Never* apply direct flame to a chlorine cylinder.
(12) Use the oldest chlorine cylinder in stock first.
(13) Always keep valve protection hoods in place until the chlorine cylinders are ready for connection.
(14) Except to repair a leak, do not tamper with the fusible plugs on chlorine cylinders.
(15) Wear SCBA whenever changing a chlorine cylinder and have at least one other person with a standby SCBA unit outside the immediate area.
(16) Inspect all threads and surfaces of chlorine cylinders.
(17) Use new lead gaskets each time a chlorine cylinder connection is made.
(18) Use only the specified wrench to operate chlorine cylinder valves.
(19) Open chlorine cylinder valves slowly, no more than one full turn.
(20) Do not hammer, bang, or force chlorine cylinder valves under any circumstances.
(21) Check for chlorine leaks as soon as the chlorine cylinder connection is made. Leaks are checked for by gently expelling ammonia mist from a plastic squeeze bottle filled with approximately two ounces of liquid ammonia solution. Do not put liquid ammonia on valves or equipment.
(22) Correct all minor chlorine leaks at the chlorine cylinder connection immediately.
(23) Except for automatic systems, draw chlorine from only one manifolded chlorine cylinder at a time. *Never* simultaneously open two or more chlorine cylinders connected to a common manifold pulling liquid chlorine. Two or more cylinders connected to a common manifold pulling gaseous chlorine is acceptable.
(24) Wear SCBA and chemical protective clothing covering face, arms, and hands before entering an enclosed chlorine area to investigate a chlorine odor or chlorine leak—two-person rule required.
(25) Provide positive ventilation to a contaminated chlorine atmosphere before entering whenever possible.
(26) Have at least two personnel present before entering a chlorine atmosphere: One person to enter the chlorine atmosphere, the other to observe in the event of an emergency. *Never* enter a chlorine atmosphere unattended. Remember, OSHA mandates that only fully qualified Level III HAZMAT responders are authorized to aggressively attack a hazardous materials leak such as chlorine.
(27) Use supplied-air breathing equipment when entering a chlorine atmosphere. *Never* use canister-type gas masks when entering a chlorine atmosphere.

(28) Ensure that supplied-air breathing apparatus has been properly maintained in accordance with the plant's Self-Contained Breathing Apparatus Inspection Guidelines as specified in the plant's Respiratory Protection Program.
(29) Stay upwind from all chlorine leak danger areas unless involved with making repairs. Look to plant wind socks for wind direction.
(30) Contact trained plant personnel to repair chlorine leaks.
(31) Roll uncontrollably leaking chlorine cylinders so that the chlorine escapes as a gas, not as a liquid.
(32) Stop leaking chlorine cylinders or leaking chlorine equipment (by closing off valve(s) if possible) prior to attempting repair.
(33) Connect uncontrollably leaking chlorine cylinders to the chlorination equipment, and feed the maximum chlorine feed rate possible.
(34) Keep leaking chlorine cylinders at the plant site. Chlorine cylinders received at the plant site must be inspected for leaks prior to taking delivery from the shipper. *Never* ship a leaking chlorine cylinder back to the supplier after it has been accepted (bill of lading has been signed by plant personnel) from the shipper; instead, repair or stop the leak first.
(35) Keep moisture away from a chlorine leak. *Never* put water onto a chlorine leak.
(36) Call the fire department or rescue squad if a person is incapacitated by chlorine.
(37) Administer CPR (use barrier mask if possible) immediately to a person who has been incapacitated by chlorine.
(38) Breathe shallow rather than deep if exposed to chlorine without the appropriate respiratory protection.
(39) Place a person who does not have difficulty breathing and is heavily contaminated with chlorine into a deluge shower. Remove his or her clothing under the water and flush all body parts that were exposed to chlorine.
(40) Flush eyes contaminated with chlorine with copious quantities of lukewarm running water for at least 15 minutes.
(41) Drink milk if throat is irritated by chlorine.
(42) *Never* store other materials in chlorine cylinder storage areas; substances like acetylene and propane are not compatible with chlorine.

✓ *Note:* In the event of fire, the fusible plug in the chlorine cylinder is designed to melt at 150 to 162°F to prevent the cylinder from exploding.

✓ *Note:* A chlorine leak can be detected by ammonia solution.

13.2.4 HYPOCHLORITE

Hypochlorite, though there are some minor hazards associated with its use (skin irritation, nose irritation, and burning eyes), is relatively safe to work with. It is normally available in liquid form or in dry form as a white powder, pellet, or tablet. It can be added directly using a dry chemical feeder or dissolved and fed as a solution.

13.3 DECHLORINATION

In order to comply with the low levels of chlorine allowed by the Water Quality Standard, many treatment systems have had to add additional treatment steps to remove chlorine prior to discharge.

The process, known as dechlorination, uses chemicals (sulfur dioxide, sodium sulfite, sodium metabisulfite) that react quickly with chlorine to convert it to a less harmful form. Because the reactions occur very quickly, no additional contact tanks are required. The dechlorinating process does require additional chemical feed and monitoring equipment. In most cases, the equipment required for dechlorination will be similar to that required for chlorination. The specific equipment is dependent on the chemical used. Due to the fact that chemicals used for dechlorination also react with dissolved oxygen, the effluent from dechlorination usually requires aeration prior to discharge.

13.3.1 DECLORINATING WITH SULFUR DIOXIDE

Sulfur dioxide is a gaseous material that is shipped in cylinders similar to those used for chlorine. Cylinders are handled and transported using the same procedures used when handling chlorine. Sulfur dioxide can cause damage to the central nervous system and should be handled with care.

✓ *Note:* Mixing of chlorine gas and sulfur dioxide can cause a violent reaction. Never switch metering equipment from one gas to the other without first flushing thoroughly with clean, dry air or an inert gas, such as nitrogen.

Sulfur dioxide is usually applied to the chlorinated wastestream right before it outfalls the plant. Liquid sulfur dioxide is converted to gaseous form in an evaporator. From the evaporator, the gaseous sulfur dioxide enters the sulfonater, which is similar in design and function to a chlorinator. Sulfonators are typically equipped with a rotameter, orifice, feed adjustment, and pressure and vacuum valves. From the sulfonator, gaseous sulfur dioxide is injected into the wastestream to form sulfurous acid, which is then transported to the application site. At the application site, mixing should be sufficient to ensure uniform distribution of the solution in the wastestream. No contact tank is required because reaction time is very short.

13.4 ULTRAVIOLET (UV) IRRADIATION

Although ultraviolet disinfection was recognized as a method for achieving disinfection in the late nineteenth century, its application virtually disappeared with the evolution of chlorination technologies. However, in recent years, there has been a resurgence in its use in the wastewater field, largely as a consequence of concern for discharge of toxic chlorine residual. Even more recently, UV has gained more attention because of the tough new regulations on chlorine use imposed by both OSHA and USEPA. Because of this relatively recent increased regulatory pressure, many facilities are actively engaged in substituting chlorine for other disinfection alternatives. Moreover, UV technology itself has made many improvements, which now makes UV attractive as a disinfection alternative.

Ultraviolet light has very good germicidal qualities and is very effective in destroying microorganisms. It is used in hospitals, biological testing facilities, and many other similar locations. In wastewater treatment, the plant effluent is exposed to ultraviolet light of a specified wavelength and intensity for a specified contact period. The effectiveness of the process is dependent upon

- UV light intensity
- contact time
- wastewater quality (turbidity)

The Achilles' heel of UV for disinfecting wastewater is turbidity. If the wastewater quality is poor, the ultraviolet light will be unable to penetrate the solids, and the effectiveness of the process decreases dramatically. For this reason, many states limit the use of UV disinfection to facilities that can reasonably be expected to produce an effluent containing ≤30 mg/L or less of BOD_5 and total suspended solids.

In the operation of a UV system, UV lamps must be readily available when replacements are required. The best lamps are those with a stated operating life of at least 7,500 hours and those that do not produce significant amounts of ozone or hydrogen peroxide. The lamps must also meet technical specifications for intensity, output, and arc length. If the UV light tubes are submerged in the wastestream, they must be protected inside quartz tubes, which not only protect the lights but also make cleaning and replacement easier.

Contact tanks must be used with UV disinfection. They must be designed with the banks of UV lights in a horizontal position, either parallel or perpendicular to the flow or with banks of lights placed in a vertical position perpendicular to the flow.

✓ *Note*: The contact tank must provide, at a minimum, 10-second exposure time.

We stated earlier that turbidity problems have been the problem with using UV in wastewater treatment—and this is the case. However, if turbidity is its Achilles' heel, then the need for increased maintenance (as compared to other disinfection alternatives) is the toe of the same foot.

UV maintenance requires that the tubes be cleaned on a regular basis or as needed. In addition, periodic acid washing is also required to remove chemical buildup.

In operating a UV disinfection system, routine monitoring is required. Monitoring to check on bulb burnout, buildup of solids on quartz tubes, and UV light intensity is required.

✓ *Note:* UV light is extremely hazardous to the eyes. Never enter an area where UV lights are in operation without proper eye protection. Never look directly into the ultraviolet light.

13.5 OZONATION

Ozone is a strong oxidizing gas that reacts with most organic and many inorganic molecules. It is produced when oxygen molecules separate, collide with other oxygen atoms, and form a molecule consisting of three oxygen atoms. For high-quality effluents, ozone is a very effective disinfectant. Current regulations for domestic treatment systems limit use of ozonation to filtered effluents unless the system's effectiveness can be demonstrated prior to installation.

✓ *Note:* Effluent quality is the key performance factor for ozonation.

For ozonation of wastewater, the facility must have the capability to generate pure oxygen along with an ozone generator. A contact tank with ≥10-minute contact time at design average daily flow is required. Off-gas monitoring for process control is also required. In addition, safety equipment capable of monitoring ozone in the atmosphere and a ventilation system to prevent ozone levels exceeding 0.1 ppm is required.

The actual operation of the ozonation process consists of monitoring and adjusting the ozone generator and monitoring the control system to maintain the required ozone concentration in the off-gas. The process must also be evaluated periodically using biological testing to assess its effectiveness.

✓ *Note:* Ozone is an extremely toxic substance. Concentrations in air should not exceed 0.1 ppm. It also has the potential to create an explosive atmosphere. Sufficient ventilation and purging capabilities should be provided.

increases DO in the effluent; (2) ozone has a briefer contact time; (3) ozone has no undesirable effects on marine organisms; and (4) ozone decreases turbidity and odor.

13.6 BROMINE CHLORIDE

Bromine chloride is a mixture of bromine and chlorine. It forms hydrocarbons and hydrochloric acid when mixed with water. Bromine chloride is an excellent disinfectant that reacts quickly and normally does not produce any long-term residuals.

✓ *Note:* Bromine chloride is an extremely corrosive compound in the presence of low concentrations of moisture.

The reactions occurring when bromine chloride is added to the wastewater are similar to those occurring when chlorine is added. The major difference is the production of bromamine compounds rather than chloramines. The bromamine compounds are excellent disinfectants but are less stable and dissipate quickly. In most cases, the bromamines decay into other, less toxic compounds rapidly and are undetectable in the plant effluent.

The factors that affect performance are similar to those affecting the performance of the chlorine disinfection process. Effluent quality, contact time, etc., have a direct impact on the performance of the process.

13.7 NO DISINFECTION

In a very limited number of cases, treated wastewater discharges without disinfection are permitted. These are approved on a case-by-case basis. Each request must be evaluated based upon the point of discharge, the quality of the discharge, the potential for human contact, and many other factors.

13.8 PROCESS CONTROL CALCULATIONS

There are several calculations that may be useful in operating a chlorination system. Many of these calculations are discussed and illustrated in this section.

13.8.1 CHLORINE DEMAND

Chlorine demand is the amount of chlorine in milligrams per liter that must be added to the wastewater to complete all of the chemical reactions that must occur prior to producing a residual.

$$\text{chlorine demand} = \text{chlorine dose, mg/L} - \text{chlorine residual, mg/L} \qquad (13.1)$$

Example 13.1

Problem:

The plant effluent currently requires a chlorine dose of 7.3 mg/L to produce the required 1.0 mg/L chlorine residual in the chlorine contact tank. What is the chlorine demand in milligrams per liter?

Solution:

$$\text{chlorine demand, mg/L} = 7.3\ \text{mg/L} - 1.0\ \text{mg/L} = 6.3\ \text{mg/L}$$

13.8.2 CHLORINE FEED RATE

Chlorine feed rate is the amount of chlorine added to the wastewater in pounds per day.

$$\text{chlorine feed rate} = \text{dose, mg/L} \times \text{flow, MGD} \times 8.34\ \text{lb/mg/L/MG} \tag{13.2}$$

Example 13.2

Problem:

The current chlorine dose is 5.50 mg/L. What is the feed rate in pounds per day if the flow is 21.69 MGD?

Solution:

$$\text{feed, lb/day} = 5.50\ \text{mg/L} \times 21.69\ \text{MGD} \times 8.34\ \text{lb/mg/L/MG} = 995\ \text{lb/day}$$

13.8.3 CHLORINE DOSE

Chlorine dose is the concentration of chlorine being added to the wastewater. It is expressed in milligrams per liter.

$$\text{dose, mg/L} = \frac{\text{chlorine feed rate in pounds/day}}{\text{flow in million gallons/day} \times 8.34\ \text{lb/mg/L/MG}} \tag{13.3}$$

Example 13.3

Problem:

Three hundred pounds of chlorine are added per day to a wastewater flow of 6.60 MGD. What is the chlorine dose in milligrams per liter?

Solution:

$$\text{dose, mg/L} = \frac{300\ \text{lb/day}}{6.60\ \text{MGD} \times 8.34\ \text{lb/mg/L/MG}} = 5.45\ \text{mg/L}$$

13.8.4 AVAILABLE CHLORINE

When hypochlorite forms of chlorine are used, the available chlorine is listed on the label. In these cases, the amount of chemical added must be converted to the actual amount of chlorine using the following calculation.

$$\text{available chlorine} = \text{amount of hypochlorite} \times \%\ \text{available chlorine} \tag{13.4}$$

Example 13.4

Problem:

The calcium hypochlorite used for chlorination contains 62.0% available chlorine. How many pounds of chlorine are added to the plant effluent if the current feed rate is 32 pounds of calcium hypochlorite per day?

Solution:

$$\text{quantity of chlorine} = 32\ \text{lb} \times 0.62 = 19.84\ \text{lb chlorine}$$

13.8.5 REQUIRED QUANTITY OF DRY HYPOCHLORITE

This calculation is used to determine the amount of hypochlorite needed to achieve the desired dose of chlorine.

$$\text{hypochlorite quantity, lb/day} = \frac{\text{required chlorine dose, mg/L} \times \text{flow, MGD} \times 8.34\ \text{lb/mg/L/MG}}{\%\ \text{available chlorine}} \tag{13.5}$$

Example 13.5

Problem:

The laboratory reports that the chlorine dose required to maintain the desired residual level is 8.0 mg/L. Today's flow rate is 3.20 MGD. The hypochlorite powder used for disinfection is 70% available chlorine. How many pounds of hypochlorite must be used?

Solution:

$$\text{hypochlorite quantity} = \frac{8.0\ \text{mg/L} \times 3.20\ \text{MGD} \times 8.34\ \text{lb/mg/L/MG}}{0.70}$$

$$= 305\ \text{lb/day}$$

13.8.6 REQUIRED QUANTITY OF LIQUID HYPOCHLORITE

$$\text{hypochlorite needed, lb/day} = \frac{\text{required chlorine dose, mg/L} \times \text{flow, MGD} \times 8.34\ \text{lb/mg/L/MG}}{\%\ \text{available chlorine} \times 8.34 \times \text{hypochlorite solution spec. gravity}} \tag{13.6}$$

Example 13.6

Problem:

The chlorine dose is 8.6 mg/L, and the flow rate is 3.20 MGD. The hypochlorite solution is 71% available chlorine and has a specific gravity of 1.20. How many pounds of hypochlorite must be used?

Solution:

$$\text{hypochlorite quantity} = \frac{8.6\ \text{mg/L} \times 3.20\ \text{MGD} \times 8.34\ \text{lb/mg/L/MG}}{0.71 \times 8.34\ \text{lb/gal} \times 1.20}$$

$$= 32.3\ \text{gal/day}$$

13.8.7 CHLORINE ORDERING

Because disinfection must be continuous, the supply of chlorine must never be allowed to run out. The following calculation provides a simple method for determining when additional supplies must be ordered. The process consists of three steps:

(1) Adjust the flow, and use variations if projected changes are provided.

(2) If an increase in flow and/or required dosage is projected, current flow rate and/or dose must be adjusted to reflect the projected change.

(3) $\text{projected flow} = \text{current flow, MGD} \times (1.0 + \%\ \text{change})$ (13.7)

$$\text{projected dose} = \text{current dose, mg/L} \times (1.0 + \%\ \text{change})$$

Example 13.7

Problem:

Based on the available information for the past 12 months, the operator projects that the effluent flow rate will increase by 7.5% during the next year. If the average daily flow has been 4.0 MGD, what will be the projected flow for the next 12 months?

Solution:

$$\text{projected flow, MGD} = 4.0\ \text{MGD} \times (1.0 + 0.075) = 4.3\ \text{MGD}$$

Determine the amount of chlorine required for a given period.

$$\text{chlorine required} = \text{feed rate, lb/day} \times \#\ \text{of days required}$$

Example 13.8

Problem:

The plant currently uses 95 lb of chlorine per day. The town wishes to order enough chlorine to supply the plant for four months (assume 31 days/month). How many pounds of chlorine should be ordered to provide the needed supply?

Solution:

$$\text{chlorine required} = 95\ \text{lb/day} \times 124\ \text{days} = 11{,}780\ \text{lb}$$

✓ In some instances, projections for flow or dose changes are not available, but the plant operator wishes to include an extra amount of chlorine as a safety factor. This safety factor can be stated as a specific quantity or as a percentage of the projected usage.

Safety factor as a specific quantity can be expressed as follows:

$$\text{total required } Cl_2 = \text{chlorine required, lb} + \text{safety factor}$$

✓ Because chlorine is only shipped in full containers, unless asked specifically for the amount of chlorine actually required or used during a specified period, all decimal parts of a cylinder are rounded up to the next highest number of full cylinders.

13.9 TROUBLESHOOTING OPERATIONAL PROBLEMS

On occasion, operational problems with the plant's disinfection process develop. The wastewater operator must not only be able to recognize these problems but also to correct them. In this section, we point out various problems that can occur with the plant's disinfection process, the causes, and the corrective action(s) that should be taken.

13.9.1 SYMPTOM 1

Coliform count fails to meet required standards for disinfection.

(1) *Cause:* Inadequate chlorination equipment capacity
Corrective action: Replace equipment as necessary to provide treatment based on maximum flow through the pipe.

(2) *Cause:* Inadequate chlorine residual control
Corrective action: Use chlorine residual analyzer to monitor and control chlorine dosage automatically.

(3) *Cause:* Short-circuiting in chlorine contact chamber
Corrective action: Install baffling in the chlorine contact chamber; install mixing device in chlorine contact chamber.

(4) *Cause:* Solids buildup in contact chamber
Corrective action: Clean contact chamber.

(5) *Cause:* Chlorine residual is too low
Corrective action: Increase contact time and/or increase chlorine feed rate.

13.9.2 SYMPTOM 2

Low chlorine gas pressure at the chlorinator.

(1) *Cause:* Insufficient number of cylinders connected to the system
Corrective action: Connect enough cylinders to system so that feed rate does not exceed recommended withdrawal rate for cylinders.

(2) *Cause:* Stoppage or restriction of flow between cylinders and chlorinator
Corrective action: Disassemble chlorine header system at point where cooling begins, locate stoppage, and clean with solvent.

13.9.3 SYMPTOM 3

No chlorine gas pressure at the chlorinator.

(1) *Cause:* Chlorine cylinders empty or not connected to the system
Corrective action: Connect cylinders, or replace empty cylinders.

(2) *Cause:* Plugged or damaged pressure reducing valve
Corrective action: Repair reducing valve after shutting cylinder valves and decreasing gas in the header system.

13.9.4 SYMPTOM 4

Chlorinator will not feed any chlorine.

(1) *Cause:* Pressure reducing valve in chlorinator is dirty
Corrective action: Disassemble chlorinator and clean valve stem and seat; precede valve with filter/sediment trap.

(2) *Cause:* Chlorine cylinder is hotter than chlorine control aparatus (chlorinator)
Corrective action: Reduce temperature in cylinder area; do not connect a new cylinder that has been sitting in the sun.

13.9.5 SYMPTOM 5

Chlorine gas escaping from the chlorine pressure reducing valve (CPRV).

(1) *Cause:* Main diaphragm of CPRV ruptured
Corrective action: Disassemble valve and diaphragm; inspect chlorine supply system for moisture intrusion.

13.9.6 SYMPTOM 6

Inability to maintain chlorine feed rate without icing of chlorine system.

(1) *Cause:* Insufficient evaporator capacity
Corrective action: Reduce feed rate to 75% of evaporator capacity. If this eliminates problem, then main diaphragm of CPRV is ruptured.

(2) *Cause:* External CPRV cartridge is clogged
Corrective action: Flush and clean cartridge.

13.9.7 SYMPTOM 7

Chlorinator system is unable to maintain sufficient water bath temperature to keep external CPRV open.

(1) *Cause:* Heating element malfunction
Corrective action: Remove and replace heating element.

13.9.8 SYMPTOM 8

Inability to obtain maximum feed rate from chlorinator.

(1) *Cause:* Inadequate chlorine gas pressure
Corrective action: Increase pressure, replace empty or low cylinders.

(2) *Cause:* Water pump injector clogged with deposits
Corrective action: Clean injector parts using muriatic acid. Rinse parts with fresh water and place back in service.

(3) *Cause:* Leak in vacuum relief valve
Corrective action: Disassemble vacuum relief valve, and replace all springs.

(4) *Cause:* Vacuum Leak in joints, gaskets, tubing, etc., in chlorinator system
Corrective action: Repair all vacuum leaks by tightening joints, replacing gaskets, and replacing tubing and/or compression nuts.

13.9.9 SYMPTOM 9

Inability to maintain adequate chlorine feed rate.

(1) *Cause:* Malfunction or deterioration of chlorine water supply pump
Corrective action: Overhaul pump (if turbine pump is used, try closing valve to maintain proper discharge pressure).

13.9.10 SYMPTOM 10

Chlorine residual too high in plant effluent to meet requirements.

(1) *Cause:* Chlorine residual too high
Corrective action: Install dechlorination facilities.

13.9.11 SYMPTOM 11

Wide variation in chlorine residual produced in the effluent.

(1) *Cause:* Chlorine flow proportion meter capacity inadequate to meet plant flow rates
Corrective action: Replace with higher capacity chlorinator meter.
(2) *Cause:* Malfunctioning controls
Corrective action: Call manufacturer technical representative.
(3) *Cause:* Solids settled in chlorine contact chamber
Corrective action: Clean chlorine contact tank.
(4) *Cause:* Flow proportioning control device not zeroed or spanned correctly
Corrective action: Re-zero and span the device in accordance with manufacturer's instructions.

13.9.12 SYMPTOM 12

Unable to obtain chlorine residual.

(1) *Cause:* High chemical demand
Corrective action: Locate and correct the source of the high demand.
(2) *Cause:* Test interference
Corrective action: Add sulfuric acid to samples to reduce interference.

13.9.13 SYMPTOM 13

Chlorine residual analyzer, recorder, controller does not control chlorine residual properly.

(1) *Cause:* Electrodes fouled
Corrective action: Clean electrodes.
(2) *Cause:* Loop time is too long
Corrective action: Reduce control loop time by

- moving the injector closer to the point of application
- increasing the velocity in the sample line to the analyzer
- moving the cell closer to the sample point
- moving the sample point closer to the point of application

(3) *Cause:* Insufficient potassium iodide being added for the amount of residual being measured
Corrective action: Adjust potassium iodide feed to correspond with the chlorine residual being measured.
(4) *Cause:* Buffer additive system is malfunctioning
Corrective action: Repair buffer additive system.

(5) *Cause:* Malfunctioning of analyzer cell
Corrective action: Call authorized service personnel to repair electrical components.
(6) *Cause:* Poor mixing of chlorine at point of application
Corrective action: Install mixing device to cause turbulence at point of application.
(7) *Cause:* Rotameter tube range is improperly set
Corrective action: Replace rotameter with a proper range of feed rate.

13.10 REFERENCES

Spellman, F. R., *A Guide to Compliance for PSM/RMP.* Lancaster, PA: Technomic Publishing Company, Inc., 1997.

Spellman, F. R., *Safe Work Practices for Wastewater Treatment Plants.* Lancaster, PA: Technomic Publishing Company, Inc., 1996.

White, G. C., *Handbook of Chlorination,* 2nd ed. New York: Van Nostrand Reinhold, 1986.

13.11 CHAPTER REVIEW QUESTIONS

13-1 Name one factor that affects the performance of the ultraviolet irradiation process.

13-2 Explain the difference between disinfection and sterilization.

13-3 To be effective enough, chlorine must be added to satisfy the _________ and produce a __________mg/L __________for at least __________ minutes at design flow rates.

13-4 Elemental chlorine is __________ in color and is __________ times heavier than air.

13-5 Why must you take safety precautions when working with chlorine?

13-6 What problems are created when chlorine is used for disinfection?

13-7 Describe the ultraviolet irradiation process for disinfection.

13-8 Describe the ozonation disinfection process.

13-9 What are the safety hazards associated with the ultraviolet irradiation and ozonation processes?

13-10 What is the major advantage of bromine chloride when compared with chlorine for disinfection?

13-11 You are currently adding 450 lb of chlorine per day to a wastewater flow of 6.55 MGD. What is the chlorine dose in mg/L?

13-12 The chlorine dose is 8.22 mg/L. If the residual is 1.10 mg/L, the chlorine demand is ____________.

13-13 Why is dechlorination required to be installed (in many facilities) following chlorination for disinfection?

13-14 The plant adds 350 lb per day of dry hypochlorite powder to the plant effluent. The hypochlorite powder is 40% available chlorine. What is the chlorine feed rate in pounds per day?

13-15 The plant uses liquid HTH, which is 69% available chlorine and has a specific gravity of 1.28. The required feed rate to comply with the plant's discharge permit total residual chlorine limit is 280 lb/day. What is the required flow rate for HTH solution in gallons per day?

13-16 The plant currently uses 45.8 lb of chlorine per day. Assuming the chlorine usage will increase by 10% during the next year, how many 2,000-lb cylinders of chlorine will be needed for the year (365 days)?

13-17 Why are chlorine additions to critical waters, such as natural trout streams, prohibited?

CHAPTER 14

Solids Thickening

14.1 INTRODUCTION

THE most costly and complex aspect of wastewater treatment can be the collection, processing, and disposal of wastewater solids (or sludge). This is the case because the quantity of solids produced may be as high as 2% of the original volume of wastewater, depending somewhat on the treatment process being used.

Simply put, wastewater solids (sludge) contain large volumes of water. Because sludge can be as much as 97% water content, and because the cost of disposal will be related to the volume of sludge being processed, one of the primary purposes or goals of sludge treatment (along with stabilizing it so it is no longer objectionable or environmentally damaging) is to separate as much of the water from the solids as possible. Solids treatment methods may be designed to accomplish both of these purposes. One of the sludge treatment methods that is designed to accomplish both is the subject of this chapter: solids thickening.

✓ *Note:* As pointed out earlier in Chapter 2, Section 2.1, sludge is the commonly accepted name for wastewater solids. However, as part of efforts to improve public perception and acceptance of wastewater solids reuse, the word "sludge" is being replaced by the two terms "residual" and "biosolids." If wastewater solids are used for beneficial reuse (e.g., as a soil amendment or fertilizer), most modern references prefer the term "biosolids" to sludge and limit use of the word "sludge" to the activated sludge process.

14.2 SOLIDS THICKENING

Solids thickening (or concentration) is a unit process used to increase the solids content of the biosolids by removing a portion of the liquid fraction (see Figure 14.1). By increasing the solids content, more economical treatment of the solids can be effected.

✓ Simply stated, the purpose of solids thickening is to reduce process residual volume. Thickened biosolids require less tank capacity and chemical dosage for stabilization (see Chapter 15) and smaller piping and pumping equipment for transport. To illustrate the importance of thickening, if waste activated sludge, which is typically pumped from secondary settling tanks with a content of 0.8% solids, can be thickened to a content of 4% solids, then a five-fold decrease in biosolids volume is achieved (Metcalf & Eddy, 1991).

Solids thickening processes include the following:

- gravity thickeners
- flotation thickeners

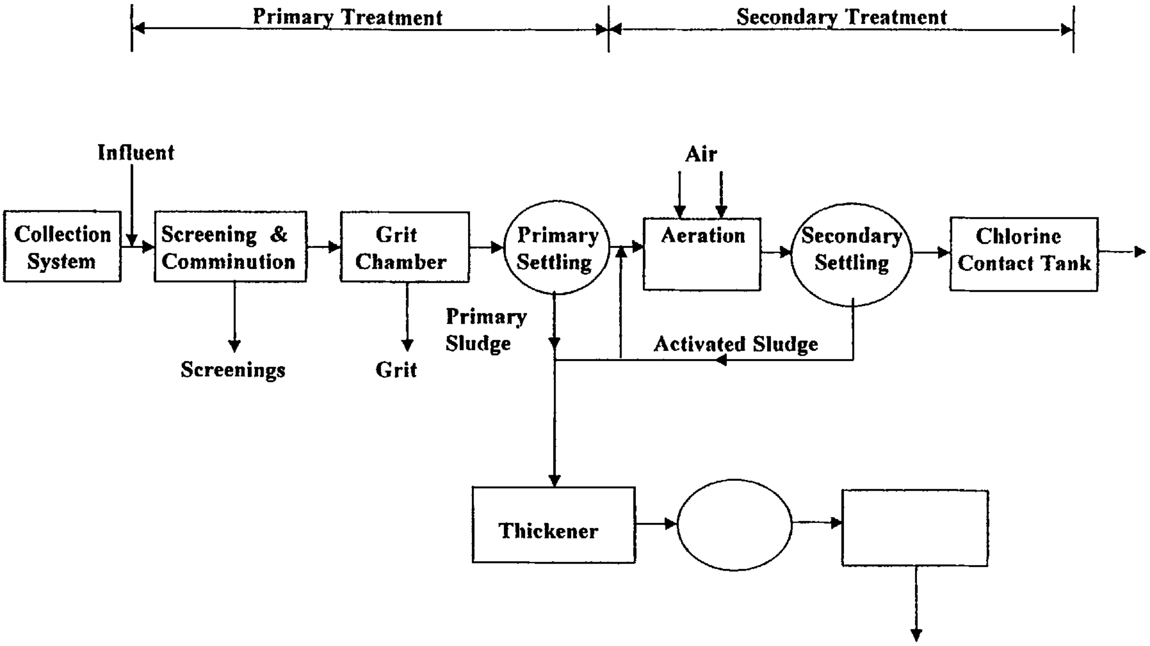


Figure 14.1 Solids thickening.

- solids concentrators
- centrifuges

14.2.1 GRAVITY THICKENING

Gravity thickening is most effective on primary sludge, and process units employed are very similar in design and operation to the secondary clarifiers used in suspended-growth systems. Factors that affect performance of gravity thickeners include (1) source of process residuals (i.e., primary, activated sludge); (2) temperature and age of the residual; (3) solids loading and blanket depth; (4) hydraulic loading and length of time the solids remain in tank (solids detention time); and (5) the hydraulic detention time.

In operation, solids are withdrawn from primary treatment (and sometimes secondary treatment) and pumped to the thickener. Solids coming into the thickener separate into three distinct zones. The top layer is a relatively clear liquid (supernatant). The next layer is the sedimentation zone, which usually contains denser solids. In the thickening zone, the solids buildup forms a solids blanket on the bottom. The weight of the blanket compresses the solids on the bottom and "squeezes" the water out. By adjusting the blanket thickness, the percent solids in the underflow (solids withdrawn from the bottom of the thickener) can be increased or decreased. The supernatant (clear water) rises to the surface and is returned to plant flow for further treatment.

Daily operations of the thickening process include pumping, observation, sampling and testing, process control calculations, maintenance, and housekeeping.

✓ The equipment employed in thickening depends on the specific thickening processes used.

Equipment used for gravity thickening consists of a thickening tank that is similar in design to the settling tank used in primary treatment (see Figure 14.2). Generally, the tank is circular and provides thickener pumping facilities (i.e., pump and flow measurement) are used for withdrawal of thickened solids.

Performance of gravity thickeners (i.e., the solids concentrations achieved) typically results in producing 8 to 10% solids from primary underflow, 2 to 4% solids from waste activated sludge, 7 to 9% solids from trickling filter residuals, and 4 to 9% solids from combined primary and secondary residuals.

14.2.1.1 Operational Factors

The rate of addition and withdrawal must be monitored and adjusted to obtain the desired blanket depth to produce the desired concentration of solids in the underflow. In addition, the quality of the supernatant being returned to the wastewater and the quality of the underflow must be monitored for odors, color, etc.

Unit process control sampling and testing should include influent and underflow percent of solids and volatile matter and pH. The depth of blanket must be measured. BOD_5, total suspended solids, and pH for the supernatant must also be sampled and tested periodically.

✓ *Note:* Gravity thickeners typically require frequent cleaning to eliminate potential odor sources.

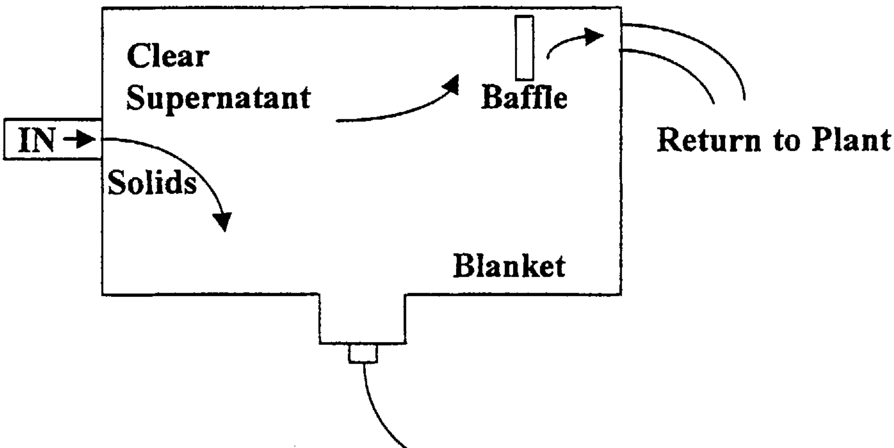
14.2.1.2 Process Control Calculations

In this section, we describe and illustrate solids pumping calculations applied throughout the wastewater treatment and the solids handling portions of the plant, including solids thickening. Additional calculations specifically designed to assist in control and operation of thickener performance are also covered.

14.2.1.2.1 Estimated Pump Rate

The calculation for estimation of the required residual solids pumping rate is used to establish an initial pumping rate for adequate removal of solids from a settling tank or gravity thickener.

$$\text{estimated pump rate} = \frac{(\text{infl. TSS conc.} - \text{effl. TSS conc.}) \times 8.34}{\%\ \text{solids in sludge} \times 8.34 \times 1{,}440\ \text{min/day}} \tag{14.1}$$



Example 14.1

Problem:

The sludge withdrawn from the primary settling tank contains 1.5% solids. The unit influent contains 297 mg/L TSS, and the effluent contains 143 mg/L TSS. If the influent flow rate is 5.55 MGD, what is the estimated sludge withdrawal rate in gallons per minute (assuming the pump operates continuously)?

Solution:

$$\text{sludge rate} = \frac{(297\text{ mg/L} - 143\text{ mg/L}) \times 5.55 \times 8.34}{0.015 \times 8.34 \times 1{,}440\text{ min/day}}$$

$$= 39.5\text{ or }40\text{ gpm}$$

14.2.1.2.2 Sludge Pump Operating Time

Sludge pump operating time is the total time the pump operates during a 24-hour period in minutes.

$$\text{pump operating time} = \text{time/cycle, minutes} \times \text{cycles/day} \tag{14.2}$$

Example 14.2

Problem:

The sludge pump operates 15 minutes per hour. The pump delivers 30 gal/min of sludge. Lab tests indicated that the sludge is 5.3% solids and 66% volatile matter. How many pounds of volatile matter are transferred from the settling tank to the digester?

Solution:

Step 1:

$$\text{pump operating time} = 15\text{ min/hr} \times 24\text{ hr (cycles)/day} = 360\text{ min/day}$$

Step 2: Gallons of sludge pumped/day

$$\text{sludge, gpd} = \text{operating time, min/day} \times \text{pump rate, gpm}$$

$$= 360\text{ min/day} \times 30\text{ gpm}$$

$$= 10{,}800\text{ gpd}$$

Step 3: Pounds of sludge pumped/day

$$\text{sludge, lb/day} = \text{gallons of sludge pumped} \times 8.34$$

$$= 10{,}800\text{ gpd} \times 8.34\text{ lb/gal}$$

$$= 90{,}072\text{ lb/day}$$

Step 4: Pounds of solids pumped/day

$$\text{solids pumped, lb/day} = \text{sludge pumped, gpd} \times \%\ \text{solids}$$

$$= 90{,}072\ \text{lb/day} \times 0.053$$

$$= 4{,}774\ \text{lb/day}$$

Step 5: Pounds of volatile matter pumped/day

$$\text{vol. matter, lb/day} = \text{solids pumped, lb/day} \times \%\ \text{volatile matter}$$

$$= 4{,}774\ \text{lb/day} \times 0.66$$

$$= 3{,}151\ \text{lb/day}$$

14.2.1.2.3 Hydraulic Loading

For the thickener, hydraulic loading is the influent applied per square foot of thickener per day.

$$\text{hydraulic loading, gpd/ft}^2 = \frac{\text{total thickener infl. flow, gpd}}{\text{thickener area, ft}^2} \tag{14.3}$$

Example 14.3

Problem:

Given the following data, determine hydraulic loading

Thickener influent flow = 165 gpm
Thickener diameter = 30 ft

Solution:

$$\text{HL, gpd/ft}^2 = \frac{165\ \text{gpm} \times 1{,}440\ \text{min/day}}{0.785 \times 30\ \text{ft} \times 30\ \text{ft}}$$

$$= 336\ \text{gpd/ft}^2$$

✓ *Note:* Typical design values for gravity thickener hydraulic loading are

Primary residuals	400–800 gpd/ft^2
Waste activated sludge	100–200 gpd/ft^2

14.2.1.2.4 Solids Loading

The solids loading is expressed as the pounds of solids applied to one square foot of thickener per day or per hour.

$$\text{solids loading, lb/day/ft}^2 = \frac{\text{solids applied, lb/day}}{\text{thickener area, ft}^2} \tag{14.4}$$

$$\text{solids loading, lb/hr/ft}^2 = \frac{\text{solids applied, lb/hour}}{\text{thickener area, ft}^2} \tag{14.5}$$

✓ *Note:* Typical design levels for gravity thickener solids loading are

Primary residuals	20–30 lb/day/ft^2
Waste activated sludge	5–8 lb/day/ft^2
Trickling filter residuals	8–10 lb/day/ft^2
Combined primary and activated sludge	6–12 lb/day/ft^2

14.2.1.2.5 Solids Volume Ratio

The solids volume ratio is the time in days that the residuals are in the thickener. To determine the solids volume ratio (SVR), you must know the volume of the blanket and the volume of residual added in gallons per day.

$$\text{SVR} = \frac{\text{solids blanket volume, gal}}{\text{thickener influent flow, gal/day}} \tag{14.6}$$

Example 14.4

Problem:

Given the following data, determine the SVR.

Thickener influent flow = 30 gal/min
Thickener diameter = 40 ft
Solids blanket = 4 ft

Solution:

$$\text{SVR} = \frac{0.785 \times 40\text{ ft} \times 40\text{ ft} \times 4\text{ ft} \times 7.48\text{ gal/ft}^3}{30\text{ gpm} \times 1{,}440\text{ min/day}}$$

$$= 0.87\text{ days or }20.9\text{ hours}$$

14.2.1.2.6 Concentration Factor

The concentration factor permits easy comparison of the daily performance of the thickener. The concentration factor is determined by dividing the percent solids of the underflow by the percent solids in the thickener influent.

Normal range	
Primary solids	≥ 2.0
Secondary solids	≥ 3.0

$$\text{CF} = \frac{\text{\% solids in underflow}}{\text{\% solids in thickener influent}} \tag{14.7}$$

Example 14.5

Problem:

% Solids thickener influent = 3.0%
% Solids thickener underflow = 9.2%

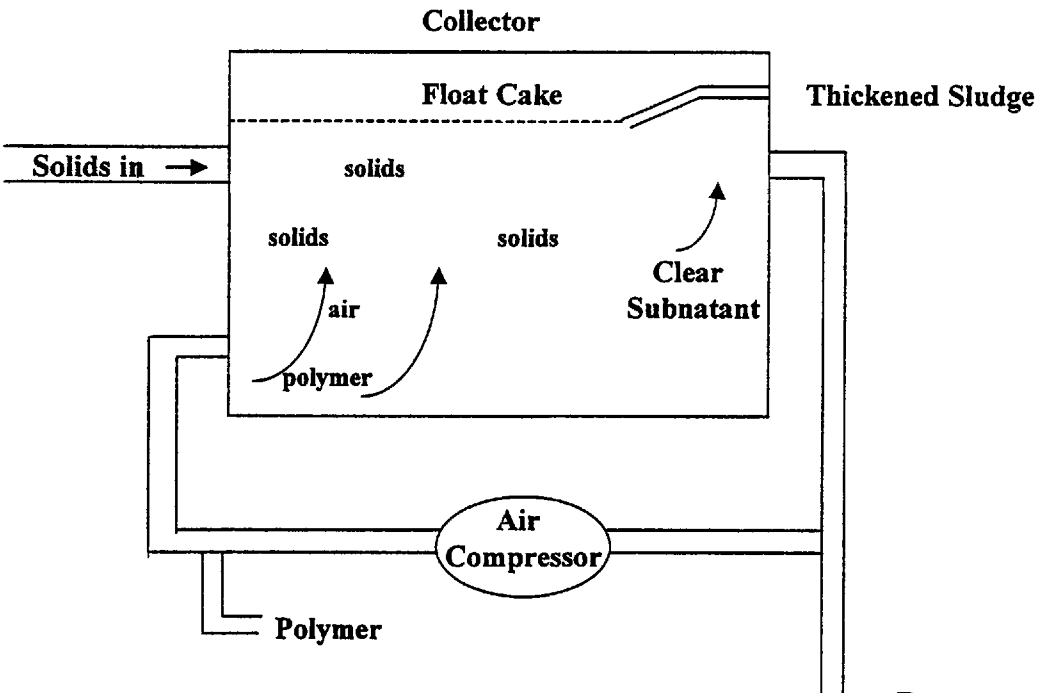
Solution:

$$CF = \frac{9.2\,\%}{3.0\,\%} = 3.1$$

14.2.2 FLOTATION THICKENERS

Flotation thickening is used most efficiently for waste sludges from suspended-growth biological treatment process, such as the activated sludge process. In operation, a small quantity of recycled water from the flotation thickener is aerated under pressure. This supersaturated liquid is released near the bottom of the tank through which the sludge is passed at atmospheric pressure. During this time, the water absorbs more air than it would under normal pressure. The recycled flow, together with chemical additives (if used), is mixed with the flow. When the mixture enters the flotation thickener, the excess air is released in the form of fine bubbles (see Figure 14.3). These bubbles become attached to the solids and lift them toward the surface. The accumulation of solids on the surface is called the float cake. As more solids are added to the bottom of the float cake, it becomes thicker, and water drains from the upper levels of the cake. The solids are then moved up an inclined plane by a scraper and discharged. The supernatant leaves the tank below the surface of the float solids and is recycled or returned to the wastestream for treatment. Typically, flotation thickener performance is 3 to 5% solids for waste activated sludge with polymer addition and 2 to 4% solids without polymer addition.

✓ *Note:* Flotation thickening is especially effective on activated sludge, which is difficult to thicken by gravity.



In regards to equipment requirements, the flotation thickening process requires pressurized air, a vessel for mixing the air with all or part of the process residual flow, a tank for the flotation process to occur (see Figure 14.3), and solids collector mechanisms to remove the float cake (solids) from the top of the tank and accumulated heavy solids from the bottom of the tank. Because the process normally requires chemicals be added to improve separation, chemical mixing equipment, storage tanks, and metering equipment to dispense the chemicals at the desired dose are required.

Normal operation requires the operator to monitor and control the aeration rate (air to solids ratio), the recycle rate, the chemical dose, and the float solids thickness. The operator should start the recycle flow and the chemical addition at least 15 minutes before solids are discharged to the system. This ensures the flotation process will be working properly ("charged") when the solids enter.

The operator should also ensure that routine cleaning of the flotation thickener and support equipment is accomplished to avoid odors and operational problems.

14.2.2.1 Process Control Calculations

Typical process control calculations used in flotation thickener operations include determining hydraulic loading, solids loading, and air-to-solids ratio.

14.2.2.1.1 Hydraulic Loading (gph/ft^2)

$$\text{hydraulic loading, gph/ft}^2 = \frac{\text{thickener infl. flow, gph}}{\text{thickener area, ft}^2} \tag{14.8}$$

✓ *Note:* Typical hydraulic loading values for flotation thickeners are 0.5 to 2.0 gph/ft^2 (with polymer) and 0.5 to 1.5 gph/ft^2 (without polymer).

14.2.2.1.2 Solids Loading, (lbs/hr/ft^2)

$$\text{solids loading, lb/hr/ft}^2 = \frac{\text{solids applied, lb/hr}}{\text{thickener area, ft}^2} \tag{14.9}$$

✓ *Note:* Typical solids loading values for flotation thickeners are 1 to 2 lb/hr/ft^2 (with polymer) and 0.4 to 1.0 lb/hr/ft^2 (without polymer).

14.2.2.1.3 Air-to-Solids Ratio

The air-to-solids ratio is often used to evaluate the operation of the flotation thickener.

$$\text{air to solids} = \frac{\text{air applied, lb/min}}{\text{thickener influent solids, lb/min}} \tag{14.10}$$

$$\text{air applied, lb/minute} = \text{air flow, scfm} \times 0.075\ \text{lb/scf}$$

$$\text{solids} = \text{influent flow, gpm} \times \%\ \text{solids} \times 8.34\ \text{lb/gallon}$$

✓ *Note:* Air-to-solids ratio varies with temperature, elevation, and/or barometric pressure.

14.2.3 SOLIDS CONCENTRATORS

The solids concentrator (belt thickener) is a continuous process usually consisting of a mixing tank, chemical storage and metering equipment, and a moving porous belt. In operation, the process residual flow is chemically treated and then spread evenly over the surface of the moving porous belt. As the flow is carried down the belt (similar to a conveyor belt), the solids are mechanically turned or agitated, and water drains through the belt. This process is primarily used in facilities where space is limited.

14.2.4 CENTRIFUGES

Primarily used for solids dewatering, centrifuges can also be effective for thickening process residuals prior to stabilization. Several facilities are currently evaluating use of one centrifuge design for both thickening and solids dewatering.

14.3 REFERENCE

Metcalf & Eddy, *Wastewater Engineering: Treatment, Disposal, and Reuse*, 3rd ed. New York: McGraw-Hill, 1991.

14.4 CHAPTER REVIEW QUESTIONS

14-1 What is the advantage of thickening biosolids before they move on in the treatment process?

14-2 Which thickening process is best for thickening process residuals from primary treatment?

14-3 Which thickening process is best for thickening process residuals from secondary treatment?

14-4 Name three devices that can be used to thicken waste activated sludge.

14-5 Name three factors that affect the performance of the gravity thickener.

CHAPTER 15

Biosolids Stabilization

15.1 INTRODUCTION

The purpose of biosolids stabilization is to reduce volume, stabilize the organic matter, and eliminate pathogenic organisms to permit reuse or disposal. The equipment required for stabilization depends on the specific process used. Biosolids stabilization processes include the following:

- aerobic digestion
- anaerobic digestion (see Figure 15.1)
- composting
- lime stabilization
- wet air oxidation (heat treatment)
- chemical oxidation (chlorine oxidation)
- incineration

15.2 AEROBIC DIGESTION

The function of aerobic digestion is to stabilize waste solids by long-term aeration, thereby reducing the BOD and destroying volatile solids. Aerobic digestion is accomplished in one or more tanks (digester) that are similar in design to the aeration tank used for the activated sludge process (see Figure 15.2). Either diffused or mechanical aeration equipment is necessary to maintain the aerobic conditions in the tank. Solids and supernatant removal equipment is also required.

In operation, process residuals (sludge) are added to the digester and are aerated to maintain a dissolved oxygen (DO) concentration of 1.0 mg/L. Aeration also ensures that the tank contents are well mixed. Generally, aeration continues for approximately 20 days retention time. Periodically, aeration is stopped, and the solids are allowed to settle. Sludge and the clear liquid supernatant is withdrawn as needed to provide more room in the digester. When no additional volume is available, mixing is stopped for 12 to 24 hours before solids are withdrawn for disposal. Process control testing should include alkalinity, pH, percent solids, percent volatile solids for influent sludge, supernatant, digested sludge, and digester contents.

Normal operating levels for an aerobic digester are listed in Table 15.1.

A typical operational problem associated with an aerobic digester is pH control. When pH drops, for example, this may indicate normal biological activity or may indicate low influent alkalinity. This problem is corrected by adding alkalinity. This alkalinity may be in the form of lime, caustic soda, sodium bicarbonate, or other alkaline substances.

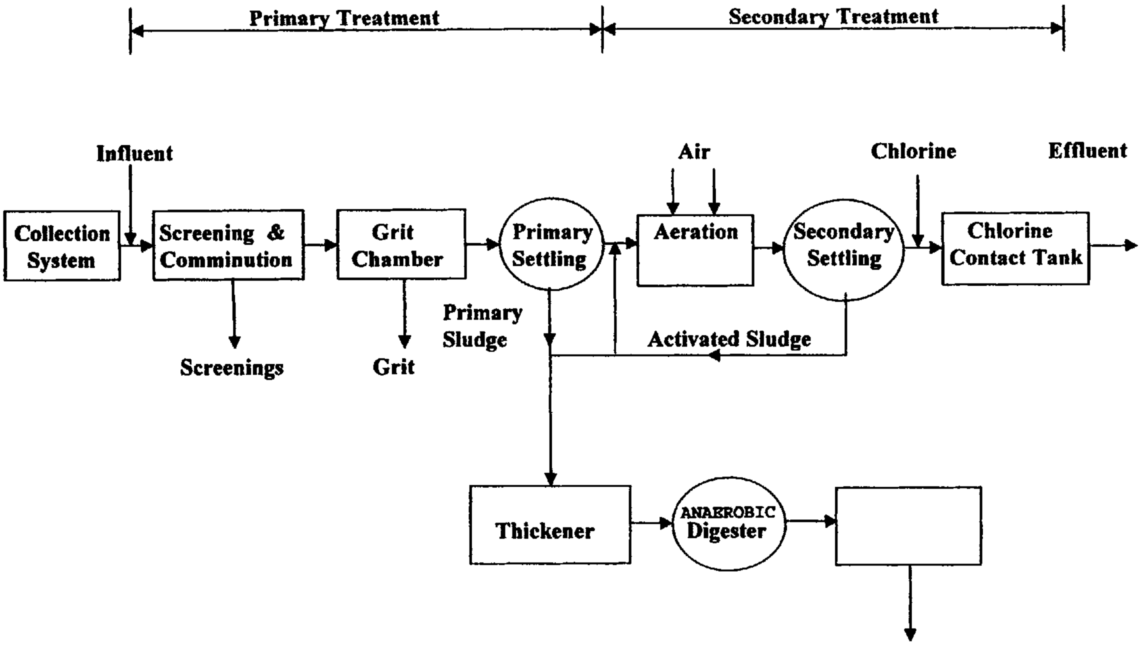


Figure 15.1 Anaerobic digester unit process.

15.2.1 PROCESS CONTROL CALCULATIONS: AEROBIC DIGESTER

Process control calculations for aerobic digester operations include determining volatile solids loading, digestion time, digester efficiency, and pH adjustment.

15.2.1.1 Volatile Solids Loading

Volatile solids loading for the aerobic digester is expressed in pounds of volatile solids entering the digester per day per cubic foot of digester capacity.

$$\text{volatile solids loading} = \frac{\text{volatile solids added, lb/day}}{\text{digester volume, ft}^3} \tag{15.1}$$

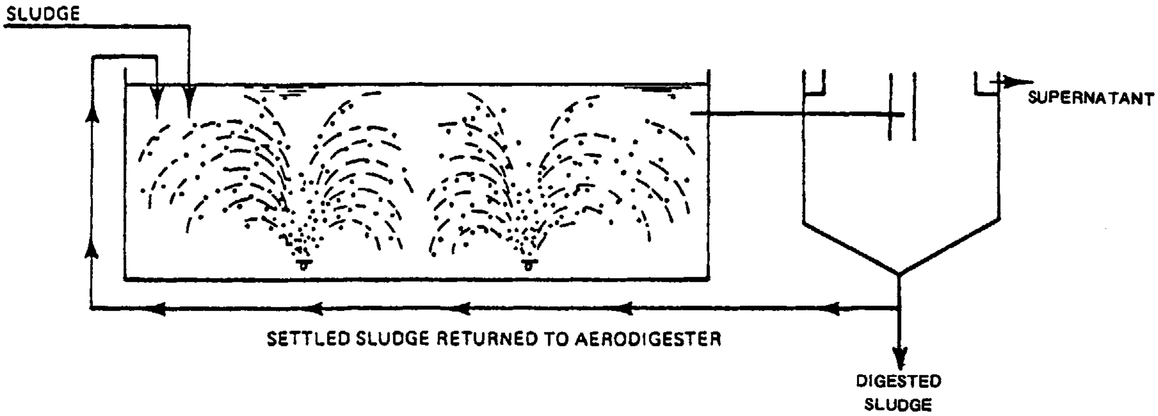


Figure 15.2 Schematic of aerobic digestion system. *Source:* USEPA (1978), *Sludge Handling & Conditioning,* p. IV-2.

TABLE 15.1. Normal Operating Levels—Aerobic Digester.

Parameter	Normal Levels
Detention time, days	10–20
Volatile solids loading lb/ft^3/day	0.1–0.3
DO mg/L	1.0
pH	5.9–7.7
Volatile solids reduction	40–50%

Example 15.1

Problem:

The aerobic digester is 30 feet in diameter and has an operating depth of 22 feet. The sludge added to the digester daily contains 1,250 lb of volatile solids. What is the volatile solids loading in pounds per day per cubic foot?

Solution:

$$\text{volatile solids loading} = \frac{1{,}250\ \text{lb/day}}{0.785 \times 30\ \text{ft} \times 30\ \text{ft} \times 22\text{ft}}$$

$$= 0.08\ \text{lb/day/ft}^3$$

15.2.1.2 Digestion Time, Days

Digestion time (hydraulic detention time) is the theoretical time the sludge remains in the aerobic digester.

$$\text{digestion time, days} = \frac{\text{digester volume, gallons}}{\text{sludge added, gpd}} \tag{15.2}$$

Example 15.2

Problem:

Digester volume is 220,000 gallons. Sludge is being added to the digester at the rate of 13,000 gpd. What is the digestion time in days?

Solution:

$$\text{digestion time, days} = \frac{220{,}000\ \text{gal}}{13{,}000\ \text{gpd}} = 16.9\ \text{days}$$

15.2.1.3 pH Adjustment

Occasionally, the pH of the aerobic digester will fall below the levels required for good biological activity. When this occurs, the operator must perform a laboratory test to determine the amount of alkalinity required to raise the pH to the desired level. The results of the lab test must then be converted to the actual quantity of chemical (usually lime) required by the digester.

$$\text{chemical required, lb} = \frac{\text{chemical used in lab test, mg}}{\text{sample volume, L}} \times \text{dig. vol., MG} \times 8.34 \qquad (15.3)$$

Example 15.3

Problem:

The lab reports that it took 220 mg of lime to increase pH of a 1-L sample of the aerobic digester contents to pH 7.0. The digester volume is 230,000 gallons. How many pounds of lime will be required to increase the digester pH to 7.0?

Solution:

$$\text{chemical required, lb} = \frac{220\ \text{mg} \times 230{,}000\ \text{gal} \times 3.785\ \text{L/gal}}{1\ \text{L} \times 454\ \text{g/lb} \times 1{,}000\ \text{mg/g}}$$

$$= 422\ \text{lb}$$

15.3 ANAEROBIC DIGESTION

Anaerobic digestion is the traditional method used in biosolids stabilization. Anaerobic treatment is characterized by a high degree of waste stabilization, low production of waste biological sludge, low nutrient requirements, and no oxygen requirements. It consists of two distinct stages that occur simultaneously in digesting biosolids. The first consists of hydrolysis of the high-molecular-weight organic compounds and conversion to organic acids by acid-forming bacteria. The second stage is gasification of the organic acids to methane and carbon dioxide by the acid-splitting bacteria.

✓ *Note:* In an anaerobic digester, both acid forming reactions and the methane fermentation reactions are dependent upon pH, temperature, and food conditions.

✓ *Note:* From 0.5 to 1.3 ft^3 per capita per day of sludge gas is produced in an anaerobic digester from primary sludge.

The bacteria used in the anaerobic digestion thrive in the absence of oxygen. The anaerobic digestion process is slower than aerobic digestion, but has the advantage that only a small percentage of the wastes are converted into new bacterial cells. Instead, most of the organics are converted into carbon dioxide and methane gas.

✓ *Note:* In a well-operating anaerobic digester, the range of carbon dioxide typically is 35 to 40%.

✓ *Note:* Methane-forming bacteria's sensitivity to changes in environment often results in anaerobic digester upset.

✓ *Note:* In an anaerobic digester, the entrance of air should be prevented because of the potential for air mixed with the gas produced in the digester, which could create an explosive mixture.

Equipment required for anaerobic digestion includes a sealed digestion tank with either a fixed or a floating cover (see Figure 15.3), heating and mixing equipment, gas storage tanks, solids and

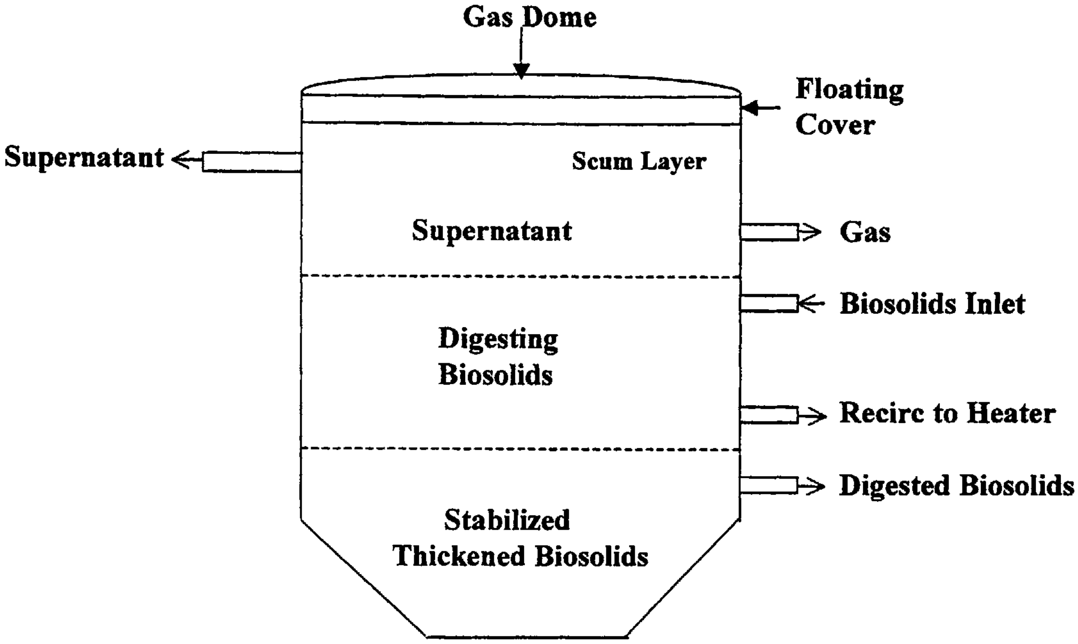


Figure 15.3 Cross-section of a floating-cover anaerobic digester.

✓ *Note:* In an anaerobic digestion system with both primary and secondary digesters, only the primary tank is heated and mixed. The purpose of heating and mixing a primary anaerobic digester is to increase the digestion rate.

In operation, process residual (thickened or unthickened sludge) is pumped into the sealed digester. The organic matter digests anaerobically by a two-stage process. Sugars, starches, and carbohydrates are converted to volatile acids, carbon dioxide, and hydrogen sulfide. The volatile acids are then converted to methane gas. This operation can occur in a single tank (single stage) or in two tanks (two stage). In a single-stage system, supernatant and/or digested solids must be removed whenever flow is added. In a two-stage operation, solids and liquids from the first stage flow into the second stage each time fresh solids are added. Supernatant is withdrawn from the second stage to provide additional treatment space. Periodically, solids are withdrawn for dewatering or disposal. The methane gas produced in the process may be used for many plant activities.

✓ *Note:* The primary purpose of a secondary digester is to allow for solids separation.

Various performance factors affect the operation of the anaerobic digester. For example, percent volatile matter in raw sludge, digester temperature, mixing, volatile acids/alkalinity ratio, feed rate, percent solids in raw sludge, and pH are all important operational parameters the operator must monitor. Along with being able to recognize normal/abnormal anaerobic digester performance parameters, wastewater operators must also know and understand normal operating procedures. Normal operating procedures include sludge additions, supernatant withdrawal, sludge withdrawal, pH control, temperature control, mixing, and safety requirements. Important performance parameters are listed in Table 15.2.

15.3.1 BIOSOLIDS ADDITIONS

Biosolids must be pumped (in small amounts) several times each day to achieve the desired organic loading and optimum performance.

TABLE 15.2. **Anaerobic Digester—Sludge Parameters.**

Raw Sludge Solids	Impact
<4% Solids	Loss of alkalinity Decreased sludge retention time Increased heating requirements Decreased volatile acid/alkalinity ratio
4–8% Solids	Normal operation
>8% Solids	Poor mixing Organic overloading Decreased volatile acid: alkalinity ratio

✓ *Note:* Keep in mind that, in fixed cover operations, additions must be balanced by withdrawals. If not, structural damage occurs.

15.3.2 SUPERNATANT WITHDRAWAL

Supernatant withdrawal must be controlled for maximum biosolids digestion time. When sampling, sample all drawoff points, and select level with the best quality.

15.3.3 BIOSOLIDS WITHDRAWAL

Digested biosolids withdrawal is only made when necessary—always leave at least 25% seed.

15.3.4 pH CONTROL

pH should be adjusted to maintain 6.8 to 7.2 pH by adjusting feed rate, biosolids withdrawal, or alkalinity additions.

✓ *Note:* The buffer capacity of an anaerobic digester is indicated by the volatile acid/alkalinity relationship. Decreases in alkalinity cause a corresponding increase in ratio.

✓ *Note*: When neutralizing a sour digester, a rough rule of thumb is to use 1 lb of lime for each 1,000 gal of biosolids to be treated.

15.3.5 TEMPERATURE CONTROL

If the digester is heated, the temperature must be controlled to a normal temperature range of 90 to 95°F. Never adjust the temperature by more than 1°F per day.

15.3.6 MIXING

If the digester is equipped with mixers, mixing should be accomplished to ensure organisms are exposed to food materials.

15.3.7 SAFETY

To prevent such failures, safety equipment such as pressure relief and vacuum relief valves, flame traps, condensate traps, and gas collection safety devices, are installed. It is important that these critical safety devices be checked and maintained for proper operation.

✓ *Note:* Because of the inherent danger involved with working inside anaerobic digesters, they are automatically classified as permit-required confined spaces. Therefore, all operations involving internal entry must be made in accordance with OSHA's confined space entry standard.

15.3.8 PROCESS CONTROL TESTING

During operation, anaerobic digesters must be monitored and tested to ensure proper operation. Testing should be accomplished to determine supernatant pH, volatile acids, alkalinity, BOD or COD, total solids, and temperature. Sludge (in and out) should be routinely tested for percent solids and percent volatile matter. Normal operating parameters are listed in Table 15.3.

15.3.9 ANAEROBIC DIGESTER: PROCESS CONTROL CALCULATIONS

Process control calculations involved with anaerobic digester operation include determining the required seed volume, volatile acid-to-alkalinity ratio, sludge retention time, estimated gas production, volatile matter reduction, and percent moisture reduction in digester sludge. Examples on how to make these calculations are provided in the following sections.

15.3.9.1 Digestion Time (Based on Flow)

The digestion time based upon the volume of residual added to the digester per day and the volume of the digester is determined by

$$\text{digestion time, days} = \frac{\text{digester volume, gallons}}{\text{influent flow, gpd}} \tag{15.4}$$

TABLE 15.3. Anaerobic Digester—Normal Operating Ranges.

Parameter	Normal Ranges
Sludge retention time	
Heated	30–60 days
Unheated	180+ days
Volatile solids loading	0.04–0.1 lb VM/day/ft^3
Operating temperature	
Heated	90–95°F
Unheated	Varies with season
Mixing	
Heated—primary	Yes
Unheated—secondary	No
% Methane in gas	60–72%
% Carbon dioxide in gas	28–40%
pH	6.8–7.2
Volatile acids: alkalinity ratio	≤0.1
Volatile solids reduction	40–60%
Moisture reduction	40–60%

15.3.9.2 Digestion Time (Based on Solids)

The digestion time based upon the quantity of solids in the digester and the quantity of solids added each day can be determined by

$$\text{digestion time, days} = \frac{\text{digester solids, pounds}}{\text{influent solids, lb / day}} \tag{15.5}$$

15.3.9.3 Volatile Acids/Alkalinity Ratio

The volatile acids-to-alkalinity ratio can be used to control operation of an anaerobic digester (see Table 15.4).

$$\text{ratio} = \frac{\text{volatile acids concentration, mg / L}}{\text{alkalinity concentration, mg / L}} \tag{15.6}$$

✓ *Note:* Variation in the volatile acids/alkalinity ratio is a very sensitive indicator of process condition. Variations in the ratio will normally begin *before* any of the other process control indicators begin to change.

✓ *Note:* The volatile acid/alkalinity relationship is useful in digester control because it is one of the first indicators that the digestion process is going sour.

15.3.9.4 Volatile Matter Reduction, Percent

Because of the changes occurring during sludge digestion, the calculation used to determine percent volatile matter reduction is more complicated.

$$\%\ \text{reduction} = \frac{(\%\ \text{volatile matter}_{\text{in}} - \%\ \text{volatile matter}_{\text{out}}) \times 100}{[\%\ \text{volatile matter}_{\text{in}} - (\%\ \text{volatile matter}_{\text{in}} \times \text{volatile matter}_{\text{out}})]} \tag{15.7}$$

15.3.9.5 Organic Loading

The pounds of organic matter applied per cubic foot of digester volume can be determined by:

$$\text{volatile solids loading, lb / day / ft}^3 = \frac{\text{vol. solids added, lb / day}}{\text{digester volume, ft}^3} \tag{15.8}$$

TABLE 15.4.

Operating Condition	VA/Alkalinity Ratio
Optimum	≤0.1
Acceptable range	0.1–0.3
% Carbon dioxide in gas increase	≥0.5
pH Decreases	≥0.8

15.4 COMPOSTING

The purpose of composting biosolids is to stabilize the organic matter, reduce volume, eliminate pathogenic organisms, and produce a product that can be used as a soil amendment or conditioner. Composting is a biological process (see Figure 15.4). In a composting operation, dewatered solids are usually mixed with a bulking agent (i.e., hardwood chips) and stored until biological stabilization occurs. The composting mixture is ventilated during storage to provide sufficient oxygen for oxidation and to prevent odors. After the solids are stabilized, they are separated from the bulking agent. The composted solids are then stored for curing and are applied to farm lands or other beneficial uses. Expected performance of the composting operation for both percent volatile matter reduction and percent moisture reduction ranges from 40 to 60%+.

Performance factors related to biosolids composting include moisture content, temperature, pH, nutrient availability, and aeration.

The biosolids must contain sufficient moisture to support the biological activity. If the moisture level is too low (40% or less), biological activity will be reduced or stopped. At the same time, if the moisture level exceeds approximately 60%, it will prevent sufficient air flow through the mixture.

The composting process operates best when the temperature is maintained within an operating range of 130 to 140°F. Biological activity provides enough heat to increase the temperature well above this range. Forced air ventilation or mixing is used to remove heat and maintain the desired operating temperature range.

The temperature of the composting solids when maintained at the required levels will be sufficient to remove pathogenic organisms.

The influent pH can affect the performance of the process if extreme (less than 6.0 or greater than 11.0). The pH during composting may have some impact on the biological activity but does not appear to be a major factor. Composted biosolids generally have a pH in the range of 6.8 to 7.5.

The critical nutrient in the composting process is nitrogen. The process works best when the ratio of nitrogen to carbon is in the range of 26 to 30 carbon to one nitrogen. Above this ratio, composting is slowed. Below this ratio, the nitrogen content of the final product may be less attractive as a compost.

Aeration is essential to provide oxygen to the process and to control the temperature. In forced air processes, some means of odor control should be included in the design of the aeration system.

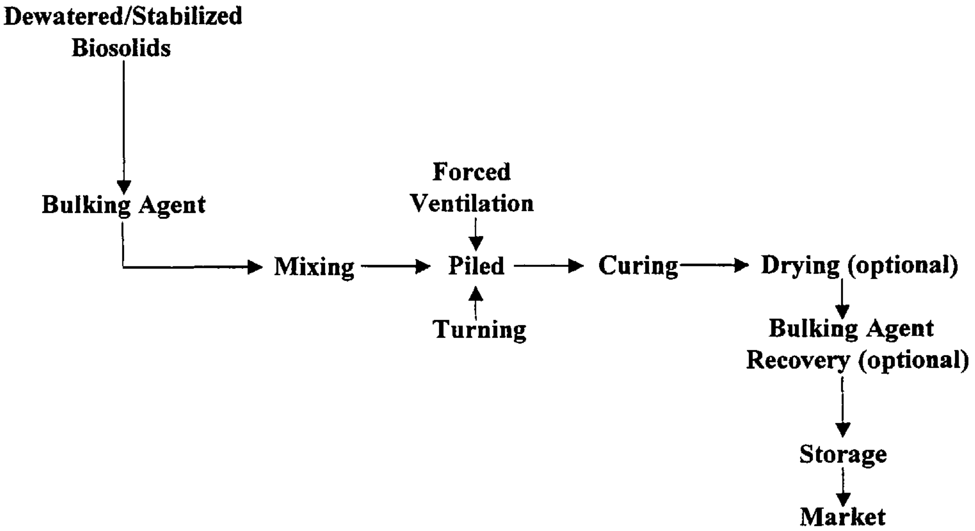


Figure 15.4 Flow diagram for composting biosolids.

15.5 LIME STABILIZATION

In lime stabilization, process residuals are mixed with lime to achieve a pH of approximately 12.0. This pH is maintained for at least two hours. During this time, all of the microorganisms are destroyed. The treated solids can then be dewatered for disposal or directly land applied. Factors affecting operation include type of solids being treated and solids concentration.

During lime stabilization, the solids will also undergo several chemical changes. For example, volatile suspended solids will be reduced 10 to 35%. In addition, total suspended solids will increase, total dissolved solids will decrease, soluble phosphorus level will decrease, and total alkalinity will increase.

15.6 WET AIR OXIDATION

Wet air oxidation or thermal treatment uses moderate to high pressures and heat to chemically oxidize the organic matter in a closed reactor vessel. The process grinds the solids to produce a uniform material, pressurizes the mixture by adding air or passing through high pressure pumps, heats the mixture to the required temperature, oxidizes the organic matter in the pressurized reactor, separates the oxidized solids from the liquid, returns the liquid to the wastewater treatment plant, and transfers the solids to a dewatering device. This process substantially improves dewatering and reduces the volume of material for disposal. It also produces a very high strength waste that must be returned to the wastewater treatment system for further treatment. *Note:* This can cause overloading of the wastewater treatment system.

Wet air oxidation requires less space than many other stabilization processes. In addition, the process can be started and stopped based upon need. On the other hand, disadvantages include a large amount of mechanical equipment requiring frequent maintenance; very high energy requirements; and high pressure and temperatures that are potential safety risks for operators.

15.7 CHLORINE OXIDATION

Chlorine oxidation uses chlorine to oxidize the organic solids and also occurs in a closed vessel. In this process, chlorine (100 to 1,000 mg/L) is mixed with a recycled solids flow. The recycled flow and process residual flow are mixed in the reactor. The solids and water are separated after leaving the reactor vessel. The water is returned to the wastewater treatment system, and the treated solids are dewatered for disposal. The main advantages of chlorine oxidation include lower space requirements and that it can be operated intermittently. The main disadvantage is production of extremely low pH and high chlorine content in the supernatant.

15.8 BIOSOLIDS INCINERATION

Incineration of wastewater biosolids provides the highest levels of moisture, organic matter, pathogenic organism, and volume reduction of any sludge treatment process. However, the process has not been widely used because of the high costs of construction and strict regulatory compliance requirements (i.e., Clean Air Act).

The biosolids incineration process will achieve maximum reductions if sufficient fuel, air, time, temperature, and turbulence are provided. The process begins with drying the biosolids and involves the following steps:

- raising the temperature of the biosolids feed to 212°F

- increasing the temperature of the dried biosolids volatile solids to the ignition point

Currently, two major incineration systems are used for biosolids incineration: multiple-hearth and fluidized-bed incinerators.

15.8.1 MULTIPLE-HEARTH INCINERATOR

The multiple-hearth furnace contains several hearths arranged in a vertical stack. Dewatered biosolids are placed on the outer edge of the top hearth. The rotating rabble arms move them slowly to the center of the hearth. At the center of the hearth, the solids fall through ports to the second level. The process is repeated in the opposite direction. Solids are dried by hot gases produced by burning on lower hearths. The dry solids pass to the lower hearths where the high temperature ignites the solids. Burning continues to completion. Ash materials discharge to the lower cooling hearth and are discharged for disposal. Internal equipment is continuously cooled by air flowing inside the center column and rabble arms.

15.8.2 FLUIDIZED BED

The fluidized-bed incinerator utilizes a hot sand reservoir in which hot air is blown from below to expand and fluidize the bed. Air is pumped into the bottom of the unit where it expands (fluidizes) the sand bed. The fluidized bed is heated to its operating temperature (1,200 to 1,500°F). Auxiliary fuel is added when needed to maintain operating temperature. Biosolids are injected into the heated sand bed. Moisture is immediately evaporated. Organic matter is ignited and is reduced to ash. Residues are ground to fine ash by the sand movement. Fine ash particles flow up and out of the unit with exhaust gases. Ash particles are removed using common air pollution control processes. The air flow rate is controlled by oxygen analyzers in the exhaust gas.

A major advantage of the fluidized-bed incinerator is that it can be operated as little as four hours per day with little or no reheating because of the high amount of heat retained in the sand.

15.9 CHAPTER REVIEW QUESTIONS

15-1 Name three processes that use biological activity to stabilize wastewater solids.

15-2 When operating an aerobic digester, the dissolved oxygen level should be maintained at __________ mg/L or higher.

15-3 What is the normal operating temperature of a heated anaerobic digester?

15-4 Any daily temperature change of more than __________ °F will cause the anaerobic digester production of methane gas to decrease.

15-5 The supernatant contains 340 mg/L volatile acids and 1,830 mg/L of alkalinity. What is the volatile solids to alkalinity ratio. Based upon the ratio, is the digester operating properly?

15-6 The digester is 40 feet in diameter and has a depth of 25 feet. Solids are pumped to the digester at the rate of 5,000 gallons per day. What is the digestion time based upon flow?

15-7 The primary treatment residual solids pumped to the digester contain 70% volatile matter. The digested biosolids removed from the digester contain 48% volatile matter. What is the percent volatile matter reduction?

15-8 When sludge is pumped from primary settling directly to the anaerobic digester, pumping should be controlled to produce a sludge with _______________ solids.

15-9 To oxidize biosolids using lime stabilization, what is required?

15-10 Can sludge be added to a floating cover anaerobic digester without withdrawing an equal amount of supernatant or sludge?

15-11 What are the digestion rate and the volatile matter reductions achieved by an anaerobic digester dependent on?

15-12 What is the volatile acids/alkalinity ratio when the anaerobic digester contains 387 mg/L of volatile acids and 5,805 mg/L of alkalinity?

CHAPTER 16

Dewatering Biosolids

16.1 INTRODUCTION

USUALLY employed after anaerobic digestion (see Figure 16.1), dewatering is the wastewater treatment unit process whereby various unit processes are employed to remove water from biosolids and alter their form from a liquid to a damp solid. An ideal dewatering operation would capture all of the biosolids at minimum cost, and the resultant dry biosolids or cake would be capable of being handled without causing unnecessary problems. Process reliability, ease of operation, and compatibility with the plant environment would also be optimum. Dewatering processes include sand drying beds, vacuum filters, centrifuges, and filter presses (belt and plate).

16.2 DRYING BEDS

Drying beds have been used successfully for years to dewater biosolids. They are generally used for dewatering well-digested biosolids (attempts to air dry raw sludge usually result in odor and insect problems). Comprised of a sand bed (consisting of a gravel base, underdrains, and 8 to 12 inches of filter grade sand), drying beds include an inlet pipe, splash pad containment walls, and a system to return filtrate (water) for treatment [see Figure 16.2(a)–(d)]. In some cases, the sand beds are covered to provide drying solids protection from the elements.

Dewatering using natural methods involves two processes: drainage and evaporation. First, solids are pumped to the sand bed and are allowed to drain off excess water through the sand. Second, moisture is released to the atmosphere by evaporation. When the biosolids reach the desired percent solids, the dewatered biosolids are removed from the bed [see Figure 16.2(b)] and are transported to the point of disposal/reuse.

✓ *Note:* Drying beds are the simplest and cheapest method for dewatering biosolids. Moreover, no special training or expertise is required. However, there is a downside; namely, drying beds require a great deal of manpower to clean beds; they can create odor and insect problems; and they can cause biosolids buildup during inclement weather.

16.2.1 PERFORMANCE FACTORS

Various factors affect the performance of drying beds. The length of time required to achieve the desired solids concentrations is affected by climate, depth of biosolids applied, type of biosolids

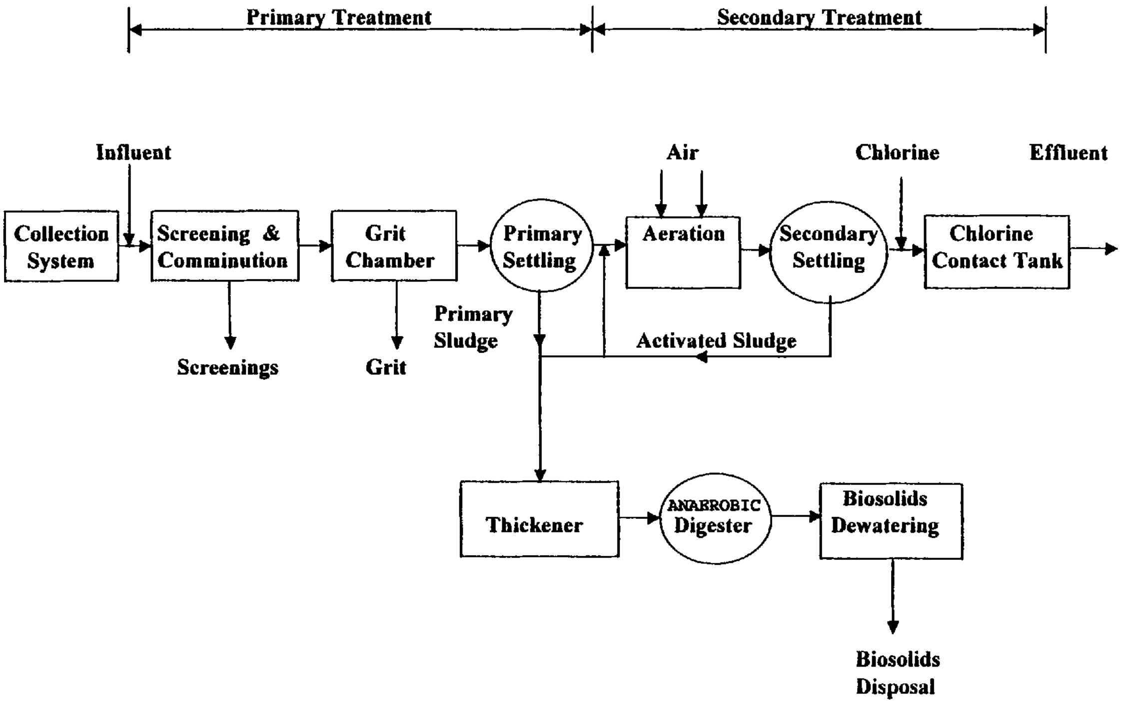


Figure 16.1 Sludge treatment unit process.

The depth of the biosolids drawn onto the bed has a major impact on the required drying time. Deeper biosolids layers require longer drying times.

The quality and solids concentration of the biosolids placed on the drying media will affect the time requirements.

Covered drying beds prevent re-wetting of the biosolids during storm events. In most cases, this will reduce the average drying time required to reach the desired solids levels.

16.3 VACUUM FILTRATION

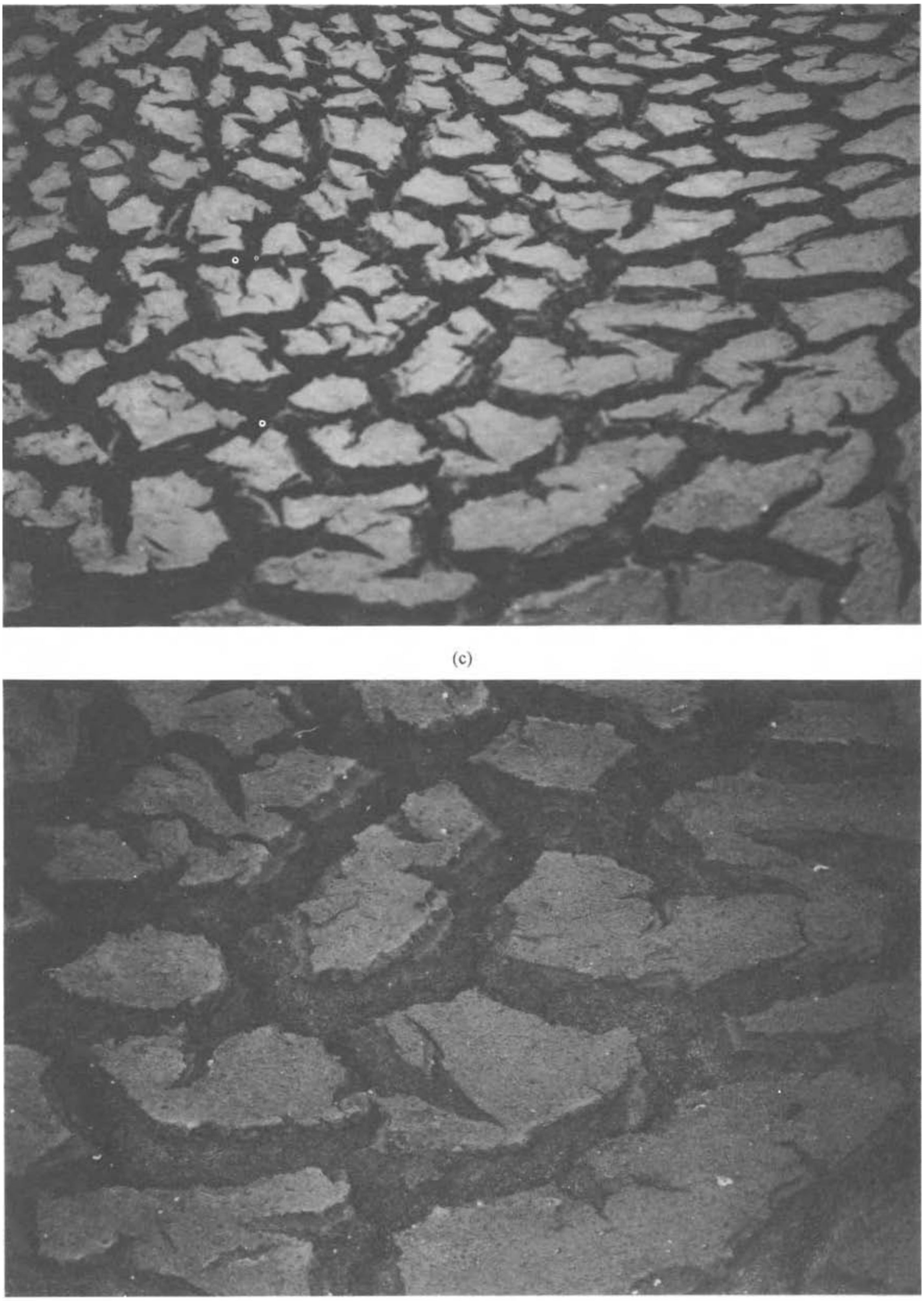
Vacuum filters have also been used for many years to dewater sludge. The rotary vacuum filter includes filter media (belt, cloth, or metal coils), media support (drum), vacuum system, chemical feed equipment, and conveyor belt(s) to transport the dewatered solids. Solids concentrations of 15 to 40% can be achieved.

In operation, chemically treated solids are pumped to a vat or tank in which a rotating drum is submerged. As the drum rotates, a vacuum is applied to the drum. Solids collect on the media and are held there by the vacuum as the drum rotates out of the tank. The vacuum removes additional water from the captured solids. When solids reach the discharge zone, the vacuum is released, and the dewatered solids are discharged onto a conveyor belt for disposal. The media are then washed prior to returning to the start of the cycle.

16.3.1 PROCESS CONTROL CALCULATIONS

Probably the most frequent calculation vacuum filter operators make is for determining filter yield. Example 16.1 illustrates how this calculation is made.

(a)


(c)

(d)

Figure 16.2 (continued) (a) Drying bed, (b) dried biosolids ready for removal and disposal, (c) and (d) close up shots of dried biosolids.

16.3.1.1 Filter Yield (lb/hr/ft^2): Vacuum Filter

Example 16.1

Problem:

Thickened thermally conditioned biosolids are pumped to a vacuum filter at a rate of 40 gpm. The vacuum area of the filter is 12 ft wide with a drum diameter of 9.7 ft. If the sludge concentration is 11%, what is the filter yield in lb/hr/ft^2? Assume the sludge weighs 8.34 lb/gal.

Solution:

First calculate the filter surface area.

$$\text{area of a cylinder side} = 3.14 \times \text{diameter} \times \text{length}$$

$$= 3.14 \times 9.7\ \text{ft} \times 12\ \text{ft} = 365.5\ \text{ft}^2$$

Next calculate the pounds of solids per hour.

$$\frac{40\ \text{gpm}}{1\ \text{min}} \times \frac{60\ \text{min}}{1\ \text{hr}} \times \frac{8.34\ \text{lb}}{1\ \text{gal}} \times \frac{11\%}{100\%} = 2{,}201.8\ \text{lb/hr}$$

Dividing the two:

$$\frac{2{,}201.8\ \text{lb/hr}}{365.5\ \text{ft}^2} = 6.02\ \text{lb/hr/ft}^2$$

16.4 PRESSURE FILTRATION

Pressure filtration uses a positive pressure to force liquid through the filter media. Filter presses (belt or plate and frame types) are used to dewater biosolids. The belt filter includes two or more porous belts, rollers, and related handling systems for chemical makeup and feed, and supernatant and solids collection and transport.

The plate and frame filter consists of a support frame, filter plates covered with porous material, a hydraulic or mechanical mechanism for pressing plates together, and related handling systems for chemical makeup and feed, and supernatant and solids collection and transport.

In operation, the belt filter uses a coagulant (polymer) mixed with the influent solids. The chemically treated solids are discharged between two moving belts. First, water drains from the solids by gravity. Then, as the two belts move between a series of rollers, pressure "squeezes" additional water out of the solids. The solids are then discharged onto a conveyor belt for transport to storage/disposal.

In the plate and frame filter, solids are pumped (sandwiched) between plates. Pressure (200 to 250 psi) is applied to the plates, and water is "squeezed" from the solids. At the end of the cycle, the pressure is released, and, as the plates separate, the solids drop out onto a conveyor belt for transport to storage or disposal.

Filter presses have lower operation and maintenance costs than vacuum filters or centrifuges. They typically produce a good quality cake and can be batch operated. However, construction and installation costs are high. Moreover, chemical addition is required, and the presses must be operated by skilled personnel.

16.4.1 PROCESS CONTROL CALCULATIONS

The process control calculation most commonly used in operating the belt filter press determines the hydraulic loading rate on the unit. The most commonly used process control calculation used in operation of plate and filter presses determines the pounds of solids pressed per hour. Both of these calculations are shown below.

16.4.1.1 Hydraulic Loading Rate: Belt Filter Press

Example 16.2

Problem:

A belt filter press receives a daily biosolids flow of 0.40 MG. If the belt is 60 inches wide, what is the hydraulic loading rate on the unit in gallons per minute for each foot of belt width (gpm/ft)?

Solution:

$$\frac{0.40\ \text{MG}}{1\ \text{d}} \times \frac{1{,}000{,}000\ \text{gal}}{1\ \text{MG}} \times \frac{1\ \text{d}}{1{,}440\ \text{min}} = \frac{277.7\ \text{gal}}{1\ \text{min}}$$

$$60\ \text{in} \times \frac{1\ \text{ft}}{12\ \text{in}} = 5\ \text{ft}$$

$$\frac{277.7\ \text{gal}}{5\ \text{ft}} = 55.6\ \text{gpm/ft}$$

16.4.1.2 Pounds of Solids Pressed Per Hour: Plate and Frame Press

Example 16.3

Problem:

A plate and frame filter press can process 800 gal of biosolids during its 120-min operating cycle. If the biosolids concentration is 3.7%, and if the plate surface area is 140 ft^2, how many pounds of solids are pressed per hour for each square foot of plate surface area?

Solution:

$$800\ \text{gal} \times \frac{3.7\%}{100\%} \times \frac{8.34\ \text{lb}}{1\ \text{gal}} = 246.9\ \text{lb}$$

$$\frac{246.9\ \text{lb}}{120\ \text{min}} \times \frac{60\ \text{min}}{1\ \text{hr}} = 123.4\ \text{lb/hr}$$

$$\frac{123.4\ \text{lb/hr}}{140\ \text{ft}^2} = 0.88\ \text{lb/hr/ft}^2$$

16.5 CENTRIFUGES

gaining popularity. The most common system employed is the continuous feed, solid bowl conveyor-type centrifuge. Depending on the type of centrifuge used, in addition to centrifuge pumping equipment for solids feed and centrate removal, chemical makeup and feed equipment and support systems for removal of dewatered solids are required.

In operation, the centrifuge spins at a very high speed. The centrifugal force it creates "throws" the solids out of the water. Chemically conditioned solids are pumped into the centrifuge. The spinning action "throws" the solids to the outer wall of the centrifuge. The solids held against the outer wall are scraped to a discharge point by an internal scroll moving slightly faster or slower than the centrifuge speed of rotation. Clear liquid centrate overflows the weir and is discharged.

16.6 CHAPTER REVIEW QUESTIONS

16-1 The biosolids pump operates 30 minutes every three hours. The pump delivers 65 gpm. If the biosolids is 5.1% solids and has a volatile matter content of 64%, how many pounds of volatile solids are removed from the settling tank each day?

16-2 Name three general ways that biosolids can be dewatered.

16-3 What two actions take place in a biosolids drying bed?

16-4 Thickened thermally conditioned biosolids are pumped to a vacuum filter at a rate of 30 gpm. The vacuum area of the filter is 10 ft wide with a drum diameter of 8.4 ft. If the biosolids concentration is 11%, what is the filter yield in lb/hr/ft^2? Assume the sludge weight is 8.34 lb/gal.

CHAPTER 17

Land Application of Biosolids

17.1 INTRODUCTION

THE purpose of land application of biosolids is to dispose of the treated biosolids in an environmentally sound manner by recycling nutrients and soil conditioners. In order to be land applied, wastewater biosolids must comply with state and federal biosolids management/disposal regulations. Biosolids must not contain materials that are dangerous to human health (i.e., toxicity, pathogenic organisms, etc.) or dangerous to the environment (i.e., toxicity, pesticides, heavy metals, etc.).

Treated biosolids are land applied by either direct injection or application and plowing in (incorporation).

17.2 REGULATORY REQUIREMENTS

USEPA, under its *Domestic Septage Regulatory Guidance: A Guide to the EPA 503 Rule* (1993), mandates that sewage biosolids be used or disposed of in a way that protects human health and the environment. Part 503 imposes requirements for the land application, surface disposal, and incineration of biosolids.

Under Part 503, USEPA defines land application as the spreading, spraying, injection, or incorporation of biosolids, including a material derived from sewage sludge (e.g., compost and pelletized sewage biosolids), onto or below the surface of the land to take advantage of the soil-enhancing qualities of the biosolids. Biosolids are land applied to improve the structure of the soil. They are also applied as a fertilizer to supply nutrients to crops and other vegetation grown in the soil. Biosolids are commonly applied to agricultural land (including pasture and range land, forests, reclamation sites, public contact sites—e.g., parks, turf farms, highway median strips, golf courses), lawns, and home gardens.

Biosolids are land applied in bulk form or are sold or given away in a bag or similar container for application to the land. The term "bulk" implies biosolids that are applied generally in large quantities to large parcels of land. Bulk biosolids are typically used by commercial and municipal appliers for agriculture, tree and turf farms, golf courses, parks, and reclamation, construction, or surface mining sites. Biosolids sold or given away in a bag or other container are generally used by the smaller scale user, such as a home gardener or landscaper.

✓ *Note:* The agronomic rate is the whole biosolids application rate designed to (1) provide the amount of nitrogen needed by a crop or vegetation grown on the land and (2) minimize the amount of nitrogen in the biosolids that passes below the root zone of the crop or vegetation grown on the land to the groundwater.

In disturbed areas such as mining sites, where there is no soil substrate from which to sustain vegetation, large amounts of nitrogen and organic material may be required to re-establish basic plant cover. When biosolids are used in these areas to supply the adequate substrate, it is often necessary to apply quantities that exceed the agronomic rate. In such cases, biosolids are generally applied once, and then the site is seeded. Because of the highly soluble nature of nitrates, which are the main nutritive component of both biosolids and standard fertilizer products, biosolids applied in this manner have the potential for nitrate contamination of groundwater if not properly managed. Therefore, any time biosolids are going to be applied at greater than agronomic rates, the land applier must first seek approval from the permitting authority. In some instances, the permitting authority may require a specific permit for this practice.

Surface disposal is another regulated use or disposal practice for biosolids that is similar to land application in that it entails the placement of biosolids on the land. The main difference between the two is that, in the case of surface disposal, biosolids are placed on the land for the purpose of final disposal, without regard for the soil-enhancing qualities of the biosolids.

17.3 REFERENCE

USEPA, *Domestic Septage Regulatory Guidance: A Guide to the EPA 503 Rule.* Washington, D.C.: EPA, 1993.

CHAPTER 18

Fecal Coliform Testing

18.1 INTRODUCTION

THE specific disease-producing organisms present in water are not easily identified. The techniques for comprehensive bacteriological examination are complex and time-consuming. Thus, it has been necessary to develop tests that indicate the relative degree of contamination in terms of an easily defined quantity. The most widely used test involves estimation of the number of bacteria of the coliform group, which are always present in fecal wastes and which outnumber disease-producing organisms.

In this chapter, we discuss fecal coliform testing.

18.2 FECAL COLIFORM TESTING: WHAT IS IT?

Fecal coliform bacteria are non-disease-causing organisms that are found in the intestinal tract of all warm-blooded animals. Each discharge of body wastes contains large amounts of these organisms. In water, the presence of fecal coliform bacteria indicates the possible presence of pathogenic organisms. The correlation between coliforms and human pathogens in natural waters is not absolute; however, because these bacteria can originate from the feces of both humans and other warm-blooded animals and if the number of fecal coliform bacteria present is known, they are a good indicator of the amount of pollution present in the water. Keep in mind that coliforms from the intestinal tract of a human cannot be distinguished from those of animals. Therefore, the significance of testing in pollution surveys depends on a knowledge of the water body and probable source of the observed fecal coliforms.

✓ *Note*: Coliform bacteria are indicators.

18.3 FECAL COLIFORM TESTING PROCEDURES

Federal regulations cite two approved methods for the determination of fecal coliform in wastewater: (1) multiple tube fermentation or most probable number (MPN) procedure; and (2) membrane filter (MF) procedure.

✓ *Note:* Because the MF procedure can yield low or highly variable results for chlorinated wastewater, USEPA requires verification of results using the MPN procedure to resolve any controversies.

✓ Each of these procedures is briefly discussed in the following sections. However, do not attempt to perform the fecal coliform test using the summary information provided within this handbook.

Instead, refer to the appropriate reference cited in the Federal Regulations for a complete discussion of these procedures.

18.4 TESTING PREPARATIONS

18.4.1 EQUIPMENT AND TECHNIQUES

Whenever microbiological testing of water samples is performed, certain general considerations and techniques will be required. Because these are basically the same for each test procedure, they are reviewed here prior to specific discussions of the two test methods.

- *Reagents and Media*—all reagents and media utilized in performing microbiological tests on water samples must meet the standards specified in the reference cited in Federal Regulations.
- *Reagent Grade Water*—deionized water that is tested annually and found to be free of dissolved metals and bactericidal or inhibitory compounds is preferred for use in preparing culture media and test reagents, although distilled water may be used.
- *Chemicals*—all chemicals used in fecal coliform monitoring must be ACS reagent grade or equivalent.
- *Media*—to ensure uniformity in the test procedures, the use of dehydrated media is recommended. Sterilized, prepared media in sealed test tubes, ampules, or dehydrated media pads are also acceptable for use in this test.
- *Glassware and Disposable Supplies*—all glassware, equipment, and supplies used in microbiological testing should meet the standards specified in the references cited in the Federal Regulations.

18.4.2 PREPARATION OF EQUIPMENT AND CHEMICALS

All glassware used for bacteriological testing must be thoroughly cleaned using a suitable detergent and hot water. The glassware should be rinsed with hot water to remove all traces of residual from the detergent and, finally, should be rinsed with distilled water. Laboratories should use a detergent certified to meet bacteriological standards or, at a minimum, rinse all glassware after washing with two tap water rinses followed by five distilled waster rinses.

For sterilization of equipment, the hot air sterilizer or autoclave can be used. When using the hot air sterilizer, all equipment should be wrapped in high-quality (Kraft) paper or placed in containers prior to hot air sterilization. All glassware, except those in metal containers, should be sterilized for a minimum of 60 minutes at 170°C. Sterilization of glassware in metal containers should require a minimum of two hours. Hot air sterilization cannot be used for liquids.

When using an autoclave, sample bottles, dilution water, culture media, and glassware may be sterilized by autoclaving at 121°C for 15 minutes.

18.4.3 STERILE DILUTION WATER PREPARATION

The dilution water used for making sample serial dilutions is prepared by adding 1.25 mL of stock buffer solution and 5.0 mL of magnesium chloride solution to 1,000 mL of distilled or deionized water. The stock solutions of each chemical should be prepared as outlined in the reference cited by the Federal Regulations. The dilution water is then dispensed in sufficient quantities to produce 9 or 99 mL in each dilution bottle following sterilization. If the membrane filter procedure is used, additional 60- to 100-mL portions of dilution water should be prepared and sterilized to provide rinse water required by the procedure.

18.4.4 SERIAL DILUTION PROCEDURE

At times, the density of the organisms in a sample makes it difficult to accurately determine the actual number of organisms in the sample. When this occurs, the sample size may need to be reduced to as little as one millionth of a milliliter. In order to obtain such small volumes, a technique known as serial dilutions has been developed.

18.4.5 BACTERIOLOGICAL SAMPLING

To obtain valid test results that can be utilized in the evaluation of process efficiency of water quality, proper technique, equipment, and sample preservation are critical. These factors are especially critical in bacteriological sampling.

- *Sample dechlorination*—when samples of chlorinated effluents are to be collected and tested, the sample must be dechlorinated. Prior to sterilization, place enough sodium thiosulfate solution (10%) in a clean sample container to produce a concentration of 100 mg/L in the sample (for a 120-mL sample bottle, 0.1 mL is usually sufficient). Sterilize the sample container as previously described.
- *Sampling procedure*
  - (1) Keep the sample bottle unopened after sterilization until the sample is to be collected.
  - (2) Remove the bottle stopper and hood or cap as one unit. Do not touch or contaminate the cap or the neck of the bottle.
  - (3) Submerge the sample bottle in the water to be sampled.
  - (4) Fill the sample bottle approximately 3/4 full, but not less than 100 mL.
  - (5) Aseptically replace the stopper or cap on the bottle.
  - (6) Record the date, time, and location of sampling, as well as the sampler's name and any other descriptive information pertaining to the sample.
- *Sample preservation and storage*—examination of bacteriological water samples should be performed immediately after collection. If testing cannot be started within one hour of sampling, the sample should be iced or refrigerated at 4°C or less. The maximum recommended holding time for fecal coliform samples from wastewater is six hours. The storage temperature and holding time should be recorded as part of the test data.

✓ *Note:* The fecal coliform sample preserved at 4°C can be held up to six hours before starting the test.

18.5 MULTIPLE TUBE FERMENTATION TECHNIQUE

The multiple tube fermentation technique for fecal coliform testing is useful in determining the fecal coliform density in most water, solid, or semisolid samples. Wastewater testing normally requires use of the presumptive and confirming test procedures. It is recognized as the method of choice for any samples that may be controversial (enforcement related). The technique is based on the most probable number of bacteria present in a sample that produces gas in a series of fermentation tubes with various volumes of diluted sample. The MPN is obtained from charts based on statistical studies of known concentrations of bacteria.

The technique utilizes a two-step incubation procedure (see Figure 18.1). The sample dilutions are first incubated in lauryl (sulfonate) tryptose broth for 24 to 48 hours (presumptive test). Positive samples are then transferred to EC broth and incubated for an additional 24 hours (confirming test). Positive samples from this second incubation are used to statistically determine the MPN from the appropriate reference chart.

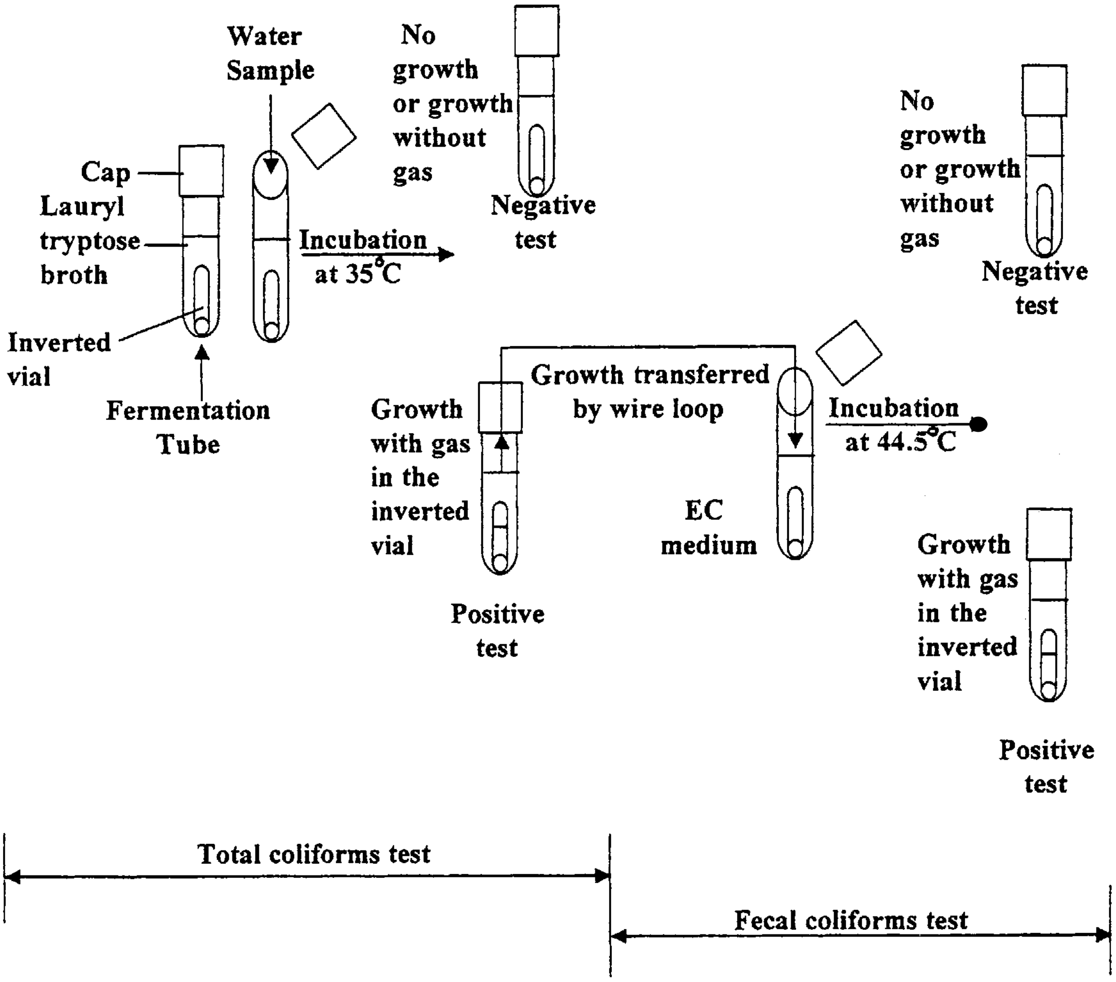


Figure 18.1 Diagram of the basic test for total coliforms and second-phase confirmatory test for thermotolerant fecal coliforms.

A single media, 24-hour procedure is also acceptable. In this procedure, sample dilutions are inoculated in A-1 media and are incubated for three hours at 35°C then incubated the remaining 20 hours at 44.5°C. Positive samples from these inoculations are then used to statistically determine the MPN value from the appropriate chart.

18.5.1 FECAL COLIFORM MPN PRESUMPTIVE TEST PROCEDURE

(1) Prepare dilutions and inoculate five fermentation tubes for each dilution.
(2) Cap all tubes, and transfer to incubator.
(3) Incubate 24 + 2 hours at 35 ± 0.5°C.
(4) Examine tubes for gas.
  Gas present = Positive test – transfer
  No gas = Continue incubation
(5) Incubate total time 48 ± 3 hours at 35 ± 0.5°C
(6) Examine tubes for gas.
  Gas present = Positive test – transfer
  No gas = Negative test

✓ *Note:* Keep in mind that the fecal coliform MPN confirming procedure or fecal coliform procedure using A-1 broth test is used to determine the MPN/100 mL.

✓ *Note:* The MPN procedure for fecal coliform determinations requires a minimum of three dilutions with five tubes/dilution.

18.5.2 CALCULATION OF MOST PROBABLE NUMBER (MPN)/100 mL

The calculation of the MPN test results requires selection of a valid series of three consecutive dilutions. The number of positive tubes in each of the three selected dilution inoculations is used to determine the MPN/100 mL. In selecting the dilution inoculations to be used in the calculation, each dilution is expressed as a ratio of positive tubes per tubes inoculated in the dilution, i.e., three positive/five inoculated (3/5). There are several rules to follow in determining the most valid series of dilutions. In the following examples, four dilutions were used for the test.

(1) Using the confirming test data, select the highest dilution showing all positive results (no lower dilution showing less than all positive) and the next two higher dilutions.
(2) If a series shows all negative values with the exception of one dilution, select the series that places the only positive dilution in the middle of the selected series.
(3) If a series shows a positive result in a dilution higher than the selected series (using rule #1), it should be incorporated into the highest dilution of the selected series.

After selecting the valid series, the MPN/100 mL is determined by locating the selected series on the MPN reference chart. If the selected dilution series matches the dilution series of the reference chart, the MPN value from the chart is the reported value for the test. If the dilution series used for the test does not match the dilution series of the chart, the test result must be calculated.

$$\text{MPN}/10\text{ mL} = \text{MPN}_{\text{chart}} \times \frac{\text{sample volume in first dilution}_{\text{chart}}}{\text{sample volume in first dilution}_{\text{sample}}} \tag{18.1}$$

Example 18.1

Problem:

Using the results recorded in Table 18.1, calculate the MPN/100 mL of the example.

Solution:

(1) Select the highest dilution (tube with the lowest amount of sample) with all positive tubes (1.0 mL dilution). Select the next two higher dilutions (0.1 mL and 0.01 mL). In this case, the selected series will be 5-3-1.

TABLE 18.1.

mL of Sample in Each Serial Dilution	Positive Tubes/Tubes Inoculated
10.0	5/5
1.0	5/5
0.1	3/5
0.01	1/5
0.001	1/5

TABLE 18.2. MPN Reference Chart.

Sample Volume, mL				Sample Volume, mL			
10	1.0	0.1	MPN/100 mL	10	1.0	0.1	MPN/100 mL
0	0	0	0	4	2	0	22
0	0	1	2	4	2	1	26
0	1	0	2	4	3	0	27
0	2	0	4	4	3	1	33
				4	4	0	34
1	0	0	2				
1	0	1	4	5	0	0	23
1	1	0	4	5	0	1	31
1	1	1	6	5	0	2	43
1	2	0	6	5	1	0	33
				5	1	1	46
2	0	0	5	5	1	2	63
2	0	1	7				
2	1	0	7	5	2	0	49
2	1	1	9	5	2	1	70
2	2	0	9	5	2	2	94
2	3	0	12	5	3	0	79
				5	3	1	110
3	0	0	8	5	3	2	140
3	0	1	11				
3	1	0	11	5	3	3	180
3	1	1	14	5	4	0	130
3	2	0	14	5	4	1	170
3	2	1	17	5	4	2	220
				5	4	3	280
4	0	0	13	5	4	4	350
4	0	1	17				
4	1	0	17	5	5	0	240
4	1	1	21	5	5	1	350
4	1	2	26	5	5	2	540
				5	5	3	920
				5	5	4	1600
				5	5	5	≥2400

(2) Include any positive results in dilutions higher than the selected series (0.001 mL dilution 1/5). This changes the selected series to 5-3-2.

(3) Using the first three columns in Table 18.2, locate this series (5-3-2).

(4) Read the MPN value from the fourth column (140).

(5) In Table 18.2, the dilution series begins with 10 mL. For this test, the series begins with 1.0 mL.

$$\text{MPN}/100\,\text{mL} = 140\,\text{MPN}/100\,\text{mL} \times \frac{10\,\text{mL}}{1\,\text{mL}}$$

$$= 1{,}400\,\text{MPN}/100\,\text{mL}$$

18.6 MEMBRANE FILTRATION TECHNIQUE

The membrane filtration technique can be useful for determining the fecal coliform density in wastewater effluents, except for primary treated wastewaters that have not been chlorinated or wastewaters containing toxic metals or phenols. Chlorinated secondary or tertiary effluents may be tested using this method, but results are subject to verification by MPN technique.

The membrane filter technique utilizes a specially designed filter pad with uniformly sized pores (openings) that are small enough to prevent bacteria from entering the filter (see Figure 18.2).

Another unique characteristic of the filter allows liquids, such as the media, placed under the filter to pass upward through the filter to provide nourishment required for bacterial growth.

✓ *Note:* In the membrane filter method, the number of coliforms is estimated by the number of colonies grown.

18.6.1 MEMBRANE FILTER PROCEDURE

(1) Sample filtration

- Select a filter, and aseptically separate it from the sterile package.
- Place the filter on the support plate with the grid side up.
- Place the funnel assembly on the support; secure as needed (see Figure 18.2).
- Pour 100 mL of sample or serial dilution onto the filter, apply vacuum.

✓ *Note:* The sample size and/or necessary serial dilution should produce a growth of 20 to 60 fecal coliform colonies on at least one filter. The selected dilutions must also be capable of showing permit excursions.

- Allow all of the liquid to pass through the filter.
- Rinse the funnel and filter with three portions (20–30 mL) of sterile, buffered dilution water. (Allow each portion to pass through the filter before the next addition).
- Remove the filter funnel, and aseptically transfer the filter, grid side up, onto the prepared media.

✓ Filtration units should be sterile at the start of each filtration series and should be sterilized again if the series is interrupted for 30 minutes or more. A rapid interim sterilization can be accomplished by 2 minutes exposure to ultraviolet (UV) light, flowing steam or boiling water.

(2) Incubation

- Place absorbent pad into culture dish using sterile forceps.

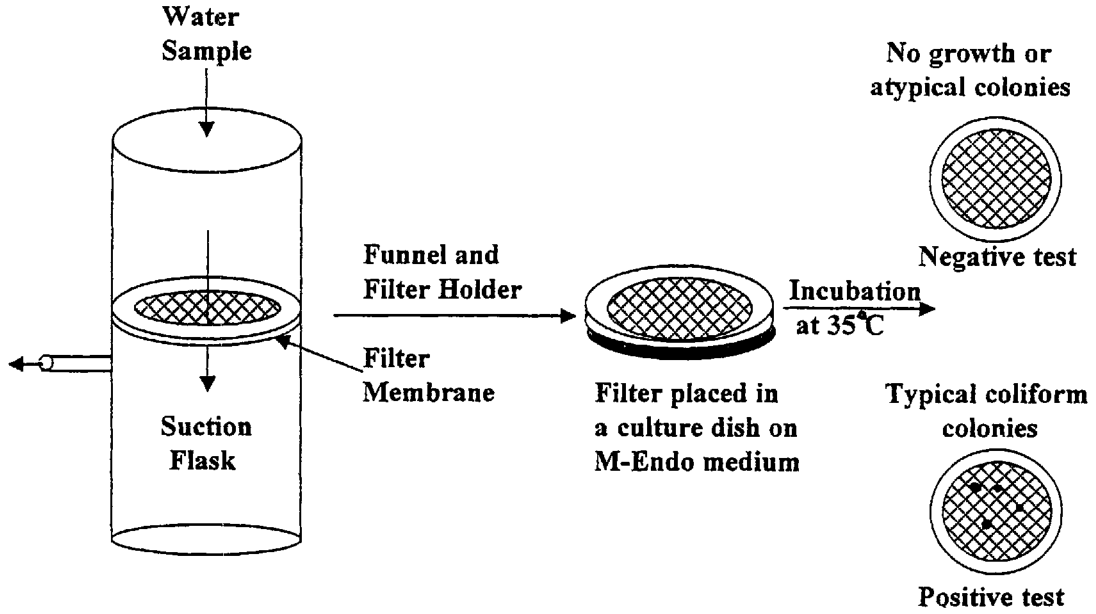


Figure 18.2 Diagram of membrane filter technique for coliform testing.

- Add 1.8 to 2.0 mL M-FC media to the absorbent pad.
- Discard any media not absorbed by the pad.
- Filter sample through sterile filter.
- Remove filter from assembly, and place on absorbent pad (grid up).
- Cover culture dish.
- Seal culture dishes in a weighted plastic bag.
- Incubate filters in a water bath for 24 hours at 44.5 ± 0.2°C.

18.6.2 COLONY COUNTING

Upon completion of the incubation period, the surface of the filter will have growths of both fecal coliform and non-fecal coliform bacterial colonies. The fecal coliform will appear blue in color, while non-fecal coliform colonies will appear gray or cream colored.

When counting the colonies the entire surface of the filter should be scanned using a 10× to 15× binocular, wide-field dissecting microscope.

The desired range of colonies, for the most valid fecal coliform determination is 20 to 60 colonies per filter. If multiple sample dilutions are used for the test, counts for each filter should be recorded on the laboratory data sheet.

- *Too many colonies*—Filters that show a growth over the entire surface of the filter with no individually identifiable colonies should be recorded as "confluent growth." Filters that show a very high number of colonies (greater than 200) should be recorded as TNTC (too numerous to count).
- *Not enough colonies*—If no single filter meets the desired minimum colony count (20 colonies), the sum of the individual filter counts and the respective sample volumes can be used in the formula to calculate the colonies/100 mL.

✓ *Note:* In each of these cases, adjustments in sample dilution volumes should be made to ensure future tests meet the criteria for obtaining a valid test result.

18.6.3 CALCULATION

The fecal coliform density can be calculated using the following formula:

$$\text{colonies}/100\,\text{mL} = \frac{\text{colonies counted}}{\text{sample volume, mL}} \times 100\,\text{mL} \tag{18.2}$$

Example 18.2

Problem:

Using the data shown below, calculate the colonies per 100 mL for the influent and effluent samples noted.

Sample Location	Inf. Sample Dilutions			Eff. Sample Dilutions		
mL of Sample	1.0	0.1	0.01	10	1.0	0.1
Colonies counted	97	48	16	10	5	3

Solution:

Step 1: Influent sample

Select the influent sample filter that has a colony count in the desired range (20 to 60). Because one filter meets this criterion, the remaining influent filters that did not meet the criterion are discarded.

$$\text{colonies}/100\text{ mL} = \frac{48\text{ colonies}}{0.1\text{ mL}} \times 100\text{ mL}$$

$$= 48{,}000\text{ colonies}/100\text{ mL}$$

Step 2: Effluent sample

Because none of the filters for the effluent sample meets the minimum test requirement, the colonies/100 mL must be determined by totaling the colonies on each filter and the sample volumes used for each filter.

$$\text{total colonies} = 10 + 5 + 3$$

$$= 18\text{ colonies}$$

$$\text{total sample} = 10.0\text{ mL} + 1.0\text{ mL} + 0.1\text{ mL}$$

$$= 11.1\text{ mL}$$

$$\text{colonies}/100\text{ mL} = \frac{18\text{ colonies}}{11.1\text{ mL}} \times 100$$

$$= 162\text{ colonies}/100\text{ mL}$$

✓ *Note:* The USEPA criterion for fecal coliform bacteria in bathing waters is a logarithmic mean of 200 per 100 mL, based on a minimum of five samples taken over a 30-day period, with not more than 10% of the total samples exceeding 400 per 100 mL. Because shellfish may be eaten without being cooked, the strictest coliform criterion applies to shellfish cultivation and harvesting. The USEPA criterion states that the mean fecal coliform concentration should not exceed 14 per 100 mL, with not more than 10% of the samples exceeding 43 per 100 mL.

18.6.4 INTERFERENCES

Large amounts of turbidity, algae, or suspended solids may interfere with this technique by blocking the filtration of the sample through the membrane filter. Dilution of these samples to prevent this problem may make the test inappropriate for samples with low fecal coliform densities because the sample volumes after dilution may be too small to give representative results. The presence of large amounts of non-coliform group bacteria in the samples may also prohibit the use of this method.

18.7 GEOMETRIC MEAN CALCULATION

Many NPDES discharge permits require fecal coliform testing. Results for fecal coliform testing must be reported as a geometric mean (average) of all the test results obtained during a reporting period. A geometric mean, unlike an arithmetic mean or average, dampens the effect of very high or low values that otherwise might cause a non-representative result.

✓ *Note:* Current regulatory requirements prohibit the reporting of zero MPN or colonies. If the test result does not produce any positive results or colonies, the test result must be reported as <1 (less than 1). In cases where test results are reported as zero or <1, a value of "1" should be used in the calculation of the geometric mean. This substitution does not affect the result of the calculation; it just ensures that the data are entered into the calculation in a usable form.

Calculation of the geometric mean can be performed by either of two methods. Both methods require a calculator that is capable of performing more advanced calculations. The first method requires a calculator that is capable of determining the *n*th root of a number (n = the number of values used in the calculation). The general formula for this method for calculation of the geometric mean is

$$\text{geometric mean} = \sqrt[n]{X_1 \times X_2 \times \ldots \times X_n} \tag{18.3}$$

This equation states that the geometric mean can be found by multiplying all of the data points for the given reporting period together and taking the *n*th root of this product.

Example 18.3

Problem:

Given the data below, determine the geometric mean using the *n*th root method.

Solution:

$$\begin{aligned}\text{geometric mean} &= \sqrt[4]{5 \times 7 \times 90 \times 1{,}000}\\ &= \sqrt[4]{3{,}150{,}000}\\ &= 42\ \text{colonies}/100\ \text{mL}\end{aligned}$$

The second method for calculation of the geometric mean requires a calculator that can compute logarithms (log) and antilogarithms (antilog).

$$\text{geometric mean} = \text{antilog}\left(\frac{\log X_1 + \log X_2 + \log X_3 + \ldots + \log X_n}{N_1\ \text{number of tests}}\right) \tag{18.4}$$

Procedure:

(1) If there are any reported values of "0," replace them with <1.
(2) Using the calculator, determine the logarithm of each test result.
(3) Add the logarithms of all of the test results.
(4) Divide the sum by the number of test results (*N*).
(5) Enter this number into the calculator.
(6) Press "2nd" or "INV" then "LOG"
(7) The calculator displays the geometric mean.

Example 18.4

Problem:

Given the data below, determine the geometric mean.

Data:

Week 1	12 MPN/100 mL
Week 2	28 MPN/100 mL
Week 3	37 MPN/100 mL
Week 4	25 MPN/100 mL

Solution:

$$\text{geometric mean} = \text{antilog}\left(\frac{1.079182 + 1.447158 + 1.568202 + 1.397940}{4}\right)$$

$$= \text{antilog}\left(\frac{5.492481}{4}\right)$$

$$= \text{antilog}\, 1.373120$$

$$= 23.6\ \text{MPN}/100\ \text{mL}$$

18.8 CHAPTER REVIEW QUESTION

18-1 Explain (in simple terms) the methods involved in analyzing for total coliforms in an effluent sample.

CHAPTER 19

Safety and Health Implications

19.1 INTRODUCTION

OVER the years, several statistical reports on accident rates have given us evidence that the wastewater treatment industry is an extremely unsafe occupational field. Treatment plant personnel experience extremely high injury rates.

This high injury rate occurs for several reasons. Chief among them is that all of the major classifications of hazards exist at wastewater treatment facilities—with the exception (usually) of radioactivity. These classifications include the following:

- oxygen deficiency (less than 19.5% oxygen)
- physical hazards
- toxic gases and vapors
- infections
- fire
- explosions
- electrocution

Obviously, though, many industries have many of the same types of hazards in their workplaces. If this is the case—and it is—then why are those industry rates lower than water/wastewater treatment facility injury rates?

In this chapter, we answer this question. More importantly, we discuss a paradigm (a model or prototype) that has been used successfully to decrease the rate of on-the-job injuries in both the water and wastewater professions.

19.2 WATER/WASTEWATER WORK: HOW DANGEROUS IS IT?

When you explain to water/wastewater workers that they must use care and caution while working with water/wastewater and associated equipment and unit processes, they usually listen. However, they don't always absorb exactly what it is you (or anyone else) are trying to tell them about safeguarding themselves from harm's way.

Because of this, having workers stop for a moment to take a look at a graphic example of the risks you are trying to get across to them can help convey your message. Instead of using the standard 2 × 4, sometimes using an example that strikes close to the heart—showing them

Case Study 19.1[4]

Jake McRoy, driving his truck through light drizzle, wondered if the rain would ever end. He was sure they'd had rain for two weeks straight, now, and still it fell insistently against the windshield, a light patter swept aside by the wiper blades. Jake turned the company truck off Katy's Creek Plant road and onto the Interstate, on his way into the city. He had news to deliver.

The trip took about 30 minutes on a rainy day, through traffic. "This is taking too long. I just want to get this over with," Jake thought, turning the truck right at the corner, and slowly edging down the street, hunting the house number. Then, "Not long enough," as he pulled the truck up to a cream-colored house with dark green shutters, second on the right. He eased the truck over to the curb a little past the house and turned the key to kill the motor.

The drizzle tapped away at the truck's roof as he sat in the truck for a long couple of minutes. Jake wondered if he was strong enough to do this.

The property was obviously loved and well cared for. The big house's flower beds were freshly mulched, and the lawn neatly mowed. Water puddled in low spots on the lawn from the rain. The flowered plantings were new and looked a little like they appear early in the growing season.

Jake sighed heavily as he opened the truck door and stepped out into the gray rain. Closing the truck door behind him, he slowly walked around the truck, avoiding puddles on his way along the walkway to the front porch—but mostly trying not to look at where he was going.

A blue and yellow wagon, a tricycle, and a dollhouse were tucked out of the path to the door. Seeing them in the shadows of the porch stopped him cold. His stomach clenched into a hard, tight knot.

He couldn't bring himself to lift the doorknocker, once he walked past the toys to the front door. He stood there, hesitating, reaching out to lift the doorknocker, but unable to find the will, the nerve, the guts to let it fall.

As he reached out again with a trembling hand, his eyes teared, and he couldn't swallow past the lump in his throat. It had grown too large for him to speak. Finally, he firmly knocked—one, two, three times—and rubbed his hand over his eyes.

The sound echoed inside the house, and in a whirlwind, the children came running toward a welcome diversion on a rainy day. He heard a clear, high voice yell, "Mom, someone's at the door!" then the murmur of sound that was her reply.

The door opened after the noise of a brief squabble over possession of the doorknob. Jake looked down into three small faces, two boys and a small girl stared up at him. They all grinned, but were suddenly too shy to speak to a grown-up stranger. The little girl's piercingly sweet treble broke the silence. "You work with my daddy! He wears a hat just like you!" Jake tipped the hardhat off his head, suddenly glad to have something to hold in his hands.

Jake wished deeply and fervently for a place to hide. But of course, he couldn't avoid this part of his job, any more than he could avoid any other. This was another part of his duty, part of a plant safety engineer's job—the worst part. But knowing it was part of his job didn't make it any easier.

Jake tried to smile and say hello, but couldn't get past the lump. He cleared his throat as the little girl reached up and tugged him inside the house. Jake's unspoken message burdened him—the weight of it heavy on his shoulders.

He gently brushed fine blonde hair out of the little girl's eyes as her mother, Rachel Morgan, came into the room to greet him. As soon as she saw him, Rachel Morgan knew why Jake must have come. In an instant, blank concern replaced her smile. Jake could see the questions rise before she could ask them—she didn't need to ask him. "What is he doing here . . . has something happened?"

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[4] Adapted from F. R. Spellman and N. E. Whiting, pp. 285–286, 1999.

Jake stood, not speaking, for what seemed like forever. The little girl tugged at his rain slicker, and he managed to pull himself together. Jake was sure her bright blue eyes never left his face.

"Mrs. Morgan . . . I . . . I have some bad news for you, I'm afraid. We'd better sit down."

Jake hardly knew where the words came from as he told Rachel Morgan what had happened. Her husband, Frank Morgan, had died in an accident at the plant site, just hours earlier. An explosion had killed three workers, Frank among them. Two other workers had been badly injured.

A few minutes later, Jake left the Morgan house, carrying with him a deep sense of grief. Two things had hit him hard. They were wedged in his mind and his gut as he returned to the truck.

Rachel had asked him, "What happened . . . how did it happen?" These were straightforward questions that seemed like what anyone would want to know. But those particular questions he had to find answers to, and knowing the answers he was likely to find didn't help the ache in his gut.

He drove away from the Morgan home with the second thing gnawing at him. Those three kids . . . they were so young, so small, so . . . so innocent. Jake's own kids were older than these children, by far, but he recognized that he was terrifyingly vulnerable where his own kids were concerned, and his heart ached for the Morgan children. When he left the house, they were changed. He had changed their lives forever. When he left them, the children were huddled around their mother, tears pouring down their faces for something they were still too little to grasp. He could still hear them wailing in the new knowledge of something they were still too young to understand—that daddy would never come home again, could never come home again. Their tears and heartbreak had been more than Jake could stand. To his shame, he had dashed for the door, for the outside, for the truck, for the interstate and the road back to work, for some peace. But thoughts of the Morgan family didn't leave him. Jake knew finding peace would take a lifetime—his lifetime. This moment would never entirely leave him.

Later in this chapter, we will recount the events that led to the incident at Katy's Creek and discuss Jake's findings, his answers to the questions Rachel Morgan asked: "What happened . . . how did it happen?" What bothered Jake McRoy the most was the question that Rachel Morgan did not ask, "Why did it happen?" As safety engineer, Jake had to find the answers to these questions.

As we review this case study, we have to ask ourselves a few questions: Have we been there? Have we witnessed such an incident as described above? More importantly, are we headed in the same direction—to the same tragic end?

Obviously, none of us ever want to be put into the position Jake McRoy was in . . . and, of course, none of us want to be the subject of such a message delivered to those we love.

So, the BIG question is, "How do we avoid it?"

Again, the simple and compound answer to this vital question is what this chapter is all about.

19.3 SAFETY PRECAUTIONS

Safe work practices for water/wastewater operators have evolved over time around certain standard safety precautions, which usually include the following:

- compliance with plant safety policy
- compliance with plant safety rules
- using required safety equipment
- compliance with state and federal safety regulations
- investigation of accidents
- correction of identified safety hazards
- use of adequate personal hygiene
- implementation of an aggressive safety program

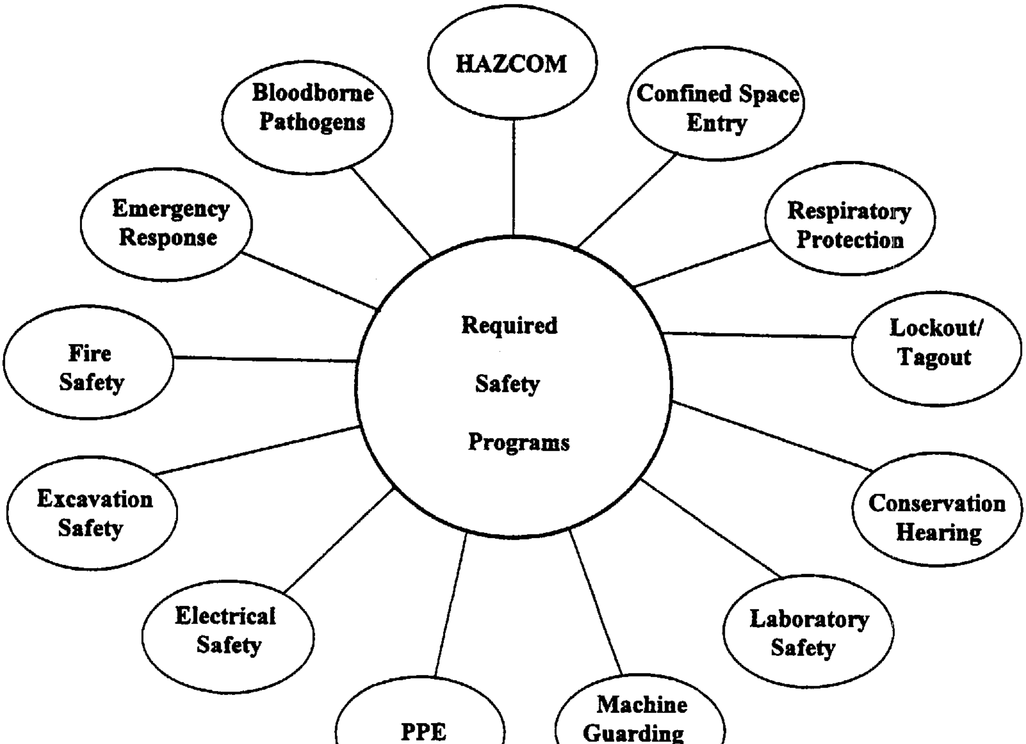
Some argue that instituting these safety precautions is all that is required to ensure the safety and health of workers in water/wastewater operations. Few reasonable people would want to discredit the validity of and need for such precautions. However, stating that implementing a list of safety precautions will ensure the safety and health of "any" worker is ludicrous—simply, safety involves more than that, much more, from both management and workers.

Any facility can institute safe work practices and written safety programs, rules, guidelines, etc. Instituting them is easy. However, if these procedures and practices do not have the full and strong support of top management, in essence, that facility has no safety policy. Under such conditions, written safe work practices, safety programs, rules, guidelines, etc., are nothing but empty words. They will provide little or no relevance in effecting workplace practices—or protection—for workers.

In addition to upper management support and written safety programs/practices, other elements are needed for an effective safety program in any organization. Worker training is an absolute necessity. Management support and written safety practices are worthless unless workers are informed of management's safety policy and written safety practices. Remember, too, that when safety training is conducted, it must be documented. Providing extensive, expensive, time-consuming training is an empty effort if this training is not properly recorded.

Enforcement is another important ingredient in the mix that makes up an effective safety program. Written rules and guidelines must be followed to be effective. Ensuring that they are followed is the responsibility of every supervisor and worker.

Worker input is important to any safety program. Common sense dictates that those who work with or around hazards probably have a better feel or sense for the needed safety precautions (or rules) to protect themselves than would someone unfamiliar with the hazard. One thing is certain: putting together any program on paper, then forcing it upon organizational members without their input has little chance of success.



Another major element of any organizational safety program is compliance with the regulators; namely, compliance with OSHA.

The items mentioned to this point (management support, written safe work practices, training, enforcement, and worker input) are all important. However, all of these elements must be blended in with the main ingredient that drives safety programs: regulatory compliance.

Typically, in many water and wastewater treatment plants, specific OSHA standards are applicable (see Figure 19.1). Typical OSHA standards that apply include the following:

- hazard communication
- confined space entry
- lockout/tagout
- respiratory protection
- hearing conservation
- laboratory safety
- machine guarding
- personal protective equipment (PPE)
- electrical safety
- excavation safety
- fire safety
- hazardous materials emergency response
- bloodborne pathogens

We discuss each one of these OSHA-required programs in the following sections.

19.4 OSHA-REQUIRED SAFETY PROGRAMS FOR WATER/WASTEWATER

✓ *Note:* Keep in mind that the guidance provided in the following sections discusses the "minimal" compliance requirements. Each plant must evaluate its own particular compliance requirements, whether the requirements are local, state, or federal requirements, and ensure implementation.

✓ *Note:* Written programs are the cornerstone of compliance with OSHA standards and are always requested by OSHA inspectors.

19.4.1 HAZARD COMMUNICATION

OSHA's Hazard Communication Standard (a.k.a. HazCom or Employees' Right to Know Standard), 29 CFR 1910.1200, is the most frequently cited OSHA violation—and the only standard that applies equally to all industries. HazCom requires that employers alert (communicate to) workers to the existence of potentially dangerous substances in the workplace. HazCom also mandates that employers provide their employees with the proper means and methods to protect themselves against hazards.

With respect to communicating chemical hazards to employees, HazCom requires each employer to do the following:

(1) Make Material Safety Data Sheets (MSDS) available to all employees, designated representatives, contractors, visitors, and OSHA.

(2) Instruct employees to label all portable containers containing hazardous substances not intended for their immediate use.

(3) Train each employee about the main features of the standard: labels, MSDS, the written program, list of hazardous materials, and required training. Also inform each employee how to recognize, understand, and protect themselves from hazards they will encounter in the workplace.

19.4.2 CONFINED SPACE ENTRY PROGRAM

Whether the confined space be a manhole, chemical storage tank, pumping station wet well, or other process vault or vessel, confined space entry and water/wastewater treatment are intertwined. Along with the requirement to develop a written confined space program, employers are required under OSHA's Confined Space Entry Standard (29 CFR 1910.146) to do the following:

(1) Identify and properly label all workplace confined spaces.
(2) Train confined space entrants, attendants, and "competent" persons on all aspects of safe confined space entry (document the training).
(3) Train and station a qualified rescue team at each entry location whenever required.
(4) Ensure that someone qualified and trained in CPR/first aid is readily available any time confined space entry is effected.
(5) Provide approved safety equipment to ensure safe confined space entry (air monitoring, etc.)

19.4.3 LOCKOUT/TAGOUT PROGRAM

Maintenance and servicing of plant machinery often requires that existing safeguarding be removed or disengaged to provide access to machine parts and controls. During these operations, isolation and deenergizing of the equipment by the person or people performing the work is required to protect the worker(s) from unexpected start-up of the machine or release of energy. This is called lockout/tagout and is covered under OSHA's 29 CFR 1910.147 Standard. Lockout, which involves placement of a lockout device on an energy isolating device, is the most effective means to protect maintenance personnel. Energy isolating devices are mechanical devices that physically prevent the transmission or release of energy. Examples include manually operated electric circuit breakers, disconnect switches, and line valves. Tagout, which involves placement of a warning tag on or near the energy isolating device, can be adequate to protect personnel if all tagout procedures are understood and followed by all employees.

Along with a written lockout/tagout program, employers are required to do the following:

(1) Develop energy control procedures (in writing).
(2) Provide to employees the protective materials and hardware required to properly effect lockout/tagout.
(3) Ensure that lockout/tagout devices are used only for energy control.
(4) Ensure that lockout/tagout devices are substantial enough to prevent removal without excessive force or unusual techniques.
(5) Ensure that lockout/tagout devices identify the specific employee applying the device.
(6) Conduct periodic inspections of the energy control procedures at least annually.
(7) Ensure all employees are trained on recognition of applicable hazardous energy sources; the type and magnitude of the energy available in the workplace; and the methods and means necessary to control and isolate energy. (Document training.)

19.4.4 RESPIRATORY PROTECTION PROGRAM

Water/wastewater workers may need protection from airborne contaminants that are health hazards. Proper protection from airborne contaminants is the responsibility of the employer. When airborne hazards cannot be eliminated by other methods of control, proper selection and use of protection demands that a well-planned program be implemented, including medical evaluation, evaluation of the airborne hazard, proper selection of respirators, fit testing, regular maintenance, and employee training. In the past, employers supplied respirators to workers without first establishing a comprehensive respirator program, relying on the excuse that the respirators are not really required because contaminant concentrations in the work environment do not exceed permissible exposure limits (PELs). This practice is strictly prohibited by OSHA regulations. At any rate, the practice of issuing workers with respirators implies a hazard exists.

In addition to a written program, the employer is required to do the following:

(1) Evaluate the workplace for respiratory hazards.
(2) Select respirators based on the hazards present.
(3) Determine the types of respirators to be used.
(4) Provide instructions, training, and fit testing of the user.
(5) Provide instructions on how to clean and disinfect respirators.
(6) Provide proper storage for respirators.
(7) Maintain and inspect respirators.
(8) Evaluate the Respiratory Protection Program on a periodic basis.
(9) Ensure that workers who are required to don respirators are medically fit to do so.
(10) Ensure that only approved and certified respirators are used in the workplace.

19.4.5 HEARING CONSERVATION PROGRAM

While many of the unit processes in water and wastewater treatment are quiescent processes (they don't make much noise), other treatment processes require machinery. Machines make noise—a safety and health hazard. Noise-induced hearing loss has long been recognized by safety and health professionals and OSHA. The hearing loss can be temporary or permanent, depending on the noise level and length of exposure. Hearing protection is required for cases in which engineering or administrative controls are not effective in reducing employee exposures below permissible levels.

The OSHA Occupational Noise Exposure Standard (29 CFR 1910.95) was implemented to protect workers from noise-induced hearing loss in the workplace. Along with having a written Hearing Conservation Program, under the standard, the employer is required to do the following:

(1) Identify any areas or production processes that may overexpose an employee or employees to noise (i.e., conduct a workplace noise level survey and document the results—make the results of the survey available to employees).
(2) Obtain personal noise dosimetry measurements for employees assigned to these areas.
(3) Conduct initial and annual audiometric testing of employees exposed to noise levels 85 dBA and above.
(4) Maintain records for each employee assigned to work in high-noise areas (i.e., record of exposure to high noise levels and records of workers' hearing acuity).
(5) Provide hearing protection (at no cost to workers).
(6) Provide and document training on hearing conservation, hearing protection, and other related issues.
(7) Post warning signs/labels in high-noise areas.

19.4.6 LABORATORY SAFETY

Most water/wastewater treatment plants have their own laboratories. Whether the laboratory is a small- or large-scale operation, it is still required to comply with OSHA's Laboratory Standard (29 CFR 1910.1450). Remember, no matter what the size of the laboratory, safety plays a key role in maintaining worker well-being and compliance with applicable health, safety, and environmental standards. Along with written Lab Safety Program or Chemical Hygiene Plan (CHP), the employer is required to do the following:

(1) Provide the same kinds of safety programs for lab workers that are provided for all workers.

(2) In addition, a water/wastewater laboratory that handles hazardous chemicals must have a written Chemical Hygiene Program (CHP). The written CHP must include the following:
   - procedures for minimizing chemical exposure
   - procedures for determining hazards
   - ventilation requirements
   - assigned responsibilities for safety and health of all
   - lab personnel
   - basic safety rules and procedures
   - spill response plan
   - training
   - environmental monitoring
   - procedures for disposal of wastes
   - broken glass disposal procedure
   - personal protective equipment provided to lab workers at no cost to the workers
   - medical surveillance program for those lab workers exposed to hazards
   - MSDS
   - labeling procedures

19.4.7 MACHINE GUARDING

While machines allow more efficient, productive work, water/wastewater workers must use them with great caution. OSHA has put forth several regulations that apply to the use of machinery and machine guarding. These rules can be found in 29 CFR 1910.211–.247. Along with written machine guarding procedures, the employer must do the following:

(1) Provide employee training on the hazards related to machines.

(2) Institute a program whereby all machines/machinery are routinely inspected to ensure guards are in place and/or in good working condition.

(3) Institute a lockout/tagout program that will ensure that when machines are put out of commission for any reason, they present no hazard to workers.

(4) Ensure employees wear appropriate clothing when operating or working around hazardous machines. Loose, oversized clothing can easily catch on machine parts. Employees should wear chemical-resistant clothing and shoes if the machine creates an exposure potential to lubricating oils or other substances. Employees with long hair may need to wear hats or hairnets if the long hair represents a hazard due to the proximity of moving machinery.

19.4.8 PERSONAL PROTECTIVE EQUIPMENT (PPE)

The primary objective of the water/wastewater safety program is worker protection. It is the responsibility of plant management to carry out this objective. Under OSHA's PPE Standard, 29 CFR 1910.132–138, part of this responsibility includes protecting workers from exposure to or engineering controls. When hazardous workplace exposures cannot be controlled by these measures, personal protective equipment (PPE) becomes necessary. When looking at hazardous workplace exposures, keep in mind that OSHA regulations consider PPE the last alternative in worker protection—because it does not eliminate the hazards. PPE only provides a barrier between the worker and the hazard. If PPE must be used as a control alternative, a positive attitude and strong commitment by management is required.

Along with a written PPE safety program, the employer is required to do the following:

(1) Select proper type of PPE based on the hazards.
(2) Implement an effective and thorough training program.
(3) Make an assessment of the workplace to determine what hazards are present and what type of PPE is required to protect workers from the hazards.
(4) Familiarize workers with correct usage and maintenance of PPE.
(5) Enforce the usage of PPE.

19.4.9 ELECTRICAL SAFETY

Water/wastewater operators could not easily perform their assigned duties without the aid of electricity and electrical devices and machinery. Electricity has become such an integral part of our lives in the workplace and at home that we tend to take its power for granted. But here is a sobering fact. The Bureau of Labor Statistics (BLS) reported that during 1994, more than 300 work-related deaths resulted from electrocution. Electrical accidents in water/wastewater treatment plants can, for the most part, be avoided if safe electrical equipment and work practices are incorporated into the plant's safety program.

Along with abiding by the requirements of OSHA's 29 CFR 1910.301–.399 (Electrical Safety Requirements), the employer must develop a written Electrical Safety Program that includes the following elements:

(1) Workers must be trained on safe work practices for working with and/or around electrical equipment.
(2) Workers must be made aware of the hazards involved with electricity.
(3) Appropriate lockout/tagout procedures must be used any time electrical machinery/equipment is to be worked on.
(4) Electrical hazards must be appropriately marked or labeled (e.g., Danger: High Voltage).
(5) Only approved electrical equipment should be used in the workplace.

19.4.10 EXCAVATION SAFETY

In water and wastewater work, workers are frequently required to excavate, to repair broken collection or interceptor system piping. OSHA regulations pertaining to excavation work (trenching and shoring) can be found in 29 CFR 1926.650–.652.

An effective excavation safety program begins with knowing the hazards. Workers must know the hazards they face during these operations and how to safeguard themselves from the hazards. Excavation work literally holds no room for error.

Along with developing a written excavation safety program, the employer should do the following:

(1) Train all workers involved in excavation work on the proper procedures to use in excavating.
(2) Contact utility companies before digging begins, to ensure underground installations are found.
(3) Assign a "competent" person to supervise the excavation.

✓ *Note:* OSHA defines the "competent" person as someone trained and capable of identifying existing and predictable hazards that are unsanitary, hazardous, or dangerous to workers. This person is responsible for performing the soil classification analysis; he or she has the authority to take prompt corrective measures to eliminate any hazards; he or she may be responsible for coordination and direction of emergency response; and he or she must inspect the excavation and adjacent areas at least once a day for possible cave-ins, failures of protective systems and equipment, hazardous atmospheres, or other hazardous conditions.

(4) Have emergency response procedures in place and emergency rescue equipment ready, in case an accident occurs.

19.4.11 FIRE SAFETY

Fire can occur in any workplace. For plants handling large quantities of flammable materials, fire safety is the single most important safety program area. For others, fire still usually represents an extreme hazard, given the potential for economic damage and human tragedy. Clearly, fire safety is very important—important enough for OSHA to have mandated two separate fire protection standards: 29 CFR 1910.38 and .157.

Along with a written fire prevention safety program, the employer must do the following:

(1) Train all employees on the hazards of fires, fire chemistry, the causes of fires, proper use and storage of flammable materials, and types of portable fire extinguishers and how to use them properly.
(2) Develop a fire prevention control program.
(3) Conduct periodic plant inspections to ensure fire hazards are removed or are properly controlled.

19.4.12 HAZARDOUS MATERIALS EMERGENCY RESPONSE

If the water/wastewater treatment plant uses or produces hazardous materials on the plant site, OSHA, under its 29 CFR 1910.120 Standard, requires the facility to develop an Emergency Response Plan for Chemical Emergencies. Under this Standard, the employer is to do the following:

(1) Develop a written emergency response plan for chemical, fire, and medical emergencies.
(2) If plant employees are required to respond aggressively to chemical spills, fires, or provide emergency medical assistance (first aid/CPR), they must be fully trained to do so.
(3) If employees are required to respond to chemical spills, fires, or medical emergencies by calling 911 or other emergency phone numbers, they must be trained on how to do this.
(4) Whatever choice the employer makes for emergency response, the plan must be coordinated with local emergency responders (i.e., fire department, local HazMat Team, etc.).

19.4.13 BLOODBORNE PATHOGENS

Although the Centers for Disease Control (CDC) has determined that HIV and other bloodborne pathogens are not found in wastewater flow (except in strictly controlled laboratory conditions), CDC does warn that people who do provide emergency first aid/CPR could become contaminated. For example, if a worker finds another worker or other person unconscious and not breathing, the worker could become contaminated with a bloodborne pathogen disease if the worker renders CPR to the victim without proper personal protection. If a worker attempts to aid another worker or other

Rendering any kind of first aid assistance whereby the rescuer could be exposed to another person's body fluids must be done with caution and personal protection.

In order to protect employees from bloodborne pathogens (HIV and hepatitis B), the employer must do the following:

(1) Train all employees on the hazards of bloodborne pathogens.
(2) Equip all company first aid kits with rescue barrier masks to prevent mouth-to-mouth contact, latex protective gloves to prevent contact with body fluids, eye protection, and a biohazard bag for disposal of cleanup materials.
(3) Afford the exposed employee medical attention, including immunizations for self-protection, at no cost to the employee as mandated by 29 CFR 1910.1030.

19.5 SAFETY INSPECTIONS

Written safety programs and their implementation are important. Ensuring their effectiveness is even more important. Periodically, the plant should be inspected by the safety officer or some other designated person to ensure that safe work practices are being followed, that safety rules and policies are being abided by, and that the material condition of the plant site is in good shape.

Whenever safety inspections are conducted, some type of procedure whereby discrepancies discovered are corrected must be in place. Thus, the written report of the safety inspection must be placed in the hands of those plant officials responsible for ensuring safety compliance. In addition, after a reasonable length of time, any discrepancies that were discovered during the inspection should be re-checked to verify that they have been corrected. If they have not been corrected, action must be taken to ensure that they are corrected.

A copy of all safety inspections must be kept on file. This is important for OSHA compliance.

19.6 ACCIDENT INVESTIGATIONS

No matter how good the plant's safety program is, accidents do and will occur. When they do occur, finding the causal factors is essential. Once identified, these causal factors must be corrected as soon as possible. In addition, the results of accident investigations (i.e., the causal factors) are usually a good source of lessons learned. These lessons must be passed on to all employees to avoid recurrence.

In Case Study 19.1, we detailed the pain-filled end result of some of the events that occurred at the Katy's Creek Wastewater Treatment Plant. We end this section now with the remainder of the Katy's Creek story to deliberately make a point we often forget—that when serious on-the-job injuries/illness occur, often there is more than just one victim and more than just one result.

What we describe here (for the purpose of illustrating the correct procedure to use in this type of investigation) are the actions taken by Jake McRoy. As Katy's Creek safety engineer, Jake's job was finding the causal factors, and his subsequent remediation efforts are designed to ensure that this particular incident (or any like it) could not possibly occur again. When you have to deliver the Grim Reaper's message, once is not only enough, it is far too much—much more of a burden than anyone should have to bear.

A 60 million gallon per day (60 MGD) treatment facility, Katy's Creek Wastewater Treatment Plant was first constructed in 1948 and was upgraded several times. Beginning as a basic primary

Plant influent sources include a city of 350,000 people and the residents in the surrounding county (another 150,000 people). Katy's Creek (which is actually a large stream, not a creek) takes the plant effluent outfalls. Katy's Creek Sanitation District includes Katy's Creek treatment plant, the main pumping station, collection systems, ancillary maintenance facilities, a state-of-the-art environmental laboratory, and a finance and administration facility.

Katy's Creek WWTP operation needed upgrades (retrofits) to modernize the facility. The plant was designed to treat 2.5 MGD. The original 2.5 MGD plant was converted years before to a large pumping station, which provided pressure for the forcemain feeding the city's influent to the plant. County influent to the plant from residents came in primarily through a gravity-fed main. The incident we describe occurred at the old plant influent channels—now part of the pumping station. Although on the new treatment plant grounds, the pumping station (located in the northwest corner of the 60-acre site) is completely fenced off from the rest of the plant.

Jake McRoy sat in his office at Katy's Creek Wastewater Treatment Plant. It was almost noon. At 10:00 A.M., he had delivered his devastating message to the Morgan family, and he still felt sick at heart. He couldn't get the little Morgan girl's smiling blue eyes out of his mind.

The thought of her made him feel worse. Jake McRoy had been a safety professional for about 20 years. He'd learned his trade in the military, specializing in accident investigation. He'd seen death, blood, gore, and worse many times, more often than he wanted to remember. But this was death in both more and less a personal way. He hadn't had to deal with the physical carnage this time, but he had never had to deliver the "message" to family members before, and what he had seen at the Morgan household was worse. He hoped—he swore that he would never have to do it again. Jake had worked at Katy's Creek Treatment Plant for just three months, practically to the day. The district's safety program had been close to non-existent before his arrival and was just beginning to take shape. The general manager (GM) had hired him because the on-the-job injury records had been growing in number and severity each year. Clearly, something had to be done to reduce them, and Jake was the answer.

As a seasoned professional, Jake McRoy understood that the worst part of his job was just about to begin. The GM and the Human Resources Manager had delivered the other "messages" to the families of the other dead and injured workers. The GM had told him that as soon as the families had all been notified that Jake was to start a full-scale investigation of the incident. He was to report to the GM as soon as he knew what had occurred and why.

Jake understood the urgency in the GM's voice, as the senior person responsible for the entire sanitation district confines—not only for the good, but also from the bad, and the ugly. And nothing in this incident could be characterized as good—this was all very bad and extremely ugly.

The worksite superintendent had completed his investigation. The written reports were on their way to him. Because of the fatalities, OSHA had been called in right away and had arrived at the scene within 30 minutes of the occurrence. They had left the plant just before Jake's return.

When they arrived on his desk, Jake immediately read the plant superintendent's first report of accident forms—five separate copies, one for each of the five victims: three fatalities, two injured. All five reports were exactly the same, barring items 1–6, of course, the personal data (name, social security number, department, time of incident, date of incident, and job classification).

Item 7 on each form read as follows: At 0700 (on that date), a methane gas explosion occurred at the influent channels for the plant's main pumping station. Three employees (employee's names included here) were killed instantly. Two employees (employee's names included here) were severely burned. The explosion was ignited by a cigarette lighter struck by Foreman Mike Monk as he came up the stairway leading to the influent channel where the five workers had been standing. Mike Monk was slightly injured from the blast, but did not require medical attention.

The spark from the cigarette lighter ignited methane gas rising from the influent channels to the area where the victims were standing. A tremendous fireball blew up from the channel bottom and roared up the chute and out the top. It reached up to the cement roof overhang, leaving a huge burn mark. The fireball burned all three victims to death. One victim (Frank Morgan) was blown into the channel and landed on his head 15 feet below. The two injured victims, severely burned by the fireball, were blown away from the channel openings by the force. The force threw them to the grass about 10 feet to their backs. The injured victims, transported immediately to Mercy Hospital, are undergoing treatment.

Item 8 was blank on all forms. Interviewing the two survivors was impossible because of the severity of their injuries.

Item 9 was succinct and to the point. Superintendent Monk had no idea that his crew had found methane in the influent channels, or that they were waiting for the gas to vent off before entering the channel to work. This was purely accidental.

Item 10 was also short and to the point. "The design engineers should be called in pronto to find out why this channel produced methane and caused this explosion—this is definitely an unsafe situation that needs to be corrected." Then, the plant superintendent had signed and dated his reports.

What did Jake McRoy, the seasoned military saftey professional, think about the plant superintendent's first reports of accident? He'd been involved in the investigation of the U.S.S. Forrestal explosion, which killed more than 140 sailors in July of 1967 in the South China Sea, and disasters at military bases. "Typical," he thought. He had seen hundreds of first reports, all very much like the reports in front of him now—lack of detail, lack of information. "Typical—just no other way to describe them," he told himself.

After rereading the reports for the sixth time, Jake had a step-by-step process outlined in his notes that he intended to follow in conducting his follow-up investigation of what the press called the Katy's Creek Incident.

We recount Jake McRoy's findings from his follow-up investigation of the Katy's Creek Incident. Though Jake was not able to interview the victims (the two injured victims were transferred out of the region to a hospital for burn victims), he pieced together a complete account of what actually happened, from interviewing three witnesses who observed the incident from a distance, from physical evidence at the scene, and from other plant personnel interviews on other matters related to the incident. We leave out many of Jake's preliminary and secondary notes to simplify the report—to illustrate his findings succinctly.

Around 4:00 P.M. the next day, Jake McRoy sat back in his chair, after having written up his final report. He now knew as much as anyone would ever know about the Katy's Creek Incident—and more. He knew where the blame fell—the blame was multifaceted. He felt guilt himself, because he clearly was partially at fault. He had not done all he should or could have done to prevent the incident. Though he could have written the report to leave all the blame on others (upper management would have recognized that he had not been on the job long enough to correct everything that he had found wrong, everything that needed to be corrected), Jake McRoy had a serious, heart-numbing problem. It overwhelmed him—the biggest reason he blamed himself. A little girl's bright blue eyes filling her smiling face . . . those bright eyes deserved more. For those blue eyes, he could not evade the blame. Her eyes deserved the truth—demanded it. Jake McRoy could not deny her the truth.

Jake's follow-up accident report related the following about the Katy's Creek Incident. The six-person interceptor maintenance crew arrived in the crew truck at the pumping station gates on the morning of the incident. Mike Monk (the foreperson) directed five of the workers to go ahead and get things set up to replace the valve between #1 and #2 influent channels. Monk told his crew that he would be back in about 15 minutes; he left to pick up the replacement valve they needed.

When Monk drove off, the maintenance crew unlocked the main gate and headed for the influent channels. Once they arrived, the lead-person directed the other four workers to remove the channel covers. After the channel covers were set aside, the lead-person lowered the remote probe of the air monitor into the first (to her left as she faced it) channel, to measure for oxygen content, toxics, and flammability. In a few seconds, the alarm went off in her handheld monitor. Looking down at the sensor's LED screen, she saw that the alarm was from the flammability section. She guessed that the reading showed about 50% of LEL (it was a guess because she had no training on how to use the instrument. She had learned what she knew from limited experience).

✓ *Note:* LEL or Lower Explosive Level and LFL or Lower Flammable Limit are interchangeable terms. They mean that when the vapor-air mixture is near either the LEL or UEL, an explosion is possible—one less intense than what it would be in the intermediate range. Between the LEL and UEL (in the intermediate range), the explosion would be intense. No matter what, at the moment, this signified a dangerous situation at the very least. The LEL-UEL range for methane (the gas the instrument was detecting) is from 5.0 to 15.0. At 50% LEL, the lead-person was reading approximately 50% of 5.0 LEL. OSHA specifically states that an explosive environment may exist at 10% of LEL, and prohibits personnel from working in such dangerous areas or situations.

She told the other workers of the potentially explosive atmosphere in Channel #1. They would have to wait until natural ventilation lowered the level to a safe reading (below 10% LEL minimum).

While they waited for Channel #1 to vent, the lead-person lowered the remote probe into Channel #2. Almost immediately, the LEL alarm sounded. The meter screen indication was very erratic—the LED indicator flashed from 50% to off-scale. She instantly recognized that inside Channel #2, the level of explosive vapor was much higher than that in Channel #1.

The members of the work crew stood at Channel #2 opening, waiting for her to give them the word that they could enter. While they waited, the lead-person explained what the pending valve replacement job would entail. She told two crewmembers to bring to the platform the ladder they needed for entry and the tools they needed to work on the valve.

Frank Morgan leaned over the second channel, assessing the condition of the long valve stem. It reached from the valve wheel (positioned topside between the two channels) and the valve itself at the bottom of Channel #1 and #2, where the channels were separated by a concrete wall. Intended to divert flow from one channel to the other, the old valve had seen better days. An original installation, it was installed in the 1940s and repaired several times.

Frank stood up. "I think we have room down there to install a chain-fall, to get a good grip on the valve body and yank her right out of there. What do you think?" he said to the lead-person.

She bent over and tried to look down at the valve, her view partially blocked by the overhanging channel top she stood on. "I can't really see it well from here."

"You've got to stand over here—take a look," Frank said, and moved sideways, as she edged onto the top of the surface that overlooked the channels.

When Frank had moved out of the way, the lead-person gingerly moved along the right wall, along an 8 ledge between the wall and Channel #2 opening.

Looking inside the channel opening, she stood and shuffled back to the top platform. "You are right. This won't be too much trouble." She checked the readings on her air monitor—still too high. Frank moved back onto the ledge and continued to peer inside the channel.

Out front, Mike Monk pulled up and parked at the main gate. He discussed business on the radio with his boss for a few minutes before he signed off, got out, and walked toward his crew.

As he got to the four stairs leading to the channel top platform, Monk reached inside his shirt pocket and removed a cigarette out of his pack. He pulled his lighter from his pants pocket. Putting the cigarette in his mouth, he struck the lighter, and the place exploded.

The first fireball came out of Channel #2. Too fast to distinguish between them, another fireball came out of Channel #1. The lead-person and another crewperson, standing at the lip of Channel #2, were killed instantly. The other two crew members (the injured victims), standing a few feet back from the channel lip when the explosion occurred, were severely burned by the blast's force and were thrown from the platform. Frank Morgan stood on the narrow ledge of Channel #2, his back to the wall, when the explosion occurred. The intensity of the blast forced him against the wall and burned him to death instantly. When the fireball dissipated, Frank Morgan fell forward into the channel, head first.

Mike Monk was thrown off backward from the platform approximately 20 feet, landing on the grassy slope. He sustained minor cuts and bruises.

While the report explained many other things that occurred right after the explosion, Jake McRoy's findings and recommendations are of chief interest.

19.6.1 FINDINGS AND RECOMMENDATIONS

19.6.1.1 Finding

19.6.1.1.1 Structural and Design Problems

Channel #1 was the original intake for plant influent for the original Katy's Creek Treatment Plant when it was built in 1948. Channel #2 was built in 1949 as a redundant system to aid in maintaining flow while conducting necessary maintenance on one channel. Valve #1 was installed at the same time Channel #2 was built. Valve #1, a segregation valve, was obviously meant to separate flow (prevent backflow from distribution box #1 into #2), while Channel #1 was in operation, and to allow flow from Channel #2 distribution box into distribution box #1 to the 48″ inlet pipe to pumps. Valve #2 was installed to isolate Channel #1 when Channel #2 was in operation.

Both channel/distribution box systems worked well as designed when they were first built, because flow was continuous to treatment processes downstream. Plant specifications, drawings, and operating records showed clearly that very little residual volume was maintained in the on-line distribution box at any given time. Flow was constant at a very high rate.

Today, however, while true that at present, the downstream pumps maintain a constant suction on the contents of the distribution box, the wastestream typically stores a volume of up to four feet in depth (depending on flow rate). This is a major problem, because the distribution boxes were originally designed for a constant influent stream to enter the screening devices (first stage of treatment process) via gravity flow. They have no history of ever having a residual volume stored within them of more than the depth of the flow, constantly moving, and definitely not retained for any more than a few seconds before the flow moved on.

The reduced flow rate caused by the modification from gravity to pressurized but metered flow causes residual time in the distribution boxes, which now allows enough time for the buildup of dangerous levels of methane gas and higher than normal levels of hydrogen sulfide (>100 ppm).

Methane gas buildup (the result of and a by-product of the anaerobic decomposition of the organic matter in the wastestream) occurs in these distribution boxes because of the way in which the distribution boxes are designed. Bottom deposits of organic material build up in distribution box #2, and to a lesser degree in distribution box #1. The reduced level of oxygen (typically measured at less than 18%, but also measured to levels below 10%) allows anaerobic decomposition to occur. The distribution boxes provide excellent areas for build-up and storage of methane gas. In readings I took no more than 15 minutes ago, the air monitor indicated methane levels in the intermediate (explosive) range in both distribution boxes #1 and #2.

19.6.1.2 Recommendations: Engineering Controls

Methane is a colorless, odorless, very explosive gas. Ignition of methane gas vapors caused the explosion and the subsequent fatalities and injuries.

We can alleviate the methane generation problem for both distribution boxes #1 and #2 in two ways:

(1) The presently installed distribution boxes #1 and #2 can be redesigned and reconfigured so that organic material cannot accumulate as bottom deposits and generate methane.

(2) A ventilation system should be installed. According to my calculations (based on the volume of the distribution boxes and the pattern of accumulation of organics), a continuously running ventilation system that provides at least 12 air changes per hour (ach) should be installed and vented above roof level.

When the covers are removed from either distribution box, the opening to each distribution box (a gaping hole) is a safety hazard. No guardrails are installed to prevent people from falling in. Because the top work area is coated with grease, oil, and muck, this presents a higher level of risk than is immediately apparent. Workers informed me that this area is always a slip hazard. This area needs better housekeeping practices, and a non-skid-type surface (to prevent falls, slips, skids, and injuries) should be laid down, covering the entire surface area of the top working platform.

19.6.1.2.1 Administrative Problems

The personnel involved in this project (though well-intentioned) were not adequately trained to perform the work required for this project, as the results of the incident prove. Shortcomings that were pertinent to the results of this incident include the following:

- Clearly, work required to be performed in either distribution box required training in confined space entry. These spaces meet OSHA's definition of a permit-required confined space.
- According to comments made by several employees, workers have known for several years that the distribution boxes generate and store methane, as well as high levels of deadly hydrogen sulfide. Yet, no warning labels are posted anywhere near these spaces.
- I find no procedure or safe work practice included for accomplishing the type of work the crew was performing at the time of the incident, in reviewing the Katy's Creek Treatment Plant safety program (which I have been rewriting since my arrival).
- In reviewing our scant training records, I find that apparently none of the workers involved with this incident had been trained on hazard communication, lockout/tagout, confined space entry, respiratory protection, or any other OSHA-required safety training.
- The air monitor used to test the atmosphere in the distribution boxes was barely functioning. The oxygen-sensing cell did not function at all, and the flammable cell was erratic. No evidence exists that the monitor was ever calibrated by anyone at anytime at Katy's Creek. When I queried several workers about their knowledge concerning air monitoring and air monitors in general, they were unable to explain to me the air monitor's purpose or how to use it. No one understood the need to calibrate it before use (and on a regular basis) or how to calibrate it. No record exists that shows the crew members involved in this incident had any knowledge concerning proper use of and calibration procedures for an air monitor.
- I can find no evidence of any training in basic first aid and CPR. For work of the nature that took place during this incident, OSHA requires (as part of 29 CFR 1910.146 Confined

field that our collection crews work in and around daily, the need for a confined space entry program, associated training, and required equipment cannot be overstated.

- The two distribution boxes are not properly labeled for methane, hydrogen sulfide, or as confined spaces. In any district location that produces methane or other explosive mixtures, signs strictly prohibiting smoking or hot work should be posted.
- I can find no documented evidence that shows that an engineer or other competent person has ever evaluated any of the district's spaces as to their suitability in allowing work operations to take place safely.

19.6.1.3 Recommendations: Administrative Controls

(1) Immediately write an OSHA-approved District Confined Space Entry Program. Label all permit-required confined spaces as required by OSHA. Responsibility: District Safety Engineer.
(2) Install warning labels at all locations where dangerous situations and/or conditions exist. Responsibility: Safety Engineer.
(3) Write a safe work practice for this type of work and for the following:
    - work in aeration tanks
    - work in anaerobic digesters
    - manhole entry
    - work inside collection piping
    - digester cleaning—anaerobic
    - handling ash
    - handling grit
    - personal hygiene and safety
    - office and clerical work
    - excavation, trenching, and shoring
    - traffic control devices (for construction sites)
    - traffic
    - safety chains
    - rotating equipment
    - hand tools, power tools, and portable power equipment
    - coating/painting operations
    - high-noise areas
    - lighting
    - lifting, rigging, and hoisting
    - ladders
    - environmental laboratory
    - housekeeping
    - landscaping equipment
    - garage safety
    - forklift operation
    - fire control and prevention
    - hazardous materials
    - compressed gas cylinders
    - chemical handling
    - electrical
    - lead-based paint
    - asbestos
    - vehicular and operating equipment

- ventilation
- drinking (potable) water
- welding and torch cutting
- pump station wetwell entry
- fall protection—general practice
- fall protection—guardrail systems
- fall protection—safety net systems
- fall protection—personal fall arrest systems
- sandblasting
- calibration of air-monitoring equipment
- storage batteries
- oil-burning heaters (salamanders)
- working during lightning storms
- hot work
- scaffolding
- mechanical power-transmission apparatus
- personal protective equipment

Along with writing the safe work practices listed above, all employees who might perform any of these actions must be thoroughly trained on the requirements. Responsibility: Safety Engineer.

(4) A District Hazard Communication, Lockout/Tagout, Respiratory Protection, and any other OSHA-required safety program must be written, and required training must be completed. Responsibility: Safety Engineer.

(5) For those employees required to operate air-monitoring equipment, training must be conducted not only on the proper operation of such equipment but also on the proper calibration procedures. Responsibility: Safety Engineer.

(6) Basic first aid and CPR training should be provided to as many district employees as possible; this training should also include the requirement to be retrained/recertified as required. Responsibility: Safety Engineer.

(7) Smoking must be strictly prohibited where posted (all such spaces are to be posted). A written Hot Work Permitting System must be put into effect as soon as possible. All spaces where a Hot Work Permit is required must be posted. Training on the guidelines of the Hot Work Permit System and the use of Hot Work Permits must be conducted as soon as possible. Responsibility: Safety Engineer.

(8) All district spaces must be audited on a routine basis (no less than once per quarter). Audit reports must be submitted to work center supervisors. If discrepancies are found, the work center must be reinspected until all discrepancies are cleared. Responsibility: Safety Engineer.

19.6.1.4 Results of Jake McRoy's Investigation and Written Report

Jake McRoy's list of recommendations (which gave the responsibility for enactment to himself), might make you ask how one person could possibly accomplish so much. While it is true that it would be difficult, if not impossible, if he had to do everything at once, by himself, in all actuality, this is not the case.

Jake hand-delivered a copy of his report to the General Manager and sat in the office while the GM read the report. After he read it, the GM looked at Jake and asked him what he needed in the way of his help to accomplish all his recommendations. Jake replied that he wanted a representative to incorporate. After a few seconds of thought, the GM replied: "I want you to get somebody in here pronto to start installing that ventilation system you recommended. And when anyone wants to do anything in that space, he or she must have your approval first. During the next plant retrofit next year, we'll modify those channels as per your recommendation—that job will be at the top of my list. What else do you need from me?"

Jake didn't hesitate. "Just your complete support, sir. I'm going to get some flack when I start pulling workers away to get them trained, and . . . ."

"There will be no flack, resistance, or anything else, Jake. Just do it, and let me know when this entire list is completed."

"Yes, sir. Thanks for your support."

19.6.1.5 Conclusion

According to the National Safety Council, a fatal injury occurs every six minutes, and a disabling injury occurs every two seconds. Many of these incidents occur to workers while on the job. Because this is the case, why is it, you might ask, that companies are hesitant to provide the kind of support to the safety and health effort to protect workers that common sense, the statistics, and OSHA demands? Why is it that a major catastrophe has to occur before a company or industry like Katy's Creek puts the kind of emphasis in place that is needed to ensure the safety and health of workers?

These are good questions—questions that safety professionals (and workers) have been asking for years. We can only say that after more than 30 years of experience in safety and health, we have found that the answers vary. And when you add up all the answers, they are not worth one small smile from a young blue-eyed little girl—not one. No one understood this better than Jake McRoy.

19.7 REFERENCE

Spellman, F. R. and Whiting, N. E., *Safety Engineering: Concepts & Applications*. Rockville, MD: Government Institutes, 1999.

19.8 CHAPTER REVIEW QUESTIONS

19-1 A safety program begins by
- A) Developing a policy statement
- B) Assuring compliance with all OSHA standards
- C) Soliciting support of the Facilities Department
- D) None of the above

19-2 Arrange the following steps in hazard control in the proper sequence: (1) guard the hazard, (2) engineer the hazard out if possible, (3) educate personnel
- A) 2,1,3
- B) 3,1,2
- C) 1,2,3
- D) 3,2,1

19-3 The most important feature of a maintenance department's safety program is
- A) Written and enforced lockout/tagout program
- B) Training
- C) Proper safety gear
- D) Knowledge of the production process

19-4 The primary reason for accident investigation is to
A) Punish wrongdoers
B) Provide OSHA with facts
C) Prepare insurance forms to recover loss
D) Correct the conditions that caused the accident

19-5 Lockout/tagout programs only apply to electrical systems. True or False:
A) True
B) False

19-6 At the scene of an incident, which concern should be given the highest priority?
A) Protecting emergency response personnel
B) Satisfying legal requirements
C) Minimizing effects on wildlife

CHAPTER 20

Final Review Exam

20.1 INTRODUCTION

Now that you have reviewed each lesson and completed the chapter review questions, you may test your overall knowledge of the material contained in handbook Volume 2 by completing the final review examination. For the questions you have difficulty answering or that you answer incorrectly, review the pertinent sections containing the applicable subject matter. Successful review and completion of all the material presented in Volumes 1 and 2 of the handbook should prepare you for the Class III/II or Grade II/III licensing examinations and set the stage for successful completion of the Class I/Grade III/IV examinations. For those operators preparing for the Class I/Grade III/IV licensing exams, review and completion of the requirements in handbook Volume 3 (Advanced Level) is highly recommended.

Unlike the actual state licensure examinations, which contain an assortment of different types of questions (i.e., multiple choice, true or false, essay, completion questions, etc.), the final review examination presented in each volume of the handbook requires a written response to each question. The questions have been formatted to be answered in this manner because experience has shown that when studying for an exam (any exam), it is always best to write out the "correct" answer (for retention purposes). Moreover, when studying for an exam, it is best to view only the correct answer instead of several different choices (e.g., multiple choice questions) that might be confused as being the correct answer, which, in turn, may cause the test taker to select the wrong answer on the licensure exam. We are interested in only those answers that are correct, obviously.

Upon completion of the final review exam, check your answers with those given in Appendix B.

20.2 FINAL REVIEW EXAM

20-1 What is the purpose of the sludge recirculation system?

20-2 Give three reasons for treating wastewater.

20-3 The trickling filter is 100 feet in diameter and 5.5 feet deep. The influent flow rate is 2.25 MGD, and the recirculation rate is 0.5:1. What is the hydraulic loading for the trickling filter in gallons per day per square foot?

20-4 Name two types of solids based on physical characteristics.

20-5 The trickling filter is 80 feet in diameter and 3.5 feet deep. The influent flow rate is 3.40 MGD, and the recirculation rate is 0.25:1. What is the organic loading in pounds of BOD per day per 1,000 cubic feet if the primary effluent BOD is 112 mg/L?

20-6 Define organic and inorganic.

20-7 The highest organic loading in a rotating biological contactor (RBC) train usually occurs ________________.

20-8 Name four types of microorganisms that may be present in wastewater.

20-9 Microscopic examination of activated sludge is a useful tool.What should the operator be trying to identify?

20-10 When organic matter is decomposed aerobically, what materials are produced?

20-11 Define flocculation.

20-12 Name three materials or pollutants that are not removed by the natural purification process.

20-13 What are the used water and solids from a community that flow to a treatment plant called?

20-14 Where do disease-causing bacteria in wastewater come from?

20-15 What does the term pathogenic mean?

20-16 What is wastewater called that comes from the household?

20-17 What is wastewater called that comes from industrial complexes?

The following information is used for questions 20-18 through 20-21.

Primary settling	Number	2
	Length	190 ft
	Width	120 ft
	Water depth	12 ft
Aeration tank	Number	4
	Length	200 ft
	Width	80 ft
	Water depth	12 ft
Secondary settling tank	Number	4
	Diameter	110 ft
	Water depth	18 ft

20-18 The effluent weir on the secondary settling tank is located along the outer edge of the tank. What is the weir length in feet for each settling tank?

20-19 What is the surface area of each of the primary settling tanks in square feet?

20-20 What is the volume of each of the aeration tanks in cubic feet?

20-21 You wish to install a fence around each aeration tank to prevent falls into the tanks. How many feet of fence must be ordered?

20-22 The lab test indicates that a 500-gram sample of sludge contains 22 grams of solids. What is the percent solids in the sludge sample?

20-23 The depth of water in the grit channel is 28 inches. What is the depth in feet?

20-24 The fecal coliform sample preserved at 4°C can be held up to how many hours before starting the test?

20-25 Mixing biosolids with a filler material and allowing it to stand in piles (windrows) to permit natural oxidation to occur is known as ______________.

20-26 The operator withdraws 5,350 gallons of solids from the digester. How many pounds of solids have been removed?

20-27 Sludge added to the digester causes a 1,900 cubic foot change in the volume of sludge in the digester. How many gallons of sludge have been added?

20-28 What is the purpose of heating and mixing a primary anaerobic digester?

20-29 A composite sample will give a(n) ______________.

20-30 The main action of a mixed media filter is ______________.

20-31 The plant effluent contains 32 mg/L solids. The effluent flow rate is 3.10 MGD. How many pounds per day of solids are discharged?

20-32 The plant effluent contains 25 mg/L BOD_5. The effluent flow rate is 7.00 MGD. How many kilograms per day of BOD_5 are being discharged?

20-33 The operator wishes to remove 3,000 pounds per day of solids from the activated sludge process. The waste activated sludge concentration is 3,050 mg/L. What is the required flow rate in million gallons per day?

20-34 The plant influent includes an industrial flow that contains 220 mg/L BOD. The industrial flow is 0.70 MGD. What is the population equivalent for the industrial contribution in people per day?

20-35 The label of hypochlorite solution states that the specific gravity of the solution is 1.1588. What is the weight of one gallon of the hypochlorite solution?

The following information is used for questions 20-36 through 20-39.

Plant influent	Flow	8.40 MGD
	Suspended solids	360 mg/L
	BOD	240 mg/L
Primary effluent	Flow	8.40 MGD
	Suspended solids	130 mg/L
	BOD	160 mg/L
Activated sludge effluent	Flow	8.34 mg/L
	Suspended solids	17 mg/L
	BOD	20 mg/L
Anaerobic digester	Solids in	6.6%
	Solids out	13.5%
	Volatile matter in	65.5%
	Volatile matter out	47.9%

20-36 What is the plant percent removal for BOD_5?

20-37 What is the plant percent removal for TSS?

20-38 What is the primary treatment percent removal for BOD_5?

20-39 What is the percent volatile matter reduction in the digestion process?

The following information is used for review questions 20-40 through 20-42.

Plant influent	Flow	8.45 MGD
Grit channel	Number of channels	2
	Channel length	45 ft
	Channel width	3 ft
	Water depth	3.5 ft
Primary settling	Number	2
	Length	150 ft
	Width	110 ft
	Water depth	10 ft
Anaerobic digester	Flow	18,000 gpd
	Volume	110,000 ft^3

20-40 What is the hydraulic detention time in hours for primary settling when both tanks are in service?

20-41 What is the hydraulic detention time in the grit channel in minutes when both channels are in service?

20-42 What is the hydraulic detention time of the anaerobic digester in days?

20-43 Appreciable quantities of septic sludge "burping" to the surface of primary settling tanks could indicate _______________.

20-44 When a high organic waste load reaches an activated sludge plant, the operator's first indicator is a decrease in _______________.

20-45 What is the purpose of the bar screen?

20-46 What two methods are available for cleaning a bar screen?

20-47 Name two ways to dispose of screenings.

20-48 Turbidity in wastewater is caused by ______________.

20-49 What must be done to the cutters in a comminutor to ensure proper operation?

20-50 The comminutor jams frequently. A review of the maintenance records indicates that the cutters were changed approximately two weeks ago and the cutter alignment was checked yesterday. What are the possible causes for the continued jamming problem? What actions would you recommend to identify the specific cause?

20-51 The reaction of chlorine and ammonia in wastewater produces a compound that is called ______________.

20-52 The most critical criterion for determining when a mixed media filter should be backwashed is ______________.

20-53 What is grit? Give three examples of material that is considered to be grit.

20-54 The plant has three channels in service. Each channel is 2 feet wide and has a water depth of 4 feet. What is the velocity in the channel when the flow rate is 9.0 MGD?

20-55 What is the concentration of hydrogen ions at a pH of 7.0?

20-56 How are the results of a membrane filter test reported?

20-57 In a membrane filter test for fecal coliform, there are blue, green, black, and yellow dots. Which ones should be counted?

20-58 Where should chlorine vents be placed?

20-59 The grit from the aerated grit channel has a strong hydrogen sulfide odor upon standing in a storage container. What does this indicate, and what action should be taken to correct the problem?

20-60 What is the purpose of primary treatment?

20-61 What is the purpose of the settling tank in the secondary or biological treatment process?

20-62 Belt filter presses are operated as a _______________ process.

20-63 An incubator for the BOD test should be controlled at _______°C.

20-64 The circular settling tank is 80 ft in diameter and has a depth of 12 ft. The effluent weir extends around the circumference of the tank. The flow rate is 2.20 MGD. What is the detention time in hours, surface loading rate in gallons/day/ft^2, and weir overflow rate in gallons/day/foot?

The following information is used for questions 20-65 through 20-68.

Plant effluent	Flow	0.40 MGD
	Suspended solids	370 mg/L
	BOD	380 mg/L
Town population	People	2,850 people
Industrial contribution	Flow	0.039 MGD
	Suspended solids	650 mg/L
	BOD	970 mg/L
Pond	Length	1,400 ft
	Width	1,100 ft
	Operating depth	4.1 ft

20-65 What is the pond area in acres?

20-66 What is the pond volume in acre-feet?

20-67 What is the influent flow rate in acre-feet per day?

20-68 What is the influent flow rate in acre-inches per day?

20-69 Give three classifications of ponds based upon their location in the treatment system.

20-70 What kind of odors can scrubbers be effectively used for?

20-71 The optimum velocity through a bar screen is ______________.

20-72 About how much (%) of an RBC is submerged?

20-73 At what depth should the sludge blanket be maintained?

20-74 What is disinfection?

20-75 Describe the processes occurring in a raw sewage stabilization pond (facultative).

20-76 How do changes in the season affect the quality of the discharge from a stabilization pond?

20-77 What are the two most common sources of oxygen for lagoons?

20-78 What is the normal depth range of a facultative pond?

20-79 What is the advantage of using mechanical or diffused aeration equipment to provide oxygen?

20-80 Describe how the dissolved oxygen level of the pond changes during the day.

20-81 What is the purpose of the polishing pond?

The following information is used for questions 20-82 through 20-86.

Plant effluent	Flow	2.10 MGD
	Suspended solids	2.05 mg/L
	BOD_5	190 mg/L
Trickling filters	Number	2
	Diameter	90 ft
	Media depth	8 ft
Recirculation	Ratio	1.5:1.0

20-82 What is the total flow to each filter in million gallons per day? (Assume the flow is equally split.)

20-83 What will the total flow to each filter be in million gallons per day if the operator changes the recirculation rate to 0.70:1.0? (Assume the flow is equally split between the two filters).

20-84 What is the hydraulic loading in gallons/day/sq ft for each filter at a 1.5:1.0 recirculation rate? (Assume the flow is equally split between the two filters.)

20-85 What is the hydraulic loading in gallons per day per square foot for each filter at a 0.75:1.0 recirculation rate? (Assume the flow is equally split between the two filters.)

20-86 What is the organic loading in pounds of BOD per 1,000 ft^3 for each filter at a 0.80:1.0 recirculation rate? (Assume the flow is equally split between the filters.)

20-87 What chemical is commonly added to a lagoon to increase available nitrate?

20-88 What chemical is normally required in the operating of a gravity belt thickener?

20-89 What two chemicals can be added to anaerobic digesters to increase alkalinity?

20-90 Name three main parts of the trickling filter, and give the purposes of each part.

20-91 Name three classifications of trickling filters, and identify the classification that produces the highest quality effluent.

The following information is used for questions 20-92 through 20-94.

RBC influent	Flow	8.40 MGD
	Suspended solids	150 mg/L
	BOD_5	190 mg/L
RBC design	Number of stages	8
	Media area—Stage 1	240,000 ft^2
	Media area—Stage 2	210,000 ft^2
	Media area—Stages 3, 4, 5, 6, 7, 8	160,000 ft^2 (each)
	k Factor	0.55
	Hydraulic loading	7.1 gpd/ft^2
	SOL	6.5 lb BOD/1,000 ft^2

20-92 What is the hydraulic loading in gallons/day/square foot?

20-93 What is the total organic loading (TOL) in pounds of BOD/day/1,000 square feet of media?

20-94 What is the soluble BOD organic loading (SOL) in pounds of BOD/day/1,000 square feet of media?

20-95 Name the two chemicals responsible for the majority of inorganic odor in wastewater treatment.

20-96 Describe the process occurring in the rotating biological contactor process.

20-97 What makes the RBC process similar to the trickling filter?

20-98 Describe the appearance of the slime when the RBC is operating properly. What happens if the RBC is exposed to a wastewater containing high amounts of sulfur?

20-99 What is the slime that grows on a trickling filter called?

The following information is used for questions 20-100 through 20-104.

Influent	Flow	2.10 MGD
	BOD	230 mg/L
	TSS	370 mg/L
Primary effluent	Flow	2.10 MGD
	BOD	175 mg/L
	TSS	130 mg/L
Activated sludge process effluent	Flow	2.10 MGD
	BOD	22 mg/L
	TSS	18 mg/L
Aeration tank	Volume	1,255,000 gal
	MLSS	2,700 mg/L
	MLVSS	1,800 mg/L
SSV test	Sample	2,000 mL
	30 Minutes	1,850 mL
	60 Minutes	1,150 mL
Waste	Flow	0.090 MGD
	Solids	6,120 mg/L
	Volatile	66%
Return	Flow	0.50 MGD
	Solids	5,750 mg/L
Settling tank	Volume	880,000 gal
Desired F/M ratio		0.25 lb/lb
Desired MCRT		6.5 days

20-100 What is the percent SSV_{30}?

20-101 What is the SSV_{60} milliliters/liter?

20-102 Using the SSV_{30} in milliliters/liter, what is the sludge volume index?

20-103 What is the food-to-microorganism (F/M) ratio?

20-104 What is the mean cell residence time in days? (Assume the clarifier solids concentration equals the aeration tank MLSS.)

20-105 What happens when lime is mixed with water?

20-106 Microscopic examination reveals a predominance of rotifers. What process adjustment does this indicate is required?

20-107 Increasing the wasting rate will______________ the MLSS, ______________ the return concentration, ______________ the MCRT, ______________ the F/M ratio, and ______________ the SVI.

20-108 The plant adds 300 pounds per day of dry hypochlorite powder to the plant effluent. The hypochlorite powder is 45% available chlorine. What is the chlorine feed rate in pounds per day?

20-109 The plant uses liquid HTH, which is 67.9% available chlorine and has a specific gravity of 1.18. The required feed rate to comply with the plant's discharge permit total residual chlorine limit is 280 pounds/day. What is the required flow rate for HTH solution in gallons per day?

20-110 The plant currently uses 40.8 pounds of chlorine per day. Assuming the chlorine usage will increase by 10% during the next year, how many 2,000 pound cylinders of chlorine will be needed for the year (365 days)?

20-111 The plant has six 2,000-lb cylinders on hand. The current dose of chlorine being used to disinfect the effluent is 6.0 mg/L. The average effluent flow rate is 2.55 MGD. Allowing 15 days for ordering and shipment, when should the next order for chlorine be made?

20-112 The plant feeds 40 pounds of chlorine per day and uses 150-pound cylinders. Chlorine use is expected to increase by 11% next year. The chlorine supplier has stated that the current price of chlorine ($0.170 per pound) will increase by 7.5% next year. How much money should the town budget for chlorine purchases for the next year (365 days)?

20-113 Name two chemicals used to dechlorinate.

20-114 When chlorine reacts with hydrogen sulfide gas, the hydrogen sulfide is_______________.

20-115 The first reading in the multiple tube fermentation test from the presumptive and confirmed test takes place after approximately _______________.

20-116 List three characteristics of the coliform group of bacteria.

20-117 Define mean cell residence time (MCRT).

20-118 What are the major sources of food for rotifers?

20-119 What is the difference between disinfection and sterilization?

20-120 To be effective, chlorine must be added to satisfy the _____________ and produce a _________mg/L ___________ for at least ___________ minutes at design flow rates.

20-122 Why are fecal coliform bacteria referred to as indicator organisms?

20-123 The sludge pump operates 30 minutes every three hours. The pump delivers 75 gpm. If the sludge is 5.0% solids and has a volatile matter content of 66%, how many pounds of volatile solids are removed from the settling tank each day?

20-124 The aerobic digester has a volume of 65,000 gallons. The laboratory test indicates that 40 milligrams of lime were required to increase the pH of a one-liter sample of digesting sludge from 6.0 to the desired 7.1. How many pounds of lime must be added to the digester to increase the pH of the unit to 7.4?

20-125 What type of water should be used for media and dilution water preparation for the fecal coliform tests?

20-126 Describe the procedure used to obtain a dilution to 0.00001 mL of original solution.

20-127 Describe the procedure for collecting a fecal coliform sample.

20-128 What does MPN stand for?

20-129 The digester has a volume of 75,500 gallons. Sludge is added to the digester at the rate of 2,850 gallons per day. What is the sludge retention time in days?

20-130 What is the normal operating temperature of a heated anaerobic digester? What is the maximum change that should be made in a day to avoid reductions in gas production?

20-131 Why is the geometric mean useful in reporting results of fecal coliform testing?

20-132 When the sludge volume index increases, the activated sludge is becoming ______________ dense and occupies ________________ space in the settleometer.

20-133 The current SVI is 115. The plant operates best when the SVI is 150 to 170. What actions should you take?

20-134 In general, when the MLSS increases, the SVI will _______________.

20-135 The supernatant contains 350 mg/L volatile acids and 1,800 mg/L alkalinity. What is the volatile acids alkalinity ratio?

20-136 The digester is 50 feet in diameter and has a depth of 25 feet. Sludge is pumped to the digester at a rate of 6,000 gallons per day. What is the sludge retention time?

20-137 What conditions can cause the pH of the aeration tank effluent to decrease rapidly?

20-138 Why is it necessary to add copper sulfate sulfamic acid solution to activated sludge samples if the DO is to be determined by lab analysis rather than field determination?

20-139 The raw sludge pumped to the digester contains 72% volatile matter. The digested sludge removed from the digester contains 46% volatile matter. What is the percent volatile matter reduction?

20-140 Who must sign the DMR?

20-141 What does NPDES stand for?

20-142 Name five potential safety hazards that could affect lab workers.

20-143 A pH of 5.5 would indicate that there are more ______________ than ______________ in the sample.

20-144 What type of sample must be used for pH measurements?

20-145 How can primary sludge be freshened going into a gravity thickener?

20-146 What are the two most important factors affecting the operation of a centrifuge?

20-147 What are the approved methods for determination of DO?

20-148 A vacuum filter, in order to be effective, requires what type of sludge conditioning?

20-149 A neutral solution has what pH value?

20-150 What problems may occur if solids remain in a sedimentation unit too long?

20-151 Why is the seeded BOD test required for some samples?

20-152 What is the foremost advantage of the COD over the BOD?

20-153 The flow-through rate for grit channels is usually ______________.

20-154 What is short-circuiting? Give two examples of conditions that may cause short-circuiting.

20-155 Proportional weirs are usually located at ______________.

20-156 The main difference between primary and secondary clarifiers is the ______________.

20-157 What condition can be caused by an over-abundance of phosphorus in a receiving stream?

20-158 The presence of a "rotten egg" odor in the area of a trickling filter generally indicates ______________.

20-159 The volatile/alkalinity relationship of an anaerobic digester is an indication of the buffer

20-160 What three types of solids make up the suspended solids in wastewater?

20-161 Approximately what percent of wastewater is made up of solids?

20-162 What can cause losses or gains in weight of solids during the drying process of the various solids tests?

20-163 What equipment, apparatus, or instrumentation is required to perform the total solids test?

20-164 What does the COD test measure?

20-165 Name the two most common interferences in the COD test and the reagent used to counteract the interferences.

APPENDIX A

Answers to Chapter Review Questions

Chapter 3 Review Questions:

3-1 $52''/12'' = 4.3\text{ ft}$

3-2 $5{,}690\text{ gallons} \times 8.34\text{ lb/gal} = 47{,}455\text{ lb}$

3-3 $2{,}996\text{ ft}^3 \times 7.48\text{ gal/ft}^3 = 22{,}410\text{ gal}$

3-4 $45\text{ mg/L} \times 3.96\text{ MGD} \times 8.34\text{ lb/MG/mg/L} = 1{,}486.2\text{ lb/day}$

3-5 $36\text{ mg/L} \times 7.50\text{ MGD} \times 3.785\text{ KG/MG/mg/L} = 1{,}022\text{ KG/day}$

3-6 $$\frac{3{,}540\text{ lb/day}}{3{,}450\text{ mg/L} \times 8.34\text{ lb/MG/L}} = 0.123\text{ MG}$$

3-7 $$\text{concentration} = \frac{500\text{ lb/day}}{10.0\text{ MGD} \times 8.34\text{ lb/MG/mg/L}}$$
$$= 5.995\text{ or }6.0\text{ mg/L}$$

Chapter 4 Review Questions:

4-1 $$\frac{6.55}{100} \times 9{,}000 = 590\text{ gal} \times 8.34\text{ lb/gal} = 4{,}916\text{ lb}$$

4-2 $$\frac{3{,}440\text{ lb/day}}{3{,}224\text{ mg/L} \times 8.34\text{ lb/MG/L}} = 0.128\text{ MGD}$$

4-3 $$\frac{240\text{ mg/L} \times 0.90\text{ MGD} \times 8.34\text{ lb/MG/mg/L}}{0.17\text{ lb BOD}_5\text{/person}} = 10{,}597\text{ people}$$

4-4 $$\frac{0.29\text{ lb/capita}\cdot\text{d} \times 10^6\text{ gal/m gal}}{8.34\text{ lb/M gal}\cdot(\text{mg/L}) \times 120\text{ gal/capita}\cdot\text{d}} = 290\text{ mg/L BOD}$$
$$\text{SS} = \frac{0.22 \times 1{,}000{,}000}{8.34 \times 120} = 220\text{ mg/L}$$

4-5 $8.34\text{ lb/gal} \times 1.1347 = 9.46\text{ lb/gal}$

4-6 $$\frac{(225\text{ mg/L} - 24\text{ mg/L}) \times 100}{225\text{ mg/L}} = 89\%$$

4-7 $$\frac{(350\text{ mg/L} - 17\text{ mg/L}) \times 100}{350\text{ mg/L}} = 95\%$$

4-8 $$\frac{(225\text{ mg/L} - 175\text{ mg/L}) \times 100}{225\text{ mg/L}} = 22\%$$

4-9 $\dfrac{(350\text{ mg/L} - 144\text{ mg/L}) \times 100}{350\text{ mg/L}} = 59\%$

4-10 $\dfrac{(0.663 - 0.491) \times 100}{[0.663 - (0.663 \times 0.491)]} = 51\%$

4-11 $80\text{ ft} \times 15\text{ ft} \times 12\text{ ft} \times 7.48\text{ gal/ft}^3 = 107{,}712\text{ gal}$

$1.30\text{ MGD} = 1{,}300{,}000/1\text{ day}$

$\text{DT} = 107{,}712\text{ gal} \times 1\text{ day}/1{,}300{,}000 \times 24\text{ hr}/1\text{ day} = 2.0\text{ hr}$

4-12 $\dfrac{160\text{ ft} \times 110\text{ ft} \times 12\text{ ft} \times 2\text{ tanks} \times 7.48\text{ gal/ft}^3 \times 24\text{ hr/day}}{8.40\text{ MGD} \times 1{,}000{,}000\text{ gal/MG}} = 9\text{ hours}$

4-13 $\dfrac{60\text{ ft} \times 4\text{ ft} \times 2.6\text{ ft} \times 2\text{ channels} \times 7.48\text{ gal/ft}^3 \times 1{,}440\text{ min/d}}{8.40\text{ MGD} \times 1{,}000{,}000\text{ gal/MG}} = 1.6\text{ minutes}$

4-14 $\dfrac{110{,}000\text{ ft}^3 \times 7.48\text{ gal/ft}^3}{19{,}000\text{ gpd}} = 43\text{ days}$

4-15 $\text{TSS lb/day} = 348\text{ mg/L} \times 8.55\text{ MGD} \times 8.34\text{ lb/mg/L/MG} = 24{,}815\text{ lb/day}$

4-16 $\text{DT Days} = \dfrac{0.785 \times 60\text{ ft} \times 60\text{ ft} \times 26\text{ ft} \times 7.48\text{ gal/ft}^3}{5{,}200\text{ gal/day}} = 106\text{ days}$

4-17 $\text{solids, lb} = 4{,}000\text{ gal} \times 8.34\text{ lb/gallon}$

$= 33{,}360\text{ lb}$

4-18 $\text{primary BOD removal} = \dfrac{240\text{ mg/L} - 180\text{ mg/L}}{240\text{ mg/L}} \times 100 = 25\%$

$\text{plant BOD removal} = \dfrac{240\text{ mg/L} - 22\text{ mg/L}}{240\text{ mg/L}} \times 100 = 91\%$

4-19 $\text{population equivalent} = \dfrac{335\text{ mg/L} \times 0.68\text{ MGD} \times 8.34}{0.17\text{ people/lb of BOD}} = 11{,}176\text{ people}$

4-20 $8.34\text{ lb/gal} \times 1.1435 = 9.54\text{ lb}$

4-21 $\text{return, MGD} = (5.0\text{ MGD} + 2.0\text{ MGD}) \times 0.36 = 2.52\text{ MGD}$

4-22 $\text{waste, MGD} = \dfrac{12{,}000\text{ lb/day}}{5{,}500\text{ mg/L} \times 8.34} = 0.261\text{ MGD}$

$\text{waste, gpm} = \dfrac{0.261\text{ MGD} \times 1{,}000{,}000\text{ gal/MG}}{1{,}440\text{ minutes/day}} = 181\text{ gpm}$

4-23 $\text{demand mg/L} = 7.0\text{ mg/L} - 1.1\text{ mg/L} = 5.9\text{ mg/L}$

4-24 $\text{volume ferric chloride} = \dfrac{6{,}000\text{ gal} \times 0.0350}{0.420} = 500\text{ gal}$

4-25 $\text{SRT} = \dfrac{560{,}000\text{ gal}}{12{,}500\text{ gpd}} = 44.8\text{ days}$

Chapter 6 Review Questions:

6-3 To remove large solids (rags, sticks, rocks, etc.).

6-4 Manual, mechanical.

6-5 Burial, incineration, grinding, and return to flow.

6-6 Measure flow.

6-7 Sharpen and align.

6-8 The rate of flow, the depth of the wastewater in the channel, the width of the channel and number of channels in service.

6-9 $\text{V, fps} = \dfrac{9.0\,\text{MGD} \times 1.55\,\text{cfs/MGD}}{3\,\text{channels} \times (2.5\,\text{ft}) \times (3\,\text{ft})} = 0.62\,\text{fps}$

6-10 Try to start the machine to ensure you have all energy sources off/de-energized.

6-11 Reduce odors, freshen septic wastes, reduce BOD, prevent corrosion, and improve settling and flotation.

6-12 To prevent excessive wear grit causes to pumps and to prevent it from taking up valuable space in downstream units.

6-13 1 ft/s

6-14 1 ft/s

6-15 $\dfrac{4.0\,\text{MG}}{1\text{d}} \times \dfrac{1\text{d}}{24\,\text{hr}} \times \dfrac{64\,\text{hr}}{1} = 10.7\,\text{MG}$

$$\frac{4\,\text{ft} \times 6\,\text{ft} \times 2\,\text{ft}}{10.7\,\text{MG}} = 4.5\,\text{ft}^3/\text{MG}$$

6-16 Anaerobic.

6-17 Flow rate in open channels.

6-18 Decrease slowly, then return to saturation slowly.

6-19 Slow the wastewater so that the heavy inorganic material will settle out.

6-20 Remove settleable solids.

6-21 Reduce odors, neutralize acids and bases, reduce corrosion, reduce BOD, improve solids and grease removal, and reduce loadings on plant.

6-22 weir loading = Q ÷ weir length = 4.5 MGD ÷ 500 ft = 9,000 gpd/ft

Chapter 7 Review Questions:

7-1 To reduce settleable and flotable solids.

7-2 $\text{VM lb/day} = 70\,\text{gpm} \times \dfrac{20\,\text{min}}{3\,\text{hr}} \times \dfrac{24\,\text{hr}}{\text{day}} \times \dfrac{5.0\%}{100} \times \dfrac{64\%}{100} \times \dfrac{8.34\,\text{lb}}{\text{gal}} = 2{,}989\,\text{lb/day}$

7-3 $\dfrac{0.785 \times 90\,\text{ft} \times 90\,\text{ft} \times 10\,\text{ft} \times 7.48\,\text{gal/ft}^3 \times 24\,\text{hr/day}}{2.5\,\text{MGD} \times 1{,}000{,}000\,\text{gal/mg}} = 4.6\,\text{hours}$

$$\frac{2.5\,\text{MGD} \times 1{,}000{,}000\,\text{gal/MG}}{0.785 \times 90\,\text{ft} \times 90\,\text{ft}} = 393.2\,\text{gpd/ft}^2$$

$$\frac{2.5\,\text{MGD} \times 1{,}000{,}000\,\text{gal/MG}}{3.14 \times 90\,\text{ft}} = 8{,}846\,\text{gpd/ft}$$

7-4 Operate sludge pumping often enough to prevent large amounts of septic solids on the surface of the settling tank while maintaining a percent sludge solids of 4 to 8%.

7-5 To prevent flotable solids (scum) from leaving the tanks.

7-6 Ninety to 95% of the settleable solids.

7-7 1.5 to 2.5 hours.

7-8 $\text{surface} = 90\text{ ft} \times 25\text{ ft} = 2{,}250\text{ ft}^2$

$$\text{surface overflow rate} = \frac{1{,}600{,}000\text{ gal}}{2{,}250\text{ ft}^2} = 711.1\text{ gpd}$$

7-9 $\text{WOR} = \dfrac{1{,}350{,}000\text{ gal}}{90\text{ ft}} = 15{,}000\text{ gpd/ft}$

7-10 $\text{tank vol.} = 90\text{ ft} \times 15\text{ ft} \times 10\text{ ft} \times 7.48\text{ gal/ft}^2 = 100{,}980\text{ gal}$

$$\text{det. time} = 3 \times 100{,}980\text{ gal} \times 1\text{ d}/6{,}000{,}000 \times 24\text{ hr}/1\text{ d} \times 60\text{ min}/1\text{ hr} = 72.7\text{ min}$$

$$\text{SOR} = \frac{6{,}000{,}000\text{ gpd}}{3 \times 90\text{ ft} \times 15\text{ ft}} = 1{,}481\text{ gpd/ft}^2$$

$$\text{WOR} = \frac{6{,}000{,}000\text{ gpd}}{3 \times 80\text{ ft}} = 25{,}000$$

7-11 $\text{dt} = 2.8\text{ hours}$

7-12 To remove the settleable solids formed by the biological activity.

7-13 $\dfrac{0.785 \times 90\text{ ft} \times 90\text{ ft} \times 10\text{ ft} \times 7.48\text{ gal/ft}^3 \times 24\text{ hr/day}}{3.7\text{ MGD} \times 1{,}000{,}000\text{ gal/MG}} = 3.1\text{ hr}$

$$\frac{3.7\text{ MGD} \times 1{,}000{,}000\text{ gal/MG}}{0.785 \times 90\text{ ft} \times 90\text{ ft}} = 581.9\text{ gpd/ft}^2$$

$$\frac{3.7\text{ MGD} \times 1{,}000{,}000\text{ gal/MG}}{3.14 \times 90\text{ ft}} = 13{,}093\text{ gpd/ft}$$

7-14 $\text{VM lb/day} = 80\text{ gpm} \times \dfrac{30\text{ min}}{3\text{ hr}} \times \dfrac{24\text{ hr}}{\text{day}} \times \dfrac{5.0\%}{100} \times \dfrac{66\%}{100} \times 8.34\text{ lb/gal} = 5{,}284\text{ hr}$

7-15 $\text{DT hr} = \dfrac{0.785 \times 80\text{ ft} \times 80\text{ ft} \times 9\text{ ft} \times 7.5\text{ gal/ft}^3 \times 24\text{ hr/day}}{2.60\text{ MGD} \times 1{,}000{,}000\text{ gpd/MGD}} = 3.1\text{ hr}$

$$\text{SLR, gpd/ft}^2 = \frac{2.60\text{ MGD} \times 1{,}000{,}000\text{ gpd/MGD}}{0.785 \times 80\text{ ft} \times 80\text{ ft}} = 518\text{ gpd/ft}^2$$

$$\text{WOR, gpd/ft} = \frac{2.6\text{ MGD} \times 1{,}000{,}000\text{ gpd/MGD}}{3.14 \times 80\text{ ft}} = 10{,}350\text{ gpd/ft}$$

7-16 It is most likely that the pump rate has resulted in a hole in the solids blanket (coning). The operator should reduce the pump rate and increase the frequency of pumping.

7-17 There is most likely a short circuit in the clarifier flow pattern. Clarifier short circuits can be caused by unlevel effluent weirs or damaged/missing inlet baffles. Corrective action should include: adjusting weir level, repairing or installing baffles at the head of the clarifiers.

7-18 DT = 2.2 hours

Chapter 8 Review Questions:

8-1 $680\,\text{ft}\times 420\,\text{ft}\times 6\,\text{ft}\times \frac{7.48\,\text{gal}}{1\,\text{ft}^3} = 12{,}817{,}728\,\text{gal}$

$12{,}817{,}728\,\text{gal}\times \frac{1\,\text{d}}{310{,}000\,\text{gal}} = 41.3\,\text{days}$

8-2 $740\,\text{ft}\times 400\,\text{ft}\times \frac{1\,\text{ac}}{43{,}560\,\text{ft}^2} = 6.8\,\text{ac}$

$\frac{6.65\text{ ac-ft day}}{6.8\,\text{ac}} = 0.0958\,\text{ft/d} = 1.15\,\text{in/day}$

8-3 $\text{vol, acre-feet} = \frac{440\,\text{ft}\times 270\,\text{ ft}\times 3.5\,\text{ft}}{43{,}560\,\text{ft}^3\text{/acre-foot}} = 9.5\text{ acre-foot}$

$\text{flow}_{\text{in}} = 0.08\,\text{MGD}\times 3.069\,\text{acre-feet/MGD} = 0.245\text{ acre-feet}$

$\text{HDT} = \frac{9.5\text{ acre-feet}}{0.245\text{ acre-feet}} = 39\text{ days}$

8-4 Recirculate plant effluent to the pond effluent.

8-5 2.56 days.

Chapter 9 Review Questions:

9-1 Filter loadings (organic and hydraulic); temperature; recirculation.

9-2 Distribution systems—to distribute the hydraulic and organic loading evenly over the filter.
Media—to support the biological growth.
Underdrains—to collect and remove treated wastewater and sloughings from the filter. To provide ventilation.

9-3 Standard rate trickling filter operates at lower organic and hydraulic loads than the high rate filter.

9-4 Daily.

9-5 Hydraulic overloads.

9-6 BOD loading =

Q × BOD conc. × (fraction of BOD not removed by the primary clarifier) × 8.34

$$= 1.6\,\text{MGD}\times 140\,\text{mg/L BOD}\times \frac{(100-25)}{100\%}\times 8.34$$
$$= 1.6\times 140\times 0.75\times 8.34$$
$$= 1{,}401.1\,\text{lb/d BOD}$$

9-7 Standard, intermediate, high rate, super high rate, roughing.

9-8 To keep biological slimes from drying out.

9-9 total 2.2 MGD × 1.85 = 4.07 MGD

9-10 To remove sloughings from the wastewater prior to discharge.

9-11 $\frac{4.20}{3.5} = 1.2$

9-12 Arm movement, distribution, orifice clogging, odors, operational problems.

9-13 Total = 2.4 × 1.85 = 4.44 MGD

9-14 $\text{total flow, MGD} = 1.40\,\text{MGD} \times (1 + 0.5) = 2.1\,\text{MGD}$

$$\text{HL} = \frac{2.1\,\text{MGD} \times 1{,}000{,}000\,\text{gal/MG}}{[0.785 \times 80\,\text{ft} \times 80\,\text{ft}]}$$

$$= \frac{2{,}100{,}000\,\text{gpd}}{5{,}024\,\text{ft}^2} = 418.0\,\text{gpd/ft}^2$$

9-15 $\text{OL} = \dfrac{140\,\text{mg/L} \times 1.40\,\text{MGD} \times 8.34 \times 1{,}000}{0.785 \times 80' \times 80' \times 6'}$

$= 54.2\,\text{lb BOD}/1{,}000\,\text{cu ft}$

9-16 $\dfrac{2.40\,\text{MGD} \times (1.0 + 1.5)}{2\,\text{filters}} = 3\,\text{MGD}$

9-17 $\dfrac{2.40\,\text{MGD} \times (1.0 + 0.75)}{2\,\text{filters}} = 2.1\,\text{MGD}$

9-18 $\dfrac{2.40\,\text{MGD} \times (1.0 + 1.5)}{0.785 \times 90' \times 90'} = 471.8\,\text{gpd/ft}^2$

9-19 $\dfrac{2.40\,\text{MGD} \times (1.0 + 0.75)}{2\,\text{filters}} = 2.1\,\text{MGD}$

$\dfrac{2.1\,\text{MGD} \times 1{,}000{,}000\,\text{gal/MG}}{0.785 \times 90' \times 90'} = 330.0\,\text{gpd/ft}^2$

9-20 $\dfrac{196\,\text{mg/L} \times 2.40\,\text{MGD} \times 8.34\,\text{lb/MG/mg/L} \times 1{,}000}{2\,\text{filters} \times 0.785 \times 90\,\text{ft} \times 8\,\text{ft}}$

$= 38.6\,\text{lb BOD}_5/1{,}000\,\text{ft}^3$

9-21 Wastewater is spread evenly over the media. As it moves down through the filter, microorganisms attached to the media remove organic matter and use it for food. This process uses oxygen and creates stable end products like carbon dioxide, nitrates, and more organisms. As the slime becomes thicker, it will break off and flow out of the filter through the under-drains with the treated wastewater.

9-22 It sloughs off and comes out of the filter through the under-drains.

9-23 Hydraulic pressure (water pressure).

9-24 To ensure good growth and ventilation.

9-25 Forced air and natural (most common).

Chapter 10 Review Questions:

10-1 The units are normally covered and maintain the same temperature throughout the year.

10-2 Consists of circular sheets of media mounted side by side on a shaft.

10-3 Disks covered with biological growth rotate in wastewater. Organisms collect food during submergence. Oxygen is transferred during exposure to air. Organisms oxidize organic matter. Waste products and sloughings are discharged to wastewater flow for removal in settling tanks.

10-4 Gray, shaggy, translucent is normal.

10-5 No. An RBC must follow primary settling in order to remove the settleable solids. An RBC is designed to treat only soluble material.

10-6 Nitrification is occurring in the later stages of the process.

10-7 Indicates filamentous bacteria growth.

10-8 $\text{HL} = \dfrac{2.7\ \text{MGD} \times 1{,}000{,}000\ \text{gal/MG}}{500{,}000\ \text{ft}^2} = 5.4\ \text{gpd/ft}^2$

10-9 Standard density and high density.

10-10 The use of fixed film biological organisms.

10-11 $\text{TOL} = \dfrac{170\ \text{mg/L} \times 2.35\ \text{MGD} \times 8.34 \times 1{,}000}{430{,}000\ \text{ft}^2} = 7.7\ \text{lb/BOD/d/1,000 ft}^2$

10-12 $\text{SBOD}_5 = 205\ \text{mg/L} - (0.65 \times 176\ \text{mg/L}) = 90.6\ \text{mg/L}$

$$\text{SOL} = \frac{90.6\ \text{mg/L} \times 2.90\ \text{MGD} \times 8.34 \times 1{,}000}{650{,}000\ \text{ft}^2}$$

$$= 3.4\ \text{lb of BOD}_5\text{/d/1,000 ft}^2$$

10-13 $\dfrac{400{,}000\ \text{gpd}}{210{,}000\ \text{ft}^2} = 1.9\ \text{gpd/ft}^3$

Chapter 11 Review Questions:

11-1 Decrease, decrease, decrease, increase, increase.

11-2 Provides the needed oxygen for the microorganisms and the required mixing to put the food and microorganisms together.

11-3 $\dfrac{2{,}780\ \text{mg/L} \times (1.27\ \text{MG} + 0.88\ \text{MG}) \times 8.34}{(6{,}125\ \text{mg/L} \times 0.09\ \text{MGD} \times 8.34) + (18\ \text{mg/L} \times 2.10\ \text{MGD} \times 8.34)} = 10.1\ \text{days}$

11-4 $\dfrac{175\ \text{mg/L} \times 2.10\ \text{MGD} \times 8.34}{1{,}860\ \text{mg/L} \times 1.27\ \text{MG} \times 8.34} = 0.16\ \text{lb BOD}_5\text{/lb MLSS}$

11-5 $\dfrac{1{,}050\ \text{mL}}{2\text{L}} = 525\ \text{mL/L}$

11-6 $\dfrac{525 \times 1{,}000\ \text{mL}}{2{,}780\ \text{L}} = 189\ \text{mL/L}$

11-7 Decrease the waste rate.

11-8 Activated sludge.

11-9 Mixed liquor.

11-10 Food, oxygen, and organisms.

11-11 To remove BOD.

11-12 Mechanical and diffused.

11-13 Aeration tank color, foam, odors, settling tank capacity, solids loss, aeration rates, process control tests, etc.

11-14 $\dfrac{1{,}200\ \text{mL} \times 1{,}000}{2{,}100\ \text{mL}} = 571$

11-15 $\dfrac{425 \times 1{,}000}{2{,}240\ \text{mg/L}} = 190$

11-16 $\text{waste lb/day} = 8{,}180\ \text{mg/L} \times 0.067\ \text{MGD} \times 8.34 = 4{,}571$

11-17 Contact stabilization.

11-18 Waste rate should be increased slightly.

11-19 lb (MLSS under aeration)

$$= \text{Q (MGD)} \times \text{Primary eff. ss (mg/L)} \times 8.34 \times \text{sludge age (days)}$$
$$= 2.2\ \text{MGD} \times 125\ \text{mg/L} \times 8.34 \times 5\ \text{days}$$
$$= 11{,}468\ \text{lb MLSS}$$

11-20 Thick, greasy, brown or tan foam, dark brown sludge color, ash or pin floc in effluent, possibly rising sludge in settling tank.

11-21 (1) Bulking occurs when solids do not settle.
(2) Rising sludge occurs when the solids settle but rise back into the flow quickly.
(3) Ashing results from excessively old sludge with discrete settling.

11-22 Color could be the result of outside factors, such as stormwater or industrial waste.

11-23 Chocolate brown sludge color, musty odor, uniform blanket settling, light, crisp white foam, low solids in effluent, very clear effluent.

11-24 This helps eliminate variations that are not the result of changes in the sludge settling characteristics.

11-25 Increased flow, increased temperature, sludge bulking, decreased sludge age, increased organic loading.

11-26 The most widely used unit consists of a 15- to 20-foot long clear plastic pipe marked at six-inch intervals; the pipe is equipped with a ball valve at the bottom.

Chapter 12 Review Questions:

12-1 Removal of nutrients (mainly phosphorus). Other reasons would include increased BOD and TSS removal.

12-2 Coagulation or rapid mix.
Flocculation.
Sedimentation or filtration (solids separation).

12-3 Lime, iron salts (ferric & ferrous chloride, sulfate), aluminum salts (alum, sodium aluminate).

12-4 $\text{lb/day} = 19.0\ \text{mg/L} \times 4.0\ \text{MGD} \times 8.34 = 634\ \text{lb/day}$

$$\text{gal/day} = \frac{634\ \text{lb/day}}{3.0\ \text{lb/gal}} = 211\ \text{gal/day}$$

$$\text{gal/day} = \frac{211\ \text{gal/day}}{1{,}440\ \text{min/day}} = 0.15\ \text{gal/min}$$

12-5 $\text{aluminum sulfate required} = 1{,}000\ \text{gal} \times 8.34 \times 0.06 = 500\ \text{lb}$

$$= \frac{500\ \text{lb}}{0.16} = 3{,}125\ \text{lb alum}$$

12-6 981 lb/day

12-7 Phosphorus.

12-8 Burns, explosions, loss of eyesight.

12-9 Jar tests.

Chapter 13 Review Questions:

13-1 Turbidity, maintenance, intensity of bulbs, contact time, age of bulbs.

13-2 Disinfection destroys pathogenic organisms. Sterilization destroys all organisms.

13-3 Demand, 1, residual, 30.

13-4 Yellow green, 2.5.

13-5 Chlorine is a toxic substance.

13-6 Toxic to aquatic organisms, reduce fish population, retards shellfish reproduction and growth.

13-7 Wastewater is exposed to UV irradiation of a specified intensity for at least 10 seconds.

13-8 Ozone is produced on-site at the treatment plant. It is added to the wastewater to achieve specified ozone concentration in the off gas. Use is limited to filtered effluents. It may be used for other effluents only if proven to be effective.

13-9 UV—severe eye injury can occur from exposure to the direct light.
Ozone—highly toxic gas that is capable of creating flammable and/or explosive atmospheres.

13-10 Bromine chloride requires less contact time, produces bromamines that remain in wastewater for shorter periods of time. The amount of toxic material still present when the flow is released to the environment is significantly reduced.

13-11 $\text{dose, mg/L} = \dfrac{450\ \text{lb/day}}{(6.55\ \text{MGD} \times 8.34)} = 8.24\ \text{mg/L}$

13-12 7.1 mg/L

13-13 May be required by plant's permit because chlorine is very toxic to aquatic organisms and must be removed to prevent stream damage.

13-14 350 HTH/day × 0.40 available chlorine = 140 lb chlorine/day

13-15 $\dfrac{280\ \text{lb/chlorine/day}}{0.69\%\ \text{avail. chlorine} \times 8.34\ \text{lb/gal} \times 1.28} = 48.7\ \text{gal/day}$

13-16 $\dfrac{45.8\ \text{lb/day} \times 1.10 \times 365\ \text{days}}{2{,}000\ \text{lb/containers}} = 9.2\ (10\ \text{containers})$

13-17 Chlorine and its by-products (i.e., chloramines) are very toxic.

Chapter 14 Review Questions:

14-1 Removes water from biosolids; reduces the volume of biosolids; better results and lower costs.

14-2 Gravity thickener.

14-3 Gravity thickener.

14-4 Gravity thickener, flotation thickener, belt thickener.

14-5 Age of solids, blanket depth, hydraulic dt, temperature, solids retention time.

Chapter 15 Review Questions:

15-1 Aerobic digestion, anaerobic digestion, composting.

15-2 1.0

15-3 95–98°F

15-4 1°F

15-5 $\mathrm{VA/alk.} = \dfrac{340\ \mathrm{mg/L}}{1{,}830\ \mathrm{mg/L}} = 0.19$ (this is acceptable)

15-6 $$\frac{0.785 \times 40' \times 40' \times 25' \times 7.48\ \mathrm{gal/ft}^3}{5{,}000\ \mathrm{gpd}}$$

$\mathrm{dt} = 47.0\ \mathrm{days}$

15-7 $$\frac{(070 - 0.48) \times 100}{[0.70 - (0.70 \times 0.48)]} = 60.4\%$$

15-8 4–8%

15-9 pH adjustment.

15-10 Yes.

15-11 The degree of mixing provided, the temperature of the digester, the volatile matter concentration of the raw sludge.

15-12 0.07

Chapter 16 Review Questions:

16-1 30 min/cyc × 24 hr/3 hr/cyc × 65 gpm × 8.34 lb/gal × 0.051 × .64 = 4,247 lb/day

16-2 Drying beds, vacuum and pressure filtration and centrifugation.

16-3 Drainage and evaporation.

16-4 $\mathrm{area} = 3.14 \times 10\ \mathrm{ft} \times 8.34\ \mathrm{ft} = 263.8\ \mathrm{ft}^2$

$$\frac{30\ \mathrm{gpm}}{1\mathrm{min}} \times \frac{60\ \mathrm{min}}{1\ \mathrm{hr}} \times \frac{8.34\ \mathrm{lb}}{1\ \mathrm{gal}} \times \frac{11\%}{100} = 1651.3\ \mathrm{lb/hr}/263.8 = 6.26\ \mathrm{lb/hr/ft}^2$$

Chapter 18 Review Question:

18-1 The test for coliform bacteria is used to measure the effectiveness of the disinfection process. The bacteria detected by this test are normally found in the intestinal tract of humans and other warm-blooded animals. These bacteria are, therefore, found in wastewater, numbering as many as 1,000,000 per milliliter. Coliform bacteria are considered to be harmless. However, their presence does indicate the possible presence of other disease-producing organisms. As a result, when coliform bacteria are found in a water sample, the water is suspected of being polluted by human waste discharges or of being insufficiently disinfected.

Samples for analysis of coliform bacteria are collected in sterile bottles and transported to a lab. After shaking to mix thoroughly, the sample is transferred, using sterile technique, and checked at 24 and 48 hours. A smaller tube inserted inside the medium will collect any gas formed, which indicates a positive response. A small amount of sample is aseptically transferred into another tube containing another, more sensitive medium. Again, the tubes are checked at 24 and 48 hours for gas formation. Based on the number of positive tubes in this second step, a number (called the Most Probable Number—MPN) can be statistically derived (there are tables available), indicating the degree of pollution detected or disinfection achieved.

Chapter 19 Review Questions:

19-1	A
19-2	A
19-3	A
19-4	D
19-5	B
19-6	A

APPENDIX B

Answers to Final Review Exam: Chapter 20

20-1 Maintain control of digester at proper temperature.
20-2 Prevent disease.
Protect aquatic organisms.
Protect water quality.
20-3 430 gpd/ft^2
20-4 Dissolved and suspended.
20-5 181 lb BOD_5/day/1,000 ft^3
20-6 Organic indicates matter that is made up mainly of carbon, hydrogen, and oxygen and will decompose into mainly carbon dioxide and water at 550°C. Inorganic: without carbon.
20-7 On the first stage.
20-8 Algae, bacteria, protozoa, rotifers, virus.
20-9 The predominant groups of organisms.
20-10 Carbon dioxide, water, more organisms, stable solids.
20-11 “Grows” fine solids into larger more settleable solids.
20-12 Toxic matter, inorganic dissolved solids, pathogenic organisms.
20-13 Effluent.
20-14 From body wastes of humans who have disease.
20-15 Disease-causing.
20-16 Domestic waste.
20-17 Industrial waste.
20-18 $3.14 \times 110\text{ ft} = 345\text{ ft}$
20-19 $190\text{ ft} \times 120\text{ ft} = 22{,}800\text{ ft}^2$
20-20 $200\text{ ft} \times 80\text{ ft} \times 12\text{ ft} = 192{,}000\text{ ft}^3$
20-21 $[(2 \times 200\text{ ft}) + (2 \times 80\text{ ft})] \times 4 = 2{,}240\text{ ft}$
20-22 $\dfrac{22\text{ grams} \times 100}{500\text{ grams}} = 4.4\%$
20-23 2.33 ft.
20-24 6 hours.
20-25 Composting.
20-26 $5{,}350\text{ gal} \times 8.34\text{ lb/gal} = 44{,}619\text{ lb}$
20-27 $1{,}900\text{ ft}^3 \times 7.48\text{ gal/ft}^3 = 14{,}212\text{ gal}$
20-28 To increase the digestion rate.
20-29 Representative long-term sample.

20-30 Straining.

20-31 32 mg/L × 3.10 MGD × 8.34 lb/MG/mg/L = 827.3 lb/day

20-32 25 mg/L × 7.00 MGD × 3.785 KG/MG/mg/L = 662.3 KG/day

20-33 $\frac{3{,}000\text{ lb/day}}{3{,}050\text{ mg/L} \times 8.34\text{ lb/MG/mg/L}} = 0.118\text{ MGD}$

20-34 $\frac{220\text{ mg/L} \times 0.70\text{ MGD} \times 8.34\text{ lb/MG/mg/L}}{0.17\text{ lb BOD}_5\text{/person/day}} = 7{,}555\text{ people}$

20-35 $8.34\text{ lb/gallon} \times 1.1588 = 9.66\text{ lb/gallon}$

20-36 $\frac{(240\text{ mg/L} - 20\text{ mg/L}) \times 100}{240\text{ mg/L}} = 91.6\%$

20-37 $\frac{(360\text{ mg/L} - 17\text{ mg/L}) \times 100}{360\text{ mg/L}} = 95.3\%$

20-38 $\frac{(240\text{ mg/L} - 160\text{ mg/L}) \times 100}{240\text{ mg/L}} = 33\%$

20-39 $\frac{(0.655 - 0.479) \times 100}{[0.655 - (0.655 \times 0.479)]} = 52\%$

20-40 $\frac{150' \times 110' \times 10' \times 2\text{ tanks} \times 7.48\text{ gal/ft}^3 \times 24\text{ hr/day}}{8.45\text{ MGD} \times 1{,}000{,}000\text{ MGD}} = 7.0\text{ hr}$

20-41 $\frac{45' \times 3' \times 3.5' \times 2\text{ channels} \times 7.48\text{ gal/ft}^3 \times 1{,}440\text{ min/day}}{8.45\text{ MGD} \times 1{,}000{,}000\text{ gal/MG}} = 1.2\text{ minutes}$

20-42 $\frac{110{,}000 \times 7.48\text{ gal/ft}^3}{18{,}000\text{ gpd}} = 45.7\text{ days}$

20-43 Sludge is not being pumped in sufficient quantities.

20-44 DO residual in the aeration tank.

20-45 To remove large objects.

20-46 Manual and mechanical cleaners.

20-47 Burial in an approved landfill; incineration.

20-48 Finely divided suspended material.

20-49 Cutter must be sharpened and/or replaced when needed. Cutter alignment must be adjusted as needed.

20-50 Because the cutters have been replaced and the alignment has been checked, the most likely cause is excessive solids in the plant effluent. Corrective actions would include identifying the source, implementing/creating a sewer use ordinance, and/or installing a bar screen upstream of the comminutor to decrease load it receives.

20-51 Chloramine.

20-52 Filter effluent quality.

20-53 Grit is heavy inorganic matter. Sand, gravel, metal filings, egg shells, coffee grounds, etc.

20-54 $\frac{9.0\text{ MGD} \times 1.55\text{ cfs/MGD}}{3\text{ channels} \times 2' \times 4'} = 0.6\text{ fps}$

20-55 0.1 µg/L.

20-56 As count per 100 mL.

20-57 Blue dots only.

20-58 Near or at floor level because chlorine is heavier than air.

20-59 There is a large amount of organic matter in the grit. The aeration rate must be increased to prevent settling of the organic solids.

20-60 To remove settleable and flotable solids.

20-61 To remove the settleable solids formed by the biological activity.

20-62 Continuous.

20-63 20°C.

20-64 $$\frac{0.785 \times 80' \times 80' \times 12' \times 7.48\,\text{gal}/\text{ft}^3 \times 24\,\text{hr}/\text{day}}{2.20\,\text{MGD} \times 1{,}000{,}000\,\text{gal}/\text{MG}} = 4.9\,\text{hr}$$

$$\frac{2.20\,\text{MGD} \times 1{,}000{,}000\,\text{gal}/\text{MG}}{0.785 \times 80' \times 80'} = 438\,\text{gpd}/\text{ft}^2$$

$$\frac{2.20\,\text{MGD} \times 1{,}000{,}000\,\text{gal}/\text{MG}}{3.14 \times 80'} = 8{,}758\,\text{gpd}/\text{ft}$$

20-65 $$\frac{1{,}400' \times 1{,}000'}{43{,}560\,\text{ft}^3/\text{acre - feet}} = 32.1\,\text{acres}$$

20-66 $$\frac{1{,}400' \times 1{,}000' \times 4.1'}{43{,}560\,\text{ft}^3/\text{acre - feet}} = 132\,\text{acre - feet}$$

20-67 0.40 MGD x 3.069 acre-ft/MG = 1.23 acre-feet

20-68 0.40 MGD x 36.8 acre-in/MG = 14.7 ac-in/day

20-69 Stabilization pond, oxidation pond, polishing pond.

20-70 Inorganic odors because inorganics dissolve better in water.

20-71 1.5 ft/s.

20-72 40%.

20-73 2 feet (secondary settling tank).

20-74 Refers to the process in which certain carbon users will break down nitrate for its oxygen if no DO is in the water.

20-75 Settling, anaerobic digestion of settled solids, aerobic/anaerobic decomposition of dissolved and colloidal organic solids by bacteria producing stable solids and carbon dioxide, photosynthesis production of oxygen by algae.

20-76 Summer effluent is high in solids (algae) and low in BOD_5.
Winter effluent is low in solids and high in BOD_5.

20-77 Algae and surface aerators.

20-78 Between 3 and 6 ft.

20-79 Eliminates wide diurnal and seasonal variation in pond DO.

20-80 Increases during the daylight hours, and decreases during darkness.

20-81 Reduces fecal coliform, BOD_5, TSS, and nutrient levels.

20-82 $$\frac{2.10\,\text{MGD} \times (1.0 + 1.5)}{2} = 2.6\,\text{MGD}$$

20-83 $$\frac{2.10\,\text{MGD} \times (1.0 + 0.70)}{2} = 1.8\,\text{MGD}$$

20-84 $\dfrac{2.10\text{ MGD}\times(1.0+1.5)\times1{,}000{,}000\text{ gal/MG}}{0.785\times90'\times90'\times2}=412.8\text{ gpd/ft}^2$

20-85 $\dfrac{2.10\text{ MGD}\times(1.0+0.75)\times1{,}000{,}000\text{ gal/MG}}{0.785\times90'\times90'\times2}=289\text{ gpd/ft}^2$

20-86 $\dfrac{190\text{ mg/L}\times2.10\text{ MGD}\times8.34\text{ lb/MG/mg/L}\times1{,}000}{2\text{ filters}\times0.785\times90'\times90'\times8'}=32.7\text{ lb/BOD}_5\text{/1,000 ft}^3$

20-87 Sodium nitrate.

20-88 Polymer.

20-89 Lime and bicarbonate.

20-90 Distribution system—to distribute the hydraulic and organic loading evenly over the filter media.
Media—to support the biological growth.
Underdrains—to collect and remove treated wastewater and sloughings from the filter. To provide ventilation.

20-91 Standard (best effluent quality), high rate, and roughing.

20-92 $240{,}000\text{ ft}^2+210{,}000\text{ ft}^2+(6\times160{,}000\text{ ft}^2)=1{,}410{,}000\text{ ft}^2$

$$\frac{8.40\text{ MGD}\times1{,}000{,}000\text{ gal/MG}}{1{,}370{,}000\text{ ft}^2}=6.1\text{ gpd/ft}^2$$

20-93 $\dfrac{190\text{ mg/L}\times8.40\text{ MGD}\times8.34\text{ lb/MG/mg/L}\times1{,}000}{1{,}410{,}000\text{ ft}^2}=9.44\text{ lb BOD}_5\text{/1,000 ft}^2$

20-94 $190\text{ mg/L}-(150\text{ mg/L}\times0.55)=107\text{ mg/L}$

$$\text{SOL}=\frac{107\text{ mg/L}\times8.40\text{ MGD}\times8.34\text{ lb/MG/mg/L}\times1{,}000}{1{,}410{,}000\text{ ft}^2}$$

$$=5.3\text{ lb BOD}_5\text{/day/1,000 ft}^3$$

20-95 Hydrogen sulfide and ammonia.

20-96 Disks covered with biological growth rotate in wastewater. Organisms collect food during submergence. Oxygen is transferred during exposure to air. Organisms oxidize organic matter. Waste products and sloughings are discharged to wastewater flow for removal in settling tank.

20-97 The use of fixed film biological organisms.

20-98 Normal—gray, shaggy
High sulfur—chalky, white

20-99 The zoogleal mass

20-100 $\dfrac{1{,}850\text{ mL}\times100}{2{,}000\text{ mL}}=92.5\%$

20-101 $\dfrac{1{,}150\text{ mL}}{2\text{ L}}=575\text{ mL/L}$

20-102 $\dfrac{1{,}850\text{ mL}}{2\text{ L}}=925\text{ mL/L}$

$$\frac{925\text{ mL/L}\times1{,}000}{2{,}700\text{ mg/L}}=342.5$$

20-103 $\frac{175\,\text{mg/L} \times 2.10\,\text{MGD} \times 8.34}{1{,}800\,\text{mg/L} \times 1.255\,\text{MG} \times 8.34} = 0.16\,\text{lb/d BOD}_5\text{/lb MLVSS}$

20-104 $\frac{2{,}700\,\text{mg/L} \times (1.255\,\text{MG} + 0.88) \times 8.34}{(6{,}120\,\text{mg/L} \times 0.090\,\text{MGD} \times 8.34) + (18\,\text{mg/L} \times 2.10\,\text{MGD} \times 8.34)} = 9.8\,\text{days}$

20-105 Heat is generated.

20-106 Increase waste rate.

20-107 Decrease; decrease; decrease; increases; increase.

20-108 300 lb/hypochl. x 0.45 avail. chlorine = 135 lb/chl/day

20-109 $\frac{280\,\text{lb chlorine/day}}{0.679\%\ \text{available chlorine} \times 8.34\text{lb/gal} \times 1.18} = 41.9\,\text{gal/day}$

20-110 $\frac{40.8\,\text{lb/day} \times 1.10 \times 365\,\text{days}}{2{,}000\,\text{lb/containers}} = 8.2\ (9\ \text{containers})$

20-111 $\frac{6\,\text{containers} \times 2{,}000\,\text{lb/container}}{6.0\,\text{mg/L} \times 2.55\,\text{MGD} \times 8.34\,\text{lb/MG/mg/L}} = 94 - 15\,\text{days} = 79\,\text{days}$

20-112 $\frac{40\,\text{lb/day} \times 1.11 \times 365\,\text{days}}{150\,\text{lb/cylinder}} = 108\,\text{cyl} \times 150 \times 0.17 \times 1.075 = \$2{,}961$

20-113 Sulfur dioxide and sodium bisulfite.

20-114 Oxidized and made odorless.

20-115 Twenty-four hours.

20-116 Non-spore forming; facultative anaerobic; ferment lactose with acid and gas production.

20-117 The average length of time a mixed liquor suspended solids particle remains in the activated sludge process. May also be known as sludge retention time.

20-118 Bacteria and algae.

20-119 Disinfection destroys pathogenic organisms. Sterilization destroys all organisms.

20-120 Demand; 1; residual; 30.

20-121 Yellow green; 2.5.

20-122 Because they originate in the same place as disease-causing bacteria. Their presence or absence is an indicator of the presence or absence of pathogenic organisms.

20-123 $30\,\text{min/cyc} \times 24\,\text{hr} / 3\,\text{hr/cyc} \times 75\,\text{gpm} \times 8.34\,\text{lb/gal} \times 0.05 \times 0.66 = 4{,}954\,\text{lb/day}$

20-124 $\frac{40\,\text{mg} \times 65{,}000\,\text{gal} \times 3.785\,\text{L/gal}}{1\,\text{L} \times 454\,\text{grams/lb} \times 1{,}000\,\text{mg/gram}} = 21.7\,\text{lb}$

20-125 Distilled or deionized water.

20-126 Pipette 1 mL of sample into a bottle containing 9 mL of sterile dilution water, and mix. Pipette 1 mL of the second solution into a bottle containing 9 mL of sterile dilution water, and mix. Repeat the second step three more times to obtain a serial dilution that contains 0.00001 mL of original sample of mL of dilution water.

20-127 Remove the stopper from the bottle, being careful to guard against contamination of the cap or neck of the bottle. Submerge the bottle, going against the flow, using a dipping motion in and out of the water. Collect at least 100 mL of sample, and replace the bottle stopper.

20-128 What does MPN stand for?
Most Probable Number.

20-104 $\frac{75{,}500\text{ gal}}{2{,}850\text{ gpd}} = 26.5\text{ days}$

20-130 90–95°F; 1°

20-131 It tends to level out extreme high and low values giving a better overall indication of bacterial density.

20-132 Less; more.

20-133 Increase wasting, and allow sludge to become younger and less dense.

20-134 Decrease.

20-135 $\frac{350\text{ mg/L}}{1{,}800\text{ mg/L}} = 0.19$

20-136 $\frac{0.785 \times 50' \times 50' \times 25' \times 7.48\text{ gal/ft}^3}{6{,}000\text{ gpd}} = 61.2\text{ days}$

20-137 Stormwater (acid rain) or industrial wastes.

20-138 Organisms' activity can change the DO significantly before the test is started.

20-139 $\frac{(0.72 - 0.46) \times 100}{[0.72 - (0.72 \times 0.46)]} = 67\%$

20-140 The licensed operator and the responsible official.

20-141 National Pollutant Discharge Elimination System.

20-142 Contact with corrosive chemicals, contact with toxic chemicals, fire, broken glassware, and contact with infectious materials.

20-143 Hydrogen ion; hydroxyl.

20-144 Grab sample only.

20-145 By increasing the primary sludge pumping rate or by adding dilution water.

20-146 Flow rate of the sludge is going into the unit. Pounds or kg of solids in the influent.

20-147 Winkler (azide modification) and membrane electrode methods.

20-148 Thermal conditioning.

20-149 7.0 pH.

20-150 Solids will become septic, gasify, and be resuspended. This will cause a decrease in the effluent quality.

20-151 Either because the microorganisms have been killed or are absent.

20-152 The time to do the test, 3 hours versus 5 days.

20-153 One foot per second.

20-154 A condition that allows the flow to pass through the unit very quickly. Improper inlet baffling, weirs not level, and wide variations in temperature.

20-155 Grit chambers.

20-156 Density of sludge.

20-157 Eutrophication.

20-158 Anaerobic conditions within the filter.

20-159 Decrease in alkalinity.

20-160 Flotable, settleable, and colloidal.

20-161 0.1%.

20-162 Losses—volatilization of organic material, entrapped water of hydration, and gases formed by chemical reactions during heating.
Gains—oxidation during heating.

20-163 Steam bath, drying oven (103–105°C), desiccator, analytical balance, evaporating dishes, 100 mL graduated cylinder, and dish tongs.

20-164 The amount of organic material in a sample that can be oxidized by a strong oxidizing agent.

20-165 Chloride—mercuric sulfate; nitrite nitrogen—sulfamic acid.

APPENDIX C

Commonly Used Formulae in Wastewater Treatment

Parameter	Formula
Area, ft^2	
Rectangle	Width, ft × Length, ft [(W) (L)]
Circle	0.785 (Diameter, ft)^2 [(0.785)D^2]
Volume, ft^3	
Rectangle	Width, ft × Length, ft × Height [(W) (L) (H)]
Cylinder	0.785 (Diameter, ft)^2 (Height, ft) [(0.785)D^2H]
Cone	(1/3) (π) (Radius, ft)^2 (Height , ft) [0.33 R^2H]
Sphere	(4/3) (π) (Radius, ft)^3 [4.16 R^3]
Flow, cfs	(Velocity, ft/sec) (surface area, ft^2) [(V) (A)]
Pounds	(Flow, MGD) (con,mg/L) (8.34 lb/gal) [(Q) (mg/L) (8.34)]
SVI, mL/g	$\frac{\text{volume}}{\text{MLSS concentration}} \times 100$
Circumference, ft	(π) (Diameter)
Detention Time, h	$\frac{(\text{Volume, gal})(24\text{ h/day})}{\text{Flow, gpd}}, [V/Q]$
Surface Loading Rate, gpd/ft^2	$\frac{\text{Flow, gpd}}{\text{area, ft}^2}, [Q/A]$
Organic Loading Rate	$\frac{\text{lb of BOD}}{\text{lb MLVSS}}$
Sludge Age	$\frac{\text{MLSS in aeration tank}}{\text{SS in primary effluent}}$
MCRT	$\frac{\text{SS in secondary system}}{\text{WAS/day} + \text{SS in effluent/day}}$
Volatile Solids Reduction	$\frac{\text{In} - \text{Out}}{\text{In} - (\text{In} \times \text{Out})} \times 100$
Chlorine Dose	Chlorine Demand + Chlorine Residual
Removal, %	In − Out × 100

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