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VOLUME 3
ADVANCED LEVEL

Spellman's Standard Handbook for Wastewater Operators

Frank R. Spellman

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Frank R. Spellman, Ph.D.



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For Wastewater Operators Everywhere

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Preface

I am gratified and pleased with the initial success of Volume 1 (Fundamental Level) and Volume 2 (Intermediate Level) of *Spellman's Standard Handbook for Wastewater Operators*. User feedback has also been encouraging. This series is now complete with the publication of the Advanced Level Volume (Volume 3).

✓ *Note:* “Advanced Level” material covers information that wastewater operators with several years of plant experience and training are expected to know.

Following the pattern begun in Volume 1 and continued in Volume 2, Volume 3 includes an overview of the same concepts and applications presented in the previous volumes, but the material presented is at a higher level. Volume 3 is specifically targeted for those handbook users who are preparing for Class I or Grade IV/V licensure—the highest level of licensure.

The overall goal remains the same, however—to simplify the learning process for tasks operators need to master and, thus, to develop more qualified wastewater operators. Users of this volume and the preceding volumes (building on material presented in each) will learn about wastewater treatment and other relevant subject matter—applied math, basic microbiology, and much more. Using Volume 3 of the handbook exposes the operator to advanced principles and concepts for application in the real world. More importantly, it exposes operators to the materials they must know (once they have attained their initial licensure) to advance through the various licensure levels. While these texts make no attempt to provide direct preparation for licensure, the benefits to those taking licensure examinations are evident.

The bottom line: The material presented in Volume 3 provides operators seeking advanced licensure with directly applicable and practical tools for success.

Acknowledgement

I am grateful to the Virginia Polytechnic Institute and State University (Virginia Tech) Water/Wastewater Short Course instructors who provided me with the idea of developing this three-volume set. The idea germinated as a result of our experience, which showed us that there is a real need for this series.

Introduction

1.1 INTRODUCTION

SPELLMAN'S *Standard Handbook for Wastewater Operators, Volume 3: Advanced Level* is primarily designed to provide a readily accessible, current, user-friendly source of information for review in preparing for the Class II/I or Grade IV/V Wastewater Operator Licensure Examinations. (Note: Classification or grade level is dependent upon the state in which licensure is given.)

Volume 3 provides the necessary classroom-type training-in-handbook-form to prepare the conscientious operator to successfully complete the upper Class/Grade Level examinations. Volume 3 builds upon the information presented in Volumes 1 and 2.

While true that the practical, hands-on knowledge required for licensure can only be gained through years of on-the-job experience, it is also true that successful completion of Volumes 1, 2, and 3 of *Spellman's Standard Handbook* series provides users with the knowledge required to score well on state written examinations. Wastewater operators must not only have the actual required on-the-job experience requisite for each certification level, they must also be able to pass the written licensure examination for each level.

Every attempt has been made to format this presentation to allow users to build upon information presented, step-by-step, page-by-page, as they progress through the material. This handbook represents a summary of expert information available in many other sources (see Table 1.1). For additional information or more specific material on any of the topics presented, consult one or more of the references provided in Table 1.1.

This advanced level handbook assumes readers are operators, lead operators, and/or supervisors working toward the highest certification level. We also expect that readers have completed Volumes 1 and 2 of *Spellman's Standard Handbook for Wastewater Operators* or have attained licensure at the fundamental and intermediate levels through other means—attendance at various state-run short courses, applied science community college programs, or through other study sources.

✓ *Note:* In this handbook, the “fundamental level” means entry level—the lowest level of licensure. “Intermediate level” refers to Class II/Grade III licensure. “Advanced level” refers to the highest level of licensure. (The symbol ✓ displayed in various locations throughout the handbook indicates an important point or note to which the reader should pay particular attention.)

Let us point out that no one single study guide has *all* the answers to all the questions given on any—or every—state licensure examination. The fact is, *Spellman's Standard Handbook* is not an “answer” book for any specific licensure examination; instead, it is an important tool that, if used properly, allows operators to successfully prepare for completing the written examination requirements for licensure as a wastewater operator at the advanced level. For best results, augment the information presented in this handbook with information contained in the various field study programs available from state water control boards, short courses presented by various universities

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-600/4-79-020, 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.

(e.g., Virginia Tech) and/or technical schools, and correspondence studies from such sources as California State University, Sacramento (The "Sacramento Manuals"; see Table 1.1).

Let us point out that changes in technology and regulations occur frequently in the water pollution control industry. Because of this, licensure candidates—as well as those who have achieved licensure—must work and study to stay abreast of these changes.

The handbook is divided into chapters covering specific topic areas. Many chapters include a series of review questions at the end. Read and study the 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 designed to test the level of knowledge the user has attained through study of this handbook, knowledge gained from on-the-job experience, and knowledge gained from other sources.

A score of 75% or above on the chapter review exams and the comprehensive practice examination is considered "good"—but more importantly, any questions you miss should signal the need to go back and review the applicable areas. By using the comprehensive practice examination as a measuring stick, you can gauge your level of knowledge in all pertinent areas and determine strong

and weak points. When you get right down to it, shouldn't the purpose of any examination be to measure your level of knowledge in a way that points you in the proper direction to take to attain an even greater level of knowledge? You may agree with us that this objective is worthwhile. We provide answers to the comprehensive practice examination in Appendix B and a formula sheet in Appendix C for reference; the formula sheet can and should be used when taking the comprehensive practice examination.

Actual certification or licensure examinations (type and content) vary from state to state. The examination style or format (at the advanced level) typically consists of multiple-choice, short answer, mathematical computations, and essay questions.

✓ Essay questions are usually included in the advanced level certification examinations, because people at this level are expected to be able to effectively make presentations to agency governing bodies to explain policies or situations. As such, the ability of applicants to effectively communicate in written form is a major aspect of the Class I/Grade IV exam.

The actual weighting for each of these specific question formats also varies. For example, multiple-choice questions might make up as much as or more than 30% of the questions asked on some state examinations, with short answer, math, and essay questions proportionately represented and making up the rest of the examination.

In all three volumes of *Spellman's Standard Handbook* series, questions are formatted to require the user to provide *written* short answers, fill in the blank, and standard mathematical computations. We do not provide multiple-choice or true and false type questions (as do state certification examinations). Instead, we chose a format for which you must fill in a written answer (when you write the correct answer down, you tend to remember the *right* answer, as well as the methodology actually used to obtain the *right* answer) without the opportunity to choose the wrong answer from a list of answers given. In our experience, user-generated correct responses greatly enhance learning.

Why?

Too often, those studying for any type of examination and then later testing their knowledge level are given multiple-choice questions to answer, not because they are the most effective way to determine what the candidate knows, but because they are easiest for the examiner to grade. In practice, too often, the user chooses the wrong answer and that wrong answer becomes subconsciously imbedded, becoming an indelible mental entry. Obviously, memorizing the wrong answer is not what this handbook is about.

What this handbook is about is providing the right answer—providing the means to compute the right answer—and if users obtain the wrong answer, providing the means to allow them to go back and find out “why” the answer is wrong and how to make the wrong answer correct.

1.2 THE WASTEWATER TREATMENT PROCESS: THE MODEL

Figure 1.1 shows the basic schematic of the example wastewater treatment process that provides primary and secondary treatment using the *activated sludge process* we used in Volume 1 and Volume 2 of the handbook. In Volume 3, we use this same model again. In secondary treatment (which provides BOD removal beyond what is achievable by simple sedimentation), three approaches are actually commonly used (trickling filter, activated sludge, and oxidation ponds). However, we mainly focus on trickling filters and the activated sludge process in this volume, primarily for instructive and illustrative purposes, and also because, in our experience, many of the state licensure examinations include several questions related to the activated sludge process.

Figure 1.1 (and its subsequent unit-process-specific renditions) allows you to follow the treatment process step-by-step as it is presented (and as it is actually configured in the real world) in the written material to help you understand how all the various unit processes sequentially follow and tie into

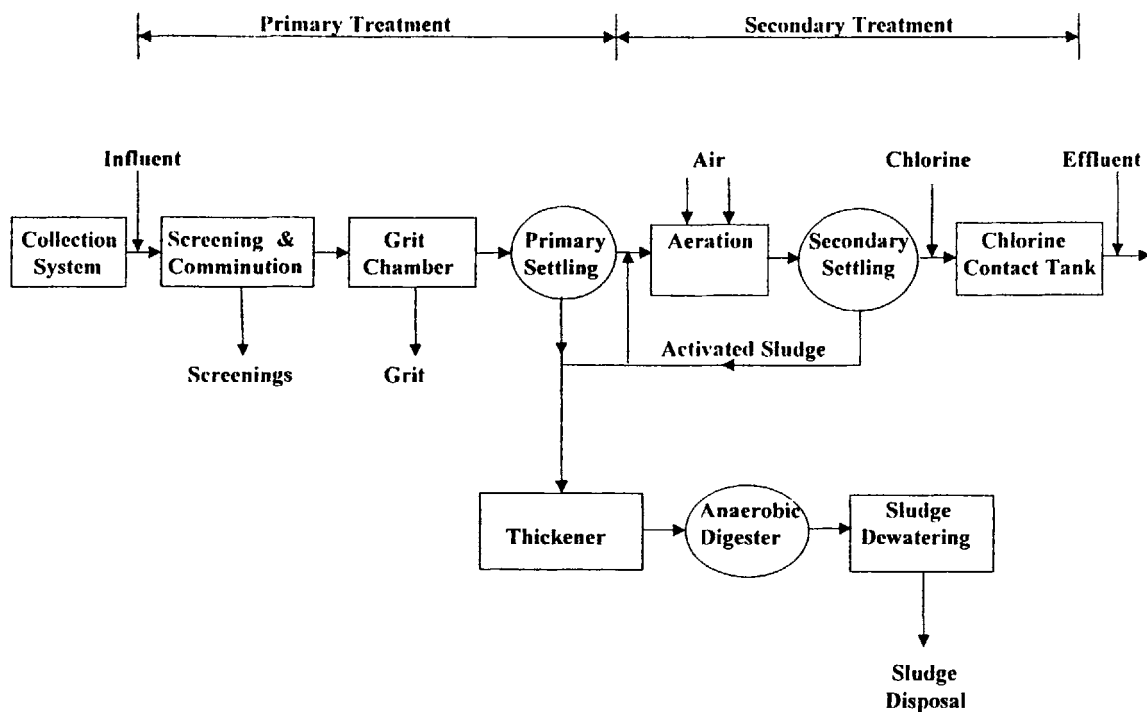


Figure 1.1 Schematic of conventional wastewater treatment process providing primary and secondary treatment using activated sludge process.

each other. In Volume 3, we again begin certain chapters (some of which discuss specific unit processes) with Figure 1.1—with the relevant subject area included in the diagram along with previously presented processes.

We begin these chapters in this manner because wastewater treatment is a series of individual steps (unit processes) that treats the wastestream as it makes its way through the entire process. Thus, it logically follows that a pictorial presentation—along with pertinent written information—should enhance the learning process. Let us point out, however, that even though the model shown in Figure 1.1 (the conventional wastewater treatment process) does not include all unit processes currently used in wastewater treatment, we do not (as stated earlier) ignore the other major processes—trickling filters and rotating biological contactors (RBCs).

While Figure 1.1 portrays the “conventional” treatment process, it does not include any of the unit processes that make up the *advanced* or *tertiary* treatment process. However, advanced treatment is an important topic, and operators at the highest levels of certification are expected (required) to know about it, including knowing the various unit processes that comprise it. Thus, Class I/Grade IV/V licensure examinations (depending on state requirements) generally include questions about various aspects of advanced treatment. We discuss advanced treatment in Chapter 13.

Let us also point out that we include other “new” subject areas in Volume 3 (ones that were not presented or only lightly touched on in Volume 1 or Volume 2). For example, Volume 3 includes a more advanced discussion of the wastewater collection system (see Chapter 5). Chapter 14 discusses solids handling, including land application of biosolids. Analysis of phosphorous and nitrogen testing are covered in Chapter 15, as well as testing for alkalinity and hardness.

Successful completion of Volume 3 of *Spellman’s Standard Handbook for Wastewater Operators* should enable the user to satisfy the purpose of this three-volume series: to develop more qualified wastewater operators.

Wastewater Terminology and Definitions

2.1 INTRODUCTION

TO learn wastewater treatment (or any other technology for that matter), you must master the language associated with the technology.

Each technology has its own terms with its own accompanying definitions. Many of the terms used are unique. Others combine or “borrow” words from many different technologies. This is the case with the wastewater treatment technology. Its language has its unique terms and also uses terms from engineering, biology, mathematics, hydrology, chemistry, physics, microbiology, hydraulics, and other technologies and/or sciences.

To speed the progress of your learning and to facilitate your ability to speak and understand the language of wastewater treatment, in this chapter we identify and define many of the terms unique and/or common to wastewater treatment. Those terms not listed or defined in the following section are defined as they appear in the text.

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* treatment technology 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.
- *Anaerobic* conditions in which no oxygen (free or combined) is available. Also used to describe organisms, biological activity, or treatment processes that function in the absence of oxygen.
- *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.
- *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, BOD₅* the amount of organic matter that can be biologically oxidized under controlled conditions (5 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 water and 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 inappropriate to use to describe biosolids. Biosolids is a product that can be reused; it has some value. Because biosolids has value, it certainly should not be classified as a “waste” product—and when biosolids for beneficial reuse is addressed, it is made clear that it is not.

- *Buffer* a substance or solution that resists changes in pH.
- *Carbonaceous biochemical oxygen demand, CBOD₅* the amount of biochemical oxygen demand that can be attributed to carbonaceous material.
- *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.
- *Comminution* a process to shred solids into smaller, less harmful particles.
- *Composite sample* a combination of individual samples taken in proportion to flow.
- *Cross-connection* a connection between a storm drain system and a sanitary collection system; a connection between two sections of a collection system to handle anticipated overloads of one system; or a connection between drinking (potable) water and an unsafe water supply or sanitary collection system.
- *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.
- *De-watering* 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 National Pollutant Discharge Elimination System (NPDES) discharge permit.
- *Dissolved oxygen (DO)* free or elemental oxygen that is dissolved in water.
- *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 discharged from point sources into state waters.
- *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.
- *Floc* solids that join together to form larger particles that will settle better.
- *Flume* a flow rate measurement device.
- *Food-to-microorganism ratio (F/M)* an activated sludge process control calculation based upon the amount of food (BOD₅ or COD) available per pound of mixed liquor volatile suspended solids.
- *Force main* a pipe that carries wastewater under pressure from the discharge side of a pump to a point of gravity flow downstream.
- *Grab sample* an individual sample collected at a randomly selected time.
- *Grit* heavy inorganic solids, such as sand, gravel, egg shells, or metal filings.
- *Hydraulic cleaning* cleaning pipe with water under enough pressure to produce high water

velocities. Hydraulic cleaning devices or machines include high-velocity cleaners, ball, kit or similar sewer-cleaning devices, scooter, and flushing.

- *Industrial wastewater* wastes associated with industrial manufacturing processes.
- *Infiltration/inflow* extraneous flows in sewers; simply, inflow is water discharged into sewer pipes or service connections from such sources as foundation drains, roof leaders, cellar and yard area drains, cooling water from air conditioners, and other clean-water discharges from commercial and industrial establishments. Defined by Metcalf and 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.
- *Lift station* a wastewater pumping station designed to “lift” the wastewater to a higher elevation. A lift station normally employs pumps or other mechanical devices to pump the wastewater and discharges into a pressure pipe called a force main.
- *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.
- *Mechanical cleaning* clearing pipe by using equipment (bucket machines, power rodders, or hand rods) that scrapes, cuts, pulls, or pushes the material out of the pipe.
- *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 equivalent to parts per million (ppm).
- *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 conditions that must be met for discharge.
- *Nutrients* substances required to support living organisms. Usually refers to nitrogen, phosphorus, iron, and other trace metals.
- *Organic* materials consisting 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.

- *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.
- *Parts per million (ppm)* an alternative (but numerically equivalent) unit used in chemistry for milligrams per liter (mg/L). As an analogy, think of one ppm as equivalent to a full shot glass in a swimming pool.
- *Preventive maintenance (PM)* Regularly scheduled servicing of machinery or other equipment using appropriate tools, tests, and lubricants. This type of maintenance can prolong the useful life of equipment and machinery and increase its efficiency by detecting and correcting problems before they cause a breakdown of the equipment.
- *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.
- *Scum* the mixture of floatable solids and water 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 (SSV₆₀ or SSV₃₀).
- *Sewage* wastewater containing human wastes.
- *Sludge* the mixture of settleable solids and water removed from the bottom of the settling tank.
- *Sludge retention time (SRT)* see mean cell residence time.
- *Sludge volume index (SVI)* a process control calculation used to evaluate the settling quality of the activated sludge. Requires the SSV₃₀ and mixed liquor suspended solids test results to calculate.
- *Storm sewer* a collection system designed to carry only stormwater runoff.
- *Stormwater* runoff resulting from rainfall and snowmelt.
- *Supernatant* in a digester, the amber-colored liquid above the sludge.
- *Wastewater* the water supply of a community after it has been soiled by use.
- *Waste activated sludge solids (WASS)* the concentration of suspended solids in the sludge 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 SUMMARY

While this chapter covers much of the core vocabulary you need to know for wastewater operation, vocabulary specifically related to individual operations can be found in those chapters.

One general task operators at the advanced level face as a daily challenge is troubleshooting, the subject of Chapter 3. Higher levels of experience should translate into greater understanding of both process and mechanics—what chemical and physical principles are at work within the unit processes and knowledge of the machinery that keeps those processes functioning properly.

2.4 REFERENCE

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

2.5 CHAPTER REVIEW QUESTIONS

2-1 Define cross-connection.

2-2 Define BOD₅.

2-3 What is a weir?

2-4 Define facultative.

2-5 Define infiltration/inflow.

2-6 What is floc?

2-7 Explain mixed liquor.

2-8 What is a point source?

2-9 What is supernatant?

2-10 How is settleability calculated?

Matching exercise: Match the definitions listed in part A with the terms listed in part B by placing the correct letter in the blank.

✓ *Note:* After completing this exercise, check your answers with those provided in Appendix A.

Part A:

- (1) Solid organic matter recovered from a sewage treatment process and used especially as a soil amendment _____.
- (2) Free oxygen dissolved in water _____.
- (3) Contains human wastes _____.
- (4) Wastes discharged from residences _____.
- (5) Shreds solids into smaller, less harmful particles _____.
- (6) Another name for biosolids _____.
- (7) Conditions in which no free, elemental oxygen is present _____.
- (8) Runoff resulting from rainfall and snowmelt _____.
- (9) Iron, sand, and gravel, etc. _____.
- (10) The solids formed when microorganisms are used to treat wastewater using the activated sludge process _____.
- (11) Heavy inorganic solids, such as sand, gravel, egg shells, or metal filings _____.
- (12) A type of bacteria used to indicate possible human or animal contamination of water _____.
- (13) This type of inflow is steady and is identified and measured along with infiltration _____.
- (14) Another name for wastewater pumping stations _____.
- (15) Wastewater that has no dissolved oxygen present _____.
- (16) Wastewater treatment plant discharge _____.
- (17) The highest allowable values for a daily discharge _____.
- (18) Type of bacteria found in bodily discharges of warm-blooded animals _____.
- (19) The amount of chemically oxidizable materials present in wastewater _____.
- (20) Common to fixed film treatment devices _____.
- (21) Pollutant discharge from a discernible, defined, and discrete conveyance _____.
- (22) Process control calculations used to evaluate settling quality of activated sludge _____.
- (23) The suspended solids concentration of mixed liquor _____.
- (24) Used to describe organisms that function in the absence of oxygen _____.
- (25) Nitrogen, phosphorus, and other trace metals _____.

Part B:

- | | | |
|----------------------------|------------------------------|---|
| a. activated sludge | j. grit | s. mixed liquor suspended solids (MLSS) |
| b. anaerobic | k. steady inflow | t. nutrients |
| c. anoxic | l. sewage | u. septic |
| d. comminution | m. stormwater | v. sanitary wastewater |
| e. coliform | n. sludge | w. point source |
| f. fecal coliform | o. sludge volume index (SVI) | x. effluent |
| g. chemical oxygen demand | p. zoogeal slime | y. biosolid |
| h. daily maximum discharge | q. inorganic | |
| i. dissolved oxygen | r. lift station | |

Troubleshooting

3.1 INTRODUCTION

THOSE involved in the troubleshooting process sometimes say that troubleshooting equipment malfunctions or system or unit process problems is more of an art than a science. The truth in this statement may in part depend upon the individual's approach to the task, but one thing is certain: a senior plant operator in wastewater treatment plant operations who can't correctly and promptly troubleshoot and determine appropriate remedial or corrective actions is at a serious disadvantage—and is in jeopardy of worse.

This makes a certain amount of sense when you digest it. The senior operator—normally the plant chief operator or supervisor—is expected to be “the” plant problem-solver. While true that senior plant operators are also required to possess good leadership and people skills to properly and efficiently manage the plant (in many instances), they are also generally responsible for ensuring that the plant operates as per design.

In the real world of wastewater treatment plant operations, the responsible person in charge (usually the senior person present, holding the highest licensure level) has one and only one major objective, one major focus, one major concern, one major driving need: *to make permit!*

We have little doubt that you have been there: feeling the pressure of harassment either directly from local officials, from local agency authorities, or from even those regulators from the state water control board who obviously (from their expectations) perceive your sole function in life as being the person responsible for ensuring your plant does indeed make its monthly National Pollutant Discharge Elimination System (NPDES) permit requirements—or from your supervisor, who is feeling (and sharing) his or her pressure.

For the uninitiated, this type of pressure—to make permit, or else—may seem out of place, like over-kill, even hyperbole taken to the extreme. However, for the initiated, we know better; we've been there.

So what is the point of these scare tactics?

Our point is simple, actually. The responsible person in charge of a wastewater treatment plant who holds the highest level of licensure is normally expected to keep the plant operating at optimal operating condition at all times.

To do this, you must be able to correctly, effectively, and promptly troubleshoot equipment and unit processes—and keep them on line—to make permit.

The problem? It's easier said than done—by far.

Troubleshooting equipment correctly, effectively, and promptly is a skill. An artful skill?

Yes; probably. Some people seem to possess a gift for it. They can make it look easy—easier than it actually is.

But artful or not, it is a skill that can be learned. Many people simply learn to do it because they need to or have to.

Keep in mind that the performance of any treatment system and/or unit process will vary from

time to time. The goal of this chapter is to provide information to assist you, the senior operator, to minimize equipment downtime and periods of poor system performance.

The bottom line: Making permit is the bottom line, and top-of-the-line troubleshooting skills and techniques are essential.

3.2 TROUBLESHOOTING: WHAT'S IT ALL ABOUT

Poor equipment operation or poor system performance may be the result of several factors: inadequate design, uncontrolled discharges to the collection system (usually toxic industrial wastes), or unanticipated equipment failures. Studies have shown, however, that, in the majority of cases, poor equipment system performance is the result of poor operation, maintenance, or management of the treatment system. Many of these same studies indicate that poor performance and permit violations can be significantly reduced if plant operating personnel can recognize problems as they develop, identify and evaluate potential causes, and quickly develop and implement reasonable control and prevention programs. In short, good operation must include routine problem-solving or troubleshooting activities.

So the obvious question is: What is troubleshooting? Simply put, *troubleshooting* is a systematic approach to solving problems. The first step in troubleshooting is to correctly identify the problem. This involves a physical inspection of the equipment or the unit process performance.

✓ Remember, the first step in troubleshooting is to first establish for sure that a problem actually exists. In our experience, often, when alerted to a “problem,” careful investigation shows that the so-called “problem” or malfunction was nothing more than operator error. In other words, careful investigation indicated that the problem was of the “phantom” variety—it once existed, but is now gone—because human error, not equipment malfunction, caused the problem.

Again, before troubleshooting can begin, a problem must exist—*determination* of such problems begins the troubleshooting process. Once begun, troubleshooting follows through until the problem is corrected. Troubleshooting includes all the actions taken to correct the existing problems and to prevent future occurrences. Troubleshooters must not only know their equipment or unit process (would you expect a carpenter to troubleshoot a nuclear reactor?), they must also understand that troubleshooting’s most important objective (and the goal of the whole troubleshooting process) is to correct the problem promptly and in the most practical and economical manner.

✓ *Note:* Recognize that troubleshooting to determine why a particular electric motor will not start is one type of troubleshooting offering few basic approaches. On the other hand, troubleshooting a wastewater unit process or the entire treatment system can be an extremely complex undertaking that may produce several reasonable approaches. The point is that the troubleshooting process seldom produces a *single* right answer.

The initial troubleshooting process begins with the troubleshooter (whoever that might be), who conjures up a large dose of common sense and proceeds to investigate the problem in a logical, step-by-step manner. In short, before the troubleshooting process can begin in earnest, the troubleshooter should verify certain things. These include the following:

- the circuit breaker is on (closed)
- operating switches are in the proper position
- for pumps, all needed suction and discharge valves are open, and seal water is available
- no obvious signs of failure are apparent, such as jammed, loose, broken, or burned equipment
- mounting bolts are tight; couplings, drive bolts, and chains are aligned and correctly tensioned

Always begin the troubleshooting process by looking for the simplest, most obvious correction to the problem. If you find no obvious problems, attempt to restart. If the equipment circuit breaker immediately opens after starting, suspect an electrical malfunction, such as a short or overcurrent condition.

If the equipment starts but runs for only a short time or displays an equipment “fail” signal or alarm, suspect an overload condition.

We stated that troubleshooting may be as much an art as a science. This is true in the sense that operators develop their senses to constantly be on the lookout for problems, for small signs that indicate problems, and for signs of potential problems. Operators learn how to determine the causes of process and equipment problems. Problems may be seen, heard, smelled, or even felt. Troubleshooting often involves an operator’s developed intuition regarding what went wrong, why, and how to fix it.

Some operators have an uncanny knack for troubleshooting any and all equipment or unit process malfunctions they confront. Others must learn the fine art of troubleshooting the hard way—through experience, much experience. The point is, troubleshooting properly can be learned—the troubleshooting process is understandable.

First, to really understand the troubleshooting process, you must understand troubleshooting’s goals. Specifically, the primary goal of any troubleshooting effort, obviously, must be to identify and correct the problem causing poor performance and/or non-compliance. In addition to this primary (and immediate) goal, other goals are essential for this process. These include the following:

- (1) Preventing a similar problem in the future
- (2) Improving overall plant performance
- (3) Reducing operation and maintenance cost

3.3 THE TROUBLESHOOTER

The *troubleshooter* in a plant where a problem causes poor performance or effluent (permit) violations is, of course, the plant operator.

In the role of troubleshooter, plant operators and other members of the operating staff assume several roles, including investigator, problem solver, mechanic, leader, and realist (see Figure 3.1).

In the role of *investigator*, the troubleshooter inquires, analyzes, examines, explores, researches, studies, and performs various tests (see Figure 3.2).

In the troubleshooting process, the investigator first inquires. One of the standard (and obvious) questions we have all asked when equipment or a process fails is, “What happened?” The troubleshooter is rarely right on the spot when the equipment or system malfunctions to witness exactly what occurred, of course. For example, consider an electrical motor controller (the device used to start, stop, and protect the motor) that suddenly starts to make unusual noises, then emits smoke. Anyone standing close to the controller—any witness—possesses valuable information, especially for the plant’s designated electrical troubleshooter (hopefully a qualified electrician), who was probably not there at the scene. While true that any electrician who opens a motor controller door and immediately notices that the internal components have melted from fire has a pretty good idea of what has occurred, if the electrician is called in much later (when the smoke and smell of burning insulation have subsided), he or she will want to know what happened—what were the symptomatic indicators (smoke, noise, heat, flame, vibration, or whatever). Thus, the electrician will inquire from witnesses (if there are any) exactly what they noticed, heard, observed, etc. These important points assist the troubleshooter in detecting the causal factors or the cause itself. When the cause of failure is known, the “fix” is much easier to effect.

Sometimes, troubleshooting inquiries are not necessary. Consider, for example, the shift operator who, while on her rounds, notices too much grit in the bar screen chamber, with water surging. This

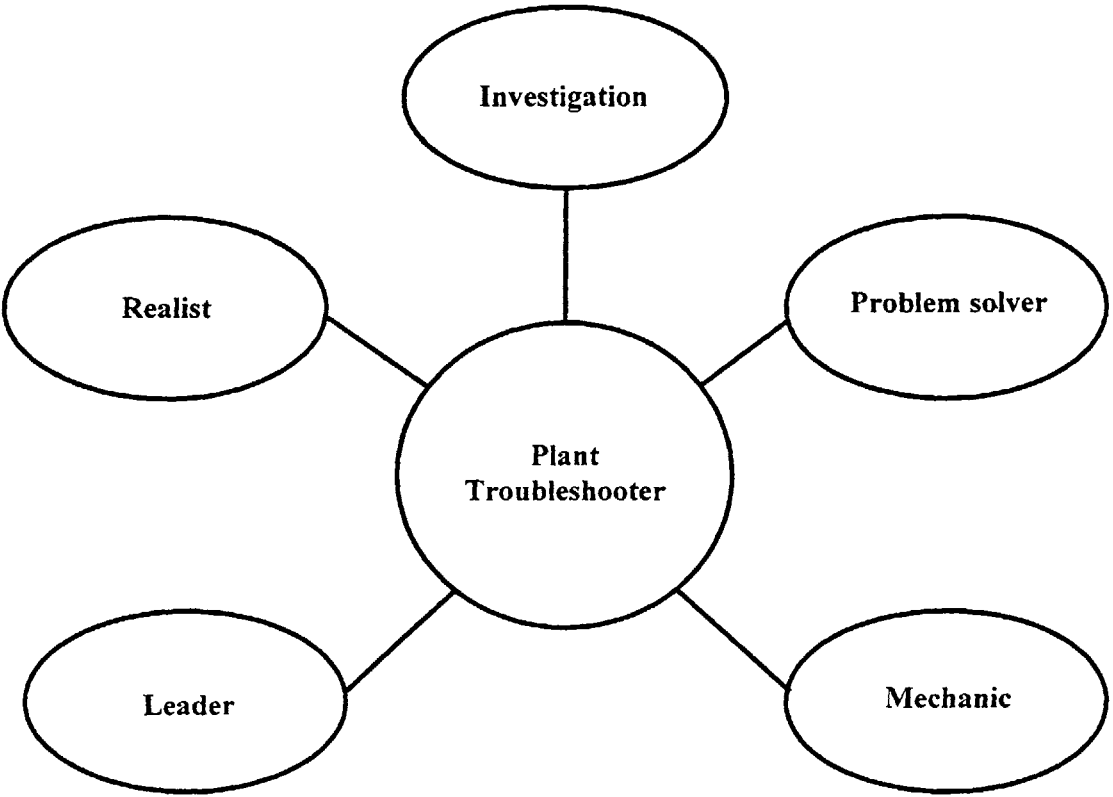


Figure 3.1 Roles of a troubleshooter.

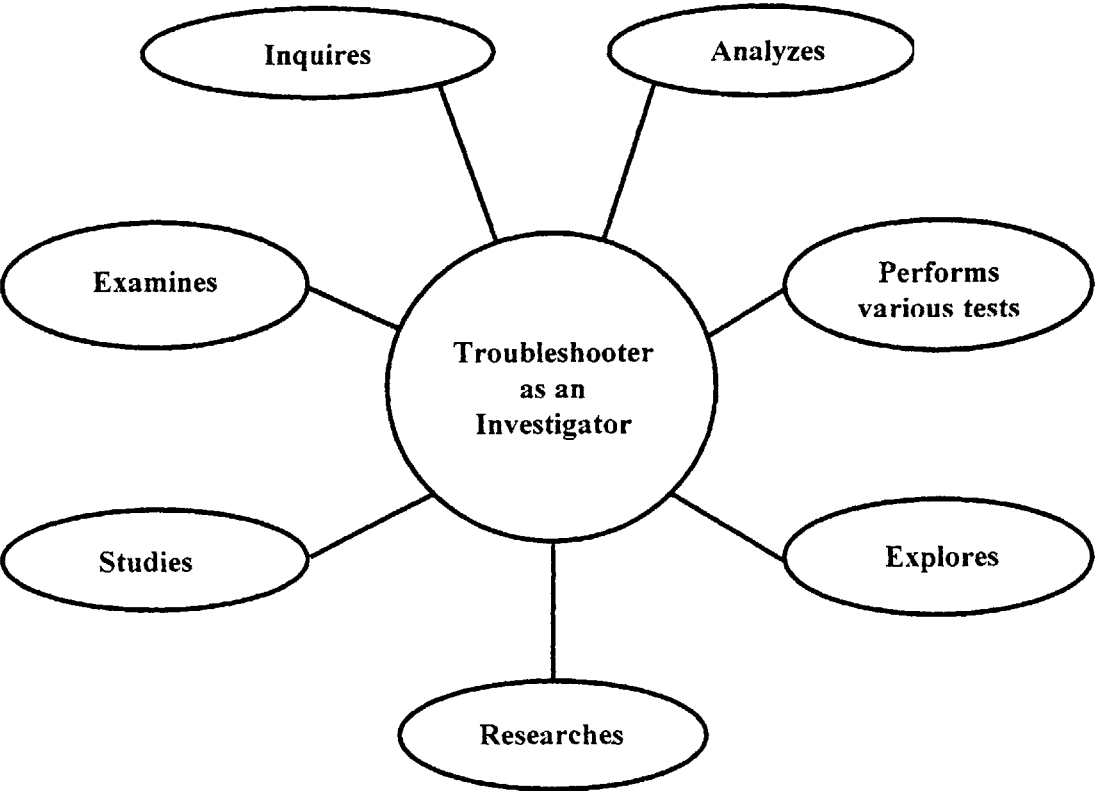


Figure 3.2 Roles of a troubleshooter as an investigator.

simple problem generally requires no outside assistance and no inquiry. The shift operator may be trained (should be trained) and knowledgeable enough to recognize the problem and to correct it on her own (remember, the operator is not only an operator, but also a troubleshooter; also remember, to keep the plant running and make permit is what operating is all about). In this particular instance, the plant operator/troubleshooter would immediately recognize the problem as symptomatic of too low-level flow velocity in the screening channel. She would take the appropriate corrective action, which is to increase the flow velocity (remove screenings more frequently), use fewer screens, or flush regularly with a high pressure hose. If corrective action is not possible, at least she would be aware of the problem, understand the implications, and make whatever adjustments can be made. If all else fails, she would simply call in a more seasoned plant operator—one who could assist her in troubleshooting and solving the problem.

As shown in Figure 3.2, investigating the problem is only one of several roles or tasks the troubleshooter performs in troubleshooting problems. The bar screen example discussed above is a simple problem that does not require the trained troubleshooter to employ all of these tasks to determine the problem and the proper corrective action.

Not all troubleshooting problems, however, are as simple to solve as this bar screen problem. Consider, for example, a primary clarification problem. The problem is poor suspended solids removal. What is the cause?

To determine the cause, the operator may not only need to investigate, but also to analyze, examine, explore, research, and study, and may be required to perform various tests to make the proper determination.

In this particular case—poor suspended solids removal in the primary clarifier—the possible causes include the following:

- hydraulic overload
- sludge buildup in tanks reduces volume and allows solids to scour out of tanks
- strong recycle flows
- industrial waste contributions
- wind currents
- temperature currents

Any one or combination of the preceding possible causes could be the culprit causing poor suspended solids removal. To determine which of these is the actual causal factor(s), the operator must analyze, examine, explore, research (Has the problem occurred previously? If so, what was the cause?), study, and/or perform various tests. If records show a history of similar problems, the troubleshooting operator, for example, knows the first causal factor to check.

In this instance, the knowledgeable operator (the troubleshooter) would check or monitor the flow; check or monitor pumping duration and sludge levels; check or monitor quality and quantity of recycle; sample and test the influent; check and monitor wind direction; and/or check and monitor wastewater temperature.

If a hydraulic overload problem causes the poor suspended solids removal, the operator checks the flow and might use all available tanks, choke back flows to increase detention time, or consider adding chemical coagulants.

If the causal factor is sludge buildup in tanks reducing volume and allowing solids to scour out of tanks, the operator checks pumping duration and sludge levels. The operator monitors sludge levels and establishes a more frequent and consistent pumping schedule.

If the operator suspects strong recycle flows, he or she checks quality and quantity of recycle and recycles at low flow periods or re-routes recycle flows to an alternate process.

If industrial waste contributions are suspected, the operator samples the influent. During this sampling/testing process, if identification of any industrial contamination is made, the source of the contamination is later identified and restricted.

If the problem is caused by wind currents, the remedial action may be to install wind barriers.

If temperature currents are identified as the cause, the operator would monitor temperature and eliminate storm flow.

From the preceding examples, clearly, troubleshooting is sometimes nothing more than pushing the “ON” button to start an electric motor. At other times, it is a much more difficult undertaking—a process that takes time, patience, experience, and intuition, but mostly skill and common sense. To troubleshoot correctly and effectively, the troubleshooter should follow certain steps:

- (1) Asking knowledgeable questions
- (2) Comparing current and past operating data
- (3) Observing operational procedures
- (4) Identifying additional data requirements
- (5) Checking operational procedures at similar facilities
- (6) Verifying the validity of available data

As the problem solver, the troubleshooter should

- (1) Analyze available data
- (2) Develop reasonable explanations for observed conditions
- (3) Identify possible corrective actions
- (4) Prioritize possible actions
- (5) Implement selected options
- (6) Factor the physical and mechanical limitations of the plant into the corrective actions
- (7) Involve the entire operating staff in development and implementation of corrective actions
- (8) Recognize that physical and financial limitations must be considered when developing corrective actions. The corrective action selected must be financially as well as physically possible, or success is impossible.

3.4 TROUBLESHOOTING PROTOCOL

Seasoned wastewater treatment plant troubleshooters usually develop a standard troubleshooting protocol or step-by-step procedure to assist them in their troubleshooting activities. No single protocol is the same; each troubleshooter proceeds based on intuition and experience. However, the simple 14-step protocol described below has worked well for those of us who have used it (*Note: Recognize that several steps may occur at the same time.*):

- (1) Recognize a problem exists.
- (2) Review all available data.
- (3) Evaluate the current plant operation.
- (4) Decide what additional information is needed.
- (5) Collect the additional data.
- (6) Test the process by making modifications and observing the results.
- (7) Develop an initial opinion as to the cause of the problem and potential solutions.
- (8) Fine tune your opinion.
- (9) Develop alternative actions to be taken.
- (10) Prioritize alternatives (i.e., prioritize based on its chances of success, how much it will cost, etc.).
- (11) Confirm your opinion.

- (12) Implement the alternative actions (this step may be repeated several times).
- (13) Observe the results of the alternative actions implemented (i.e., observe impact on effluent quality; impact on individual unit process performance; changes (trends) in the results of process control tests and calculations; and impact on operational costs).
- (14) During project completion, evaluate other, more permanent long-term solutions to the problem (such as chemical addition, improved preventive maintenance, design changes, etc.). Continue to monitor results. Document the actions taken and the results produced for use in future problems.

We've all heard the statement (usually used as a joke), "When in doubt, read the instructions." Probably the most accessible and reliable source of information can be obtained from the manufacturer's technical manual for equipment. The construction engineering firm that designed and oversaw construction of the plant usually provides unit process technical manuals that are incorporated into Standard Operating Procedures (SOPs) for the plant; these are usually excellent sources of troubleshooting information.

At times, even the most able, gifted troubleshooters may not be able to solve the problem entirely on their own. When this occurs, seeking outside assistance may be necessary. Many sources of assistance are available. For example, assistance may be obtained from the U.S. Environmental Protection Agency (USEPA), Water Environment Federation (WEF), State Department of Health, Department of Environmental Quality, colleges and universities, private consultants, and others.

3.5 TROUBLESHOOTING SAFELY

Troubleshooting any equipment and/or many unit processes without adhering to proper safe work practices does little good (and could be life-threatening). The primary safe work practice employed in troubleshooting is lockout/tagout (often referred to as control of hazardous energy). Before working on any mechanical equipment or chemical system, the troubleshooter must ensure that it is locked out, for self-protection and the safety of co-workers.

Equipment lockout involves the physical opening (disconnection) of that equipment's electrical circuit breaker and the steps taken to prevent the accidental closing (reconnection) of the circuit breaker while the equipment is being worked on.

To ensure that equipment/unit process lockout has occurred, a lockout procedure should be performed by the troubleshooter. The following general procedures are offered as a safe, logical lockout/tagout sequence to follow.

Before the troubleshooter starts to work, he or she must do the following:

- (1) Notify operations and maintenance supervisors.
- (2) Place the main power switch, valve, or operating lever in the *off, closed, or safe* position.
- (3) Check or test to make certain that the proper controls have been identified and deactivated.
Note: After locking or tagging out equipment or machinery and before beginning the work, always try to start the equipment or machine. Obviously, if it starts, it is not properly locked out.
- (4) A lock must be used to secure the disconnection whenever possible. If a lock cannot be used on electrical equipment, for example, an electrician or otherwise qualified person should remove the fuses to the circuit (or, better yet, disconnect the line leads feeding the equipment).
- (5) A hold-off tag must be attached to the switch, valve, or lever. This tag must bear the name, department, and telephone number of the employee (or division/department) performing the work.
- (6) When machine controls or auxiliary equipment are powered by separate power sources, such

equipment or controls also must be locked and tagged to prevent any hazard caused by operating the equipment or exposure to live circuits.

- (7) When equipment or processes use hydraulic or pneumatic power, pressure in the lines (or accumulations) must be relieved. If pressure-relief valves have not been provided, the equipment must be cycled until the pressure has been dissipated or the pressure lines have been opened or disconnected.
- (8) When potential or stored energy is a factor as a result of position, spring tension, or counterweighting, the equipment must be placed in the bottom (or closed) position or be blocked to prevent movement.
- (9) When work involves more than one person, additional employees must attach their locks and tags as they report.
- (10) When outside contractors are involved, the equipment is locked out and tagged in accordance with this procedure by the plant project supervisor. Only in emergency cases is equipment to be shut down by other than a plant representative.

3.6 SUMMARY

Whether or not you have a gift for being able to spot, identify, and correct problems easily, careful observation, knowledge of your facility and equipment, and logical analysis go a long way toward troubleshooting problems. As with any skill, though, your abilities improve with practice and experience—these go hand in hand with the operator's job. Troubleshooting is needed at some time or another in every plant operation. So are math concepts, which is the topic of Chapter 4.

3.7 CHAPTER REVIEW QUESTIONS

3-1 Define troubleshooting.

3-2 When would a tag be the preferred method of controlling hazardous energy?

3-3 Explain what is meant by "The troubleshooting process seldom produces a single right answer."

3-4 What is the primary goal of any troubleshooting effort?

3-5 What is the purpose of a troubleshooting protocol?

Math Concepts

4.1 INTRODUCTION

ONE of the major tools in the wastewater operator's tool bag is mathematics. Whether the task is daily computations to be made with the results transferred to the Plant's Daily Operating Log, standard process control problems, or math questions that are a significant part of licensure exams, the wastewater operator must be well-versed in basic and applied mathematical operations.

In Volumes 1 and 2 of the handbook, we provided a lengthy review of math basics. We also provided example problems involving the kind of computations normally made in process operations. In Volume 3, we provide a brief review of conversion factors, then move onto common wastewater calculations—again with example problems to work. These examples are the kind of problems operators may be required to make during plant operations, and these same kind of computations are generally included in licensure examinations.

In addition to the math problems presented in this chapter, we provide several process control example calculations and practice problems later in each applicable chapter.

A final point before we begin this chapter: We can say with some accuracy and certainty that without the ability to work basic mathematical problems—i.e., those typical to wastewater treatment—the candidate for licensure will find any attempt to successfully pass licensure exams a much more difficult proposition.

4.2 CONVERSION FACTORS

A *conversion factor* changes known quantities in one unit of measure to an equivalent quantity in another unit of measure.

✓ 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

When making conversions, confusion over whether to multiply or divide is common; on the other hand, the number that relates the two units is usually known and, thus, is not a problem. Understanding the proper methodology—the “mechanics”—to use for various operations requires practice.

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

The simplest of the conversions requires that the measurement be multiplied or divided by a constant value. For instance, if the depth of biosolids on a drying bed is 0.85 feet, multiplying by 12 inches per foot converts the measured depth to inches (10.2 inches). Likewise, if the depth of the

solids blanket in the secondary clarifier is measured as 16 inches, dividing by 12 inches per foot converts the depth measurement to feet (1.33 feet).

Table 4.1 lists many of the conversion factors used in wastewater treatment. Note that Table 4.1 is designed with a unit of measure in the left and right columns and a constant (conversion factor) in the center column.

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

4.2.1 WEIGHT, CONCENTRATION, AND FLOW

Using Table 4.1 to convert from one unit expression to another and vice versa is good practice. However, in making conversions to solve process computations in wastewater treatment, you must be familiar with conversion calculations based upon a relationship between weight, flow or volume, and concentration. The basic relationship is

Weight = Concentration × Flow or Volume × Factor

(4.1)

TABLE 4.1. 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	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

TABLE 4.2. Weight, Volume, and Concentration Calculations.

To Calculate	Formula
Pounds	Conc., mg/L × Tank Vol, MG × 8.34 lb/MG/mg/L
Pounds/Day	Conc., mg/L × Flow, MGD × 8.34 lb/MG/mg/L
Million Gallons/Day	$\frac{\text{Quantity, lb/day}}{(\text{Conc., mg/L} \times 8.34 \text{ lb/mg/L/MG})}$
Milligrams/Liter	$\frac{\text{Quantity, lb}}{(\text{Tank Volume, MG} \times 8.34 \text{ lb/mg/L/MG})}$
Kilograms	Conc., mg/L × Volume, MG × 3.785 lb/MG/mg/L
Kilograms/Day	Conc., mg/L × Flow, MGD × 3.785 lb/MG/mg/L
Pounds/Dry Ton	Conc., mg/kg × 0.002 lb/d.t./mg/kg

Table 4.2 summarizes weight, volume, and concentration calculations. With practice, many of these calculations become second nature to operators; the calculations are important relationships and are used often in wastewater treatment process control calculations, so on-the-job practice is possible.

✓ *Note:* Examples 4.1 through 4.16 provide examples of many of the conversion factors used in wastewater treatment. Use Tables 4.1 and 4.2 to make the conversions indicated. Other conversions are presented in appropriate sections of the handbook.

Example 4.1

Convert cubic feet to gallons.

$$\text{Gallons} = \text{Cubic Feet, ft}^3 \times \text{gal/ft}^3$$

Sample Problem:

How many gallons of sludge can be pumped to a digester that has 3,600 cubic feet of volume available?

$$\text{Gallons} = 3,600 \text{ ft}^3 \times 7.48 \text{ gal/ft}^3 = 26,928 \text{ gal}$$

Example 4.2

Convert gallons to cubic feet.

$$\text{Cubic Feet} = \frac{\text{gal}}{7.48 \text{ gal/ft}^3}$$

Sample Problem:

How many cubic feet of sludge are removed when 18,200 gallons are withdrawn?

$$\text{Cubic Feet} = \frac{18,200 \text{ gal}}{7.48 \text{ gal/ft}^3} = 2,433 \text{ ft}^3$$

Example 4.3

Convert gallons to pounds.

$$\text{Pounds, lb} = \text{Gal} \times 8.34 \text{ lb/gal}$$

Sample Problem:

If 1,650 gallons of solids are removed from the primary settling tank, how many pounds of solids are removed?

$$\text{Pounds} = 1,650 \text{ gal} \times 8.34 \text{ lb/gal} = 13,761 \text{ lb}$$

Example 4.4

Convert pounds to gallons.

$$\text{Gallons} = \frac{\text{lb}}{8.34 \text{ lb/gal}}$$

Sample Problem:

How many gallons of water are required to fill a tank that holds 7,540 pounds of water?

$$\text{Gallons} = \frac{7,540 \text{ lb}}{8.34 \text{ lb/gal}} = 904 \text{ gal}$$

Example 4.5

Convert milligrams/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.

$$\text{Pounds} = \text{Concentration, mg/L} \times \text{Volume, MG} \times 8.34 \text{ lb/mg/L/MG}$$

Sample Problem:

The solids concentration in the aeration tank is 2,580 mg/L. The aeration tank volume is 0.95 MG. How many pounds of solids are in the tank?

$$\text{Pounds} = 2,580 \text{ mg/L} \times 0.95 \text{ MG} \times 8.34 \text{ lb/mg/L/MG} = 20,441.3 \text{ lb}$$

Example 4.6

Convert milligrams per liter to pounds per day.

$$\text{Pounds/Day} = \text{Concentration, mg/L} \times \text{Flow, MGD} \times 8.34 \text{ lb/mg/L/MG}$$

Sample Problem:

How many pounds of solids are discharged per day when the plant effluent flow rate is 4.75 MGD and the effluent solids concentration is 26 mg/L?

$$\text{Pounds/Day} = 26 \text{ mg/L} \times 4.75 \text{ MGD} \times 8.34 \text{ lb/mg/L/MG} = 1,030 \text{ lb/day}$$

Example 4.7

Convert milligrams per liter to kilograms per day.

$$\text{kg/Day} = \text{Concentration, mg/L} \times \text{Volume, MG} \times 3.785 \text{ kg/mg/L/MG}$$

Sample Problem:

The effluent contains 26 mg/L of BOD₅. How many kilograms per day of BOD₅ are discharged when the effluent flow rate is 9.5 MGD?

$$\text{kg/Day} = 26 \text{ mg/L} \times 9.5 \text{ MG} \times 3.785 \text{ kg/mg/L/MG} = 934 \text{ kg/day}$$

Example 4.8

Convert pounds to milligrams per liter.

$$\text{Concentration, mg/L} = \frac{\text{Quantity, lb}}{\text{Volume, MG} \times 8.34 \text{ lb/mg/L/MG}}$$

Sample Problem:

The aeration tank contains 89,990 pounds of solids. The volume of the aeration tank is 4.45 MG. What is the concentration of solids in the aeration tank in mg/L?

$$\text{Concentration, mg/L} = \frac{89,990 \text{ lb}}{4.45 \text{ MG} \times 8.34 \text{ lb/mg/L/MG}} = 2,425 \text{ mg/L}$$

Example 4.9

Convert pounds per day to milligrams per liter.

$$\text{Concentration, mg/L} = \frac{\text{Quantity, lb/day}}{\text{Volume, MGD} \times 8.34 \text{ lb/mg/L/MG}}$$

Sample Problem:

The disinfection process uses 4,820 pounds per day of chlorine to disinfect a flow of 25.2 MGD. What is the concentration of chlorine applied to the effluent?

$$\text{Concentration, mg/L} = \frac{4,820}{25.2 \text{ MGD} \times 8.34 \text{ lb/mg/L/MG}} = 22.9 \text{ mg/L}$$

Example 4.10

Convert pounds to flow in million gallons per day.

$$\text{Flow} = \frac{\text{Quantity, lb/day}}{\text{Concentration, mg/L} \times 8.34 \text{ lb/mg/L/MG}}$$

Sample Problem:

You must remove 9,640 pounds of solids from the activated sludge process per day. The waste activated sludge concentration is 7,699 mg/L. How many million gallons per day of waste activated sludge must be removed?

$$\text{Flow} = \frac{9,640 \text{ lb}}{7,699 \text{ mg/L} \times 8.34 \text{ lb/MG/mg/L}} = 0.15 \text{ MGD}$$

Example 4.11

Convert million gallons per day (MGD) to gallons per minute (gpm).

$$\text{Flow} = \frac{\text{Flow, MGD} \times 1,000,000 \text{ gal/MG}}{1,440 \text{ min/day}}$$

Sample Problem:

The current flow rate is 5.55 MGD. What is the flow rate in gallons per minute?

$$\text{Flow} = \frac{5.55 \text{ MGD} \times 1,000,000 \text{ gal/MG}}{1,440 \text{ min/day}} = 3,854 \text{ gpm}$$

Example 4.12

Convert million gallons per day (MGD) to gallons per day (gpd).

$$\text{Flow} = \text{Flow, MGD} \times 1,000,000 \text{ gal/MG}$$

Sample Problem:

The influent meter reads 28.8 MGD. What is the current flow rate in gallons per day?

$$\text{Flow} = 28.8 \text{ MGD} \times 1,000,000 \text{ gal/MG} = 28,800,000 \text{ gpd}$$

Example 4.13

Convert million gallons per day (MGD) to cubic feet per second (cfs).

$$\text{Flow, cfs} = \text{Flow, MGD} \times 1.55 \text{ cfs/MGD}$$

Sample Problem:

The flow rate entering the grit channel is 2.89 MGD. What is the flow rate in cubic feet per second?

$$\text{Flow} = 2.89 \text{ MGD} \times 1.55 \text{ cfs/MGD} = 4.48 \text{ cfs}$$

Example 4.14

Convert gallons per minute (gpm) to million gallons per day (MGD).

$$\text{Flow, MGD} = \frac{\text{Flow, gpm} \times 1,440 \text{ min/day}}{1,000,000 \text{ gal/MG}}$$

Sample Problem:

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

$$\text{Flow, MGD} = \frac{1,469 \text{ gpm} \times 1,440 \text{ min/day}}{1,000,000 \text{ gal/MG}} = 2.11536 \text{ MGD}$$

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

Example 4.15

Convert gallons per day (gpd) to million gallons per day (MGD).

$$\text{Flow, MGD} = \frac{\text{Flow, gal/day}}{1,000,000 \text{ gal/MG}}$$

Sample Problem:

The totalizing flow meter indicates that 33,444,950 gallons of wastewater have entered the plant in the past 24 hours. What is the flow rate in MGD?

$$\text{Flow} = \frac{33,444,950 \text{ gal/day}}{1,000,000 \text{ gal/MG}} = 33.44495 \text{ MGD}$$

✓ Unless a higher degree of accuracy is required, round off this number to two decimal places (33.44).

Example 4.16

Convert flow in cubic feet per second (cfs) to million gallons per day (MGD).

$$\text{Flow, MGD} = \frac{\text{Flow, cfs}}{1.55 \text{ cfs/MG}}$$

Sample Problem:

The flow in a channel is determined to be 3.89 cubic feet per second (cfs). What is the flow rate in million gallons per day (MGD)?

$$\text{Flow, MGD} = \frac{3.89 \text{ cfs}}{1.55 \text{ cfs/MG}} = 2.5096774 \text{ MGD}$$

- ✓ Unless a higher degree of accuracy is required, round off this number to two decimal places (2.51 MGD).

4.2.2 TEMPERATURE CONVERSIONS

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

$$^{\circ}\text{C} = 5/9 (^{\circ}\text{F} - 32) \tag{4.2}$$

$$^{\circ}\text{F} = 9/5 (^{\circ}\text{C}) + 32 \tag{4.3}$$

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

- ✓ Probably the easiest way to recall these important formulas is to remember three basic steps for both Fahrenheit and Celsius conversions:

- (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 the two scales. The freezing point of water is 32° on the Fahrenheit scale and 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?

- ✓ Note, for example, that at the same temperature, higher numbers are associated with the Fahrenheit scale and lower numbers with the Celsius scale. This important relationship 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 4.17

Suppose that you wish to convert 240°F to Celsius. Using the three-step process, we proceed as follows:

- (1) Step 1: add 40°

$$240^{\circ} + 40^{\circ} = 280^{\circ}$$

- (2) Step 2: 280° 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 280. Through reason and observation, obviously, if 280 is multiplied by 9/5, the result would be almost the same as multiplying by 2, which would double 280 rather than make it smaller. If you multiply by 5/9, the result is about the same as multiplying by 1/2, which would cut 280 in half. Because in this problem you wish to move to a smaller number, you should multiply by 5/9:

$$(5/9) (280^{\circ}) = 156.0^{\circ}\text{C}$$

(3) Step 3: Now subtract 40°

$$156.0^{\circ}\text{C} - 40.0^{\circ}\text{C} = 116.0^{\circ}\text{C}$$

Therefore, $240^{\circ}\text{F} = 116.0^{\circ}\text{C}$

Example 4.18

Convert 22°C to Fahrenheit.

(1) Step 1: add 40°

$$22^{\circ} + 40^{\circ} = 62^{\circ}$$

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:

$$(9/5) (62^{\circ}) = 112^{\circ}$$

(3) Step 3: Subtract 40°

$$112^{\circ} - 40^{\circ} = 72^{\circ}$$

Thus, $22^{\circ}\text{C} = 72^{\circ}\text{F}$

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

4.2.3 OTHER COMMON WASTEWATER CALCULATIONS

Many common wastewater calculations are essential to evaluation and control of treatment processes. Although Volume 3 of the handbook assumes that you are familiar with calculations covered in Volumes 1 and 2 of the handbook, for convenience, in this section, we provide many of the typical calculations used in wastewater treatment. We pointed out many of the procedures that follow in Volumes 1 and 2 and present them again in the following sections to refresh your memory, and we add several other common calculations in this volume. Later, as the handbook progresses from unit process to unit process, we provide process control calculations related to the unit process.

4.2.3.1 Population Equivalent (PE) or Unit Loading Factor

When conducting a wastewater characterization study is impossible 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 we know the BOD contribution of a discharger, we can determine the loading placed upon the wastewater treatment system in terms of equivalent number of people. The BOD contribution of a person is normally assumed to be 0.17 lb BOD/day . To determine the population equivalent of a wastewater flow, divide the lb BOD/day content by the lb BOD/day contributed per person (e.g., 0.17 lb BOD/day).

$$\text{P.E., people} = \frac{\text{BOD}_5 \text{ Concentration, lb/day}}{0.17 \text{ lb BOD}_5 / \text{day/person}} \quad (4.4)$$

Example 4.19*Problem:*

A new industry wishes to connect to the city's collection system. The industrial discharge will contain an average BOD concentration of 389 mg/L, and the average daily flow will be 72,000 gallons per day. What is the population equivalent of the industrial discharge?

Solution:

First, convert flow rate to million gallons per day:

$$\text{Flow} = \frac{72,000 \text{ gpd}}{1,000,000 \text{ gal/MG}} = 0.072 \text{ MGD}$$

Next, calculate the population equivalent:

$$\text{P.E., people} = \frac{389 \text{ mg/L} \times 0.072 \text{ MGD} \times 8.34 \text{ lb/mg/L/MG}}{0.17 \text{ lb BOD/person/day}} = 1,374 \text{ people/day}$$

Example 4.20*Problem:*

An industry proposes to discharge 3,455 lb of BOD₅ to the town sewer system. What is the population equivalent of the proposed discharge?

Solution:

$$\text{P.E., people} = \frac{3,455 \text{ lb/day}}{0.17 \text{ lb BOD/person/day}} = 20,324 \text{ people}$$

Example 4.21*Problem:*

A 0.5-MGD wastewater flow has a BOD concentration of 1,600 mg/L BOD. Using an average of 0.17 lb BOD/day/person, what is the population equivalent of this wastewater flow?

Solution:

✓ Don't forget to convert mg/L BOD to lb/day BOD, then divide by 0.17 lb BOD/day/person:

$$\begin{aligned} \text{Population Equivalent} &= \frac{\text{BOD, lb/day}}{\text{lb BOD/day/person}} \\ &= \frac{(1,600 \text{ mg/L})(0.5 \text{ MGD})(8.34 \text{ lb/gal})}{0.17 \text{ lb BOD/day/person}} \\ &= 39,247 \text{ people} \end{aligned}$$

4.2.3.2 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 for liquids and solids, it is water. The specific gravity of water is 1.0 (one). Any substance with a density greater than that of water will have a specific gravity greater than 1.0, and any substance with a density less than that of water will have a specific gravity less than 1.0. Specific gravity can be used to calculate the weight of a gallon of liquid chemical.

$$\text{Chem., lb / gal} = \text{Water, lb / gal} \times \text{Specific Gravity (chem)} \quad (4.5)$$

Example 4.22

Problem:

The label states that the ferric chloride solution has a specific gravity of 1.58. What is the weight of 1 gallon of ferric chloride solution?

Solution:

$$\text{Ferric Chloride} = 8.34 \text{ lb / gal} \times 1.58 = 13.2 \text{ lb / gal}$$

Example 4.23 (Density and Specific Gravity)

Problem:

If we say that the density of gasoline is 43 lb/cu ft, what is the specific gravity of gasoline?

Solution:

The specific gravity of gasoline is the comparison—or ratio—of the density of gasoline to that of water:

$$\text{Specific Gravity} = \frac{\text{Density of Gasoline}}{\text{Density of Water}} = \frac{43 \text{ lb / cu ft (density of gasoline)}}{62.4 \text{ lb / cu ft (density of water)}} = 0.69$$

✓ *Question:* Because the specific gravity of gasoline is 0.69, will it float or sink in water?

Answer: Because gasoline's specific gravity is less than 1.0 (lower than water's specific gravity), it will float in water. If gasoline's specific gravity were greater than water's specific gravity it would sink—remember this important point.

4.2.3.3 Chemical Additions

One of the most important wastewater operator functions is to make various chemical additions to unit processes. In this section, we demonstrate how to calculate required amount of chemical (active ingredient), required amount of chemical, dry chemical feed rate, and liquid chemical feed rate.

4.2.3.3.1 Required Amount of Chemical (Active Ingredient)

(Active Ingredient) Chemical, lb / day

$$= \text{Required Dose, mg / L} \times \text{Flow, MGD} \times 8.34 \text{ lb / mg / L / MG} \quad (4.6)$$

Example 4.24*Problem:*

The laboratory jar test indicates a required dose of 4.1 mg/L of ferric chloride. The flow rate is 5.15 MGD. How many pounds of ferric chloride will be needed each day?

Solution:

$$\begin{aligned} \text{Required (Active Ingredient) Amount, lb / day} &= 4.1 \text{ mg / L} \times 5.15 \text{ MGD} \times 8.34 \text{ lb / mg / L / MG} \\ &= 176.1 \text{ lb / day} \end{aligned}$$

4.2.3.3.2 Required Amount of Chemical

Because industrial strength chemicals are normally less than 100% active ingredient, the amount of chemical must be adjusted to compensate for the inactive components.

$$\text{Required Amount, lb / day} = \frac{\text{Active Ingredient Required, lb / day}}{\% \text{ Active Ingredient}} \quad (4.7)$$

Example 4.25*Problem:*

To achieve the desired phosphorus removal, 180 pounds of ferric chloride must be added to daily flow. The feed solution is 66% ferric chloride. How many pounds of feed solution will be needed?

Solution:

$$\text{Required Amount, lb / day} = \frac{180 \text{ lb / day}}{0.66} = 273 \text{ lb / day}$$

4.2.3.3.3 Dry Chemical Feed Rate

When chemical is to be added in dry (powder, granular, etc.) form, the chemical feed rate can be expressed in units such as pounds per hour or grams per minute.

$$\text{Feed Rate, lb / hr} = \frac{\text{Required Amount, lb / day}}{24 \text{ hour / day}} \quad (4.8)$$

$$\text{Feed Rate, g / min} = \frac{\text{Required Amount, lb / day} \times 454 \text{ g / lb}}{1,440 \text{ min / day}} \quad (4.9)$$

Example 4.26*Problem:*

The plant must feed 255 pounds per day of high test hypochlorite (HTH) powder chlorine to reduce odors. What is the required feed rate in (1) pounds per hour and (2) grams per minute.

Solution:

$$(1) \text{ Feed Rate, lb/hr} = \frac{255 \text{ lb/day}}{24 \text{ hr/day}} = 10.6 \text{ lb/hr}$$

$$(2) \text{ Feed Rate, g/min} = \frac{255 \text{ lb/day} \times 454 \text{ g/lb}}{1,440 \text{ min/day}} = 80 \text{ g/min}$$

4.2.3.3.4 Liquid Chemical Feed Rate

If you feed chemical in its liquid form, the required amount (pounds, grams, etc.) of process chemical must be converted to an equivalent volume (gallons, milliliters, etc.). This volume is then converted to the measurement system of the solution feeder (gallons/day, milliliters/minute, etc.).

✓ You may find the weight of a gallon of the process chemical printed on the container label or the material safety data sheet (MSDS), or you may determine weight per gallon if the specific gravity of the chemical is supplied, using the procedure supplied earlier (see Section 4.2.3.2).

$$\text{Feed Rate, gpd} = \frac{\text{Required Amount of Chemical, lb/day}}{\text{Weight per Gallon, lb/gal}} \quad (4.10)$$

$$\text{Feed Rate, gpm} = \frac{\text{Required Amount of Chemical, lb/day}}{\text{Weight per Gallon, lb/gal} \times 1,440 \text{ min/day}} \quad (4.11)$$

$$\text{Feed Rate, ml/min} = \frac{\text{Req. Amount, lb/day} \times 3,785 \text{ ml/gal}}{\text{Wt./Gal, lb/gal} \times 1,440 \text{ min/day}} \quad (4.12)$$

Example 4.27*Problem:*

To achieve phosphorus removal, the plant must add 812 lb of ferric chloride feed solution each day. The ferric chloride solution weighs 11.1 lb/gal. What is the required feed rate (1) in gallons per day; (2) gallons per minute; and (3) milliliters per minute?

Solution:

$$(1) \text{ Feed Rate, gpd} = \frac{812 \text{ lb/day}}{11.1 \text{ lb/gal}} = 73 \text{ gpd}$$

$$(2) \text{ Feed Rate, gpm} = \frac{812 \text{ lb/day}}{11.1 \text{ lb/gal} \times 1,440 \text{ min/day}} = 0.05 \text{ gpm}$$

$$(3) \text{ Feed Rate, ml/min} = \frac{812 \text{ lb/day} \times 3,785 \text{ ml/gal}}{11.1 \text{ lb/gal} \times 1,440 \text{ min/day}} = 192 \text{ ml/min}$$

4.2.3.4 Horsepower and Energy Costs

In wastewater treatment, *horsepower* is a common expression for power. One horsepower is equal to 33,000 foot pounds of work per minute. This value is determined, for example, for selecting a pump or combination of pumps to ensure an adequate pumping capacity (a major use of calculating horsepower in wastewater treatment). Pumping capacity depends upon the flow rate desired and the feet of head against which the pump must pump (a.k.a., effective height).

Calculations of horsepower are made in conjunction with many treatment plant operations. The basic concept from which the horsepower calculation is derived is the concept of work.

Work involves the operation of a force (lb) over a specific distance (ft). The *amount of work* accomplished is measured in foot-pounds:

$$(\text{ft})(\text{lb}) = \text{ft-lb} \quad (4.13)$$

The *rate of doing work (power)* involves a time factor. Originally, the rate of doing work or power compared the power of a horse to that of the steam engine. The rate at which a horse could work was determined to be about 550 ft-lb/sec (or expressed as 33,000 ft-lb/min). This rate has become the definition of the standard unit called horsepower [see Equation (4.14)].

4.2.3.4.1 Horsepower

$$\text{Horsepower, hp} = \frac{\text{Power, ft-lb/min}}{33,000 \text{ ft-lb/min/HP}} \quad (4.14)$$

As we stated earlier, in wastewater treatment, the major use of horsepower calculation is in pumping operations. When used for this purpose, the horsepower calculation can be modified as shown in Section 4.2.3.4.1.1.

4.2.3.4.1.1 WATER HORSEPOWER

The amount of power required to move a given volume of water a specified total head is known as *water horsepower (Whp)*.

$$\text{Whp} = \frac{\text{Pump Rate, gpm} \times \text{Total Head, ft} \times 8.34 \text{ lb/gal}}{33,000 \text{ ft-lb/min/HP}} \quad (4.15)$$

Example 4.28

Problem:

A pump must deliver 1,210 gpm to total head of 130 feet. What is the required water horsepower?

Solution:

$$\text{Whp} = \frac{1,210 \text{ gpm} \times 130 \text{ ft} \times 8.34 \text{ lb/gal}}{33,000 \text{ ft-lb/min/HP}} = 40 \text{ Whp}$$

4.2.3.4.1.2 BRAKE HORSEPOWER

Brake horsepower (bhp) refers to the horsepower supplied to the pump from the motor. As power moves through the pump, additional horsepower is lost from slippage and friction of the shaft and

other factors; thus, pump efficiencies range from about 50% to 85% and pump efficiency must be taken into account.

$$\text{Bhp} = \frac{\text{Whp}}{\text{Pump \% Efficiency}} \quad (4.16)$$

Example 4.29

Problem:

Under the specified conditions, the pump efficiency is 73%. If the required water horsepower is 40 hp, what is the required brake horsepower?

Solution:

$$\text{Bhp} = \frac{40 \text{ Whp}}{0.73} = 55 \text{ Bhp}$$

4.2.3.4.1.3 MOTOR HORSEPOWER

Motor horsepower is the horsepower the motor must generate to produce the desired brake and water horsepower.

$$\text{Mhp} = \frac{\text{Brake Horsepower, Bhp}}{\text{Motor \% Efficiency}} \quad (4.17)$$

Problem:

The motor is 93% efficient. What is the required motor horsepower when the required brake horsepower is 49.0 Bhp?

Solution:

$$\text{Mhp} = \frac{49 \text{ Bhp}}{0.93} = 53 \text{ Mhp}$$

4.2.3.5 Electrical Power

On occasion, wastewater operators (especially senior operators) must make electrical power calculations—especially regarding electrical energy required/consumed during a period of time. To accomplish this, horsepower is converted to electrical energy (kilowatts), then multiplied by the hours of operation to obtain kilowatt hours.

$$\text{Kilowatt-Hours} = \text{Hp} \times 0.746 \text{ kw/hp} \times \text{Operating Time, hr} \quad (4.18)$$

Example 4.30

Problem:

A 60 horsepower motor operates at full load 12 hours per day, seven days a week. How many kilowatts of energy does it consume per day?

Solution:

$$\text{Kilowatt-Hours/day} = 60 \text{ hp} \times 0.746 \text{ kw/hp} \times 12 \text{ hr/day} = 537 \text{ kw-hr/day}$$

Given the cost per kilowatt hour, the operator (or anyone else) may calculate the cost of power for any given period of operation.

$$\text{Cost} = \text{Power Required/day} \times \text{kw-hr/day} \times \text{Days/Period} \times \text{Cost/kw-hr} \quad (4.19)$$

Example 4.31

Problem:

A 60-horsepower motor requires 458 kw-hr/day. The pump is in operation every day. The current cost of electricity is \$0.0328 per kilowatt hour. What is the yearly electrical cost for this pump?

Solution:

$$\text{Cost, \$} = 458 \text{ kw-hr/day} \times 365 \text{ days/year} \times \$0.0328/\text{kw-hr} = \$5,483.18$$

4.3 SUMMARY

Information, knowledge, and skill build on each other and on experience as well. For licensure, the advanced level exams test increasingly complicated and specialized computations. Your ability to advance in the profession depends in part on your ability with numbers and with your ability to apply your knowledge to the plant's system processes—from influent to effluent. The first system—the one that carries the influent to the plant—is the topic of Chapter 5.

4.4 CHAPTER REVIEW QUESTIONS

- 4-1 The depth of water in the grit channel is 40 inches. What is the depth in feet?
- 4-2 The operator withdraws 5,450 gallons of solids from the digester. How many pounds of solids have been removed?
- 4-3 Sludge added to the digester causes a 1,990 cubic foot change in the volume of sludge in the digester. How many gallons of sludge have been added?
- 4-4 The plant effluent contains 38 mg/L solids. The effluent flow rate is 3.89 MGD. How many pounds per day of solids are discharged?

- 4-5 The plant effluent contains 28 mg/L of BOD₅. The effluent flow rate is 7.45 MGD. How many kilograms per day of BOD₅ are being discharged?
- 4-6 The operator wishes to remove 3,840 pounds per day of solids from the activated sludge process. The waste activated sludge concentration is 3,624 mg/L. What is the required flow rate in million gallons per day?
- 4-7 The plant influent includes an industrial flow containing 255 mg/L BOD. The industrial flow is 0.80 MGD. What is the population equivalent for the industrial contribution in people per day?
- 4-8 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 110 gal/d and that the typical average per capita contributions for domestic wastewater with ground kitchen wastes are BOD 0.21 lb/capita/d; SS is 0.28 lb/capita/d.
- 4-9 The label of hypochlorite solution states that the specific gravity of the solution is 1.1540. What is the weight of a gallon of the hypochlorite solution?
- 4-10 A gallon of solution is weighed. After the weight of the container is subtracted, we determine that the weight of the solution is 8.5 lb. What is the density of the solution?
- 4-11 The density of a liquid is given at 45 lb/cu ft. What is the specific gravity of the liquid?
- 4-12 The specific gravity of a liquid is 1.4. What is the density of that liquid? (The density of water is 8.34 lb/gal.)
- 4-13 A pump must pump 1,800 gpm against a total head of 30 ft. What hp is required for this work?

- 4-14 If 25 hp is supplied to a motor (mhp), what is bhp and whp if the motor is 80% efficient and the pump is 75% efficient?
- 4-15 A total of 40 hp is required for a particular pumping application. If the pump efficiency is 80%, what is the brake hp required?

Wastewater Collection System

5.1 INTRODUCTION

IN Volume 1 of the handbook, we describe a typical wastewater collection system designed to collect and carry wastewater to the treatment plant. We point out that the complexity of the system depends on the size of the community and the type of system selected. We also describe the methods of collection and conveyance of wastewater, which include gravity systems, force main systems, vacuum systems, and combinations of all three types of systems. For a more in-depth discussion of the various components making up a standard wastewater collection system and their specific function, we refer you to Volume 1 of the handbook series.

Our purpose in this chapter is to discuss the wastewater collection system from the point of view of the responsible person in charge of the treatment plant. During normal shift conditions, this important position is occupied by a licensed operator, and during normal operating hours, it is typically occupied by the senior person present. Whoever is present, in charge, responsible, or senior has the responsibility to monitor the influent entering the treatment plant to prevent system upset.

Anyone who has worked in wastewater treatment plant operations for any appreciable length of time understands that preventing system upset is easier said than accomplished. The seasoned operator understands that the type, age, and condition of the collection system—as well as the contributors to the system—have a significant impact on the ability of the treatment plant to perform as designed. This chapter reviews the various ways in which the collection system can impact plant performance.

5.2 POTENTIAL TREATMENT PROBLEMS

Wastewater collection systems inherently cause treatment plant operations problems for operators. Sometimes, these problems are minor; sometimes, they don't amount to much at all; and at other times, they have a big impact on plant operations. Let's take a look at some potential plant operations problems created by the wastewater collection system.

Combined sewers carry both wastewater and stormwater runoff. Although new combined sewer systems are no longer being built in the United States, they are an extensive part of the existing infrastructure in many locations, particularly in older urban areas. Wastewater operations that receive influent from older urban areas are subject to problems inherent with combined sewers. The kinds of problems commonly encountered include the following:

- hydraulic overloading
- surge flows
- excessive sand, gravel, and other inorganic solids
- organic overloading
- toxicity

Potential problems are also created in wastewater collections systems whenever *industrial contributors* are connected to the system. The kinds of problems commonly encountered include the following:

- hydraulic overloading
- surge flows
- organic overloading
- organic underloading
- wide variations in pH and/or temperature
- toxicity
- wide variations in color and odor

Contributions to the collection system from *domestic contributors* can also cause potential treatment problems. The kinds of problems commonly encountered include the following:

- hydraulic overloading (roof drains, illegal connections)
- organic overloading
- toxicity

Septic tank cleaners are another source of potential problems for the wastewater operator. The kinds of problems commonly encountered include the following:

- organic overloading
- high sulfur/sulfide concentrations
- low pH
- toxicity
- surge flows

Pumping stations commonly cause potential influent problems in wastewater treatment operations. The kinds of problems commonly encountered include the following:

- surge flows
- hydraulic overloads
- septic wastes
- odors
- organic overloading

Probably the number one source of potential problems created in/by wastewater collection systems is *old/decaying systems*. The kinds of problems commonly encountered include the following:

- hydraulic overloading
- high sand, gravel, and inorganic solids content

5.3 INVESTIGATING COLLECTION SYSTEM PROBLEMS

Our experience indicates that many licensed wastewater operators do not have a clue about solving collection system problems, in many instances, because the treatment facility is large enough to employ full-time licensed operators—and a separate collections or interceptor division. Thus, in this type of situation, two areas of specialty develop: wastewater operators and collection system operators.

This can cause other problems, too. Along with not necessarily having the experience and knowledge to troubleshoot a wastewater collection system, the operator is at a decided disadvantage for a number of reasons. In the first place, by its design and placement (remember, many collection

systems are buried underground), the collection system is a difficult place to find and correct conditions that may be causing major difficulties like process upset within the treatment plant. Secondly, keep in mind that, in addition to the hundreds or even thousands of legal discharges to the system, in many other remote locations, less reputable people can discharge almost anything into the collection system (this is a common and damaging practice, of course). Add to this the fact that anything discharged into the system at a remote location becomes more difficult to detect as it is diluted by mixing with other contributions as it flows to the plant, and identification of the source of a problem becomes even more difficult.

To combat these very real problems, many large sanitation districts incorporate the use of an Industrial Waste Division, which has the sole responsibility of continuously monitoring discharges of industrial waste into the collection system and/or to help industry implement pretreatment programs. When the district determines that a discharger is dumping something that is not allowed or is dumping in quantities beyond a certain set limit, the culprits are usually cited and fined. Many industry wastewater bills are based on (or tabulated from) not only the amount of discharge, but also on what they are discharging to the collection system and, thus, to the treatment plant.

One thing is certain, without some type of systematic plan that is clearly understood by the plant operating staff, the potential for successfully identifying and correcting a collection system problem is, at best, a hit-or-miss proposition.

To what type of plan are we referring?

At a minimum, for example, the plan should include the following (*Note: Keep in mind that many of the elements in the plan listed below are beyond the purview of the plant operator to implement and to enforce; they must be generated by plant or district management officials.*):

- (1) Implement a sewer use ordinance to control the type and quantity of wastes discharged to the system.
- (2) Where required or appropriate, implement a pretreatment program to control industrial waste discharges.
- (3) Accomplish routine monitoring, including visual observations, meter readings, and sampling and testing of the plant influent to establish “normal” influent characteristics.
- (4) Identify industrial contributors to the system, and characterize their waste contributions.
- (5) When influent-related problems occur, increase the frequency of monitoring to establish the time(s) when the unusual waste is observed and the duration of each occurrence.
- (6) Keep data on each industrial contributor to enable identification of possible sources of unusual waste.
- (7) Isolate the source of a problem by sampling at selected points in the collection system.
- (8) Sample individual contributors to identify the specific source of a problem.
- (9) Locate illegal connections/breaks by smoke testing any time stormwater or infiltration/inflow are suspected.

5.4 TYPICAL WASTEWATER COLLECTION SYSTEM PROBLEMS

Wastewater operators need to be familiar with the indicators or observations typical of collection system and/or pumping (lift) station problems/failures. Generally, familiarity with these typical problems is gained through experience. Along with identifying collection system and/or pumping station problems, the operator must also know the proper corrective actions to take to correct the problem. Again, this ability comes with training and experience. In Table 5.1, we list some of the typical indicators/observations of collection system and/or pumping station problems, the probable cause, and the corrective action.

TABLE 5.1. Collection System/Pump Station Problems.

Indicators	Probable Cause	Solutions
Black odorous, septic wastewater	Improper operation of lift station	Identify operations problem and correct
	Lift station equipment malfunction	Repair/replace malfunctioning equipment
	Flat grades in collection system	Implement flushing program
Intermittent or surging flows	Improper adjustment of wet well sensors	Adjust sensors
	Peak flows exceed design capacity	Install surge tank
	Illegal connections to system	Perform smoke test. Eliminate illegal connections
Intermittent/surging flows during storm events	Water entering through manhole covers when streets are flooded	Seal manholes/repair cracks, etc.
	Broken lines	Repair broken lines
Pump not running	Defective controller	Repair/replace defective parts
	Defective motor	Replace motor
Pump not running/circuit breaker will not reset	Clogged pump	Open system valves
	Closed valve in discharge lines	Open system valves
Pump is running but with reduced discharge	Pump is air bound	Bleed air from pump
	Pump impeller is clogged	Remove obstruction
	Wearing rings are worn	Replace worn wearing rings
Clogged pump or suction line	Grease accumulation	Unclog line/pump and increase cleaning frequency

5.5 SUMMARY

The concept of “unit processes” is somewhat misleading. “Unit” implies that individual processes could be self-contained. But the influent moving through the individual processes carries its own characteristics with it, and those characteristics affect every treatment process. Knowing what to do depends, in part, on determining both the characteristics of the wastewater and the quantity of wastewater to be treated. That measurement (measuring flow) is the topic of Chapter 6.

5.6 CHAPTER REVIEW QUESTION

- 5-1 Explain in one paragraph why an industrial waste or pretreatment plan is important to maintaining optimal operating conditions in a wastewater treatment plant.

Measuring Flow

6.1 INTRODUCTION

IF we wanted to use an approximate (but very simple) method to determine open channel discharge, we would measure the velocity of a floating object moving in a straight uniform reach of the channel. If we know the cross-sectional geometry of the channel and have determined the depth of flow, we can compute the flow area. From the relationship $Q = A \times V$, we can estimate the discharge Q . The average velocity of flow in a reach is approximated by timing the passage of the floating object along a measured length of channel.

While a useful way to obtain a ballpark estimate for the flow rate as part of a preliminary field study, this technique is not suitable for routine measurements required in wastewater treatment plant operations.

Any seasoned wastewater operator knows that *flow measurement* is an essential part of wastewater treatment. Unit processes are designed for specific flow levels, and process adjustments (e.g., adjustments made on pumping rates, chlorination rates, aeration rates, etc.) are based upon current levels of flow and, in many cases, are controlled by flow rate adjustments. Accurate flow measurement is a key element in any attempt to identify, correct, and prevent operational problems and is, therefore, important to operators tasked with operating the plant at optimal efficiency.

In this chapter, we briefly discuss methods of measuring flow, many of the calculations used to determine flow, and various flow measurement problems. The operator at the advanced level should be familiar with all of these.

6.2 METHODS OF MEASURING FLOW

We already mentioned one method of measuring flow, using the $Q = AV$ formula method. When using this method, we measure the velocity of the flow and the channel width/water depth first, then use the formula to find flow rate. This procedure can be used in any location where you can measure the water cross-sectional area and velocity.

Another simple method used to measure flow is known as the *fill and draw method*. Accomplished by measuring the amount of time required to transfer/pump a given volume of water from one point to another, use the fill and draw method at any location where changes in liquid volume (or depth) can be measured.

From the description of the two rudimentary measurement techniques just described, we see that, even in those cases where no flow measurement is provided, some method can be found to measure—or at least estimate—flow rates. However, the majority of wastewater operators do not measure flow by these two methods. Instead, modern treatment plants and practices normally include the use of other methods—the bucket and stopwatch techniques have been replaced with other methods, up to and including complex electronic systems.

Probably the most widely used device to measure open channel flow is the *weir*. A weir is simply a dam, rectangular obstruction, or v-notch crest over which water flows, placed in the channel so that the water backs up behind it, then flows over it [see Figures 6.1(a) and 6.1(b)]. For open channel measurements, weirs can be used for rectangular and circular clarifiers (see Figure 6.2). The crest or edge allows the water to spring clear of the weir plate and to fall freely into the air. In measuring, measure the head a specified distance behind the weir (the constriction) in the channel, then use the head to calculate the flow or to determine the flow using a table or graph. A disadvantage of a weir is the relatively dead water space that occurs just upstream of the weir, where organic solids may settle out, causing odors.

Another device commonly used to measure flow in open channels is a *flume*. Figure 6.3 shows a Parshall flume—the most commonly used measuring device. In measuring flow, measure the head a specified distance behind the narrow point (throat of the flume), then use the head measurement to calculate the flow or to determine the flow using a table or graph. The advantage of using the Parshall flume is that its design and smooth construction does not offer any place where wastewater solids may collect behind the metering device.

The *Venturi meter* (a device in which the flow must pass through a section with a smaller diameter) is another device found in pipe systems in wastewater collection systems and treatment plants. The change in pressure that occurs while water passes through the smaller diameter section is related to the rate of flow through the pipe.

The *magnetic meter* is another device commonly used to measure flow of the wastestream through pipes. In operation, wastewater passes between the poles of a magnet. The flow creates an electrical current, which the meter measures. The amount of current produced is related to the amount of flow.

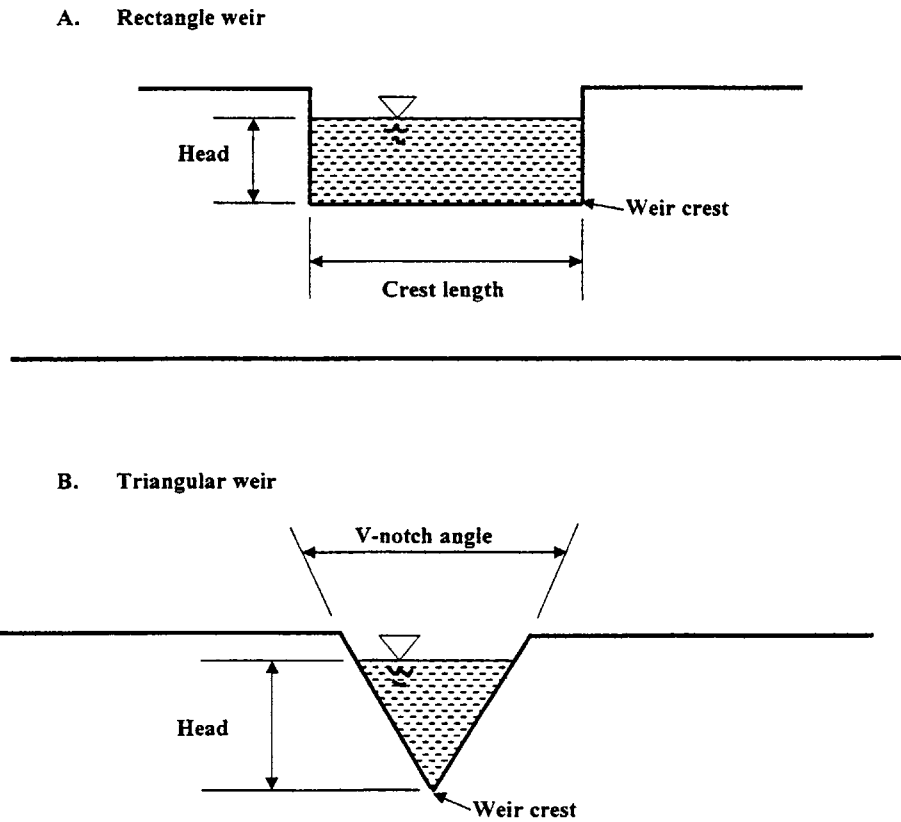


Figure 6.1 (a) Rectangular weir, (b) triangular v-notch weir.

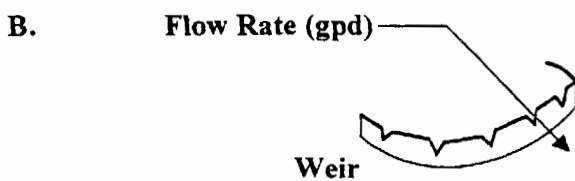
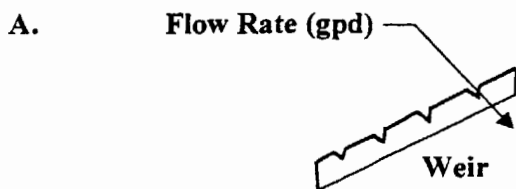


Figure 6.2 (a) Weir overflow for rectangle clarifier, (b) weir overflow for circular clarifier.

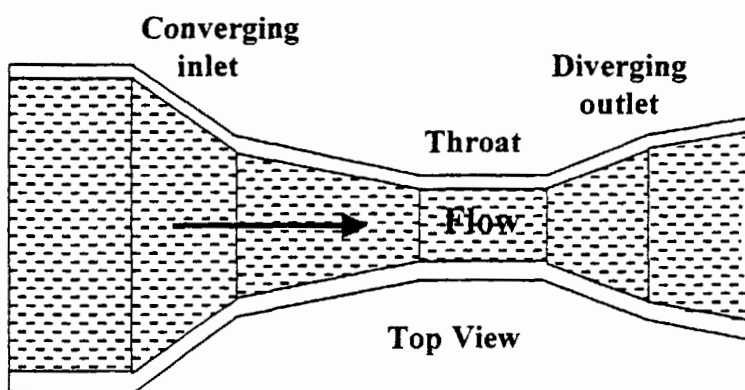


Figure 6.3 Top view of a Parshall flume.

6.3 FLOW MEASUREMENT CALCULATIONS

While true that flow can be measured electronically or by using various tables or charts, wastewater operators should be skilled in making flow computations. Let us point out that even with the use of a chart or graph, appropriate conversions and calculations must be made.

In this section, we discuss the calculations required to determine flow rates using the fill and draw, v-notch weir, and the Parshall flume. We also provide a few simple flow calculation example problems.

6.3.1 CALCULATION METHOD USED FOR FILL AND DRAW TECHNIQUE

The mathematical procedure for determining flow in gallons/minute is

$$\text{Flow, gpm} = \frac{\text{Tank Volume, ft}^3 \times 7.48 \text{ gal/ft}^3}{\text{Time Required, min}} \quad (6.1)$$

6.3.2 CALCULATION METHOD USED FOR VELOCITY/AREA TECHNIQUE

For determining flow in cfs or gpm using the velocity/area technique, the following equations can be used:

$$\text{Flow, cfs} = \text{Channel Width, ft} \times \text{Water Depth, ft} \times \text{Vel., fps} \quad (6.2)$$

$$\text{Flow, gpm} = \frac{\text{Flow, cfs} \times 1,000,000}{1.55 \text{ cfs/ MGD} \times 1,440 \text{ min/day}} \quad (6.3)$$

6.3.3 CALCULATION METHOD USED FOR V-NOTCH WEIRS

Use a chart/graph and make appropriate conversions, then use the following equation:

$$\text{Flow Rate } (Q), \text{ cfs} = K \times H^{2.5} \quad (6.4)$$

where

H = Head in feet

K = Constant related to the weir angle

For 22.5° Weirs	$K = 0.497$
For 30°	$K = 0.676$
For 45°	$K = 1.035$
For 60°	$K = 1.443$
For 90°	$K = 2.500$
For 120°	$K = 4.330$

6.3.4 CALCULATION METHOD FOR PARSHALL FLUME

As with the v-notch weir, calculating flow through a Parshall flume requires the use of charts/graphs and appropriate conversions. Then, the following equations may be used.

(1) For flume throats <12" wide

$$\text{Flow } (Q), \text{ cfs} = K \times H^n \quad (6.5)$$

where

K = Constant related to the throat width

3"	0.9920
6"	2.060
9"	3.070

n = exponent constant related to throat width

3"	1.547
6"	1.580
9"	1.530

(2) For flume throats 1–8 ft wide

$$\text{Flow } (Q), \text{ cfs} = 4 \times W \times H^{1.522L} \quad (6.6)$$

where

W = Throat width

$$L = W^{0.026}$$

6.3.5 TYPICAL FLOW MEASUREMENT PRACTICE CALCULATIONS

The answers to the examples provided in this section are derived using equation standard $Q = AV$, including conversions where appropriate.

Example 6.1

Problem:

A grit channel 3 ft wide has water flowing to a depth of 16 inches. If the velocity through the channel is 0.8 fps, what is the cfs flow rate through the channel?

Solution:

$$(3 \text{ ft}) (1.3 \text{ ft}) (0.8 \text{ fps}) = 3.2 \text{ cfs}$$

Example 6.2

Problem:

A grit channel 3 ft wide has water flowing at a velocity of 1.3 fps. If the depth of water is 15 inches, what is the gpd flow rate through the channel?

Solution:

$$(3 \text{ ft}) (1.25 \text{ ft}) (1.3 \text{ fps}) (7.48 \text{ gal / cu ft}) (60 \text{ sec / min}) (1,440 \text{ min / day}) = 3,150,576 \text{ gpd}$$

Example 6.3*Problem:*

A grit channel 35 inches wide has water flowing to a depth of 9 inches. If the velocity of the water is 0.80 fps, what is the cfs flow in the channel?

Solution:

$$(2.9 \text{ ft}) (0.75 \text{ ft}) (0.80 \text{ fps}) = 1.74 \text{ cfs}$$

6.4 FLOW MEASUREMENT PROBLEMS

Operators are often responsible for troubleshooting flow measurement problems. Our experience indicates that flow measurement problems (indicative of problems with the flow measuring method or device used) typically fall into two categories: (1) a sharp drop or increase in recorded flow or (2) inconsistent or inaccurate flow measurement using a weir.

A number of causes could be responsible for a sharp drop or increase in recorded flow. For example, the problem could be caused by an obstruction to the float (if used). This problem is corrected by removing the obstruction and/or keeping the float clean and free of grease. Another type of flow measuring device may malfunction because of improper air flow or because the bubbler tube is damaged. In correcting this problem, the bubbler tube should be cleaned, the air flow adjusted, and grease removed from the assembly. In another type of measuring device, the problem might be indicative of grease buildup on magnetic meter coils. Solving this problem is a simple matter of removing grease buildup. A weir plate clogged with debris could also cause a sharp drop in recorded flow. To correct this problem, remove the debris, and increase weir cleaning frequency.

Inconsistent or frequent inaccurate flow measurements using a weir usually indicate that the weir is not level and needs to be adjusted.

6.5 SUMMARY

Before any treatment can be applied to wastewater influent, the operator must know how much wastewater he or she is treating. Flow measurement is fundamental to treatment. Only after this determination can treatment steps proceed. Initial treatment processing (preliminary treatment) is the subject of Chapter 7.

6.6 CHAPTER REVIEW QUESTIONS

6-1 Why are flow measurements important?

6-2 A grit channel 2.5 ft wide has water flowing to a depth of 18 inches. If the velocity of the water is 0.8 fps, what is the cfs flow in the channel?

- 6-3 A grit channel is 2.5 ft wide with water flowing to a depth of 15 inches. If the flow velocity through the channel is 1.6 ft/sec, what is the gpm flow through the channel?
- 6-4 A grit channel 3 ft wide has water flowing to a depth of 10 inches. If the velocity through the channel is 1 fps, what is the cfs flow rate through the channel?
- 6-5 If you had the choice of installing a weir system or a Parshall flume flow measurement device in your plant, which one would you choose or prefer? Why?

Preliminary Treatment

7.1 INTRODUCTION

THE initial stage of treatment in the wastewater treatment process (following collection and influent pumping) is *preliminary treatment*. Process selection normally is based upon the expected characteristics of the influent flow. Raw influent entering the treatment plant may contain many kinds of materials (trash), and preliminary treatment protects downstream plant equipment by removing these materials, which could cause clogs, jams, or excessive wear in plant machinery. In addition, the removal of various materials at the beginning of the treatment process saves valuable space within the treatment plant.

Figure 7.1 shows two of the processes used in preliminary treatment: screening and grit removal. However, preliminary treatment may also include other processes, each designed to remove a specific type of material that presents a potential problem for downstream unit treatment processes. These processes include shredding, flow measurement, preaeration, chemical addition, and flow equalization. Except in extreme cases, plant design will not include all of the items. Selection of preliminary processes depends on the water source, quality, and local conditions. In this chapter, we describe and discuss each of these processes and their importance in wastewater treatment.

7.2 SCREENING

Screening removes 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 ft³ of screenings for each million gallons of influent received.

7.2.1 OVERVIEW OF THE SCREENING PROCESS

Wastewater flows through a screen bar rack (or in some cases a fine screen) to remove large floating objects that could clog pumps or pipes.

- Coarse screen or bar racks are usually made of parallel iron or steel bars spaced 2 to 4 inches apart. Fine screens are spaced 0.5 to 2 inches apart.
- Screens are usually placed in a chamber or channel at a slanted angle for easier cleaning.
- Floating material caught on the screens or racks is removed either mechanically (automatically) or manually with rakes.
- Fine screens may use a travelling screen with a spray water system to remove screenings into a trough.

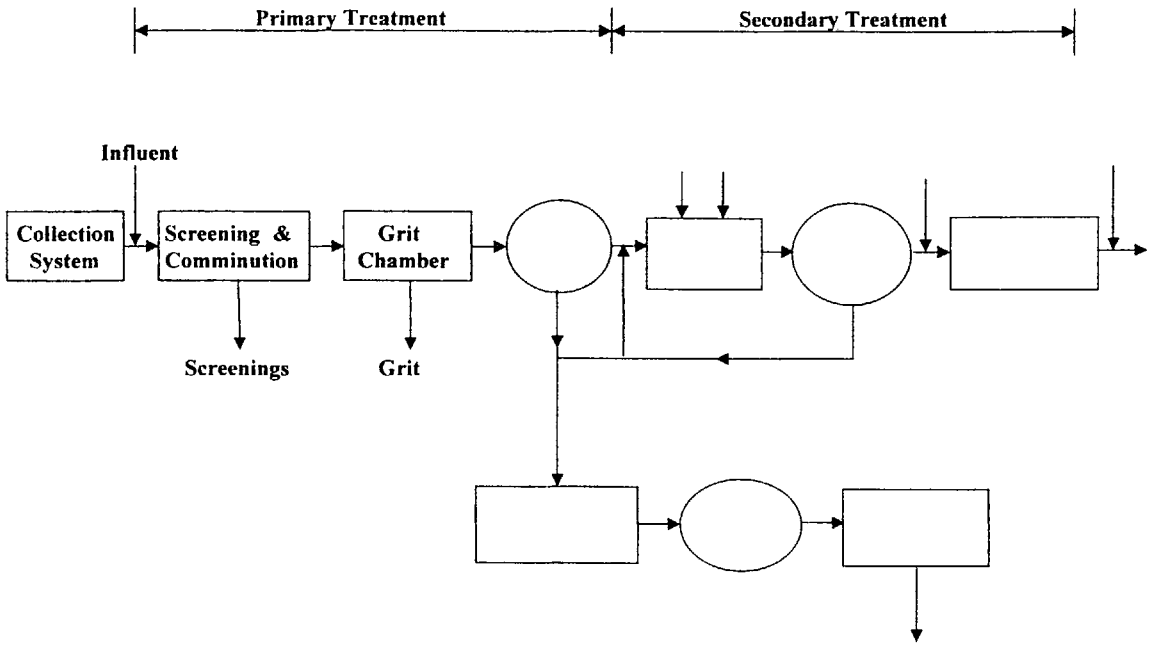


Figure 7.1 Preliminary treatment processes: Screening and grit removal.

- Flow velocity is adjusted to 2 to 4 ft/sec for best performance.
 - Screens should be cleaned frequently enough to keep water from backing up in the channel leading to the screen, which could cause flow surges.
- ✓ Screenings must be removed frequently enough to prevent accumulation from blocking the screen and causing water level buildup in front of the screen.

The bar screen may be manually cleaned (bars or screens are placed at an angle of 30° for easier solids removal) or mechanically cleaned (bars are placed at 45° to 60° angles to improve mechanical cleaner operation).

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.

7.2.1.1 Operational Observations/Problems/Troubleshooting

Operators must constantly monitor operation of the plant's screening devices. During monitoring, observations should be made on the frequency of cleaning, and to check flow before and after cleaning. Employing good housekeeping practices reduces odor, insects, and rodents. The operator should also monitor the amount of screenings produced. Paying attention to the amount of large solids passing into the plant is also important. Obviously, the operator must also constantly look for any evidence of mechanical problems.

A common troubleshooting problem includes too much grit in the bar screen chamber, with water surging. This problem is caused by low flow velocity in the screening channel. The solution requires the operator to increase cleaning frequency, to increase flow velocity in the chamber, or to flush out the chamber with a hose.

Another common problem is the bar screen clogs too often; wastewater backs up in the screening channel. This problem is usually caused by too much debris in the wastestream or inadequate cleaning frequency.

7.2.2 COMPUTATIONS: SCREENINGS REMOVAL

Operators responsible for screenings disposal are typically required to keep a record of the amount of screenings removed from the wastewater flow. To keep and maintain accurate screenings' records, the volume of screenings withdrawn must be determined. Two methods are commonly used to calculate the volume of screenings withdrawn:

$$\text{Screenings Removed, cu ft / day} = \frac{\text{Screenings, cu ft}}{\text{days}} \quad (7.1)$$

$$\text{Screenings Removed, cu ft / MG} = \frac{\text{Screenings, cu ft}}{\text{Flow, MG}} \quad (7.2)$$

Example 7.1

Problem:

A total of 65 gallons of screenings are removed from the wastewater flow during a 24-hour period. What is the screenings removal reported as cu/ft/day?

Solution:

First, convert gallons screenings to cu ft:

$$\frac{65 \text{ gal}}{7.48 \text{ gal / cu ft}} = 8.7 \text{ cu ft screenings}$$

Next, calculate screenings removed as cu ft/day:

$$\text{Screenings Removed (cu ft / day)} = \frac{8.7 \text{ cu ft}}{1 \text{ day}} = 8.7 \text{ cu ft / day}$$

Example 7.2

Problem:

During one week, a total of 310 gallons of screenings were removed from the wastewater screens. What is the average screening removal in cu ft/day?

Solution:

First, gallons screenings must be converted to cu ft screenings:

$$\frac{310 \text{ gal}}{7.48 \text{ gal / cu ft}} = 41.4 \text{ cu ft screenings}$$

Next, the screenings removal calculation is completed:

$$\text{Screenings Removed, cu ft / day} = \frac{41.4 \text{ cu ft}}{7} = 5.9 \text{ cu ft / day}$$

7.3 SHREDDING

As an alternative to screening, *shredding* (shredders) can be used to shred and reduce solids to a size that can enter the plant without causing mechanical problems or clogging, to be removed in subsequent treatment processes. Shredding processes include comminution (comminute means “cut up”) and barminution devices.

7.3.1 OVERVIEW OF SHREDDING PROCESS

Shredders and grinders reduce the size of material in the wastestream before treatment.

- A *comminutor*, the most common shredding device used in wastewater treatment, may be used by some plants to both screen and grind materials. Material shredded is returned to the wastestream.
- In some shredder/grinder units, all the wastewater flows through the unit(s), and all material is ground automatically.
- The *barminutor* uses a bar screen to collect solids, which are then shredded, ground, and passed through the bar screen for removal at a later process. In this type, the shredder/grinder may be located near the screen and grind material diverted to it, or the shredder/grinder unit may be located on the screen itself and slides up and down with the rakes.

7.3.1.1 Operational Observations/Problems/Troubleshooting

During normal operations, the plant operator should monitor comminutor or barminutor operation for evidence of mechanical problems and also for evidence of large solids carrying into the plant. This 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. Frequent unit stalls or jams usually indicate cutter misalignment, excessive debris in influent, or dull cutters. Obviously, these types of problems must be attended to promptly.

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

7.4 GRIT REMOVAL

The purpose of *grit removal* is to remove inorganic solids (sand, gravel, clay, egg shells, coffee grounds, metal filings, seeds, and other similar materials) that could cause excessive mechanical wear.

Several processes or devices are used for grit removal, all based on the fact that grit is heavier than the organic solids, which should be kept in suspension for treatment in following unit 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.

7.4.1 OVERVIEW OF GRIT REMOVAL PROCESS

- Grit chambers remove sand, grit, cinders, small stones, and other similar size and weight material.
- Grit removal equipment can be velocity controlled, aerated, or cyclone degritter type.
- *Velocity controlled grit chambers* have either flow-controlled square or rectangular chambers that can be either manually or mechanically cleaned. A chain and flight mechanism or manual cleaning efforts move the grit into a sump or bucket for disposal. Flow velocity should be about 1 ft/sec.

- *Aerated grit removal systems* inject air into a chamber to produce a spiral flow. Air flow is adjusted to provide a spiral movement while keeping the velocity low enough to allow grit to settle out.
- *Cyclone degritters* use centrifugal force in a cone-shaped unit to remove grit from the wastewater. Wastewater flows into the upper end of the cone to create a vortex that forces the grit particles to the outside of the rotating flow stream. The grit stream produced falls into a grit washer, while the degrittled flow leaves the cyclone unit through an opening near the top of the unit.
- Grit removed is usually washed to remove organic material prior to its disposal.

7.4.1.1 Operational Observations/Problems/Troubleshooting

Gravity/velocity-controlled grit removal normally occurs in a channel or tank where the speed or the velocity of the wastewater is controlled to about 1 ft per second (ideal), so that grit settles while organic matter remains suspended. As long as the velocity is controlled in the range of 0.7 to 1.4 ft per second (fps), the grit removal remains effective. Velocity is controlled by the amount of water flowing through the channel, by the depth of the water in the channel, by the width of the channel, or by the cumulative width of channels in service.

During operation, the operator must pay particular attention to grit characteristics, for evidence of organic solids in the channel, for evidence of grit carryover into plant, for evidence of mechanical problems, and for grit storage and disposal (housekeeping).

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.

During normal operation, adjusting the aeration rate produces the desired separation. This 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 grit and organics will settle out.

The operator observes the same kinds of conditions as those listed for the gravity/velocity-controlled system, but must also pay close attention to the air distribution system to ensure proper operation.

The *cyclone degritter* uses a rapid spinning motion (centrifugal force) 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 flow, washed, and discharged directly to a storage container. Grit removal performance is determined by calculating the percent removal for inorganic (fixed) suspended solids.

The operator observes the same kinds of conditions listed for the gravity/velocity-controlled and aerated grit removal systems, with the exception of the air distribution system.

Typical problems associated with grit removal include mechanical malfunctions and rotten egg odor in the grit chamber (hydrogen sulfide formation), which can lead to metal and concrete corrosion problems. Low recovery rate of grit is another typical problem. This is normally caused by bottom scour, overaeration, or not enough detention time. When these problems occur, the operator must make the required adjustments/repairs to correct the problem(s).

7.4.2 PREAERATION

In the *preaeration process* (diffused or mechanical), we aerate wastewater to achieve and maintain an aerobic state (to freshen septic wastes), strip off hydrogen sulfide (to reduce odors and corrosion),

agitate solids (to release trapped gases and improve solids separation and settling), and to reduce BOD₅. All of this can be accomplished by aerating the wastewater for 10 to 30 minutes. To reduce BOD₅, preaeration must be conducted from 45 to 60 minutes.

7.4.2.1 Operational Observations/Problems/Troubleshooting

In preaeration grit removal systems, the operator is concerned with maintaining proper operation and must be alert to any possible mechanical problems. In addition, the operator monitors dissolved oxygen levels and the impact of preaeration on influent.

7.4.3 CHEMICAL ADDITION

Chemical addition is made (either via dry chemical metering or solution feed metering) to the wastestream to improve settling, reduce odors, neutralize acids or bases, reduce corrosion, reduce BOD₅, improve solids and grease removal, reduce loading on the plant, add or remove nutrients, add organisms, and/or aid subsequent downstream processes. The particular chemical and amount used 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.

7.4.3.1 Operational Observations/Problems/Troubleshooting

In adding chemicals to the wastestream to remove grit, the operator monitors the process for evidence of mechanical problems and takes proper corrective actions when necessary. The operator also monitors the current chemical feed rate and dosage. The operator ensures that mixing at the point of addition is accomplished in accordance with Standard Operating Procedures and monitors the impact of chemical addition on influent.

7.4.4 EQUALIZATION

The purpose of *flow equalization* (whether by surge, diurnal, or complete methods) is to reduce or remove the wide swings in flow rates normally associated with wastewater treatment plant loadings; it minimizes the impact of storm flows. The 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 and requirements of the flow equalization system. Equalized flows allow the plant to perform at optimum levels by providing stable hydraulic and organic loading. The downside to flow equalization is in additional costs associated with construction and operation of the flow equalization facilities.

7.4.4.1 Operational Observations/Problems/Troubleshooting

During normal operations, the operator must monitor all mechanical systems involved with flow equalization and must watch for mechanical problems and take the appropriate corrective action. The operator also monitors dissolved oxygen levels, the impact of equalization on influent, and water levels in equalization basins, and makes necessary adjustments.

7.5 GRIT REMOVAL CALCULATIONS

Wastewater systems typically average 1 to 15 cubic feet of grit per million gallons of flow (sanitary

systems: 1 to 4 cu ft/million gal; combined wastewater systems average from 4 to 15 cu ft/million gals of flow), with higher ranges during storm events.

Generally, grit is disposed of in sanitary landfills. Because of this practice, for planning purposes, operators must keep accurate records of grit removal. Most often, the data are reported as cubic feet of grit removed per million gallons of flow:

$$\text{Grit Removed, cu ft / MG} = \frac{\text{Grit Vol., cu ft}}{\text{Flow, MG}} \quad (7.3)$$

Over a given period, the average grit removal rate at a plant (at least a seasonal average) can be determined and used for planning purposes. Typically, grit removal is calculated as cubic yards, because excavation is normally expressed in terms of cubic yards.

$$\text{Cubic Yards Grit} = \frac{\text{Total Grit, cu ft}}{27 \text{ cu ft / cu yds}} \quad (7.4)$$

Example 7.3

Problem:

A treatment plant removes 10 cu ft of grit in one day. How many cu ft of grit are removed per million gallons if the plant flow was 9 MGD?

Solution:

$$\begin{aligned} \text{Grit Removed, cu ft / MG} &= \frac{\text{Grit Vol., cu ft}}{\text{Flow, MG}} \\ &= \frac{10 \text{ cu ft}}{9 \text{ MG}} = 1.1 \text{ cu ft / MG} \end{aligned}$$

Example 7.4

Problem:

The total daily grit removed for a plant is 250 gallons. If the plant flow is 12.2 MGD, how many cubic feet of grit are removed per MG flow?

Solution:

First, convert gallons grit removed to cu ft:

$$\frac{250 \text{ gal}}{7.48 \text{ gal / cu ft}} = 33 \text{ cu ft}$$

Next, complete the calculation of cu ft/MG:

$$\begin{aligned} \text{Grit Removed, cu ft / MG} &= \frac{\text{Grit Vol., cu ft}}{\text{Flow, MG}} \\ &= \frac{33 \text{ cu ft}}{12.2 \text{ MGD}} = 2.7 \text{ cu ft / MGD} \end{aligned}$$

Example 7.5

Problem:

The monthly average grit removal is 2.5 cu ft/MG. If the monthly average flow is 2,500,000 gpd, how many cu yards must be available for grit disposal if the disposal pit is to have a 90-day capacity?

Solution:

First, calculate the grit generated each day:

$$\frac{(2.5 \text{ cu ft})}{\text{MG}} (2.5 \text{ MGD}) = 6.25 \text{ cu ft each day}$$

The cu ft grit generated for 90 days would be

$$\frac{(6.25 \text{ cu ft})}{\text{day}} (90 \text{ days}) = 562.5 \text{ cu ft}$$

Convert cu ft grit to cu yd grit:

$$\frac{562.5 \text{ cu ft}}{27 \text{ cu ft/cu yd}} = 21 \text{ cu yd}$$

7.6 PRELIMINARY TREATMENT SAMPLING AND TESTING

During normal operation of grit removal systems (with the exception of the screening and shredding processes), the plant operator is responsible for sampling and testing as shown in Table 7.1.

7.7 OTHER PRELIMINARY TREATMENT PROCESS CONTROL CALCULATIONS

The desired velocity in sewers is approximately 2 fps at peak flow, because this velocity normally prevents solids from settling from the lines. However, when the flow reaches the grit channel, the

TABLE 7.1. Sampling and Testing Grit Removal Systems.

Process	Location	Test	Frequency
Grit Removal (Velocity)	Influent	Suspended Solids (Fixed)	Variable
	Channel	Depth of Grit	Variable
	Grit	Total Solids—Fixed	Variable
	Effluent	Suspended Solids (Fixed)	Variable
Grit Removal (Aerated)	Influent	Suspended Solids (Fixed)	Variable
	Channel	Dissolved Oxygen	Variable
	Grit	Total Solids—Fixed	Variable
	Effluent	Suspended Solids (Fixed)	Variable
Chemical Addition	Influent	Jar Test	Variable
Preaeration	Influent	Dissolved Oxygen	Variable
	Effluent	Dissolved Oxygen	Variable
Equalization	Effluent	Dissolved Oxygen	Variable

velocity should decrease to about 1 fps to permit the heavy inorganic solids to settle. In the example calculations that follow, we describe how the velocity of the flow in a channel can be determined, by the float and stopwatch method and by channel dimensions.

Example 7.6

Velocity by float and stopwatch.

$$\text{Velocity, feet / second} = \frac{\text{Distance Traveled, ft}}{\text{Time Required, seconds}} \quad (7.5)$$

Problem:

A float takes 30 seconds to travel 37 feet in a grit channel. What is the velocity of the flow in the channel?

Solution:

$$\text{Velocity, fps} = \frac{37 \text{ ft}}{30 \text{ sec}} = 1.2 \text{ fps}$$

Example 7.7

Velocity by flow and channel dimensions.

- ✓ This calculation can be used for a single channel or tank or for 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.

$$\text{Velocity, fps} = \frac{\text{Flow, MGD} \times 1.55 \text{ cfs / MGD}}{\# \text{ Channels in Service} \times \text{Channel Width, ft} \times \text{Water Depth, ft}} \quad (7.6)$$

Problem:

The plant is currently using two grit channels. Each channel is 3 ft wide and has a water depth of 1.3 ft. What is the velocity when the influent flow rate is 4.0 MGD?

Solution:

$$\text{Velocity, fps} = \frac{4.0 \text{ MGD} \times 1.55 \text{ cfs / MGD}}{2 \text{ Channels} \times 3 \text{ ft} \times 1.3 \text{ ft}}$$

$$\text{Velocity, fps} = \frac{6.2 \text{ cfs}}{7.8 \text{ ft}^2} = 0.79 \text{ fps}$$

- ✓ *Note:* Because 0.79 is within the 0.7–1.4 level, the operator of this unit would not make any adjustments.
- ✓ *Note:* The channel dimensions must always be in feet. Convert inches to feet by dividing by 12 inches per foot.

Example 7.8

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. To compute the settling time, settling velocity in fps must be provided or determined by experiment in a laboratory.

$$\text{Settling Time, seconds} = \frac{\text{Liquid Depth in ft}}{\text{Settling, Velocity, fps}} \quad (7.7)$$

Problem:

The plant's grit channel is designed to remove sand, which has a settling velocity of 0.080 fps. The channel is currently operating at a depth of 2.3 ft. How many seconds will it take for a sand particle to reach the channel bottom?

Solution:

$$\text{Settling Time, sec} = \frac{2.3 \text{ ft}}{0.080 \text{ fps}} = 28.7 \text{ sec}$$

Example 7.9

Required channel length.

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

$$\text{Required Channel Length} = \frac{\text{Channel Depth, ft} \times \text{Flow Velocity, fps}}{0.080 \text{ fps}} \quad (7.8)$$

Problem:

The plant's grit channel is designed to remove sand, which has a settling velocity of 0.080 fps. The channel is currently operating at a depth of 3 ft. The calculated velocity of flow through the channel is 0.85 fps. The channel is 36 ft long. Is the channel long enough to remove the desired sand particle size?

Solution:

$$\text{Required Channel Length} = \frac{3 \text{ ft} \times 0.85 \text{ fps}}{0.080 \text{ fps}} = 31.6 \text{ ft}$$

Yes, the channel is long enough to ensure all the sand will be removed.

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

7.8 SUMMARY

Preliminary treatment processes are prerequisite to primary treatment and, in general, prepare influent for primary treatment, which we discuss in Chapter 8.

7.9 CHAPTER REVIEW QUESTIONS

- 7-1 What is the purpose of preliminary treatment?
- 7-2 What is the bar screen's purpose?
- 7-3 A total of 60 gal of screenings are removed from the wastewater flow during a 24-hour period. What is the screenings removal reported as cu ft/day?
- 7-4 During one week, a total of 275 gal of screenings were removed from the wastewater screens. What was the average screenings removal in cu ft/day?
- 7-5 A total of 40 gal of screenings are removed from the treatment plant during a 24-hour period. If the treatment plant received a flow of 2,200,000 gpd, what is the screenings removal expressed as cu ft/MG?
- 7-6 What controls velocity in a gravity-type grit channel?
- 7-7 The plant has three channels in service. Each channel is 3 ft wide and has a water depth of 2 ft. What is the velocity in the channel when the flow rate is 9.0 MGD?
- 7-8 List three reasons why you might wish to include preaeration in the preliminary treatment portion of your plant.
- 7-9 Name two reasons why we would want to remove grit.

- 7-10 Below what velocity will grit settle in the screening channel?
- 7-11 An empty screenings hopper 4 ft by 5 ft is filled to an even depth of 24 in. over the course of 80 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?
- 7-12 A v-notch weir is normally used to measure _____.
- 7-13 The main purpose of the grit chamber is to _____.
- 7-14 A stick in a grit channel travels 30 ft in 33 seconds. What is the estimated velocity in the channel in ft/sec?
- 7-15 The depth of water in a grit channel is 16 in. The channel is 34 inches wide. If the flow meter indicates a flow of 1,100 gpm, what is the velocity of flow through the channel in ft/sec?
- 7-16 A treatment plant removes 12 cu ft of grit in one day. If the plant flow is 9 MGD, what is this removal expressed as cu ft/MG?
- 7-17 The average grit removal at a particular treatment plant is 2.6 cu ft/MG. If the monthly average daily flow is 3.8 MGD, how many cu yd of grit would be removed from the wastewater flow during one month?
- 7-18 The monthly average grit removal is 2.3 cu ft/MG. If the average daily flow for the month is 4,250,000 gpd, how many cu yd must be available for grit disposal if the disposal pit is to have a 90-day capacity?

Primary Treatment

8.1 INTRODUCTION

PPRIMARY treatment (primary sedimentation or primary clarification) should remove both settleable organic and floatable solids. Poor solids removal during this step of treatment may cause organic overloading of the biological treatment processes following primary treatment. Normally, each primary clarification unit can be expected to remove 90 to 95% of settleable solids, 40 to 60% of total suspended solids, and 25 to 35% of BOD₅.

✓ *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.

In this chapter, we focus on primary sedimentation—the use of large basins in which primary settling is achieved under relatively quiescent conditions (see Figure 8.1). Within these basins, the primary settled solids collect and are mechanically scraped 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.

8.2 OVERVIEW OF PRIMARY TREATMENT

- Primary treatment reduces the organic loading on downstream treatment processes by removing a large amount of settleable, suspended, and floatable materials.
- Primary treatment reduces the velocity of the wastewater through a clarifier to approximately 1 to 2 ft/min, so that settling and floatation can take place. Slowing the flow enhances removal of suspended solids in wastewater.
- Primary settling tanks remove floated grease and scum, remove the settled sludge solids, and collect them for pumped transfer to disposal or further treatment.
- Clarifiers used may be rectangular or circular. In rectangular clarifiers, wastewater flows from one end to the other, and the settled sludge is moved to a hopper at the one end, either by flights set on parallel chains or by a single bottom scraper set on a traveling bridge. Floating material (mostly grease and oil) is collected by a surface skimmer.
- In circular tanks, the wastewater usually enters at the middle and flows outward. Settled sludge is pushed to a hopper in the middle of the tank bottom, and floating material is removed by a surface skimmer.
- Factors affecting primary clarifier performance include:
 - rate of flow through the clarifier
 - wastewater characteristics (strength; temperature; amount and type of industrial waste; and the density, size, and shapes of particles)
 - performance of pretreatment processes
 - nature and amount of any wastes recycled to the primary clarifier

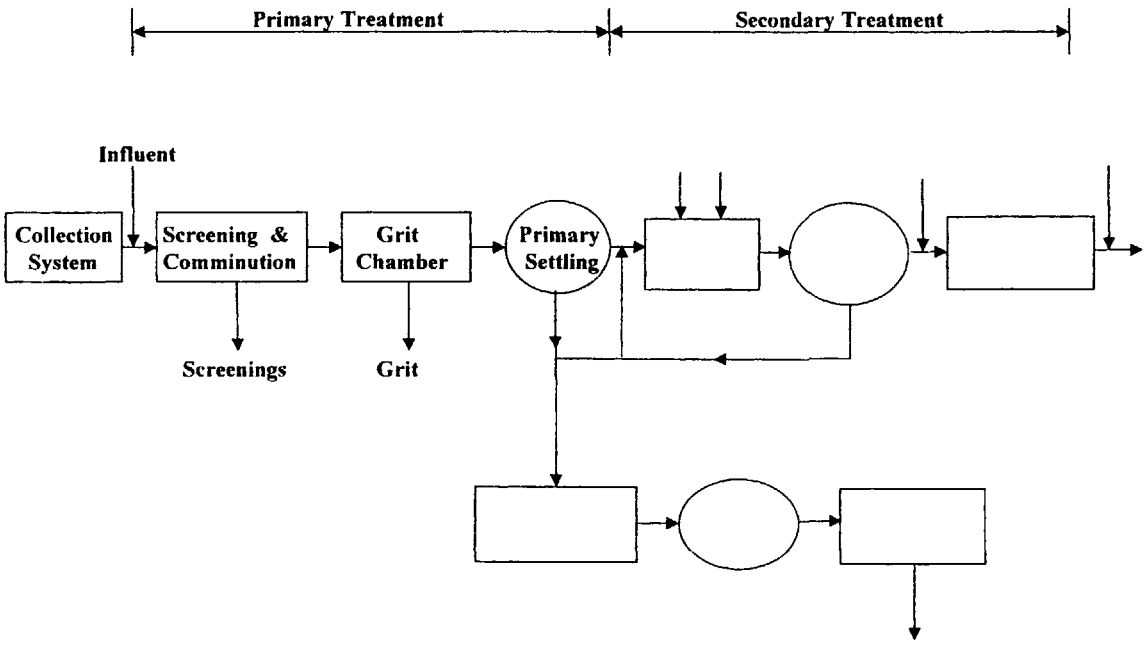


Figure 8.1 Primary treatment.

- Key factors in primary clarifier operation include the following concepts:

— Retention time, hours = $\frac{(\text{Volume, gal}) (24 \text{ hr / day})}{\text{flow, gal per day}}$

— Surface loading rate, $\frac{\text{gal / day}}{\text{sq ft}} = \frac{\text{flow, gal per day}}{\text{surface area, sq ft}}$

— Solids loading rate, $\frac{\text{lb / day}}{\text{sq ft}} = \frac{\text{Solids into clar., lb / day}}{\text{surface area, sq ft}}$

— Weir overflow rate, $\frac{\text{gal / day}}{\text{lineal ft}} = \frac{\text{flow, gal per day}}{\text{weir length, lineal ft}}$

8.3 OPERATOR OBSERVATIONS, PROCESS PROBLEMS, AND TROUBLESHOOTING

Before identifying a primary treatment problem and proceeding with the appropriate troubleshooting effort, the operator must be cognizant of what constitutes “normal” operation (i.e., is there a problem or is the system operating as per design?).

Several important items of normal operation can have a strong impact on performance. In the following section, we discuss the important operational parameters and “normal” observations.

Primary Clarification: Normal Operation:

In primary clarification, wastewater enters a settling tank or basin. Velocity reduces to approximately 1 ft/min.

- ✓ 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 heavier than water settle to the bottom while solids 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.

Primary Clarification: Operational Parameters (Normal Observations):

- Flow distribution—Normal flow distribution is indicated by flow to each in-service unit being equal and uniform. There is no indication of short-circuiting. The surface loading rate is within design specifications.
- Weir condition—Weirs are level; flow over the weir is uniform; and weir overflow rate is within design specifications.
- Scum removal—The surface is free of scum accumulations; the scum removal does not operate continuously.
- Sludge removal—No large clumps of sludge appear on the surface; system operates as designed; pumping rate is controlled to prevent coning or buildup; and sludge blanket depth is within desired levels.
- Performance—The unit is removing expected levels of BOD₅, TSS, and settleable solids.
- Unit maintenance—Mechanical equipment is maintained in accordance with planned schedules; equipment is available for service as required.

To assist the operator in judging primary treatment operation, several process control tests can be used for process evaluation and control. These tests include the following:

Process Control Tests:

- pH—normal range: 6.5–9.0
 - dissolved oxygen—normal range: < 1.0 mg/L
 - temperature—varies with climate and season
 - settleable solids, mL/L—influent: 5–15 mL/L
—effluent: 0.3–5 mL/L
 - BOD₅, mg/L—influent: 150–400 mg/L
—effluent: 50–150 mg/L
 - TSS, mg/L—influent: 150–400 mg/L
—effluent: 50–150 mg/L
 - % solids—4–8%
 - % volatile matter—40–70%
 - heavy metals—as required
 - jar tests—as required
- ✓ *Note:* Testing frequency should be determined on the basis of the process influent and effluent variability and the available resources. All should be performed periodically to provide reference information for evaluation of performance.

8.3.1 PROCESS CONTROL CALCULATIONS

As with many other wastewater treatment plant unit processes, several process control calculations may be helpful in evaluating the performance of the primary treatment 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)
- BOD and SS removed, lb/day

In the following sections, we take a closer look at a few of these process control calculations and example problems.

✓ *Note:* The calculations presented in the following sections allow you to determine values for each function performed. Keep in mind that an optimally operated primary clarifier should have values in an expected range. For example, the expected range of % removal for a primary clarifier is

- settleable solids 90–95%
- suspended solids 40–60%
- BOD₅ 25–35%

The expected range of hydraulic detention time for a primary clarifier is 1 to 3 hours. The expected range of surface loading/settling rate for a primary clarifier is 600 to 1,200 gpd/sq ft (ballpark figure). The expected range of weir overflow rate for a primary clarifier is 10,000 to 20,000 gpd/ft.

8.3.1.1 Surface Loading Rate (Surface Settling Rate/Surface Overflow Rate)

Surface loading rate is the number of gallons of wastewater passing over 1 square foot of tank per day. This can be used to compare actual conditions with design. Plant designs generally use a surface loading rate of 300 to 1,200 gal/day/ft².

Other terms used synonymously with surface loading rate are

- surface overflow rate
- surface settling rate

$$\text{Surface Settling Rate, gpd / ft}^2 = \frac{\text{gal / day}}{\text{Settling Tank Area, ft}^2} \quad (8.1)$$

Example 8.1

Problem:

The settling tank is 120 feet in diameter, and the flow to the unit is 4.5 MGD. What is the surface loading rate in gal/day/ft²?

Solution:

$$\text{Surface Loading Rate} = \frac{4.5 \text{ MGD} \times 1,000,000 \text{ gal / MGD}}{0.785 \times 120 \text{ ft} \times 120 \text{ ft}} = 398 \text{ gpd / ft}^2$$

Example 8.2

Problem:

A circular clarifier has a diameter of 50 ft. If the primary effluent flow is 2,150,000 gpd, what is the surface overflow rate in gpd/sq ft?

Solution:

✓ Remember: $\text{Area} = (0.785) (50 \text{ ft}) (50 \text{ ft})$

$$\begin{aligned}\text{Surface Overflow Rate} &= \frac{\text{Flow, gpd}}{\text{Area, sq ft}} \\ &= \frac{2,150,000}{(0.785)(50 \text{ ft})(50 \text{ ft})} = 1,096 \text{ gpd/sq ft}\end{aligned}$$

8.3.1.2 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 gal/day/ft are used in the design of a settling tank.

$$\text{Weir Overflow Rate, gpd/ft} = \frac{\text{Flow, gal/day}}{\text{Weir Length, ft}} \quad (8.2)$$

Example 8.3

Problem:

The circular settling tank is 80 feet in diameter and has a weir along its circumference. The effluent flow rate is 2.75 MGD. What is the weir overflow rate in gallons per day per foot?

Solution:

$$\text{Weir Overflow Rate, gpd/ft} = \frac{2.75 \text{ MGD} \times 1,000,000 \text{ gal/MG}}{3.14 \times 80 \text{ ft}} = 10,947 \text{ gal/day/ft}$$

✓ *Note:* Notice that 10,947 gal/day/ft is above the recommended minimum of 10,000.

8.3.1.3 Sludge Pumping

Determination of *sludge pumping* (the quantity of solids and volatile solids removed from the sedimentation tank) provides accurate information needed for process control of the sedimentation process.

(1) Solids Pumped, lb/day =

$$\text{Pump Rate, gpm} \times \text{Pump Time, min/day} \times 8.34 \text{ lb/gal} \times \% \text{ Solids} \quad (8.3)$$

(2) Volatile Solids/lb/day =

$$\text{Pump Rate} \times \text{Pump Time} \times 8.34 \times \% \text{ Solids} \times \% \text{ Volatile Matter} \quad (8.4)$$

Example 8.4

Problem:

The sludge pump operates 30 minutes per hour. The pump delivers 25 gal/min of sludge.

Laboratory tests indicate that the sludge is 5.3% solids and 68% volatile matter. How many pounds of volatile matter are transferred from the settling tank to the digester? Assume a 24-hr period.

Solution:

Pump Time = 30 min/hr
Pump Rate = 25 gpm
% Solids = 5.3%
% V.M. = 68%

$$\begin{aligned} \text{Volatile Solids, lb / day} &= 25 \text{ gpm} \times (30 \text{ min / hr} \times 24 \text{ hr / day}) \times 8.34 \text{ lb / gal} \times 0.053 \times 0.68 \\ &= 5,410 \text{ lb / day} \end{aligned}$$

8.3.1.4 Percent Total Solids (% TS)

Example 8.5

Problem:

A settling tank sludge sample is tested for solids. The sample and dish weigh 73.79 g. The dish alone weighs 21.4 g. After drying, the dish with dry solids weighs 22.4 g. What is the percent total solids (% TS) of the sample?

Solution:

Sample + Dish	73.79 g	Dish + Dry Solids	22.4 g
Dish Alone	<u>-21.4 g</u>	Dish Alone	<u>-21.4 g</u>
Sample Weight	52.39 g	Dry Solids Weight	<u>1.0 g</u>

$$\frac{1.0 \text{ g}}{52.39 \text{ g}} \times 100\% = 1.9\%$$

8.3.1.5 BOD and SS Removed, lb/day

To calculate the pounds of BOD or suspended solids removed each day, you need to know the mg/L BOD or SS removed and the plant flow. Then, you can use the mg/L to lb/day equation.

$$\text{SS Removed} = \text{mg / L} \times \text{MGD} \times 8.34 \text{ lb / gal} \tag{8.5}$$

Example 8.6

Problem:

If 120 mg/L suspended solids are removed by a primary clarifier, how many lb/day suspended solids are removed when the flow is 6,250,000 gpd?

Solution:

$$\text{SS Removed} = 120 \text{ mg / L} \times 6.25 \text{ MGD} \times 8.34 \text{ lb / gal} = 6,255 \text{ lb / day}$$

Example 8.7*Problem:*

The flow to a secondary clarifier is 1.6 MGD. If the influent BOD concentration is 200 mg/L and the effluent BOD concentration is 70 mg/L, how many pounds of BOD are removed daily?

$$\text{lb/day BOD removed} = 200 \text{ mg/L} - 70 \text{ mg/L} = 130 \text{ mg/L}$$

After calculating mg/L BOD removed, calculate lb/day BOD removed:

$$\text{BOD removed, lb/day} = (130 \text{ mg/L}) (1.6 \text{ MGD}) (8.34 \text{ lb/gal}) = 1,735 \text{ lb/day}$$

8.3.2 PROBLEM ANALYSIS

In primary treatment (as is made clear in the operation of other subsequent unit processes), the goal of the operator is to identify causes of process malfunctions, develop solutions, and prevent recurrence. In other words, the operator's goal is to be able to perform problem analysis or troubleshooting on unit processes when required and to restore the unit process to optimal operating condition. Obviously, the immediate goal in problem analysis is to solve the immediate problem. The long-term goal is to ensure that the problem does not pop up again, causing poor performance in the future.

In this section, we cover a few indicators or observations of operational problems with the primary treatment process. The observations presented are not all-inclusive, but present the most frequently confronted problems.

8.3.2.1 Poor Suspended Solids Removal (Primary Clarifier)*Causal Factors:*

- hydraulic overload
- sludge buildup in tanks and decreased volume and allows solids to scour out tanks
- strong recycle flows
- industrial waste concentrations
- wind currents
- temperature currents

8.3.2.2 Floating Sludge*Causal Factors:*

- sludge becoming septic in tank
- damaged or worn collection equipment
- recycled waste sludge
- primary sludge pumps malfunction
- sludge withdrawal line plugged
- return of well-nitrified waste-activated sludge
- too few tanks in service
- damaged or missing baffles

8.3.2.3 Primary Sludge Solids Concentration Too Low

Causal Factors:

- hydraulic overload
- overpumping of sludge
- collection system problems
- decreased influent solids loading

8.3.2.4 Septic Wastewater or Sludge

Causal Factors:

- damaged or worn collection equipment
- infrequent sludge removal
- insufficient industrial pretreatment
- septic sewage from collection system
- strong recycle flows
- primary sludge pump malfunction
- sludge withdrawal line plugged
- sludge collectors not run often enough
- septage dumpers

8.3.2.5 Primary Sludge Solids Concentrations Too Low

Causal Factors:

- hydraulic overload
- overpumping of sludge
- collection system problem
- decreased influent solids loading

8.3.2.6 Primary Sludge Solids Concentrations Too High

Causal Factors:

- excessive grit and compacted material
- primary sludge pump malfunction
- sludge withdrawal line plugged
- sludge retention time is too long
- increased influent loadings

8.4 SUMMARY

Sedimentation and clarification prepare effluent for the biological processes used in wastewater treatment. We begin our discussion of biological treatment with trickling filters, the subject of Chapter 9.

8.5 CHAPTER REVIEW QUESTIONS

8-1 What is the purpose of primary treatment (sedimentation)?

- 8-2 What is the expected range of % removal from a primary clarifier for settleable solids, suspended solids, and BOD₅?
- 8-3 The sludge pump operates 20 minutes every 3 hours. The pump delivers 70 gpm. If the sludge is 5.5% solids and has a volatile matter content of 66%, how many pounds of volatile solids are removed from the settling tank each day?
- 8-4 The circular settling tank is 70 ft in diameter and has a depth of 10 ft. The flow rate is 2.8 MGD. What is the detention time in hours, surface loading rate in gal/day/ft², and weir overflow rate in gal/day/ft?
- 8-5 How much of the settleable solids are removed by primary settling?
- 8-6 What is an average detention time in a primary clarifier?
- 8-7 A settling tank is 90 ft long, 20 ft wide, 10 ft deep, and receives a flow rate of 1.5 MGD. What is the surface overflow rate in gpd/ft²?
- 8-8 A settling tank with a total weir length of 70 ft receives a flow rate of 1.50 MGD. What is the weir overflow rate in gpd/ft?
- 8-9 A wastewater treatment plant has six primary tanks. Each tank is 90 ft long and 20 ft wide with a side water depth of 12 ft and a total weir length of 86 ft. The flow rate to the plant is 5 MGD. Three tanks are currently in service. Calculate the detention time in minutes, the surface overflow rate in gpd/ft², and the weir overflow rate in gpd/ft.
- 8-10 A primary settling tank is 80 ft in diameter and 10 ft deep. What is the detention time when the flow rate is 3.25 MGD?

- 8-11 A circular clarifier has a capacity of 160,000 gallons. If the flow through the clarifier is 1,750,000 gpd, what is the detention time in hours for the clarifier?
- 8-12 A circular clarifier receives a flow of 4,300,000 gpd. If the clarifier is 80 ft in diameter and 10 ft deep, what is the clarifier detention time in hours? Assume the flow is steady and continuous.
- 8-13 A rectangular clarifier has a total of 120 ft of weir. What is the weir overflow rate in gpd/ft when the flow is 1,400,000 gpd?
- 8-14 A circular clarifier has a diameter of 70 ft. If the primary clarifier influent flow is 2,650,000 gpd, what is the surface overflow rate in gpd/sq ft?
- 8-15 A sedimentation tank is 80 ft long and 30 ft wide. If the flow to the tank is 2,190,000 gpd, what is the surface overflow rate in gpd/sq ft?
- 8-16 If 120 mg/L suspended solids are removed by a primary clarifier, how many lb/day suspended solids are removed when the flow is 5,140,000 gpd?
- 8-17 The flow to a primary clarifier is 950,000 gpd. If the influent to the clarifier has a suspended solids concentration of 300 mg/L and the primary effluent has a suspended solids concentration of 120 mg/L, how many lb/day suspended solids are removed by the clarifier?

Trickling Filters

9.1 INTRODUCTION

THE *trickling filter* (see Figure 9.1) is one of the oldest forms of dependable biological treatment for wastewaters. During the first half of the 20th century, a large number of these units were constructed within the United States. Today, many of the trickling filter plants are still in operation.

By its very nature, the trickling filter has its advantages over other unit processes (see Figure 9.2). For example, it is a very economical and dependable process for treatment of wastewater prior to discharge. Capable of withstanding periodic shock loading, process energy demands are low because aeration is a natural process.

✓ *Note:* *Shock loading* refers to the arrival at a plant of waste toxic to organisms in sufficient quantity or strength to cause operating problems. Possible problems include odors and sloughing off of the slime on the trickling filter media.

The trickling filter's natural advantages have made it the main process available for the treatment of both municipal and industrial wastes for many years. Along with advantages, however, trickling filters have disadvantages (see Figure 9.3). For example, area requirements, cost of construction, and inability to provide the required level of treatment during cold weather have reduced the construction of new filters in recent years. However, continuing increases in energy costs have resulted in several new modifications of the trickling filter process (modifications used to treat varying hydraulic and organic loadings). These modifications [deep bed filters and rotating biological contactors (RBCs)] have proved able to produce consistent, high-quality effluent with lower energy requirements than other biological processes. Because of these modifications and the introduction of new lightweight synthetic media, the trickling filter process may once again find widespread application as a biological treatment process for domestic and industrial wastes. It may also be used as a roughing device to reduce the load on other biological treatment units.

9.2 TRICKLING FILTER DEFINITIONS

To clearly understand and correctly operate the trickling filter, the operator must be familiar with certain terms.

✓ *Note:* The following list of terms applies to the trickling filter process. We assume that other terms related to other units within the treatment system (plant) are already familiar to operators.

- *Biological towers*—a type of trickling filter that is very deep (10–20+ ft). Filled with a lightweight synthetic media, these towers are also known as oxidation or roughing towers or (because of their extremely high hydraulic loading) super-rate trickling filters.

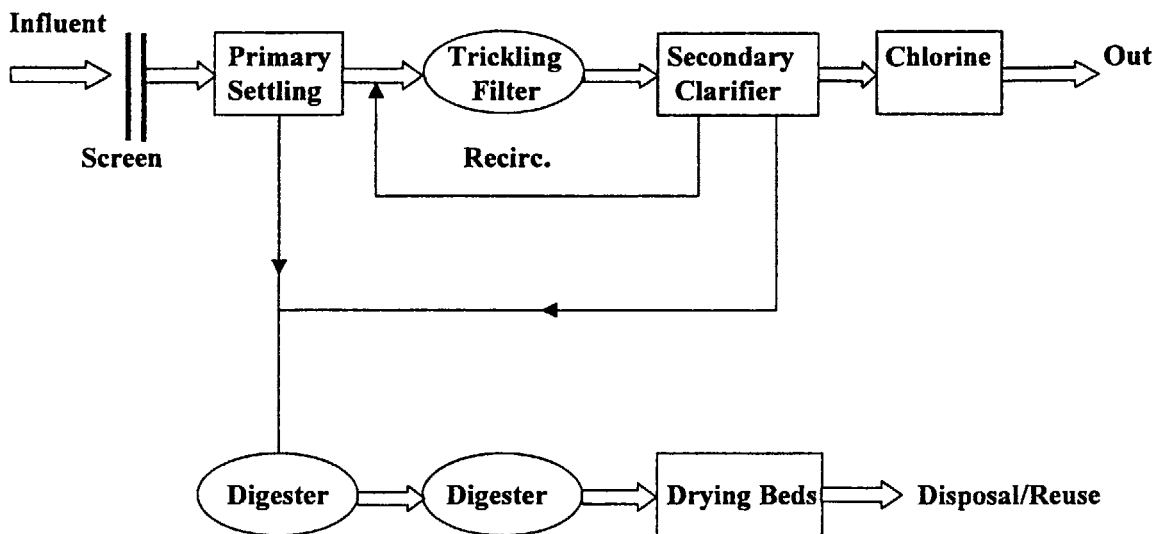


Figure 9.1 Typical trickling filter arrangement.

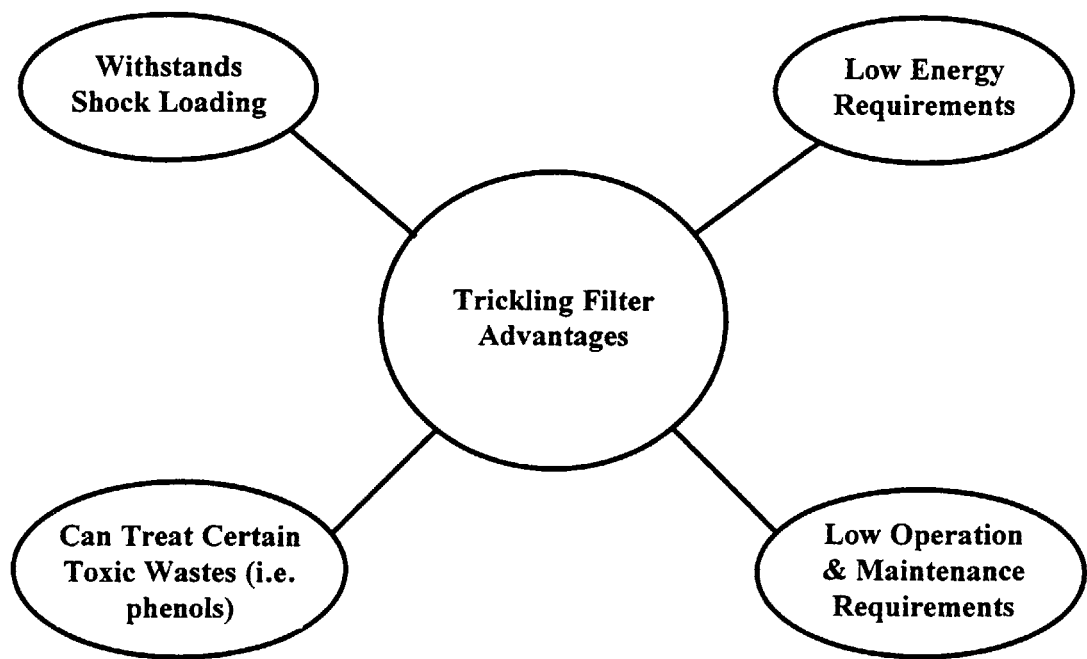


Figure 9.2 Trickling filter advantages.

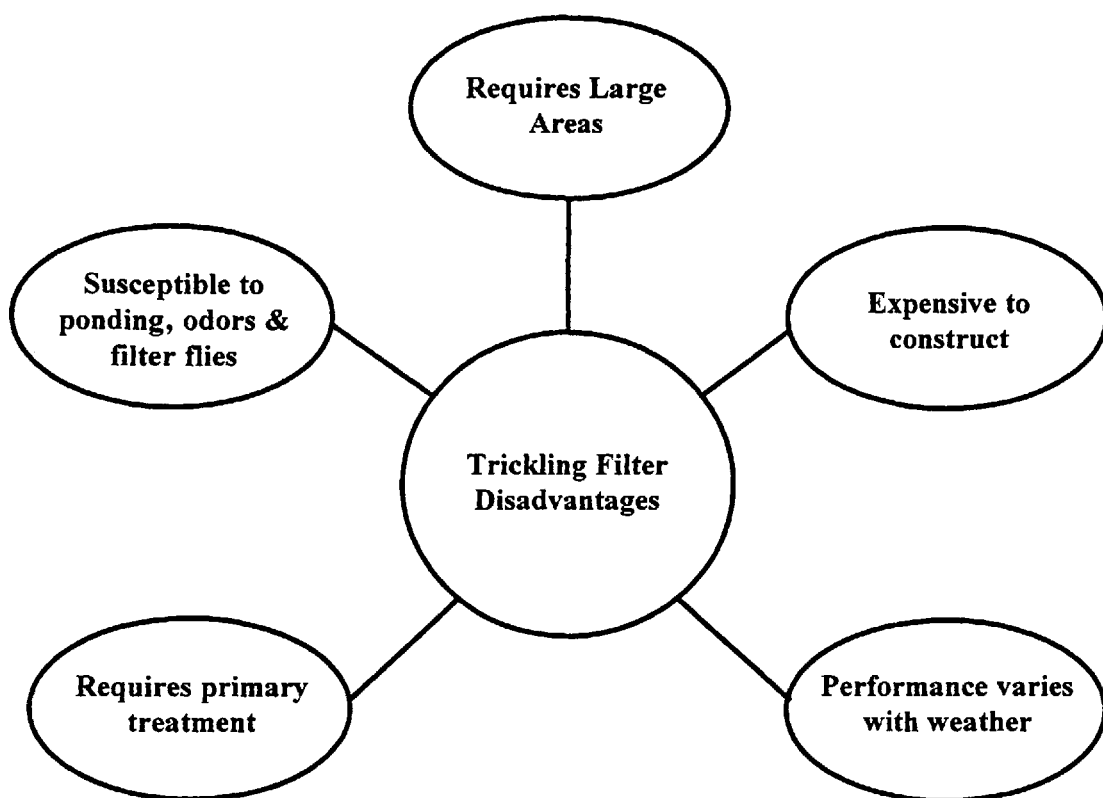


Figure 9.3 Trickling filter disadvantages.

- *Biomass*—the total mass of organisms attached to the media. Similar to solids inventory in the activated sludge process, it is sometimes referred to as the *zoogeal slime* (see Figure 9.4).
- *Distribution arm*—the device most widely used to apply wastewater evenly over the entire surface of the media. In most cases, the arm is moved by the force of the wastewater being sprayed through the orifices (see Figure 9.5).
- *Filter underdrain*—the open space provided under the media to collect the liquid (wastewater and sloughings) and to allow air to enter the filter. It has a sloped floor to collect the flow to a central channel for removal.
- *Hydraulic loading*—the amount of wastewater flow applied to the surface of the trickling filter media. It can be expressed in several ways: flow per square foot of surface per day (gpd/ft^2); flow per acre per day (MGAD); or flow per acre foot per day (MGAFD). The hydraulic loading includes all flow entering the filter.
- *High-rate trickling filters*—a classification (see Table 9.1) in which the organic loading is in the range of 25 to 100 pounds of BOD_5 per 1,000 cubic feet of media per day. The standard rate filter may also produce a highly nitrified effluent.
- *Media*—an inert substance placed in the filter to provide a surface for the microorganisms to grow on. The media can be field stone, crushed stone, slag, plastic, or redwood slats (see Figure 9.4).
- *Organic loading*—the amount of BOD_5 or chemical oxygen demand (COD) applied to a given volume of filter media. It does not include the BOD_5 or COD contributed by any recirculated flow and is commonly expressed as pounds of BOD_5 or COD per 1,000 cubic feet of media.
- *Recirculation*—the return of filter effluent back to the head of the trickling filter. It can level flow variations and assist in solving operational problems, such as ponding, filter flies, and odors.

TABLE 9.1. Trickling Filter Classification.

Filter Class	Standard	Intermediate	High Rate	Super High Rate	Roughing
Hydraulic Loading gpd/ft ²	25–90	90–230	230–900	350–2,100	>900
Organic Loading BOD ₅ per 1,000 ft ³	5–25	15–30	25–300	Up to 300	>300
Sloughing Frequency	Seasonal	Varies	Continuous	Continuous	Continuous
Distribution	Rotary	Rotary Fixed	Rotary Fixed	Rotary	Rotary Fixed
Recirculation	No	Usually	Always	Usually	Not Usually
Media Depth, ft	6–8	6–8	3–8	Up to 40	3–20
Media type	Rock	Rock	Rock	Plastic	Rock
	Plastic	Plastic	Plastic		Plastic
	Wood	Wood	Wood		Wood
Nitrification	Yes	Some	Some	Limited	None
Filter Flies	Yes	Variable	Variable	Very few	Not Usually
BOD ₅ Removal	80–85%	50–70%	65–80%	65–85%	40–65%
TSS Removal	80–85%	50–70%	65–80%	65–85%	40–65%

- *Roughing filters*—a classification of trickling filters (see Table 9.1) in which the organic loading is in excess of 200 pounds of BOD₅ per 1,000 cubic feet of media per day. A roughing filter is used to reduce the loading on other biological treatment processes to produce an industrial discharge that can be safely treated in a municipal treatment facility.
- *Sloughing*—the process in which the excess growths break away from the media and wash through the filter to the underdrains with the wastewater. These sloughings must be removed from the flow by settling.
- *Staging*—the practice of operating two or more trickling filters in series. The effluent of one filter is used as the influent of the next. This practice can produce a higher quality effluent by removing additional BOD₅ or COD.



Figure 9.4 Zoogeal slime attached to trickling filter media (rocks).

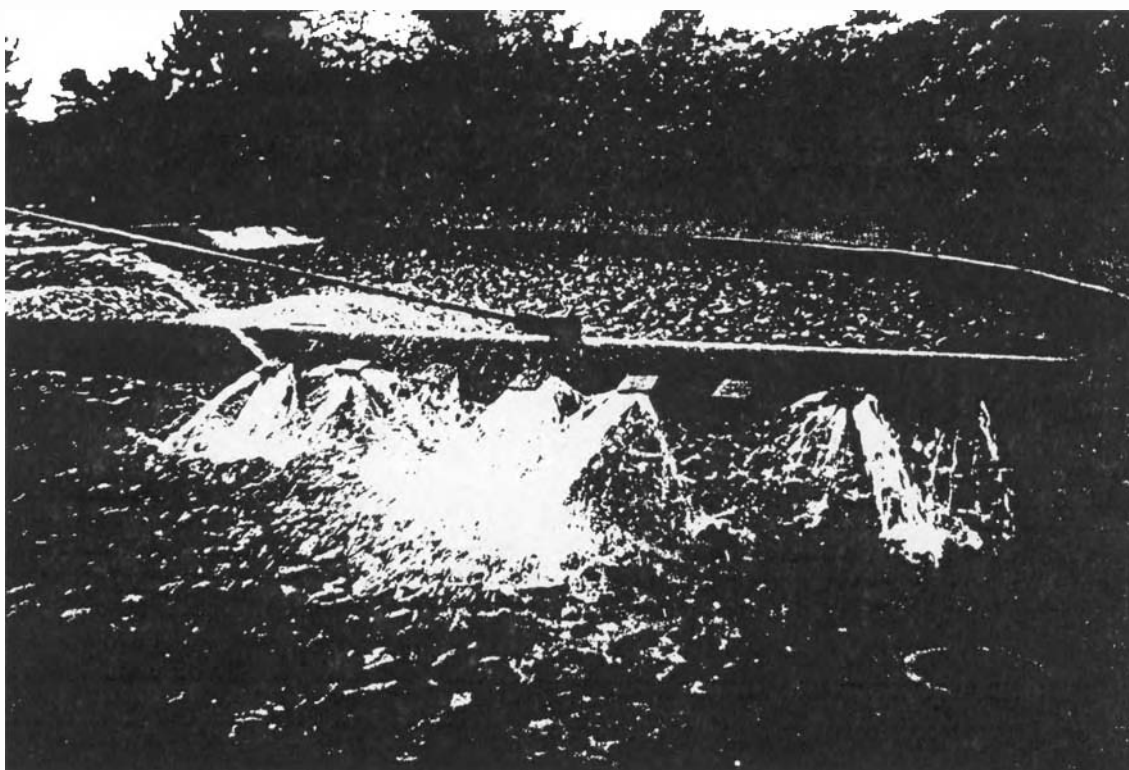
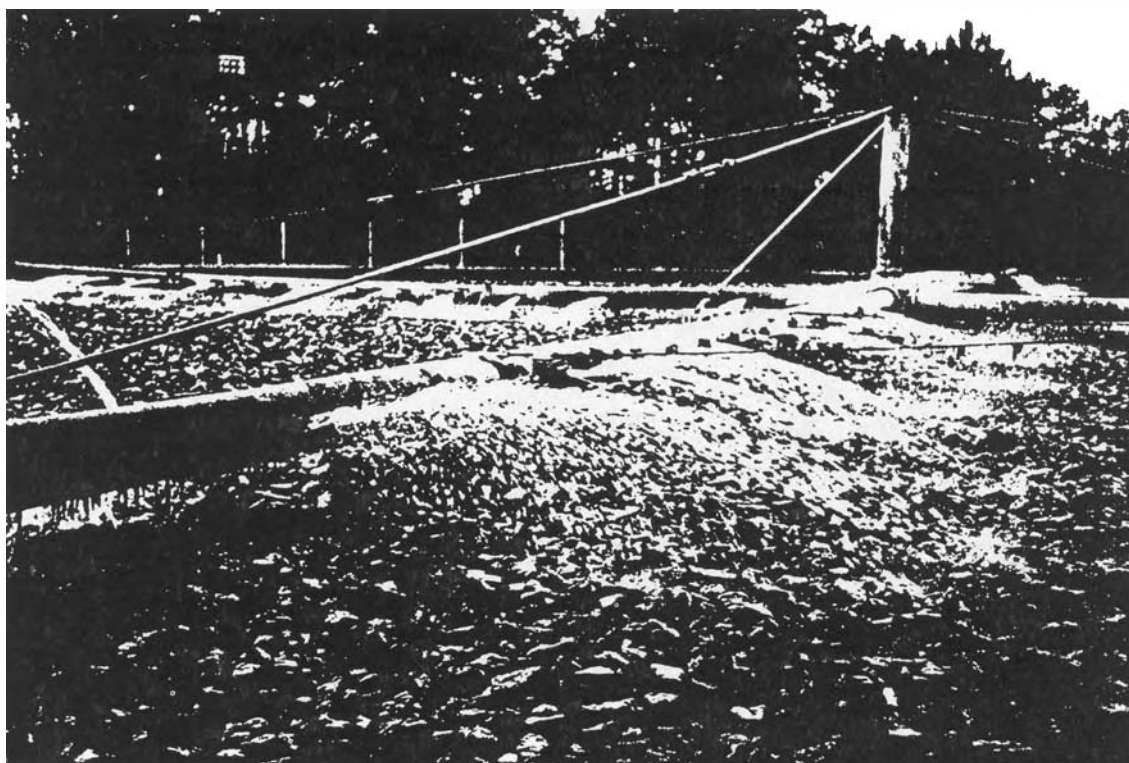


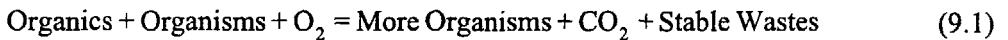
Figure 9.5 Distribution arm of trickling filter.

9.3 FILTER CLASSIFICATIONS

Trickling filters are classified by hydraulic and organic loading. The expected performance and the construction of the trickling filter are determined by the filter classification. Classification is based on depth, type of media, recirculation pattern, distribution system, dosing frequency, and the application rate. Filters are normally classified as standard, intermediate, high rate, super high rate, and/or roughing (see Table 9.1).

9.4 GENERAL PROCESS DESCRIPTION

The trickling filter process involves spraying wastewater over a solid media such as rock, plastic, or redwood slats (or laths). As the wastewater trickles over the surface of the media, a growth of microorganisms (bacteria, protozoa, fungi, algae, helminths or worms, and larvae) develops. This growth is visible as a shiny slime very similar to the slime found on rocks in a stream (see Figure 9.4). As the wastewater passes over this slime, the slime adsorbs the organic (food) matter. This organic matter is used for food by the microorganisms. At the same time, air moving through the open spaces in the filter transfers oxygen to the wastewater. This oxygen is then transferred to the slime to keep the outer layer aerobic. As the microorganisms use the food and oxygen, they produce more organisms, carbon dioxide, sulfates, nitrates, and other stable by-products (see relationship 9.1); these materials are then discarded from the slime back into the wastewater flow and are carried out of the filter.



The growth of the microorganisms and the buildup of solid wastes in the slime make it thicker and heavier. When this slime becomes too thick, the wastewater flow breaks off parts of the slime. These parts of the slime (sloughings) then travel downward through the filter to the underdrain system and must be removed in the final settling tank.

In some trickling filters, a portion of the filter effluent is returned to the head of the trickling filter to level out variations in flow and improve operations (recirculation).

9.4.1 OVERVIEW AND BRIEF SUMMARY OF TRICKLING FILTER PROCESS

- A trickling filter consists of a bed of coarse media, usually rocks or plastic, covered with microorganisms.
- ✓ *Note:* Trickling filters that use ordinary rock are normally only about 10 feet 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.
- The wastewater is applied to the media at a controlled rate, using a rotating distributor arm or fixed nozzles. Organic material is removed by contact with the microorganisms as the wastewater trickles down through the media openings. The treated wastewater is collected by an underdrain system.
- ✓ *Note:* To ensure sufficient air flow to the filter, the underdrains should never be allowed to flow more than 50% full of wastewater.
- The trickling filter is usually built into a tank that contains the media. The filter may be square, rectangular, or circular.

- The trickling filter does not provide any actual filtration. The filter media provides a large amount of surface area that the microorganisms can cling to and grow in a slime that forms on the media as they feed on the organic material in the wastewater.
- The slime growth on the trickling filter media periodically sloughs off and is settled and removed in a secondary clarifier that follows the filter.
- Key factors in trickling filter operation include the following concepts:
 - Hydraulic loading rate,

$$\frac{\text{gal/day}}{\text{sq ft}} = \frac{\text{flow, gal/day (including recirculation)}}{\text{media top surface, sq ft}}$$

—Organic loading rate,

$$\frac{\text{lb/day}}{1,000 \text{ cu ft}} = \frac{\text{BOD in filter, lb/day}}{\text{Media Vol, 1,000 cu ft}}$$

—Recirculation,

$$\text{ratio} = \frac{\text{Recirculation flow, MGD}}{\text{Ave. influent flow, MGD}}$$

9.5 OPERATOR OBSERVATIONS, PROCESS PROBLEMS, AND TROUBLESHOOTING

Trickling filter operation requires routine observation, meter readings, process control sampling and testing, and process control calculations. Comparison of daily results with expected “normal” ranges is the key to identifying problems and appropriate corrective actions.

9.5.1 OPERATOR OBSERVATIONS

- (1) *Slime*—The operator checks the thickness of slime to ensure that it is thin and uniform (normal) or thick and heavy (indicates organic overload); the operator is also concerned with ensuring that excessive recirculation is not taking place and checks slime toxicity (if any). The operator is also concerned about the color of the slime: green slime is normal; dark green/black slime indicates organic overload; other colors may indicate industrial waste or chemical additive contamination. The operator should check the subsurface growth of the slime to ensure that it is normal (thin and translucent). If growth is thick and dark, organic overload conditions are indicated. Distribution arm operation is a system function important to slime formation; it must be checked regularly for proper operation. For example, the distribution of slime should be even and uniform. Striped conditions indicate clogged orifices or nozzles.
- (2) *Flow*—Flow distribution must be checked to ensure uniformity. If non-uniform, the arms are not level or the orifices are plugged. Flow drainage is also important. Drainage should be uniform and rapid. If not, ponding may occur from media breakdown or debris on surface.
- (3) *Distributor*—Movement of the distributor is critical to proper operation of the trickling filter. Movement should be uniform and smooth. Chattering, noisy operation may indicate bearing failure. The distributor seal must be checked to ensure there is no leakage.
- (4) *Recirculation*—The operator must check the rate of recirculation to ensure that it is within design specifications. Rates above design specifications indicate hydraulic overloading; rates under design specifications indicate hydraulic underloading.

✓ *Recirculation* reduces the organic loading, improves sloughing, reduces odors, and reduces or

eliminates filter fly or ponding problems. The amount of recirculation needed depends 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.). The recirculation is always listed as the first number, and the influent flow is listed as the second number.

- ✓ *Note:* Because the second number in the ratio is always 1.0, the ratio is sometimes written as a single number (dropping the :1.0).

(5) *Media*—The operator should check to ensure that the medium is uniform.

9.5.2 PROCESS CONTROL SAMPLING AND TESTING

To ensure proper operation of the trickling filter, sampling and scheduling are important. However, for samples and the tests derived from the samples to be beneficial, operators must perform a variety of daily or variable tests. Individual tests and sampling may be needed daily, weekly, or monthly, depending on available resources and variability of the process, and for temperature readings, depending on seasonal change. Frequency may be lower during normal operations and higher during abnormal conditions.

The information gathered through collection and analysis of samples from various points in the trickling filter process is helpful in determining the current status of the process as well as identifying and correcting operational problems.

The following routine sampling points and types of tests will permit the operator to identify normal and abnormal operating conditions.

(1) *Filter influent*

Test: Dissolved oxygen
pH
Temperature
Settleable solids
BOD₅
Suspended solids
Metals

(2) *Recirculated flow*

Test: Dissolved oxygen
pH
Flow rate
Temperature

(3) *Filter effluent*

Test: Dissolved oxygen
pH
Jar tests

(4) *Process effluent*

Test: Dissolved oxygen
pH
Settleable solids
BOD₅
Suspended solids

9.5.3 TROUBLESHOOTING OPERATIONAL PROBLEMS¹

The following sections are not all-inclusive; they do not cover all of the operational problems associated with the trickling filter process. They do provide, however, information on the most common operational problems.

9.5.3.1 Ponding

Symptoms:

- small pools or puddles of water on the surface of the media
- decreased performance in the removal of BOD and TSS
- possible odors due to anaerobic conditions in the media
- poor air flow through the media

Causal Factors:

- inadequate hydraulic loading to keep the media voids flushed clear
- application of high strength wastes without sufficient recirculation to provide dilution
- non-uniform media
- degradation of the media due to aging or weathering
- medium is uniform, but is too small
- debris (moss, leaves, sticks) or living organisms (snails) that clog the void spaces

Corrective Actions:

Corrective actions are listed in increasing impact on the quality of the plant effluent.

- Remove all leaves, sticks, and other debris from the media.
- Increase recirculation of dilute, high-strength wastes to improve sloughing to keep voids open.
- Use a high-pressure stream of water to agitate and flush the ponded area.
- Rake or fork the ponded area.
- Dose the filter with chlorine solution for two to four hours. The specific dose of chlorine required will depend on the severity of the ponding problem. When using elemental chlorine, the dose must be sufficient to provide a residual at the orifices of 1–50 mg/L. If the filter is severely clogged, the higher residuals may be needed to unload the majority of the biomass. If the filter cannot be dosed by elemental chlorine, chlorinated lime or HTH powder may be used. Dosing should be in the range of 8–10 pounds of chlorine per 1,000 square feet of media.
- If the filter design permits, the filter media can be flooded for a period of four hours. Remember, if the filter is flooded, care must be taken to prevent hydraulic overloads of the final settling tank. The trickling filter should be drained slowly at low flow periods.
- Dry the media. By stopping the flow to the filter, the slime will dry and loosen. When the flow is restarted, the loosened slime will flow out of the filter. The amount of drying time will be dependent on the thickness of the slime and the amount of removal desired. Time may range from a few hours to several days.

✓ *Note:* Portions of the media can be dried without taking the filter out of service by plugging the orifices that normally service the area.

¹ Much of the information in the following sections on troubleshooting trickling filters is provided by USEPA in *Performance Evaluation and Troubleshooting at Municipal Wastewater Treatment Facilities*. Washington, DC: current edition.

- ✓ *Note:* If these corrective actions do not provide the desired improvement, the media must be carefully inspected. Remove a sample of the media from the affected area. Carefully clean it, inspect for its solidity, and determine its size uniformity (3–5 inches). If it is acceptable, the media must be carefully replaced. If the media appear to be decomposing or are not uniform, then they should be replaced.

9.5.3.2 Odors

Frequent offensive odors usually indicate an operational problem. These foul odors occur within the filter periodically and are normally associated with anaerobic conditions. Under normal circumstances, a slight anaerobic slime layer forms due to the inability of oxygen to penetrate all the way to the media. However, under normal operation, the outer slime layers will remain aerobic, and no offensive odors are produced.

Causal Factors:

- excessive organic loading due to poor filter effluent quality (recirculation); poor primary treatment operation; poor control of sludge treatment process that results in high BOD₅ recycle flows
- poor ventilation because of submerged or obstructed underdrains, flogged vent pipes, or clogged void spaces
- filter is overloaded hydraulically and/or organically
- poor housekeeping

Corrective Actions:

- Evaluate the operation of the primary treatment process. Eliminate any short circuiting. Determine any other actions that can be taken to improve the performance of the primary process.
- Evaluate and adjust control of sludge treatment processes to reduce the BOD₅ or recycle flows.
- Increase recirculation rate to add additional dissolved oxygen (DO) to filter influent. Do not increase recirculation rate if the flow rate through the underdrains would cause less than 50% open space.
- Maintain aerobic conditions in filter influent.
- Remove debris from media surface.
- Flush underdrains and vent pipes.
- Add one of the commercially available masking agents to reduce odors and prevent complaints.
- Add chlorine at a 1–2 mg/L residual for several hours at low flow. This will reduce activity and cut down on the oxygen demand. Chlorination only treats symptoms; a permanent solution must be determined and instituted.

9.5.3.3 High Clarifier Effluent Suspended Solids and/or BOD

Symptoms:

- The effluent from the trickling filter process settling unit contains a high concentration of suspended solids.

Causal Factors:

- Recirculated flows are too high, causing hydraulic overloading of the settling tank. In multiple unit operations, the flow is not evenly distributed.

- Settling tank baffles or skirts have corroded or broken.
- Sludge collection mechanism is broken or malfunctioning.
- Effluent weirs are not level.
- Short circuiting occurs because of temperature variations.
- Improper sludge withdrawal rate or frequency.
- Excessive solids loading from excessive sloughing.

Corrective Actions:

- Check hydraulic loading and adjust recirculated flow if hydraulic loading is too high.
- Adjust flow to ensure equal distribution.
- Inspect sludge removal equipment; repair broken equipment.
- Monitor sludge blanket depth and sludge solids concentration; adjust withdrawal rate and/or frequency to maintain aerobic conditions in settling tank.
- Adjust effluent weir to obtain equal flow over all parts of the weir length.
- Determine temperature in the clarifier at various points and depths throughout the clarifier. If depth temperatures are consistently 1–2°F lower than surface readings, a temperature problem exists. Baffles may be installed to help to break up these currents.
- High sloughing rates because of the biological activity or temperature changes may create excessive solids loading. Addition of 1–2 mg/L of cationic polymer may be helpful in improving solids capture. Remember, if polymer addition is used, solids withdrawal must be increased.
- High sloughings because of organic overloading, toxic wastes, or wide variations in influent flow are best controlled at their source.

9.5.3.4 Filter Flies

Symptoms:

- The trickling filter and surrounding area become populated with large numbers of very small flying insects (psychoda moths).

Causal Factors:

- poor housekeeping
- insufficient recirculation
- intermittent wet and dry conditions
- warm weather

Corrective Actions:

The corrective actions for the filter fly problem revolve around the need to disrupt the fly's life cycle (seven to 10 days in warm weather).

- Increase recirculation rate to obtain a hydraulic loading of at least 200 gpd/ft². At this rate, filter fly larvae are normally flushed out of the filter.
- Clean filter walls and remove weeds, brush, and shrubbery around the filter. This removes some of the area for fly breeding.
- Dose the filter periodically with low chlorine concentrations (less than 1 mg/L). This normally destroys larvae.
- Dry the filter media for several hours.
- Flood the filter for 24 hours.
- Spray area around the filter with insecticide. Do not use insecticide directly on the media, because of the chance of carryover and unknown effects on the slime population.

9.5.3.5 Freezing

Symptoms:

- Decreased air temperature results in visible ice formation and decreased performance.
- Distributed wastes are in a thin film or spray. This is more likely to cause ice formation.

Causal Factors:

- Recirculation causes increased temperature drops and losses.
- Strong prevailing winds cause heat losses.
- Intermittent dosing allows water to stand too long, causing freezing.

Corrective Actions:

All corrective actions are based upon a need to reduce heat loss as the wastes move through the filter.

- Reduce recirculation as much as possible to minimize cooling effects.
- Operate two stage filters in parallel to reduce heat loss.
- Adjust splash plates and orifices to obtain a coarse spray.
- Construct a wind break or plant evergreens or shrubs in the direction of the prevailing wind.
- If intermittent dosing is used, leave dump gates open.
- Cover pump wet wells and dose tanks to reduce heat losses.
- Cover filter media to reduce heat loss.
- Remove ice before it becomes large enough to cause stoppage of arms.

✓ *Note:* During periods of cold weather, the filter will show decreased performance. However, the filter should not be shut off for extended periods. Freezing of the moisture trapped within the media causes expansion and may cause structural damage.

9.5.4 PROCESS CALCULATIONS

Several calculations are useful in the operation of trickling filters: these include hydraulic loading, organic loading, and biochemical oxygen demand (BOD) and suspended solids (SS) removal. Each type of trickling filter is designed to operate with specific loading levels. These levels vary greatly depending on the filter classification. To operate the filter properly, filter loading must be within the specified levels. The main two loading parameters for the trickling filter are hydraulic loading and organic loading.

9.5.4.1 Hydraulic Loading

Calculating the hydraulic loading rate is important in accounting for both the primary effluent as well as the recirculated trickling filter effluent. These are combined before being applied to the filter surface. The hydraulic loading rate is calculated based on filter surface area.

Example 9.1

Problem:

A trickling filter 80 ft in diameter is operated with a primary effluent of 0.588 MGD and a recirculated effluent flow rate of 0.660 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, $0.588 \text{ MGD} + 0.660 \text{ MGD} = 1.248 \text{ MGD} = 1,248,000 \text{ gpd}$.

$$\text{Circular surface area} = 0.785 \times (\text{diameter})^2$$

$$= 0.785 \times (80 \text{ ft})^2$$

$$= 5,024 \text{ ft}^2$$

$$\frac{1,248,000 \text{ gpd}}{5,024 \text{ ft}^2} = 248.4 \text{ gpd / ft}^2$$

Example 9.2*Problem:*

A trickling filter 80 ft in diameter treats a primary effluent flow of 550,000 gpd. If the recirculated flow to the clarifier is 0.2 MGD, what is the hydraulic loading on the trickling filter?

Solution:

$$\begin{aligned} \text{Hydraulic loading rate} &= \frac{\text{Total Flow, gpd}}{\text{Area, sq ft}} \\ &= \frac{750,000 \text{ gpd total flow}}{(0.785)(80 \text{ ft})(80 \text{ ft})} \\ &= 149 \text{ gpd / sq ft} \end{aligned}$$

Example 9.3*Problem:*

A high-rate trickling filter receives a daily flow of 1.8 MGD. What is the dynamic loading rate in MGD/acre if the filter is 90 ft in diameter and 5 ft deep?

Solution:

$$(0.785) (90 \text{ ft}) (90 \text{ ft}) = 6,359 \text{ sq ft}$$

$$\frac{6,359 \text{ sq ft}}{43,560 \text{ sq ft / ac}} = 0.146 \text{ acres}$$

$$\text{Hydraulic Loading Rate} = \frac{1.8 \text{ MGD}}{0.146 \text{ acres}} = 12.3 \text{ MGD / ac}$$

9.5.4.2 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. In other words, the organic loading is defined as the pounds of BOD₅ or COD applied per day per 1,000 cubic feet of media—a measure of the amount of food being applied to the filter slime. To calculate the organic loading on the trickling filter, two things must be known: the pounds of BOD₅ or COD being applied to the filter media per day and the volume of the filter media in 1,000 cubic foot units. The BOD₅ and COD contribution of the recirculated flow is not included in the organic loading.

Example 9.4

Problem:

A trickling filter, 60 ft in diameter, receives a primary effluent flow rate of 0.440 MGD. Calculate the organic loading rate in units of pounds of BOD applied per day per 1,000 ft³ of media volume. The primary effluent BOD concentration is 80 mg/L. The media depth is 9 ft.

Solution:

$$0.440 \text{ MGD} \times 80 \text{ mg/L} \times 8.34 \text{ lb/gal} = 293.6 \text{ lb of BOD applied/d}$$

$$\text{Surface Area} = 0.785 \times (60)^2 = 2,826 \text{ ft}^2$$

$$\text{Area} \times \text{Depth} = \text{Volume}$$

$$2,826 \text{ ft}^2 \times 9 \text{ ft} = 25,434 \text{ (TF Volume)}$$

✓ *Note:* To determine the pounds of BOD per 1,000 ft³ in a volume of thousands of cubic feet, we must set up the equation as shown below.

$$\frac{293.6 \text{ lb BOD/d}}{25,434 \text{ ft}^3} \times \frac{1,000}{1,000}$$

Regrouping the numbers and the units together:

$$\frac{293.6 \text{ lb BOD/d} \times 1,000}{25,434 \text{ ft}^3} \times \frac{\text{lb BOD/d}}{1,000 \text{ ft}^3} = 11.5 \frac{\text{lb BOD/d}}{1,000 \text{ ft}^3}$$

9.5.4.3 BOD and SS Removed

To calculate the pounds of BOD or suspended solids removed each day, we need to know the mg/L BOD and SS removed and the plant flow.

Example 9.5

Problem:

If 120 mg/L suspended solids are removed by a trickling filter, how many lb/day suspended solids are removed when the flow is 4.0 MGD?

Solution:

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

$$(120 \text{ mg/L}) (4.0 \text{ MGD}) (8.34 \text{ lb/gal}) = 4,003 \text{ lb SS/day}$$

Example 9.6

Problem:

The 3,500,000 gpd influent flow to a trickling filter has a BOD content of 185 mg/L. If the trickling filter effluent has a BOD content of 66 mg/L, how many pounds of BOD are removed daily?

Solution:

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

$$185 \text{ mg/L} - 66 \text{ mg/L} = 119 \text{ mg/L}$$

$$(119 \text{ mg/L}) (3.5 \text{ MGD}) (8.34 \text{ lb/gal}) = 3,474 \text{ lb/day removed}$$

9.6 SUMMARY

This economical and dependable process is not the only biological process available, nor is it the best choice for every treatment plant's needs. We discuss other biological treatment processes in Chapters 10 and 11.

9.7 CHAPTER REVIEW QUESTIONS

9-1 Briefly describe the trickling filter process.

9-2 Define biomass.

9-3 What is zoogloal slime?

9-4 What is staging?

9-5 What is ponding? Describe four corrective actions that may correct the problem.

9-6 What is recirculation? What equipment is required?

- 9-7 The trickling filter shows large numbers of filter flies. List three causes and the corrective actions to take.
- 9-8 During severe cold weather, the filter experiences icing problems. List actions that could be taken to correct the problem.
- 9-9 The plant receives several complaints because of obnoxious odors. List the actions to take to identify the cause and correct the problem.
- 9-10 A trickling filter 70 ft in diameter treats a primary effluent flow of 620,000 gpd. If the recirculated flow to the trickling filter is 100,000 gpd, what is the hydraulic loading rate in gpd/sq ft on the trickling filter?
- 9-11 The total influent flow (including recirculation) to a trickling filter is 1.2 MGD. If the trickling filter is 90 ft in diameter, what is the loading rate in gpd/sq ft on the trickling filter?
- 9-12 A trickling filter 80 ft in diameter with a media depth of 6 ft receives a flow of 1,100,000 gpd. If the BOD concentration of the primary effluent is 200 mg/L, what is the organic loading on the trickling filter in lb BOD/day/1,000 cu ft?
- 9-13 A trickling filter 60 ft in diameter with a media depth of 6 ft receives a flow of 0.9 MGD. If the BOD concentration of the primary effluent is 185 mg/L, what is the organic loading on the trickling filter in BOD/day/1,000 cu ft?
- 9-14 If 120 mg/L suspended solids are removed by a trickling filter, how many lb/day suspended solids are removed when the flow is 3,150,000 gpd?
- 9-15 If 169 mg/L of BOD are removed from a trickling filter when the flow to the trickling filter is 2,750,000 gpd, how many lb/day BOD are removed?

Rotating Biological Contactors (RBCs)

10.1 INTRODUCTION

THE *rotating biological contactor (RBC)* is a biological treatment system that has been used in Europe and that, in recent years, has become an accepted method of wastewater treatment in the United States. In essence, the RBC is a variation of the attached growth idea provided by the trickling filter. 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 trickling filters.

An RBC consists of a series of closely spaced (mounted side by side), circular, plastic (synthetic) disks, typically about 11.5 ft in diameter. Attached to a rotating horizontal shaft (see Figure 10.1), approximately 40% of each disk is submersed in a tank that contains the wastewater to be treated. As the RBC rotates, the attached biomass film (zoogeleal 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 zoogeleal slime re-enters 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 cannot provide enough contact time to achieve the desired level of treatment; the resulting treatment achieved 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. 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, the level of nitrification that can be achieved by an RBC system is significant, especially when multiple stages are employed.

In an RBC system, recycling sludge is not necessary, though a secondary clarifier is needed to settle out the excess biological solids that slough off the disks as the slime layer thickens. Like the trickling filter, the efficiency of the RBC process is adversely affected by low temperatures, because the rate of metabolism of the microbes slows down when the temperature drops.

✓ *Note:* RBCs can be designed to nitrify (TKN to nitrate).

10.2 OVERVIEW OF ROTATING BIOLOGICAL CONTACTOR OPERATION

- An RBC uses a biological slime of microorganisms that grow on thin disks made of plastic mounted side by side on a shaft.
- The shaft-mounted disks are rotated slowly so that they are alternately submerged in the incoming wastewater then exposed to air. (The speed can be adjusted.)

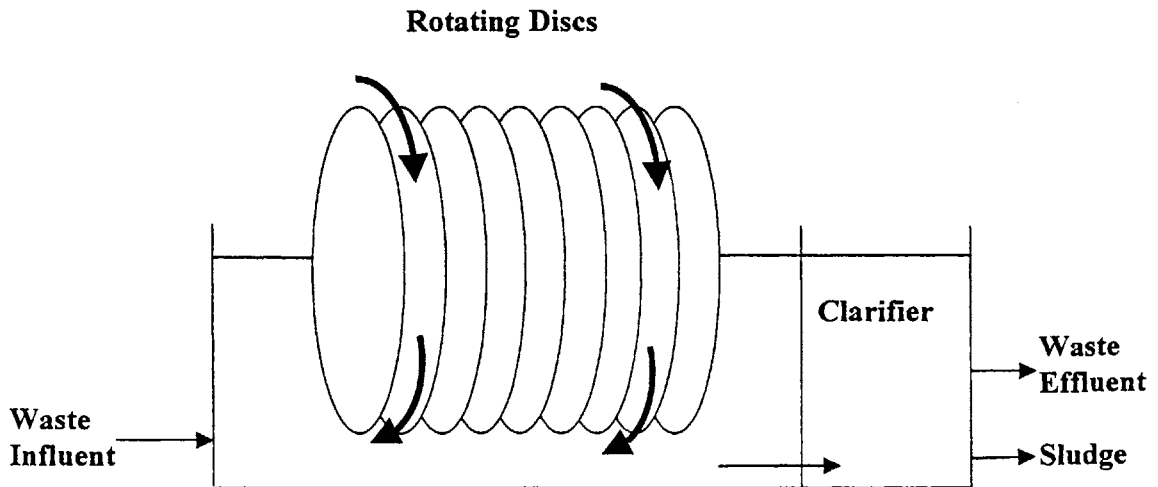


Figure 10.1 Rotating biological contactor.

- The microbes in the wastewater begin to stick to the disk surfaces and grow there until all the disks are covered with a thin layer of biological slime. The microbes get oxygen from the air as the disks are rotated.
- The excess growth breaks off from the disks and flows out to a secondary clarifier, where it is separated from the wastewater by sedimentation.
- The attached growth is similar to that of the trickling filter, except the microbes are rotated into the wastewater rather than the wastewater being distributed over the microbes.

✓ *Note:* The RBC normally produces a high-quality effluent BOD₅, 85–95%, and suspended solids removal of 85–95%. The RBC treatment process may also significantly reduce (if designed for this purpose) the levels of organic nitrogen and ammonia nitrogen.

10.3 OPERATOR OBSERVATIONS, PROCESS PROBLEMS, AND TROUBLESHOOTING

Rotating biological filter operation requires routine observation, process control sampling and testing, troubleshooting, and process control calculations. Comparison of daily results with expected “normal” ranges is the key to identifying problems and appropriate corrective actions.

10.3.1 OPERATOR OBSERVATIONS

✓ *Note:* If the RBC is covered, observations may be limited to the portion of the media that can be viewed through the access door.

- (1) *Rotation*—The operator routinely checks the operation of the RBC to ensure that smooth, uniform rotation is occurring (normal operation). Erratic, non-uniform rotation indicates a mechanical problem or uneven slime growth. If no movement is observed, mechanical problems or extreme excess of slime growth are indicated.
- (2) *Slime Color/Appearance*—Gray, shaggy slime growth on the RBC indicates normal operation. Reddish brown or golden brown shaggy growth indicates normal during nitrification. A very dark brown, shaggy growth (with worms present) indicates a very old slime. White chalky growth indicates high influent sulfur/sulfide levels. No visible slime growth on the RBC indicates a severe pH or temperature change.

10.3.2 PROCESS CONTROL SAMPLING AND TESTING

For process control, the RBC process does not require large amounts of sampling and testing to provide the information required. The frequency for performing suggested testing depends on available resources and variability of process. Frequency may be lower during normal operation and higher during abnormal conditions.

The following routine sampling points and types of tests will permit the operator to identify normal and abnormal operating conditions.

(1) *RBC train influent:*

Test: Dissolved oxygen
pH
Temperature
Settleable Solids
BOD₅
Suspended Solids
Metals

(2) *RBC:*

Test: Speed of rotation

(3) *RBC train effluent:*

Test: Dissolved oxygen
pH
Jar tests

(4) *Process effluent:*

Test: Dissolved oxygen
pH
Settleable solids
BOD₅
Suspended solids

10.3.3 TROUBLESHOOTING OPERATIONAL PROBLEMS²

The following sections are not all-inclusive; they do not cover all of the operational problems associated with the rotating biological contactor process. They do, however, provide information on the most common operational problems.

10.3.3.1 White Slime

Symptoms:

- white slime on most of the disk area

Causal Factors:

- high hydrogen sulfide in influent
- septic influent
- first stage overloaded

²Much of the information in the following sections on troubleshooting the RBC is provided by USEPA in *Performance Evaluation and Troubleshooting at Municipal Wastewater Treatment Facilities*. Washington, DC: current edition.

Corrective Actions:

- aerate RBC or plant influent
- add sodium nitrate or hydrogen peroxide to influent
- adjust baffles between stages 1 and 2 to increase fraction of total surface area in first stage

10.3.3.2 Excessive Sloughing*Symptoms:*

- loss of slime

Causal Factors:

- excessive pH variations
- toxic influent

Corrective Actions:

- implement/enforce pretreatment program
- install pH control equipment
- equalize flow to acclimate organisms

10.3.3.3 RBC Rotation*Symptoms:*

- RBC rotation is uneven

Causal Factors:

- mechanical problem
- uneven growth

Corrective Actions:

- repair mechanical problem
- increase rotational speed
- adjust baffles to decrease loading
- increase sloughing

10.3.3.4 Solids*Symptoms:*

- solids accumulating in reactors

Causal Factors:

- inadequate pretreatment

Corrective Actions:

- identify and correct grit removal problem
- identify and correct primary settling problem

10.3.3.5 Shaft Bearings

Symptoms:

- shaft bearings running hot or failing

Causal Factor:

- inadequate maintenance

Corrective Action:

- follow manufacturer's recommendations

10.3.3.6 Drive Motor

Symptoms:

- drive motor running hot

Causal Factors:

- inadequate maintenance
- improper chain drive alignment

Corrective Actions:

- follow manufacturer's recommendations
- adjust alignment

10.3.4 PROCESS CONTROL CALCULATIONS

Several process control calculations may be useful in the operation of an RBC. These include soluble BOD, total media area, organic loading rate, and hydraulic loading. Settling tank calculations and sludge pumping calculations may be helpful for evaluation and control of the settling tank following the RBC.

10.3.4.1 Soluble BOD

The *soluble BOD₅* concentration of the RBC influent can be determined experimentally in the laboratory, or it can be estimated using the suspended solids concentration and the "K" factor. The "K" factor is used to approximate the BOD₅ (particulate BOD) contributed by the suspended matter. The *K* factor must be provided or determined experimentally in the laboratory. The *K* factor for domestic wastes is normally in the range of 0.5 to 0.7.

$$\text{Soluble BOD}_5 = \text{Total BOD}_5 - (K \text{ Factor} \times \text{Total Suspended Solids}) \quad (10.1)$$

Example 10.1

Problem:

The suspended solids concentration of a wastewater is 250 mg/L. If the normal *K*-value at the plant is 0.6, what is the estimated particulate biochemical oxygen demand (BOD) concentration of the wastewater?

Solution:

✓ *Note:* The K -value of 0.6 indicates that about 60% of the suspended solids are organic suspended solids (particulate BOD).

$$(250 \text{ mg/L}) (0.6) = 150 \text{ mg/L Particulate BOD}$$

Example 10.2

Problem:

A rotating biological contactor receives a flow of 2.2 MGD with a BOD content of 170 mg/L and suspended solids (SS) concentration of 140 mg/L. If the K -value is 0.7, how many pounds of soluble BOD enter the RBC daily?

Solution:

$$\text{Total BOD} = \text{Particulate BOD} + \text{Soluble BOD}$$

$$170 \text{ mg/L} = (140 \text{ mg/L}) (0.7) + x \text{ mg/L}$$

$$170 \text{ mg/L} = 98 \text{ mg/L} + x \text{ mg/L}$$

$$170 \text{ mg/L} - 98 \text{ mg/L} = x$$

$$x = 72 \text{ mg/L Soluble BOD}$$

Now, lb/day soluble BOD may be determined:

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

$$(72 \text{ mg/L}) (2.2 \text{ MGD}) (8.34 \text{ lb/gal}) = 1,321 \text{ lb/day soluble BOD}$$

10.3.4.2 Total Media Area

Several process control calculations for the RBC use the total surface area of all the stages within the train. As was the case with the soluble BOD calculation, plant design information or information supplied by the unit manufacturer must provide the individual stage areas (or the total train area), because physical determination of this would be extremely difficult.

$$\text{Total Area} = \text{1st Stage Area} + \text{2nd Stage Area} + \dots + \text{nth Stage Area} \quad (10.2)$$

10.3.4.3 Organic Loading Rate

The *organic loading rate* can be expressed as total BOD loading in pounds per day per 1,000 square feet of media. The actual values can then be compared with plant design specifications to determine the current operating condition of the system.

$$\text{Organic Loading Rate} = \frac{\text{Sol. BOD} \times \text{Flow, MGD} \times 8.34 \text{ lb/gal}}{\text{Media Area, 1,000 sq ft}} \quad (10.3)$$

Example 10.3*Problem:*

A rotating biological contactor (RBC) has a media surface area of 500,000 sq ft and receives a flow of 1,000,000 gpd. If the soluble BOD concentration of the primary effluent is 160 mg/L, what is the organic loading on the RBC in lb/day/1,000 sq ft?

Solution:

$$\begin{aligned}
 \text{Organic Loading Rate} &= \frac{\text{Sol. BOD, lb/day}}{\text{Media Area, 1,000 sq ft}} \\
 &= \frac{(160 \text{ mg/L}) (1.0 \text{ MGD}) (8.34 \text{ lb/gal})}{500 \times 1,000 \text{ sq ft}} \\
 &= \frac{2.7 \text{ lb/day Sol. BOD}}{1,000 \text{ sq ft}}
 \end{aligned}$$

Example 10.4*Problem:*

The wastewater flow to an RBC is 3,000,000 gpd. The wastewater has a soluble BOD concentration of 120 mg/L. The RBC consists of six shafts (each 110,000 sq ft), with two shafts comprising the first stage of the system. What is the organic loading rate in lb/day/1,000 sq ft on the first stage of the system?

Solution:

$$\begin{aligned}
 \text{Organic Loading Rate} &= \frac{\text{Sol. BOD, lb/day}}{\text{Media Area, 1,000 sq ft}} \\
 &= \frac{(120 \text{ mg/L}) \times (3.0 \text{ MGD}) (8.34 \text{ lb/gal})}{220 \quad 1,000 \text{ sq ft}} \\
 &= 13.6 \text{ lb Sol. BOD/day/1,000 sq ft}
 \end{aligned}$$

10.3.4.4 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 (ft²). Hydraulic loading is expressed in terms of gallons of flow per day per square foot of media. This calculation can be helpful in evaluating the current operating status of the RBC. Comparison with design specifications can determine if the unit is hydraulically over- or underloaded. Hydraulic loading on an RBC can range from 1 to 3 gpd/ft².

Example 10.5*Problem:*

An RBC treats a primary effluent flow rate of 0.244 MGD. What is the hydraulic loading rate in gpd/ft² if the media surface area is 92,600 ft²?

Solution:

$$\frac{244,000 \text{ gpd}}{92,600 \text{ ft}^2} = 2.63 \text{ gpd / ft}^2$$

Example 10.6

Problem:

An RBC treats a flow of 3.5 MGD. The manufacturer's data indicate a media surface area of 750,000 sq ft. What is the hydraulic loading rate on the RBC?

Solution:

$$\begin{aligned} \text{Hydraulic Loading Rate} &= \frac{\text{Flow, gpd}}{\text{Media Area, sq ft}} \\ &= \frac{3,500,000 \text{ gpd}}{750,000 \text{ sq ft}} = 4.7 \text{ sq ft} \end{aligned}$$

10.4 SUMMARY

Trickling filters and RBCs have individual differences, similarities, advantages, and disadvantages. We cover the third biological treatment process (activated sludge treatment) in Chapter 11.

10.5 CHAPTER REVIEW QUESTIONS

10-1 Describe the RBC.

10-2 What makes the RBC process similar to the trickling filter?

10-3 The slime in the first stages of the RBC is gray and shaggy. The slime in the last two stages of the train is reddish brown. What does this indicate?

10-4 What happens if the RBC is exposed to a wastewater containing high amounts of hydrogen sulfide?

10-5 An RBC treats a primary effluent flow of 2.65 MGD. If the media surface area is 700,000 sq ft, what is the hydraulic loading rate in gpd/sq ft on the RBC?

- 10-6 The manufacturer data indicate a media surface area of 400,000 sq ft. An RBC treats a flow of 1.50 MGD. What is the hydraulic loading rate in gpd/sq ft on the RBC?
- 10-7 The suspended solids concentration of a wastewater is 240 mg/L. If the normal K -value at the plant is 0.5, what is the estimated particulate BOD concentration of the wastewater?
- 10-8 The wastewater entering an RBC has a BOD content of 216 mg/L. The suspended solids content is 230 mg/L. If the K -value is 0.6, what is the estimated soluble BOD (mg/L) of the wastewater?
- 10-9 An RBC has a media surface area of 850,000 sq ft and receives a flow of 4,100,000 gpd. If the soluble BOD concentration of the primary effluent is 140 mg/L, what is the organic loading rate in lb/day/1,000 sq ft on the RBC?
- 10-10 The wastewater flow to an RBC is 2,480,000 gpd. The wastewater has a soluble BOD concentration of 120 mg/L. The RBC medium has a total surface area of 620,000 sq ft. What is the organic loading rate in lb/day/1,000 sq ft on the RBC?
- 10-11 An RBC has a media surface area of 650,000 sq ft and receives a flow of 1,680,000 gpd. If the soluble BOD concentration of the primary effluent is 146 mg/L, what is the organic loading in lb/day/1,000 ft on the RBC?
- 10-12 An RBC receives a 2.5 MGD flow with a BOD concentration of 185 mg/L and suspended solids of 202 mg/L. If the K -value is 0.7, how many lb/day of soluble BOD enter the RBC?

Activated Sludge

11.1 INTRODUCTION

SIMPLY put, the *activated sludge treatment process* is a man-made process that mimics the natural self-purification process that takes place in streams. In essence, we can state that the activated sludge treatment process is a “stream within a container.”³

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 BOD₅ and suspended solids.

The basic components of an activated sludge sewage treatment system include an aeration tank and a secondary basin, settling basin, or clarifier (see Figure 11.1). Primary effluent is mixed with settled solids recycled from the secondary clarifier and is then introduced into the aeration tank. Compressed air is injected continuously into the mixture through porous diffusers located at the bottom of the tank, usually along one side.

Wastewater is fed continuously into an aerated tank, where the microorganisms metabolize and biologically flocculate the organics. Microorganisms (activated sludge) are settled from the aerated mixed liquor under quiescent conditions in the final clarifier and are returned to the aeration tank. Left uncontrolled, the number of organisms would eventually become too great; therefore, some must periodically be removed (wasted). A portion of the concentrated solids from the bottom of the settling tank must be removed from the process (waste activated sludge or WAS). Clear supernatant from the final settling tank is the plant effluent.

✓ The purpose of the secondary clarifier in an activated sludge process is to separate and return biosolids to the aeration tank.

The activated sludge process is widely used by large communities where land is expensive and where large volumes of waste must be treated efficiently and economically.

✓ *Note:* Although trickling filters and other systems cost more to build than activated sludge systems, we point out that activated sludge systems cost more to operate because they need energy to run pumps and blowers.

✓ *Note:* Activated sludge plants are capable of biochemical oxygen demand (BOD) and suspended solids removal rates of 90 to 95%.

✓ *Note:* The many variations of the activated sludge process all involve the same basic principle.

³From F. R. Spellman's *Stream Ecology and Self-Purification: An Introduction for Wastewater and Water Specialists*. Lancaster, PA: Technomic Publishing Company, Inc., 1996.

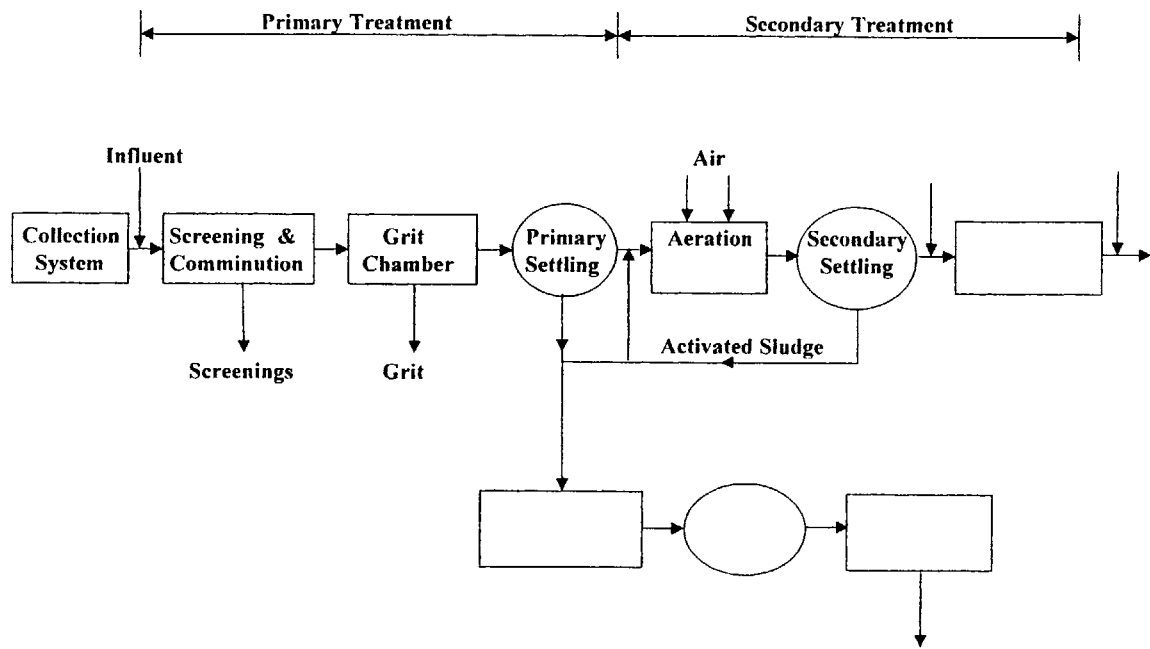


Figure 11.1 Activated sludge process and secondary settling.

11.2 ACTIVATED SLUDGE TERMINOLOGY

To better understand the discussion of the activated sludge process presented in the following sections, you must understand the terms associated with the process. Some of these terms have been used and defined earlier in the handbook, but we list them here again to refresh your memory. Review these terms and remember them. They are used throughout the discussion.

- *Absorption*—taking in or reception of one substance into the body of another by molecular or chemical actions and distribution throughout the absorber.
- *Activated*—to speed up reaction. When applied to sludge, it means that many aerobic bacteria and other microorganisms are in the sludge particles.
- *Activated sludge*—a floc or solid formed by the microorganisms. It includes organisms, accumulated food materials, and waste products from the aerobic decomposition process.
- *Activated sludge process*—a biological wastewater treatment process in which a mixture of influent and activated sludge is agitated and aerated. The activated sludge is subsequently separated from the treated mixed liquor by sedimentation and is returned to the process as needed. The treated wastewater overflows the weir of the settling tank in which separation from the sludge takes place.
- *Adsorption*—the adherence of dissolved, colloidal, or finely divided solids to the surfaces of solid bodies when they are brought into contact.
- *Aeration*—mixing air and a liquid by one of the following methods: spraying the liquid in the air; diffusing air into the liquid; or agitating the liquid to promote surface adsorption of air.
- *Aerobic*—a condition in which “free” or dissolved oxygen is present in the aquatic environment. Aerobic organisms must be in the presence of dissolved oxygen to be active.
- *Bacteria*—single-cell plants that play a vital role in stabilization of organic waste.
- *Biochemical oxygen demand (BOD)*—a measure of the amount of food available to the microorganisms in a particular waste. It is measured by the amount of dissolved oxygen used up during a specific time period (usually five days, expressed as BOD₅).

- *Biodegradable*—from “degrade” (to wear away or break down chemically) and “bio” (by living organisms). Put it all together, and you have a “substance, usually organic, which can be decomposed by biological action.”
- *Bulking*—a problem in activated sludge plants that results in poor settleability of sludge particles.
- *Coning*—a condition that may be established in a sludge hopper during sludge withdrawal, when part of the sludge moves toward the outlet while the remainder tends to stay in place. Development of a cone or channel of moving liquids surrounded by relatively stationary sludge.
- *Decomposition*—generally, in waste treatment, decomposition refers to the changing of waste matter into simpler, more stable forms that will not harm the receiving stream.
- *Diffuser*—a porous plate or tube through which air is forced and divided into tiny bubbles for diffusion in liquids. Commonly made of carborundum, aluminum, or silica sand.
- *Diffused air aeration*—a diffused air activated sludge plant takes air, compresses it, then discharges the air below the water surface to the aerator through some type of air diffusion device.
- *Dissolved oxygen*—atmospheric oxygen dissolved in water or wastewater, usually abbreviated as DO.

✓ *Note:* The typical required DO for a well-operated activated sludge plant is between 2.0 and 2.5 mg/L.

- *Facultative*—facultative bacteria can use either molecular (dissolved) oxygen or oxygen obtained from food materials. In other words, facultative bacteria can live under aerobic or anaerobic conditions.
- *Filamentous bacteria*—organisms that grow in thread or filamentous form.
- *Food-to-microorganism ratio*—a process control calculation used to evaluate the amount of food (BOD₅ or COD) available per pound of mixed liquor volatile suspended solids. This may be written as F/M ratio.

$$\frac{\text{Food}}{\text{Microorganism}} = \frac{\text{BOD, lb/day}}{\text{MLVSS, lb}} = \frac{\text{Flow, MGD} \times \text{BOD, mg/L} \times 8.34 \text{ lb/gal}}{\text{Volume, MG} \times \text{MLVSS, mg/L} \times 8.34 \text{ lb/gal}}$$

- *Fungi*—multicellular aerobic organisms.
- *Gould sludge age*—a process control calculation used to evaluate the amount of influent suspended solids available per pound of mixed liquor suspended solids.
- *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 and may also be referred to as *sludge retention rate (SRT)*.

$$\text{MCRT, days} = \frac{\text{Solids in Activated Sludge Process, lbs}}{\text{Solids Removed from Process, lb/day}}$$

- *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 (MLSS)*—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 MLSS.
- *Mixed liquor volatile suspended solids (MLVSS)*—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 normally written as MLVSS.

- *Nematodes*—microscopic worms that may appear in biological waste treatment systems.
- *Nutrients*—substances required to support plant organisms. Major nutrients are carbon, hydrogen, oxygen, sulfur, nitrogen, and phosphorus.
- *Protozoa*—single-cell animals that are easily observed under the microscope at a magnification of 100×. Bacteria and algae are prime sources of food for advanced forms of protozoa.
- *Return activated sludge*—the solids returned from the settling tank to the head of the aeration tank. This is normally written as RAS.
- *Rising sludge*—rising sludge occurs in the secondary clarifiers or activated sludge plant when the sludge settles to the bottom of the clarifier, is compacted, and then rises to the surface in relatively short time.
- *Rotifers*—multicellular animals with flexible bodies and cilia near their mouths used to attract food. Bacteria and algae are their major source of food.
- *Secondary treatment*—a wastewater treatment process used to convert dissolved or suspended materials into a form that can be removed.
- *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 (SSV₃₀ or SSV₆₀).
- *Shock load*—the arrival at a plant of a waste toxic to organisms, in sufficient quantity or strength to cause operating problems, such as odor or sloughing off of the growth of slime on the trickling filter media. Organic overloads also can cause a shock load.
- *Sludge volume index*—a process control calculation used to evaluate the settling quality of the activated sludge. Requires the SSV₃₀ and mixed liquor suspended solids test results to calculate.

$$\text{Sludge Volume Index (SVI), mL/g} = \frac{(30 \text{ min settled volume, mL/L}) (1,000 \text{ mg/g})}{\text{Mixed Liquor Suspended Solids, mg/L}}$$

- *Solids*—material in the solid state.
Dissolved—solids present in solution. Solids that will pass through a glass fiber filter.
Fixed—also known as the inorganic solids. The solids that are left after a sample is ignited at 550° Celsius (centigrade) for 15 minutes.
Floatable solids—solids that will float to the surface of still water, sewage, or other liquid. Usually composed of grease particles, oils, light plastic material, etc. Also called *scum*.
Non-settleable—finely divided suspended solids that will not sink to the bottom in still water, sewage, or other liquid in a reasonable period, usually two hours. Non-settleable solids are also known as colloidal solids.
Suspended—the solids that will not pass through a glass fiber filter.
Total—the solids in water, sewage, or other liquids; it includes the suspended solids and dissolved solids.
Volatile—the organic solids. Measured as the solids that are lost on ignition of the dry solids at 550° Celsius (centigrade).
- *Waste activated sludge*—the solids being removed from the activated sludge process. This is normally written as WAS.

11.3 OVERVIEW OF ACTIVATED SLUDGE PROCESS

The activated sludge process is a treatment technique in which wastewater and reused biological sludge full of living microorganisms are mixed and aerated. The biological solids are then separated from the treated wastewater in a clarifier and are returned to the aeration process or wasted.

The microorganisms are mixed thoroughly with the incoming organic material, and they grow and reproduce by using the organic material as food. As they grow and are mixed with air, the individual organisms cling together (flocculate). Once flocculated, they more readily settle in the secondary clarifiers.

The wastewater being treated flows continuously into an aeration tank where air is injected to mix the wastewater with the returned activated sludge and to supply the oxygen needed by the microbes to live and feed on the organics. Aeration can be supplied by injection through air diffusers in the bottom of tank or by mechanical aerators located at the surface.

The mixture of activated sludge and wastewater in the aeration tank is called the “mixed liquor.” The mixed liquor flows to a secondary clarifier where the activated sludge is allowed to settle.

The activated sludge is constantly growing, and more is produced than can be returned for use in the aeration basin. Some of this sludge must, therefore, be wasted to a sludge handling system for treatment and disposal. The volume of sludge returned to the aeration basins is normally 40 to 60% of the wastewater flow. The rest is wasted.

✓ Removal of nutrients may require inclusion of anaerobic and/or anoxic stages.

11.4 ACTIVATED SLUDGE PROCESS: FACTORS AFFECTING OPERATION

A number of factors affect the performance of an activated sludge system. These include the following:

- 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.

To fully appreciate and understand the biological process taking place in a normally functioning activated sludge process, the operator must have knowledge of the key players in the process: the organisms. This makes a certain amount of sense when you consider that the heart of the activated sludge process is the mass of settleable solids formed by aerating wastewater containing biological degradable compounds in the presence of microorganisms. Activated sludge consists of organic solids plus bacteria, fungi, protozoa, rotifers, and nematodes.

11.4.1 GROWTH CURVE

To understand the microbiological population and its function in an activated sludge process, the operator must be familiar with the microorganism *growth curve* (see Figure 11.2).

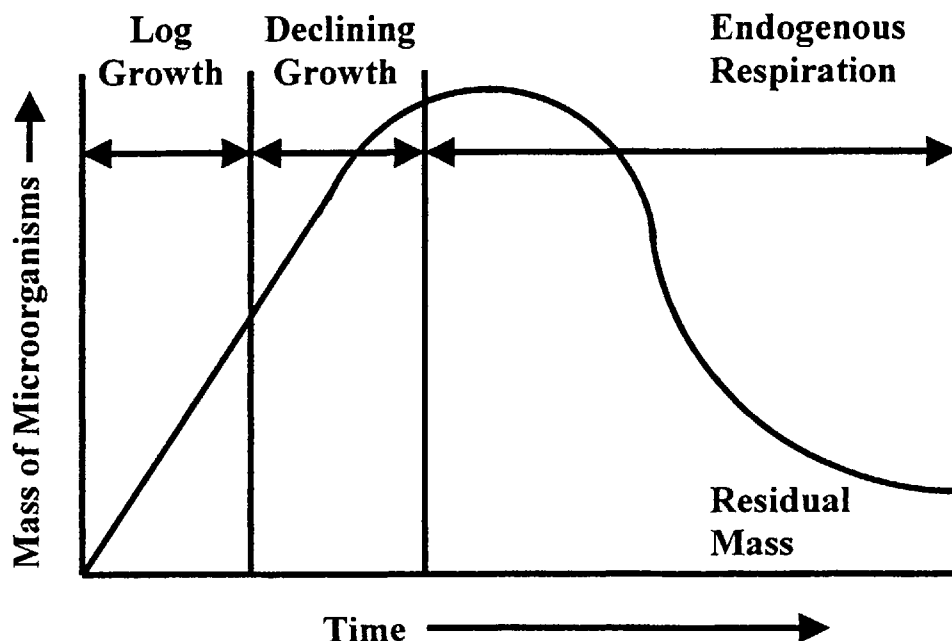


Figure 11.2 Microorganism growth curve.

In the presence of excess organic matter, the microorganisms multiply at a fast rate. The demand for food and oxygen is at its peak. Most of this is used for the production of new cells. This condition is known as the *log growth phase* (see Figure 11.2).

As time continues, the amount of food available for the organisms declines. Floc begins to form while the growth rate of bacteria and protozoa begins to decline. This is referred to as the *declining growth phase* (see Figure 11.2).

The *endogenous respiration* phase occurs as the food available becomes extremely limited and the organism mass begins to decline (see Figure 11.2). Some of the microorganisms may die and break apart, thus releasing organic matter that can be consumed by the remaining population.

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 are suspended in a liquid medium containing dissolved oxygen.

✓ *Note:* Air requirements in an activated sludge basin are governed by (1) biological oxygen demand (BOD) loading and the desired removal effluent; (2) volatile suspended solids concentration in the aerator; and (3) suspended solids concentration of the primary effluent.

11.5 ACTIVATED SLUDGE FORMATION

The formation of activated sludge is dependent on three steps. The first step is the transfer of food from wastewater to the organism. Second is the conversion of wastes to a usable form. Third is the flocculation step.

(1) *Transfer*—Organic matter (food) is transferred from the water to the organisms. Soluble material

is absorbed directly through the cell wall. Particulate and colloidal matter is adsorbed to the cell wall, where it is broken down into simpler soluble forms, then absorbed through the cell wall.

- (2) *Conversion*—Food matter is converted to cell matter by synthesis and oxidation into end products such as CO_2 , H_2O , NH_3 , stable organic waste, and new cells.
- (3) *Flocculation*—Flocculation is the gathering of fine particles into larger particles. This process begins in the aeration tank and is the basic mechanism for removal of suspended matter in the final clarifier. The concentrated *bio-floc* that settles and forms the sludge blanket in the secondary clarifier is known as activated sludge.

11.6 ACTIVATED SLUDGE: PERFORMANCE-CONTROLLING FACTORS

To maintain the working organisms in the activated sludge process, the operator must ensure that a suitable environment is maintained by being aware of the many factors influencing the process and by monitoring them repeatedly. “Control” is defined as maintaining the proper solids (floc mass) concentration in the aerator for the incoming water (food) flow by adjusting the return and waste sludge pumping rate and regulating the oxygen supply to maintain a satisfactory level of dissolved oxygen in the process.

11.6.1 AERATION

The activated sludge process must receive sufficient aeration to keep the activated sludge in suspension and to satisfy the organism oxygen requirements. Insufficient mixing results in dead spots, septic conditions, and/or loss of activated sludge.

11.6.2 ALKALINITY

The activated sludge process requires sufficient alkalinity to ensure that pH remains in the acceptable range of 6.5 to 9.0. If organic nitrogen and ammonia are being converted to nitrate (nitrification), sufficient alkalinity must be available to support this process as well.

11.6.3 NUTRIENTS

The microorganisms of the activated sludge process require nutrients (nitrogen, phosphorus, iron, and other trace metals) to function. If sufficient nutrients are not available, the process will not perform as expected. The accepted minimum ratio of carbon to nitrogen, phosphorus, and iron is 100 parts carbon to five parts nitrogen, one part phosphorus, and 0.5 parts iron.

11.6.4 pH

The pH of the mixed liquor should be maintained within the range of 6.5 to 9.0 (6.0 to 8.0 is ideal). Gradual fluctuations within this range will normally not upset the process. Rapid fluctuations or fluctuations outside this range can reduce organism activity.

11.6.5 TEMPERATURE

As temperature decreases, activity of the organisms will also decrease. Cold temperatures also require longer recovery time for systems that have been upset. Warm temperatures tend to favor denitrification and filamentous growth.

- ✓ *Note:* The activity level of bacteria within the activated sludge process increases with rise in temperature.

11.6.6 TOXICITY

Sufficient concentrations of elements or compounds that enter a treatment plant that have the ability to kill the microorganisms (the activated sludge) are known as toxic waste (shock load). Common to this group are cyanides and heavy metals.

- ✓ *Note:* A typical example of a toxic substance added by operators is the uninhibited use of chlorine for odor control or control of filamentous organisms (pre-chlorination). Chlorination is for disinfection. Chlorine is a toxicant and should not be allowed to enter the activated sludge process; it is not selective with respect to type of organisms damaged or killed. It may kill the organisms that should be retained in the process as workers. However, chlorine is very effective in disinfecting the plant effluent after treatment by the activated sludge process.

11.6.7 HYDRAULIC LOADING

Hydraulic loading is the amount of flow entering the treatment process. When compared with the design capacity of the system, it can be used to determine if the process is hydraulically overloaded or underloaded. If more flow is entering the system than it was designed to handle, the system is hydraulically overloaded. If less flow is entering the system than it was designed for, the system is hydraulically underloaded. Generally, the system is more affected by overloading than by underloading.

Overloading can be caused by stormwater, infiltration of groundwater, excessive return rates, or many other causes. Underloading normally occurs during periods of drought or in the period following initial startup when the plant has not reached its design capacity.

Excess hydraulic flow rates through the treatment plant will reduce the efficiency of the clarifier by allowing activated sludge solids to rise in the clarifier and pass over the effluent weir. This loss of solids in the effluent degrades effluent quality and reduces the amount of activated sludge in the system, in turn, reducing process performance.

11.6.8 ORGANIC LOADING

Organic loading is the amount of organic matter entering the treatment plant. It is usually measured as biochemical oxygen demand (BOD). An organic overload occurs when the amount of BOD entering the system exceeds the design capacity of the system. An organic underload occurs when the amount of BOD entering the system is significantly less than the design capacity of the plant.

Organic overloading may occur when the system receives more waste than it was designed to handle. It can also occur when an industry or other contributor discharges more wastes to the system than originally planned. Wastewater treatment plant processes can also cause organic overloads by returning high-strength wastes from the sludge treatment processes.

Regardless of the source, an organic overloading of the plant results in increased demand for oxygen. This demand may exceed the air supply available from the blowers. When this occurs, the activated sludge process may become septic.

Excessive wasting can also result in a type of organic overload. The food available exceeds the number of activated sludge organisms, resulting in increased oxygen demand and very rapid growth.

Organic underloading may occur when a new treatment plant is initially put into service. The facility may not receive enough waste to allow the plant to operate at its design level. Underloading can also occur when excessive amounts of activated sludge are allowed to remain in the system. When this occurs, the plant will have difficulty in developing and maintaining a good activated sludge.

11.7 ACTIVATED SLUDGE MODIFICATIONS

First developed in 1913, the original activated sludge process has been modified over the years to provide better performance for specific operating conditions or with different influent waste characteristics.

11.7.1 CONVENTIONAL ACTIVATED SLUDGE

- Employing the conventional activated sludge modification requires primary treatment.
- Conventional activated sludge provides excellent treatment; however, large aeration tank capacity is required, and construction costs are high.
- In operation, initial oxygen demand is high. The process is also very sensitive to operational problems (e.g., bulking).

11.7.2 STEP AERATION

- Step aeration requires primary treatment.
- It provides excellent treatment.
- Operation characteristics are similar to conventional.
- It distributes organic loading by splitting influent flow.
- It reduces oxygen demand at the head of the system.
- It reduces solids loading on settling tank.

11.7.3 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.

✓ *Note:* During the complete mix, activated sludge process organisms are in declining phase on growth curve (Section 11.4.1).

11.7.4 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.

11.7.5 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.

11.7.6 EXTENDED AERATION

- Does not require primary treatment.
- Used frequently for small flows such as schools and subdivisions.
- Uses 24-hour aeration.
- Produces low BOD₅ effluent.
- Produces the least amount of waste activated sludge.
- Process is capable of achieving 95% or more removals of BOD₅.
- Can produce effluent low in organic and ammonia nitrogen.

11.7.7 OXIDATION DITCH

- Does not require primary treatment.
- The oxidation ditch process is similar to the extended aeration process.

11.8 ACTIVATED SLUDGE: PROCESS CONTROL PARAMETERS

In operating an activated sludge process, the operator must be familiar with the many important process control parameters, which must be monitored frequently and adjusted occasionally to maintain optimal performance.

11.8.1 ALKALINITY

Monitoring alkalinity in the aeration tank is essential to control of the process. Insufficient alkalinity will reduce organism activity and may result in low effluent pH and, in some cases, extremely high chlorine demand in the disinfection process.

11.8.2 DISSOLVED OXYGEN (DO)

The activated sludge process is an aerobic process that requires some dissolved oxygen be present at all times. The amount of oxygen required is dependent on the influent food (BOD), the activity of the activated sludge, and the degree of treatment desired.

11.8.3 pH

Activated sludge microorganisms can be injured or destroyed by wide variations in pH. The pH of the aeration basin will normally be in the range of 6.5 to 9.0. Gradual variations within this range will not cause any major problems; however, rapid changes of one or more pH units can have a significant impact on performance. Industrial waste discharges, septic wastes, or significant amounts of stormwater flows may produce wide variations in pH.

pH should be monitored as part of the routine process control testing schedule. Sudden changes or abnormal pH values may indicate an industrial discharge of strongly acidic or alkaline wastes.

Because these wastes can upset the environmental balance of the activated sludge, the presence of wide pH variations can result in poor performance.

Processes undergoing nitrification may show a significant decrease in effluent pH.

11.8.4 MIXED LIQUOR SUSPENDED SOLIDS (MLSS)/MIXED LIQUOR VOLATILE SUSPENDED SOLIDS (MLVSS)/MIXED LIQUOR TOTAL SUSPENDED SOLIDS (MLTSS)

The MLSS or MLVSS can be used to represent the activated sludge or microorganisms present in the process. Process control calculations, such as sludge age and sludge volume index, cannot be calculated unless the MLSS is determined.

Adjust the MLSS and MLVSS by increasing or decreasing the waste sludge rates.

The mixed liquor total suspended solids or MLTSS is an important activated sludge control parameter. To increase the MLTSS, for example, the operator must decrease the waste rate and/or increase the MCRT. The MCRT must be decreased to prevent the MLTSS from changing when the number of aeration tanks in service are reduced.

✓ In performing the Gould Sludge Age test, assume that the source of the MLTSS in the aeration tank is influent solids.

11.8.5 RETURN ACTIVATED SLUDGE RATE AND CONCENTRATION

The sludge rate is a critical control variable. The operator must maintain a continuous return of activated sludge to the aeration tank or the process will show a drastic decrease in performance. If the rate is too low, solids remain in the settling tank, resulting in solids loss and a septic return. If the rate is too high, the aeration tank can become hydraulically overloaded, causing reduced aeration time and poor performance.

The return concentration is also important because it may be used to determine the return rate required to maintain the desired MLSS.

11.8.6 WASTE-ACTIVATED SLUDGE FLOW RATE

Because the activated sludge contains living organisms that grow, reproduce, and produce waste matter, the amount of activated sludge is continuously increasing. If the activated sludge is allowed to remain in the system too long, the performance of the process will decrease. If too much activated sludge is removed from the system, the solids become very light and will not settle quickly enough to be removed in the secondary clarifier.

11.8.7 TEMPERATURE

Because temperature directly affects the activity of the microorganisms, accurate monitoring of temperature can be helpful in identifying the causes of significant changes in organism populations or process performance.

11.8.8 SLUDGE BLANKET DEPTH

The separation of solids and liquid in the secondary clarifier results in a blanket of solids. If solids are not removed from the clarifier at the same rate they enter, the blanket will increase in depth. If this occurs, the solids may carry over into the process effluent. The sludge blanket depth may be affected by other conditions, such as temperature variation, toxic wastes, or sludge bulking.

The best sludge blanket depth is dependent upon such factors as hydraulic load, clarifier design,

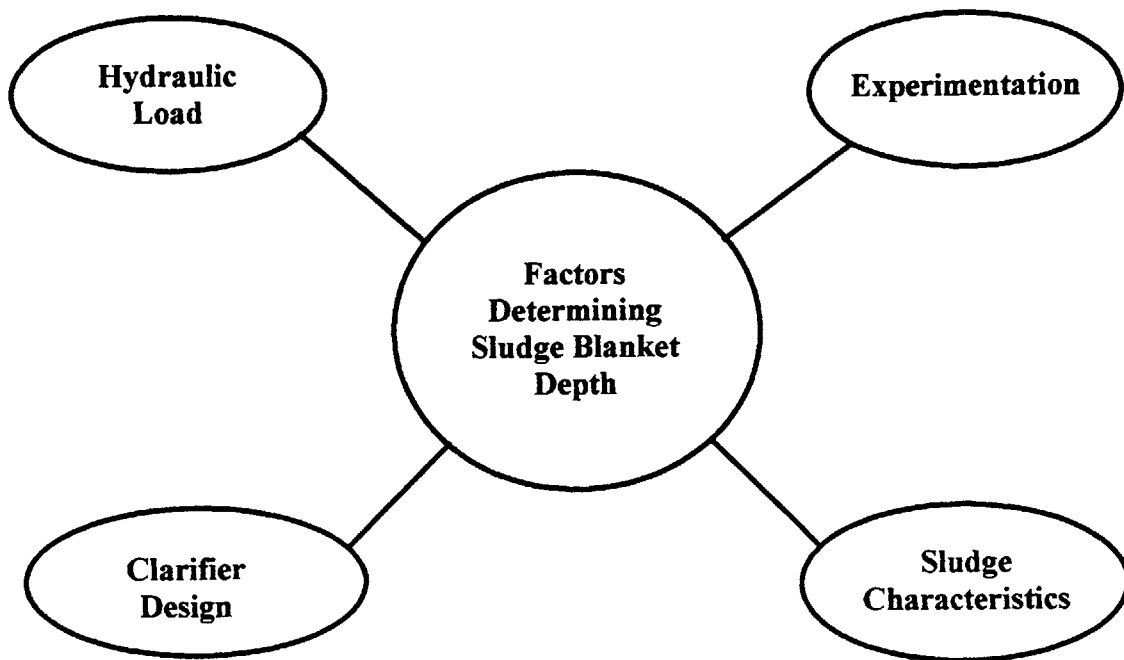


Figure 11.3 Sludge blanket depth.

sludge characteristics, and many more (see Figure 11.3). The best blanket depth must be determined on an individual basis by experimentation.

✓ *Note:* In measuring sludge blanket depth, it is general practice to use a 15–20 ft long clear plastic pipe marked at six-inch intervals; the pipe is equipped with a ball valve at the bottom.

11.9 OPERATIONAL CONTROL LEVELS⁴

The operator has two methods available to operate an activated sludge system. The operator can wait until the process performance deteriorates and make drastic changes, or the operator can establish *normal* operational levels and make minor adjustments to keep the process within the established operational levels.

✓ *Note:* *Control levels* can be defined as the upper and lower values for a process control variable that can be expected to produce the desired effluent quality.

While no method will guarantee plant performance will always be maintained within effluent limitations, the second method has a much higher probability of achieving this objective. This section discusses methods used to establish *normal* control levels for the activated sludge system.

Several major factors should be considered when establishing control levels for the activated sludge system. These include the following:

- influent characteristics
- industrial contributions
- process sidestreams

⁴Much of the information in this section is from *Activated Sludge Process Control, Part II*, 2nd ed. Richmond, VA: Virginia Water Control Board, 1990.

- seasonal variations
- required effluent quality

11.9.1 INFLUENT CHARACTERISTICS

Influent characteristics and their potential impact on plant performance were discussed earlier in Section 11.6 (performance controlling factors) and in Volumes 1 and 2 of the handbook.

A major area to consider when evaluating influent characteristics is the nature and volume of industrial contributions to the system. Waste characteristics (BOD₅, solids, pH, metals, toxicity, temperature), volume, and discharge pattern (continuous, slug, daily, weekly, etc.) should be evaluated when determining if a waste will require pretreatment by the industry or adjustments to operational control levels.

11.9.2 INDUSTRIAL CONTRIBUTORS

A significant portion of the plant loading (in many systems) is produced by one or more industrial contributors. Identifying and characterizing all industrial contributors is important. Remember, the volume of waste generated may not be as important as the characteristics of the waste. Extremely high-strength wastes can result in organic overloading and/or poor performance because of insufficient nutrient availability.

A second consideration is the presence of materials that even in small quantities are toxic to the process microorganisms or that create a toxic condition in the plant effluent or plant sludges.

Industrial contributions to a biological treatment system should be thoroughly characterized prior to acceptance, monitored frequently, and controlled by either local ordinance or by implementation of a pretreatment program.

11.9.3 PROCESS SIDESTREAMS

Process sidestreams are flows produced in other treatment processes that must be returned to the wastewater system for treatment prior to disposal. Examples of process sidestreams include the following:

- thickener supernatant
- aerobic and anaerobic digester supernatant
- liquids removed by sludge dewatering processes (filtrate, centrate, and subnate)
- supernatant from heat treatment and chlorine oxidation sludge treatment processes

Testing these flows periodically to determine both their quantity and strength is important. In many treatment systems, a significant part of the organic and/or hydraulic loading for the plant is generated by sidestream flows. The contribution of the plant sidestream flows can significantly change the operational control levels of the activated sludge system.

11.9.4 SEASONAL VARIATIONS

Seasonal variations in temperature, oxygen solubility, organism activity, and waste characteristics may require several *normal* control levels for the activated sludge process. For example, during cold months of the year, aeration tank solids levels may have to be maintained at significantly higher levels than are required during warm weather. Likewise, the aeration rate may be controlled by the mixing requirements of the system during the colder months and by the oxygen demand of the system during the warm months.

11.9.5 CONTROL LEVELS AT STARTUP

Control levels for an activated sludge system during startup are usually based upon design engineer recommendations or information available from recognized reference sources.

Although these levels provide a starting point, you should recognize that both the process control parameter sensitivity and control levels should be established on a plant-by-plant basis.

During the first 12 months of operation, you should evaluate all potential process control options, to determine the following:

- sensitivity to effluent quality changes
- seasonal variability
- potential problems

11.10 OPERATOR 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, the operator should look for three physical indicators (turbulence, surface foam and scum, and sludge color and odor), which aid in determining how the process is operating and indicate if any operational adjustments should be made.

This information should be recorded each time operational tests are performed. We summarize aeration tank and secondary settling tank observations in the following sections. Remember that many of these observations are very subjective and must be based upon experience. Plant personnel must be properly trained on the importance of ensuring that recorded information is consistent throughout the operating period.

11.10.1 VISUAL INDICATORS: INFLUENT AND/OR AERATION TANK

11.10.1.1 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.

11.10.1.2 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 the following:

- *Fresh, crisp, white foam*—a moderate amount of a crisp white foam is usually associated with activated sludge processes 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; high mixed liquor concentration; waste rate too high.
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.

11.10.1.3 Sludge Color and Odor

Though not as reliable an indicator of process operations as foam, sludge color and odor are also useful indicators. Colors and odors that are important include the following:

- (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; low dissolved oxygen concentration; air flow rate too low.
Adjustment: Increase aeration.

11.10.1.4 Mixed Liquor Color

A light chocolate brown mixed liquor color indicates a well-operated activated sludge process.

11.10.2 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 are 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 is the result of an over-oxidized sludge.

✓ *Note:* Settled activated sludge is generally thinner than raw sludge.

11.11 PROCESS CONTROL TESTING AND SAMPLING

The activated sludge process generally requires more sampling and testing to maintain adequate process control than any of the other unit processes in the wastewater treatment system. During periods of operational problems, both the parameters tested and the frequency of testing may increase substantially.

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; BOD₅ and/or chemical oxygen demand (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 many of the common process control tests.

11.11.1 AERATION INFLUENT SAMPLING

11.11.1.1 pH

pH is tested daily with a sample taken from the aeration tank influent. pH is normally close to 7.0 with the best pH range from 6.5 to 8.5 (however, a pH range of 6.5 to 9.0 is satisfactory). A pH of >9.0 may indicate toxicity from an industrial waste contributor. A pH of <6.5 may indicate loss of flocculating organisms; potential toxicity; industrial waste contributor; or acid rain storm flow.

11.11.1.2 Temperature

Temperature is important because it forecasts the following:

- (1) Temperature increases: organism activity increases, aeration efficiency decreases, and oxygen solubility decreases.
- (2) Temperature decreases: organism activity decreases, aeration efficiency increases, and oxygen solubility increases.

11.11.1.3 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.

11.11.1.4 Alkalinity

Alkalinity is essential to biological activity. Nitrification needs 7.3 mg/L alkalinity per mg/L TKN.

11.11.1.5 BOD₅

Testing showing an increase in BOD₅ indicates increased organic loading; a decrease in BOD₅ indicates decreased organic loading.

11.11.1.6 Total Suspended Solids (TSS)

An increase in total suspended solids indicates an increase in organic loading; a decrease in TSS indicates a decrease in organic loading.

11.11.1.7 Total Kjeldahl Nitrogen

Total Kjeldahl nitrogen determination is required to monitor process nitrification status and to determine alkalinity requirements.

11.11.1.8 Ammonia Nitrogen

Determination of ammonia nitrogen is required to monitor process nitrification status.

11.11.1.9 Metals

Metal contents are measured to determine toxicity levels.

11.11.2 AERATION TANK

11.11.2.1 pH

Normal pH range in the aeration tank is 6.5 to 9.0. pH decreases indicate process sidestreams or insufficient alkalinity available.

11.11.2.2 Dissolved Oxygen (DO)

Normal DO range in an aeration tank is 1 to 3 mg/L. Dissolved oxygen level decreases may indicate increased activity, increased temperature, increased organic loading, or decreased MLSS/MLVSS. An increase in dissolved oxygen could be indicative of decreased activity, decreased temperature, decreased organic loading, increased MLSS/MLVSS, or influent toxicity.

11.11.2.3 Dissolved Oxygen Profile

All dissolved oxygen profile readings should be >0.5 mg/L. Readings of <0.5 mg/L indicate inadequate aeration or poor mixing.

11.11.2.4 Mixed Liquor Suspended Solids (MLSS)

The range of mixed liquor volatile suspended solids is determined by the process modification used (see Section 11.7). When MLSS levels increase, more solids, organisms, and an older, more oxidized sludge are typical.

11.11.2.5 Microscopic Examination

Because the activated sludge process is incapable of operating without microscopic organisms, monitoring the microorganisms present within the aeration basins is important. Microscopic examination of an aeration basin sample is also used to determine the predominant type of microorganisms. Different species prefer different conditions; therefore, the presence of a predominant species is indicative of process conditions.

✓ *Note:* Let us point out that during microscopic examination, identifying all organisms present is not necessary; identification of the predominant species is required.

Table 11.1 lists process conditions indicated by the presence of certain microorganisms.

11.11.2.5.1 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

TABLE 11.1. Process Condition versus Organisms Present/Population.

Process Condition	Organism Population
Poor BOD ₅ and TSS Removal	Predominance of amoebas and flagellates
No floc formation	Mainly dispersed bacteria
Very cloudy effluent	A few ciliates present
Poor Quality Effluent	Predominance of amoebas and flagellates
Dispersed bacteria	Some free-swimming ciliates
Some floc formation	
Cloudy effluent	
Satisfactory Effluent	Predominance of free-swimming ciliates
Good floc formation	Few amoebas and flagellates
Good settleability	
Good clarity	
High-Quality Effluent	Predominance of stalked ciliates
Excellent floc formation	Some free-swimming ciliates
Excellent settleability	A few rotifers
High effluent clarity	A few flagellates
Effluent High TSS and Low BOD ₅	Predominance of rotifers
High settled sludge volume	Large numbers of stalked ciliates
Cloudy effluent	A few free-swimming ciliates
	No flagellates

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 microorganisms in the activated sludge. They perform most of the stabilization or oxidization of the organic matter and are normally present in extremely large numbers. They are not, however, normally visible with a conventional microscope operating at the recommended magnification and are not included in the Table 11.1 list of indicator organisms.

✓ *Note:* The presence of free-swimming and stalked ciliates, some flagellates, and rotifers in mixed liquor indicate a balanced, properly settling environment.

11.11.2.5.1.1 PROTOZOA

Protozoa are secondary feeders in the activated sludge process (secondary as feeders, but nonetheless definitely 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 protozoa in the activated sludge process consider the following explanation.⁵

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 present. At the start of the activated process (or recovery from an upset condition), the amoebas dominate.

⁵From F. R. Spellman, *Microbiology for Water/Wastewater Operators*. Lancaster, PA: Technomic Publishing Company, Inc., pp. 70–75, 1997.

- ✓ *Note:* Amoebas have very flexible cell walls and move by shifting fluids within the cell wall. Amoebas predominate during process startup 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” that they use 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 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 bacteria increase. 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 a large number of dispersed bacteria are present that can be used as food. Their predominance indicates a process nearing optimum conditions and effluent quality.

The process continues 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. Protozoan succession is also based on other factors, including dissolved oxygen and food availability.

Probably the best way 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 in relation to the self-purification process that takes place in a stream, you are 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. 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 for their insatiable appetites for bacteria and 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 importantly, 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 have several cilia that are used to create currents, which carry bacteria and organic matter to it. The stalked ciliated protozoa predominate when the dispersed bacteria population decreases and does not provide sufficient food for the free swimmers. Their predominance indicates a stable process, 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.

11.11.2.5.1.2 ROTIFERS

Rotifers are a higher life form normally associated with clean, unpolluted waters. Significantly larger than most of the other organisms observed in activated sludge, rotifers 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 BOD₅.

11.11.2.5.1.3 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, a predominance of amoebas indicates that the activated sludge is very young.

11.11.3 SETTLING TANK INFLUENT

11.11.3.1 Dissolved Oxygen

The dissolved oxygen level of the activated sludge settling tank should be 1 to 3 mg/L; lower levels may result in rising sludge.

11.11.3.2 pH

Normal pH range in an activated sludge settling tank should be maintained between 6.5 to 9.0. Decreases in pH may indicate alkalinity deficiency.

11.11.3.3 Alkalinity

A lack of alkalinity in an activated sludge settling tank will prevent nitrification.

11.11.3.4 Total Suspended Solids

MLSS sampling and testing is required for determining solids loading, mass balance, and return rates.

11.11.3.5 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 (SSV₃₀ and SSV₆₀) indicate settling time.

- “Normal” operation—When the process is operating properly, the solids will settle as a “blanket” (a mass), with 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, with 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 settle as discrete particles, and the boundary between the solids and the liquid is poorly defined. Large amounts of small visible solids are 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, very little or no settling is observed.

$$\text{SSV} = \frac{\text{Milliliters of Settled Sludge } 1,000 \text{ mL/L}}{\text{Milliliters of Sample}} \quad (11.1)$$

$$\% \text{SSV} = \frac{\text{Milliliters of Settled Sludge} \times 100}{\text{Milliliters of Sample}} \quad (11.2)$$

- ✓ 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 (see Figure 11.4).

11.11.3.6 Flow

Monitoring flow in settling tank influent is important for determination of mass balance.

11.11.3.7 Jar Tests

Jar tests are performed as required on settling tank influent and are beneficial in determining the best flocculant aid and appropriate doses to improve solids capture during periods of poor settling.

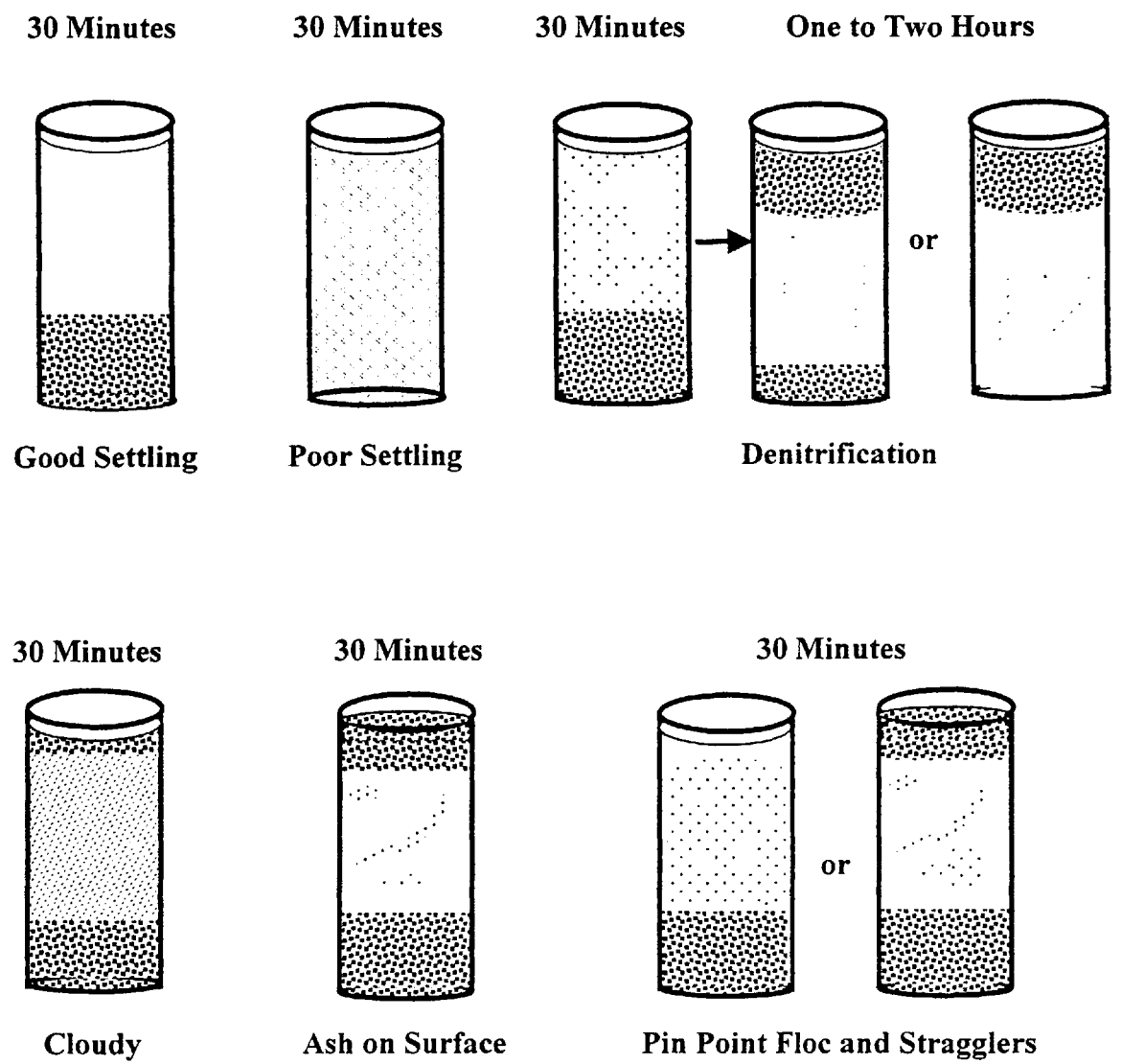


Figure 11.4 Settling test observations. *Source:* USEPA, 1977.

11.11.4 SETTLING TANK

11.11.4.1 Sludge Blanket Depth

✓ *Note:* We briefly discussed sludge blanket depth in Section 11.8.8. In this section, we discuss it in greater detail, because in proper settling tank operation, sludge blanket depth is important.

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 settling tank. 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; it will vary throughout the day.

A sludge blanket indicator is used to check the sludge blanket. Remember, when measuring sludge blanket depth, many factors can change the sludge blanket depth—factors that are not indicators of

process condition. Establishing a standard procedure for determining sludge blanket that eliminates as many of these factors as possible is best (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. 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.

✓ *Note:* Depth of sludge blanket provides an indication of sludge quality; it is used as a trend indicator. Many factors affect test result.

11.11.5 SETTLING TANK EFFLUENT

11.11.5.1 BOD₅ and Total Suspended Solids

BOD₅ and total suspended solids testing is conducted variably (daily, weekly, monthly). Increases indicate treatment performance is decreasing; decreases indicate treatment performance is increasing.

11.11.5.2 Total Kjeldahl Nitrogen (TKN)

TKN sampling and testing is variable. An increase in TKN indicates nitrification is decreasing; a decrease in TKN indicates nitrification is increasing.

11.11.5.3 Nitrate Nitrogen

Nitrate nitrogen sampling and testing are variable. Increases in nitrate nitrogen indicate nitrification is increasing or industrial contribution of nitrates. A decrease indicates reduced nitrification.

11.11.5.4 Flow

Settling tank effluent flow is sampled and tested daily. Results are required for several process control calculations.

11.11.6 RETURN-ACTIVATED SLUDGE/WASTE-ACTIVATED SLUDGE

11.11.6.1 Total Suspended Solids and Volatile Suspended Solids

Total suspended solids and total volatile suspended solids concentrations of the mixed liquor (mixed liquor suspended solids—MLSS), the return-activated sludge (RAS), and 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 produces an older, more dense sludge, while decreasing MLSS produces a younger, less dense sludge.

✓ *Note:* Control of the 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.

11.11.6.2 Flow

Test the flow of return-activated sludge daily. Test results are required to determine mass balance and for control of sludge blanket, MLSS, and MLVSS. For waste-activated sludge, flow is sampled and tested whenever sludge is wasted. Results are required to determine mass balance and to control solids level in process.

11.12 PROCESS CONTROL STRATEGIES

In the performance of their duties, wastewater operators make routine process control adjustments to various unit processes, including the activated sludge process.

Many different strategies are available for control of an activated sludge system. The strategy selected for control should

- be practical for the size and complexity of the plant
- be sensitive to reasonable process adjustments
- have a direct impact on effluent quality

The following is a summary of the process control strategies routinely employed in the activated sludge process and the result(s) that occur from adjustment of each.

11.12.1 RETURN-ACTIVATED SLUDGE FLOW

Three different process control strategies can be employed for controlling return-activated sludge flow. These strategies include constant flow, proportional to influent flow, and/or adjustment to sludge blanket. Constant flow is the simplest control method, but has potential to cause wide variations in MLSS. Proportional to influent flow provides more accurate control, but most plants do not have the required equipment. Adjustment on blanket depth strategy requires routine monitoring and adjustment, because the blanket is sensitive to many changes.

11.12.2 WASTE-ACTIVATED SLUDGE FLOW

Process control strategies employed in maintaining proper waste-activated sludge flow include constant MLSS or MLVSS, constant F/M ratio, or constant MCRT/SRT. Constant MLSS or MLVSS is the simplest method, but is difficult to employ if influent flow rates vary greatly. The constant F/M ratio requires additional testing and calculations. This strategy works to maintain desired food-to-organism ratio. The constant MCRT/SRT strategy requires additional calculations and daily wasting or averaging of waste.

11.12.3 DISSOLVED OXYGEN

The dissolved oxygen process control strategy works to maintain a constant DO range. Employing this strategy requires monitoring every two hours and process adjustments as necessary.

11.13 OPERATIONAL PROBLEMS AND TROUBLESHOOTING PROCEDURES

Among the most important functions performed by the wastewater operator are identifying process

control problems, troubleshooting the problem, and, finally, implementing appropriate corrective actions (see Section 11.13.1).

The activated sludge process is subject to a wide variety of operational problems. This makes sense when you consider the complexity of the activated sludge process. In the majority of cases, these problems can be categorized into two groups:

- Controllable
 - Hydraulic overloading
 - Imbalance between multiple units
 - Short-circuiting
 - Predictable flow variations (diurnal or industrial cycles)
 - Unpredictable flow variations (collection system cleaning)
 - Sludge
 - Old
 - Young
 - Too little
 - Too much
- Uncontrollable
 - Organic load
 - External
 - Internal
 - Toxic wastes
 - External
 - Internal

Whenever an operational problem occurs, review all available information to determine the appropriate actions to try. When possible, review available information for the past year. Problems may be the result of seasonal changes as well as operational or influent changes. Keep in mind that different plants may exhibit slightly different symptoms and require different actions for the same problem.

✓ *Note:* In troubleshooting, operators should list the symptoms they observe. From this data list, the probable cause should become obvious, but what should also become obvious is what the probable cause *is not*. Troubleshooting, then, is really nothing more than a process of elimination continued until the causal factor(s) is/are apparent.

11.13.1 TROUBLESHOOTING THE ACTIVATED SLUDGE PROCESS

Troubleshooting an activated sludge process requires careful observation to identify the type of problem. Observation of the aeration tank and final settling tank is essential. Observing and evaluating other units that may have a direct impact on the performance of the activated sludge system is also essential. For example, sidestreams from sludge processing and problems in preliminary or primary treatment can have significant impact on performance in this portion of the plant. In addition to the observations previously discussed, reviewing monitoring equipment used, locations, and accuracy is important. A monitoring device that provides inaccurate data or is not located at a point where it can be useful in making process adjustments can be a significant part of the cause of operational problems.

11.13.1.1 Troubleshooting Tools

Along with reviewing operational data, another valuable troubleshooting tool the operator may

employ in determining the status, as well as any operation problems with the activated sludge process, is *settling test observations*.⁶ The examples provided in Figure 11.4 can be used in conjunction with the troubleshooting information provided in the following sections.

11.13.2 TROUBLESHOOTING ACTIVATED SLUDGE OPERATION PROBLEMS

The following sections list indicators/observations of operational problems, casual factors, and corrective actions for various activated sludge treatment process problems.

11.13.2.1 Sludge Floating to Surface: Secondary Clarifiers

Causal Factors:

- (1) Filamentous organisms predominating in the mixed liquor (bulking sludge)

Corrective Actions:

- increase aeration tank DO if <1 mg/L
- increase pH to 7.0 or higher
- supplement deficiency of nutrients so that BOD₅-to-nutrient ratio is at least 100 BOD₅ to 5 nitrogen (total) to 1 phosphorus to 0.5 iron
- add 5–60 mg/L chlorine to return sludge until SVI is <150
- add 50–200 mg/L hydrogen peroxide to aeration tank until SVI <150
- increase MCRT or SRT
- increase return rate

- (2) Denitrification occurring in secondary clarifiers; nitrogen gas bubbles attaching to sludge particles; sludge rising to surface in clumps

Corrective Actions:

- increase sludge return rate
- increase aeration tank DO
- reduce MCRT or SRT

- (3) Broken or warped flights

Corrective Action:

- repair or replace flights

- (4) Sludge collector operating too slowly

Corrective Actions:

- increase speed or frequency of collector operation
- install skimming baffles to keep sludge away from effluent weirs

11.13.2.2 Improper Effluent Distribution: Fouled Weirs

Causal Factor:

- (1) Accumulated solids and biological growth

Corrective Actions:

- more frequent and more thorough cleaning
- prechlorination

⁶This information is contained in USEPA's *Process Control Manual for Aerobic Biological Wastewater Treatment Facilities* (EPA 430/9-77-006). Washington, DC: United States Environmental Protection Agency, 1977.

11.13.2.3 Pin Floc in Secondary Clarifier Overflow (SVI OK but Effluent Is Turbid)

Causal Factors:

- (1) Excessive turbulence in aeration tanks

Corrective Action:

- reduce aeration agitation

- (2) Overoxidize sludge

Corrective Action:

- increase sludge wasting to reduce MCRT

- (3) Anaerobic conditions in the aeration tank

Corrective Action:

- increase DO in aeration tank

- (4) Toxic shock load

Corrective Actions:

- re-seed with activated sludge from another plant, if possible
- adopt/enforce industrial waste ordinances

- (5) Clarifier short circuiting

Corrective Action:

- level weirs

- (6) Recycle of anaerobic sidestreams

Corrective Action:

- identify source and correct/control

11.13.2.4 Very Stable Dark Tan Foam on Aeration Tanks (Sprays Can't Break Up)

Causal Factor:

- (1) MCRT/SRT too high

Corrective Action:

- increase sludge wasting to reduce MCRT

11.13.2.5 Thick Billows of White Sudsy Foam on Aeration Tank

Causal Factor:

- (1) MLSS is too low

Corrective Action:

- decrease sludge wasting to increase MCRT/SRT

11.13.2.6 Aeration Tank Content Turns Black; Sludge Blanket Lost in Secondary Clarifier

Causal Factor:

- (1) Inadequate aeration

Corrective Actions:

- place another blower in service
- decrease loading by placing another aeration tank in service

- check aeration piping system for leaks
- clean any plugged air diffusers

11.13.2.7 Aeration Tanks Have Substantially Different MLSS Concentrations

Causal Factor:

- (1) Unequal flow distribution

Corrective Action:

- adjust valves and/or inlet gates

11.13.2.8 Sludge Blanket Overflowing Weirs in One Portion of the Clarifier

Causal Factors:

- (1) Clarifier short circuiting

Corrective Action:

- level clarifier weirs

- (2) Improper tank design

Corrective Action:

- correct design problem

11.13.2.9 Sludge Blanket Overflowing the Secondary Clarifier

Causal Factors:

- (1) Inadequate sludge return rate

Corrective Actions:

- If return pump is malfunctioning, place another pump in service.
- If pump is in good condition, increase return rate. Check sludge blanket depth routinely. Maintain 1–3 foot blanket depth. When blanket increases, increase return rate.
- Clean sludge return line if plugged.

- (2) Unequal flow distribution to clarifiers causing hydraulic overload

Corrective Action:

- adjust valves and/or inlet gates to provide uniform distribution of flow

- (3) Peak flows overload clarifiers

Corrective Action:

- install flow equalization facilities or expand plant

- (4) Solids loadings are too high for clarifiers

Corrective Action:

- increase wasting to deduce MLSS concentration

11.13.2.10 In Diffused Aeration Systems, Air Is Rising in Very Large Bubbles or Clumps in Some Areas

Causal Factor:

- (1) Diffusers are plugged

Corrective Action:

- Clean or replace diffusers. Check air cleaners ahead of blowers to reduce plugging from dirty air.

11.13.2.11 Mixed Liquor pH Drops to 6.7 or Lower—Sludge Becomes Less Dense

Causal Factors:

- (1) Nitrification is occurring and water alkalinity is too low

Corrective Actions:

- increase wasting to reduce MCRT/SRT if nitrification is not required
- add source of alkalinity (sodium bicarbonate or lime)

- (2) Acid wastewater is entering the system

Corrective Action:

- determine source and stop flow into the system

11.13.2.12 Sludge Concentration in Return Sludge Is Too Low (<8,000 mg/L)

Causal Factors:

- (1) Sludge return rate is too high

Corrective Action:

- reduce sludge return rate

- (2) Filamentous growth

Corrective Action:

- raise DO, raise pH, supplement nitrogen, add chlorine

- (3) Actinomyces organism predominates

Corrective Action:

- supplement iron feed if dissolved iron content is <5 mg/L

11.13.2.13 Dead Spots in the Aeration Tank

Causal Factors:

- (1) Diffusers plugged

Corrective Actions:

- clean or replace diffusers
- install air cleaners ahead of blowers to reduce plugging caused by dirty air

- (2) Underaeration resulting in low DO

Corrective Action:

- increase aeration to bring DO concentration up to 1–3 mg/L

11.13.2.14 Sludge Withdrawal Ports Plugged

Causal Factors:

- (1) High volume of heavy, compacted solids

Corrective Action:

- loosen compacted solids

- (2) Low velocity in sludge withdrawal lines

Corrective Actions:

- backflush clogged lines
- pump sludge more frequently
- revise sludge piping

11.13.2.15 Billowing Sludge in Clarifier

Causal Factors:

- (1) Hydraulic surges

Corrective Action:

- identify and eliminate at source

- (2) Density currents

Corrective Action:

- minimize sludge blanket thickness

- (3) Agitation due to scraper movement

Corrective Action:

- reduce scraper speed

11.13.2.16 Short Circuiting through the Clarifier

Causal Factors:

- (1) Excessive hydraulic loading

Corrective Action:

- additional units into service

- (2) Weir not level

Corrective Action:

- level weirs

- (3) Equipment malfunction

Corrective Action:

- replace malfunctioning equipment

- (4) Large accumulation of solids and grit

Corrective Actions:

- remove solids and/or grit
- improve grit removal operation

11.13.2.17 Excessive Torque on Rake Mechanism

Causal Factor:

- (1) Excessive loading on sludge scraper mechanism

Corrective Actions:

- repair/replace defective/worn parts
- remove any ice formation on walls/surfaces
- operate collector longer
- operate sludge pump at higher rate or for longer intervals
- dewater and inspect for debris/vandalism

11.13.2.18 Deflocculation in Settling Tank

Causal Factors:

- (1) Toxic or acid waste entering system

Corrective Actions:

- identify/correct at source
- install pH adjustment equipment

(2) Anaerobic conditions in aeration tank

Corrective Actions:

- increase aeration rate
- eliminate/control anaerobic sidestreams

(3) Aeration tank overloaded

Corrective Action:

- place additional basins in service

(4) Inadequate nitrogen/phosphorus in influent

Corrective Action:

- add required nutrients by chemical additions

✓ *Note:* 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 and chemical as well as physical factors.

11.14 PROCESS CONTROL CALCULATIONS: ACTIVATED SLUDGE PROCESS

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 many of the most frequently used activated sludge process calculations.

11.14.1 MOVING AVERAGES

When performing process control calculations, the use of a seven-day *moving average* is recommended. The moving average is a mathematical method to level the impact of any one test result. The moving average is determined by adding all of the test results collected during the past seven days and dividing by the number of tests.

$$\text{Moving Average} = \frac{\text{Test 1} + \text{Test 2} + \text{Test 3} + \dots + \text{Test 6} + \text{Test 7}}{\text{Number of Tests Performed During the Seven Days}} \quad (11.3)$$

Example 11.1

Problem:

Calculate the seven-day moving average for days 7, 8, and 9.

<u>Day</u>	<u>MLSS</u>	<u>Day</u>	<u>MLSS</u>
1	3,340	6	2,780
2	2,480	7	2,476
3	2,398	8	2,756
4	2,480	9	2,655
5	2,558	10	2,396

Solution:

$$(1) \text{ Moving Average, Day 7} = \frac{3,340 + 2,480 + 2,398 + 2,480 + 2,558 + 2,780 + 2,476}{7} = 2,645$$

$$(2) \text{ Moving Average, Day 8} = \frac{2,480 + 2,398 + 2,480 + 2,558 + 2,780 + 2,476 + 2,756}{7} = 2,561$$

$$(3) \text{ Moving Average, Day 9} = \frac{2,398 + 2,480 + 2,558 + 2,780 + 2,476 + 2,756 + 2,655}{7} = 2,586$$

✓ *Note:* While the moving average is recommended for actual plant process control, examples provided in this handbook and most examinations do not employ the moving average. On test questions, only information for the specified day should be used for computations, unless a question or example states otherwise.

11.14.2 ESTIMATING RETURN RATES FROM SSV_{60}

Many different methods are available for estimation of the proper return sludge rate. A simple method described in the *Operation of Wastewater Treatment Plants, Field Study Program* (1986), developed by the California State University, Sacramento, uses the 60-minute percent settled sludge volume. The $\%SSV_{60}$ test results can provide an approximation of the appropriate return-activated sludge rate. This calculation assumes that the SSV_{60} results are representative of the actual settling occurring in the clarifier. If this is true, the return rate in percent should be approximately equal to the SSV_{60} . To determine the approximate return rate in million gallons per day (MGD), the influent flow rate, the current return rate, and the SSV_{60} must be known. 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).

Estimated Return Rate, MGD =

$$(\text{Influent Flow, MGD} + \text{Current Return Flow, MGD}) \times \%SSV_{60} \quad (11.4)$$

$$\text{RAS Rate, GPM} = \frac{\text{Return, Sludge Rate, gpd}}{1,440 \text{ min/day}} \quad (11.5)$$

- Assumes $\%SSV_{60}$ is representative
- Assumes return rate in percent equals $\%SSV_{60}$
- Actual return rate is normally set slightly higher to ensure organisms are returned to the aeration tank as quickly as possible. The rate of return must be adequately controlled to prevent the following:
 - aeration and settling hydraulic overloads
 - low MLSS levels in the aerator
 - organic overloading of aeration
 - septic return-activated sludge
 - solids loss due to excessive sludge blanket depth

Example 11.2

Problem:

The influent flow rate is 5.0 MGD, and the current return-activated sludge flow rate is 1.8 MGD.

The SSV_{60} is 37%. Based upon this information, what should be the return sludge rate in million gallons per day (MGD)?

Solution:

$$\text{Return, MGD} = (5.0 \text{ MGD} + 1.8 \text{ MGD}) \times 0.37 = 2.5 \text{ MGD}$$

11.14.3 SLUDGE VOLUME INDEX

Sludge volume index (SVI) is a measure (an indicator) of the settling quality (a quality indicator) of the activated sludge. As the SVI increases, the sludge settles slower, does not compact as well, and is likely to result in an increase in effluent suspended solids. As the SVI decreases, the sludge becomes more dense, settling is more rapid, and the sludge ages. SVI is the volume in milliliters occupied by 1 gram of activated sludge. For the settled sludge volume (mL/L) and the mixed liquor suspended solids (MLSS) calculation, mg/L are required. The proper SVI range for any plant must be determined by comparing SVI values with plant effluent quality.

$$\text{Sludge Volume Index (SVI)} = \frac{\text{SSV, mL/L} \times 1,000}{\text{MLSS, mg/L}} \quad (11.6)$$

Example 11.3

Problem:

The SSV_{30} is 350 mL/L, and the MLSS is 2,425 mg/L. What is the SVI?

Solution:

$$\text{Sludge Volume Index (SVI)} = \frac{350 \text{ mL/L} \times 1,000}{2,425 \text{ mg/L}} = 144$$

SVI equals 144. What does this mean?
 What it means is 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 144 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
100–250	Normal operation—Good settling Low effluent turbidity
Greater than 250	Bulking sludge—Poor settling High effluent turbidity

The SVI is best used as a trend indicator to evaluate what is occurring compared to previous SVI values. Based upon this evaluation, you may determine if the SVI trend is increasing or decreasing (refer to the following chart).

SVI Value	Result	Adjustment
Increasing	Sludge is becoming less dense	Decrease waste
	Sludge is either younger or bulking	Increase return rate
	Sludge will settle more slowly	
	Sludge will compact less	
Decreasing	Sludge is becoming more dense	Increase waste rate
	Sludge is becoming older	
	Sludge will settle more rapidly	Decrease return rate
	Sludge will compact more	
Holding constant	With no other process changes sludge should continue to have its current characteristics	No changes indicated

11.14.4 FOOD-TO-MICROORGANISM RATIO (F/M RATIO)

The *food-to-microorganism ratio (F/M ratio)* is a process control method/calculation based upon maintaining a specified balance between available food materials (BOD or COD) in the aeration tank influent, and the aeration tank mixed liquor volatile suspended solids (MLVSS) concentration. The chemical oxygen demand (COD) test is sometimes used, because the results are available in a relatively short period of time.

To calculate the F/M ratio, the following information is required:

- aeration tank influent flow rate, MGD
- aeration tank influent BOD₅ or COD, mg/L
- aeration tank MLVSS, mg/L
- aeration tank volume, MG

$$F/M \text{ Ratio} = \frac{\text{Primary Eff. COD/BOD mg/L} \times \text{Flow MGD} \times 8.34 \text{ lb/mg/L/MG}}{\text{MLVSS mg/L} \times \text{Aerator Volume, MG} \times 8.34 \text{ lb/mg/L/MG}}$$

(11.7)

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
Pure Oxygen	0.25–1.0	0.5–2.0

Example 11.4

Problem:

The aeration tank influent BOD₅ is 145 mg/L, and the aeration tank influent flow rate is 1.6 MGD. What is the F/M ratio if the MLVSS is 2,300 mg/L and the aeration tank volume is 1.8 MG?

Solution:

$$\begin{aligned} \text{F/M ratio} &= \frac{145 \text{ mg/L} \times 1.6 \text{ MGD} \times 8.34 \text{ lb/mg/L/MG}}{2,300 \text{ mg/L} \times 1.8 \text{ MG} \times 8.34 \text{ lb/mg/L/MG}} \\ &= 0.06 \text{ lb BOD/lb MLVSS} \end{aligned}$$

- ✓ If the MLVSS concentration is not available, it can be calculated if the % volatile matter (% VM) of the mixed liquor suspended solids (MLSS) is known.

$$\text{MLVSS} = \text{MLSS} \times \% (\text{decimal}) \text{ Volatile Matter (VM)} \quad (11.8)$$

- ✓ *Note:* The “F” value in the F/M ratio for computing loading to an activated sludge process can be either BOD or COD. Remember, the reason for sludge production in the activated sludge process is to convert BOD to bacteria. One advantage of using COD over BOD for analysis of organic load is that COD is more accurate.

Example 11.5

Problem:

The aeration tank contains 2,885 mg/L of MLSS. Laboratory tests indicate the MLSS is 66% volatile matter. What is the MLVSS concentration in the aeration tank?

Solution:

$$\text{MLVSS, mg/L} = 2,885 \text{ mg/L} \times 0.66 = 1,904 \text{ mg/L}$$

11.14.4.1 F/M Ratio Control

Maintaining the F/M ratio within a specified range can be an excellent control method. Although the F/M ratio is affected by adjustment of the return rates, the most practical method for adjusting the ratio is through waste rate adjustments.

Increasing the waste rate will

- (1) Decrease the MLVSS
- (2) Increase the F/M ratio

Decreasing the waste rate will

- (1) Increase the MLVSS
- (2) Decrease the F/M ratio

11.14.4.2 Establishing Desired F/M Levels

The desired F/M ratio must be established on a plant-by-plant basis. Comparison of F/M ratios with plant effluent quality is the primary means to identify the most effective range for individual plants, when the range of F/M values that produce the desired effluent quality is established.

11.14.4.3 Required MLVSS Quantity (Pounds)

The pounds of MLVSS required in the aeration tank to achieve the optimum F/M ratio can be determined from the average influent food (BOD₅ or COD) and the desired F/M ratio.

$$\text{MLVSS, lb} = \frac{\text{Primary Effluent BOD or COD} \times \text{Flow, MGD} \times 8.34}{\text{Desired F/M Ratio}} \quad (11.9)$$

The required pounds of MLVSS determined by this calculation can then be converted to a concentration value by

$$\text{MLVSS, mg/L} = \frac{\text{Desired MLVSS in Pounds}}{[\text{Aeration Volume, MG} \times 8.34]} \quad (11.10)$$

Example 11.6

Problem:

The aeration tank influent flow is 4.0 MGD, and the influent COD is 145 mg/L. The aeration tank volume is 0.65 MG. The desired F/M ratio is 0.3 lb COD/lb MLVSS.

- (1) How many pounds of MLVSS must be maintained in the aeration tank to achieve the desired F/M ratio?
- (2) What is the required concentration of MLVSS in the aeration tank?

$$\text{MLVSS, lb} = \frac{145 \text{ mg/L} \times 4.0 \text{ MGD} \times 8.34 \text{ lb/gal}}{0.3 \text{ lb COD/lb MLVSS}} = 16,124 \text{ lb MLVSS}$$

$$\text{MLVSS, mg/L} = \frac{16,124 \text{ lb MLVSS}}{[0.65 \text{ MG} \times 8.34]} = 2,974 \text{ mg/L MLVSS}$$

11.14.4.4 Calculating Waste Rates Using F/M Ratio

Maintaining the desired F/M ratio is accomplished by controlling the MLVSS level in the aeration tank. This may be accomplished by adjustment of return rates; however, the most practical method is by proper control of the waste rate.

$$\text{Waste Vol. Solids, lb/day} = \text{Actual MLVSS, lb} - \text{Desired MLVSS, lb} \quad (11.11)$$

If the desired MLVSS is greater than the actual MLVSS, wasting is stopped until the desired level is achieved.

Practical considerations require that the required waste quantity be converted to a required volume to waste per day. This is accomplished by converting the waste pounds to flow rate in million gallons per day or gallons per minute.

$$\text{Waste, MGD} = \frac{\text{Waste Volatile, lb/day}}{[\text{Waste Volatile Concentration, mg/L} \times 8.34]} \quad (11.12)$$

$$\text{Waste, gpm} = \frac{\text{Waste, MGD} \times 1,000,000 \text{ gpd/MGD}}{1,440 \text{ minutes/day}} \quad (11.13)$$

✓ *Note:* When F/M ratio is used for process control, the volatile content of the waste activated sludge should be determined.

Example 11.7*Problem:*

Given the following information, determine the required waste rate in gallons per minute to maintain an F/M ratio of 0.17 lb COD/lb MLVSS.

Primary Effluent COD	140 mg/L
Primary Effluent Flow	2.2 MGD
MLVSS, mg/L	3,549 mg/L
Aeration Tank Volume	0.75 MG
Waste Volatile Concentration	4,440 mg/L (Volatile Solids)

$$\text{Actual MLVSS, lb} = 3,549 \text{ mg/L} \times 0.75 \text{ MG} \times 8.34 = 22,199 \text{ lb}$$

$$\text{Required MLVSS, lb} = \frac{140 \text{ mg/L} \times 2.2 \text{ MGD} \times 8.34}{0.17 \text{ lb COD/lb MLVSS}} = 15,110 \text{ lb MLVSS}$$

$$\text{Waste, lb/day} = 22,199 \text{ lb} - 15,110 \text{ lb} = 7,089 \text{ lb}$$

$$\text{Waste, MGD} = \frac{7,089 \text{ lb/day}}{[4,440 \text{ mg/L} \times 8.34]} = 0.19 \text{ MGD}$$

$$\text{Waste, gpm} = \frac{0.19 \text{ MGD} \times 1,000,000 \text{ gpd/MGD}}{1,440 \text{ min/day}} = 132 \text{ gpm}$$

11.14.5 MEAN CELL RESIDENCE TIME (MCRT)

Mean cell residence time (MCRT), sometimes called *sludge retention time*, is another process control calculation used for activated sludge systems. MCRT represents the average length of time an activated sludge particle remains in the activated sludge system. It can also be defined as the length of time required at the current removal rate to remove all the solids in the system.

Mean Cell Residence Time, days =

$$\frac{[\text{MLSS mg/L} \times (\text{Aeration Vol.} + \text{Clarifier Vol.}) \times 8.34 \text{ lb/mg/L/MG}]}{[(\text{WAS, mg/L} \times \text{WAS flow} \times 8.34) + (\text{TSS out} \times \text{flow out} \times 8.34)]} \quad (11.14)$$

✓ *Note:* MCRT can be calculated using only the aeration tank solids inventory. When comparing plant operational levels to reference materials, you must determine which calculation the reference manual uses to obtain its example values. Other methods are available to determine the clarifier solids concentration. However, the simplest method assumes that the average suspended solids concentration is equal to the aeration tank's solids concentration.

Example 11.8*Problem:*

Given the following data, what is the MCRT?

$$\text{Aerator Volume} = 1,000,000 \text{ gal}$$

Final Clarifier Volume	=	600,000 gal
Flow	=	5.0 MGD
Waste Rate	=	0.085 MGD
MLSS mg/L	=	2,500 mg/L
Waste mg/L	=	6,400 mg/L
Effluent TSS	=	14 mg/L

Solution:

$$MCRT = \frac{[2,500 \text{ mg/L} \times (1.0 \text{ MG} + 0.60 \text{ MG}) \times 8.34]}{[(6,400 \text{ mg/L} \times 0.085 \text{ MGD} \times 8.34) + (14 \text{ mg/L} \times 5.0 \text{ mgd} \times 8.34)]} = 6.5 \text{ days}$$

11.14.5.1 Mean Cell Residence Time Control

Because it provides an accurate evaluation of the process condition and takes all aspects of the solids inventory into account, the MCRT is an excellent process control tool. Increases in the waste rate will decrease the MCRT, as will large losses of solids over the effluent weir. Reductions in waste rate will result in increased MCRT values.

✓ *Note:* You should remember these important process control parameters:

Process Parameters and Impact on MCRT/MCRT Impact on Parameters

- To increase F/M, decrease MCRT.
- To increase MCRT, decrease waste rate.
- MCRT is increased, MLTSS and 30-minute settling increases.
- Return sludge rate has no impact on MCRT.
- MCRT has no impact on F/M change when the number of aeration tanks in service is reduced.

11.14.5.2 Typical MCRT Values

The following chart lists the various aeration process modifications and associated MCRT values.

Process	MCRT, Days
Conventional	5–15
Step Aeration	5–15
Contact Stabilization (Contact)	5–15
Extended Aeration	20–30
Oxidation Ditch	20–30
Pure Oxygen	8–20

11.14.5.3 Control Values for MCRT

Control values for the MCRT are normally established based on effluent quality. Once the MCRT range required to produce the desired effluent quality is established, it can be used to determine the waste rate required to maintain it.

11.14.5.4 Waste Quantities/Requirements

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 quantity of solids to be removed (wasted) is determined by

$$\text{Waste, lb/day} = \left[\frac{\text{MLSS} \times (\text{Aer., MG} + \text{Clarifier, MG}) \times 8.34}{\text{Desired MCRT}} \right] - [\text{TSS}_{\text{out}} \times \text{Flow} \times 8.34] \quad (11.15)$$

Example: 11.9

$$\frac{3,400 \text{ mg/L} \times (1.4 \text{ MG} + 0.50 \text{ MG}) \times 8.34}{8.6 \text{ days}} - [10 \text{ mg/L} \times 5.0 \text{ MGD} \times 8.34]$$

$$\text{Waste Quality, lb/day} = 5,848 \text{ lb}$$

11.14.5.4.1 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.

$$\text{Waste, MGD} = \frac{\text{Waste Pounds/day}}{\text{WAS Concentration, mg/L} \times 8.34} \quad (11.16)$$

$$\text{Waste, gpm} = \frac{\text{Waste MGD} \times 1,000,000 \text{ gpd/MGD}}{1,440 \text{ minutes/day}} \quad (11.17)$$

Example: 11.10

Problem:

Given the following data, determine the required waste rate to maintain an MCRT 8.8 days.

MLSS, mg/L	2,500 mg/L
Aeration Volume	1.20 MG
Clarifier Volume	0.20 MG
Effluent TSS	11 mg/L
Effluent Flow	5.0 MGD
Waste Concentration	6,000 mg/L

Solution:

$$\text{Waste, lb/day} = \frac{2,500 \text{ mg/L} \times (1.20 + 0.20) \times 8.34}{8.8 \text{ days}} - [11 \text{ mg/L} \times 5.0 \text{ MGD} \times 8.34]$$

$$= 3,317 \text{ lb/day} - 459 \text{ lb/day}$$

$$= 2,858 \text{ lb/day}$$

$$\text{Waste, MGD} = \frac{2,858 \text{ lb/day}}{[6,000 \text{ mg/L} \times 8.34]} = 0.057 \text{ MGD}$$

$$\text{Waste, gpm} = \frac{0.057 \text{ MGD} \times 1,000,000 \text{ gpd/MGD}}{1,440 \text{ min/day}} = 40 \text{ gpm}$$

11.14.6 MASS BALANCE

Mass balance is based upon the fact that solids and BOD are not “lost” in the treatment system. In simple terms, the mass balance concept states that “what comes in must equal waste that goes out.” The concept can be used to verify operational control levels and to determine if potential problems exist within the plant’s process control monitoring program.

✓ *Note:* If influent values and effluent values do not correlate within 10–15%, it usually indicates either a sampling or testing error or a process control discrepancy.

Mass balance procedures for evaluating the operation of a settling tank and a biological process are described in this section. You should recognize that, although the procedures are discussed in reference to the activated sludge process, the concepts can be applied to any settling or biological process.

11.14.6.1 Mass Balance: Settling Tank Suspended Solids

The settling tank mass balance calculation assumes that no suspended solids are produced in the settling tank. Any settling tank operation can be evaluated by comparing the solids entering the unit with the solids leaving the tank as effluent suspended solids or as sludge solids (see Figure 11.5). If sampling and testing are accurate and representative, and process control and operation are appropriate, the quantity of suspended solids entering the settling tank should equal (plus or minus 10%) the quantity of suspended solids leaving the settling tanks as sludge, scum, and effluent total suspended solids.

✓ *Note:* In most instances, the amount of suspended solids leaving the process as scum is so small that it is ignored in the calculation.

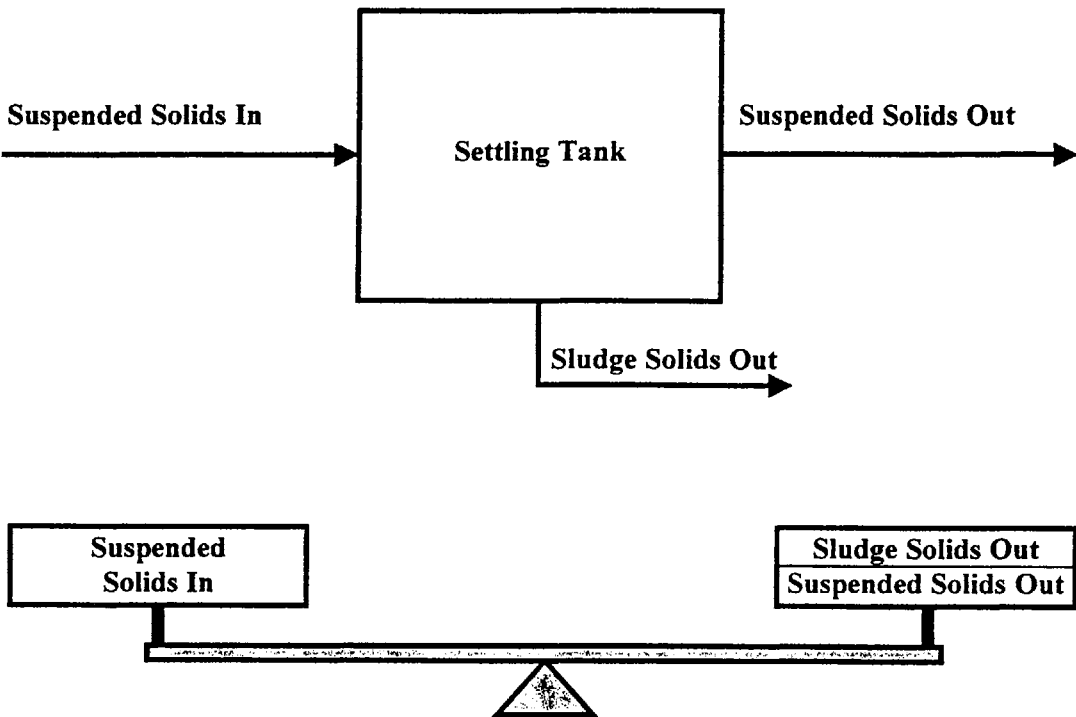


Figure 11.5 Settling tank mass balance.

11.14.6.1.1 Mass Balance Calculation

$$\text{Total Suspended Solids in, lb} = \text{TSS}_{\text{in}} \times \text{Flow, MGD} \times 8.34 \quad (11.18)$$

$$\text{Total Suspended Solids out, lb} = \text{TSS}_{\text{out}} \times \text{Flow, MGD} \times 8.34$$

$$\text{Sludge Solids} = \text{Sludge Pumped, gal} \times \% \text{ Solids} \times 8.34$$

$$\% \text{ Mass Balance} = \frac{[\text{TSS}_{\text{in}}, \text{lb} - (\text{TSS}_{\text{out}}, \text{lb} + \text{Sludge Sol, lb})] \times 100}{\text{TSS}_{\text{in}}, \text{lb}}$$

11.14.6.1.2 Explanation of Results

- (1) If the mass balance is $\pm 15\%$ or less: The process is considered to be in balance. Sludge removal should be adequate with the sludge blanket depth remaining stable. Sampling is considered to be producing representative samples that are being tested accurately.
- (2) If the mass balance is greater than $\pm 15\%$: Indicates that more solids are entering the settling tank than are being removed. Sludge blanket depth should be increasing, effluent solids may also be increasing, and effluent quality is decreasing.

If changes described are not occurring, the mass balance may indicate that sample type, location, times, or procedures and/or testing procedures are not producing representative results.

- (3) If the mass balance is greater than -15% : Indicates that fewer solids are entering the settling tank than are being removed. Sludge blanket depth should be decreasing; sludge solids concentration may also be decreasing. This could adversely impact sludge treatment processes.

If changes described are not occurring, the mass balance may indicate that sample type, location, times, or procedures and/or testing procedures are not producing representative results.

Example 11.11*Problem:*

Given the following data, determine the solids mass balance for the settling tank.

Influent	Flow	2.6 MGD
	TSS	2,445 mg/L
Effluent	Flow	2.6 MGD
	TSS	17 mg/L
Return	Flow	0.5 MGD
	TSS	8,470 mg/L

$$\text{Solids in, lb/day} = 2,445 \text{ mg/L} \times 2.6 \text{ MGD} \times 8.34 = 53,017 \text{ lb/day}$$

$$\text{Solids out, lb/day} = 17 \text{ mg/L} \times 2.6 \text{ MGD} \times 8.34 = 369 \text{ lb/day}$$

$$\text{Sludge Solids out, lb/day} = 8,470 \text{ mg/L} \times 0.5 \text{ MGD} \times 8.34 = 35,320 \text{ lb/day}$$

$$\text{Mass Balance} = \frac{[53,017 \text{ lb/day} - (369 \text{ lb/day} + 35,320 \text{ lb/day})] \times 100}{53,017 \text{ lb/day}} = 32.7\%$$

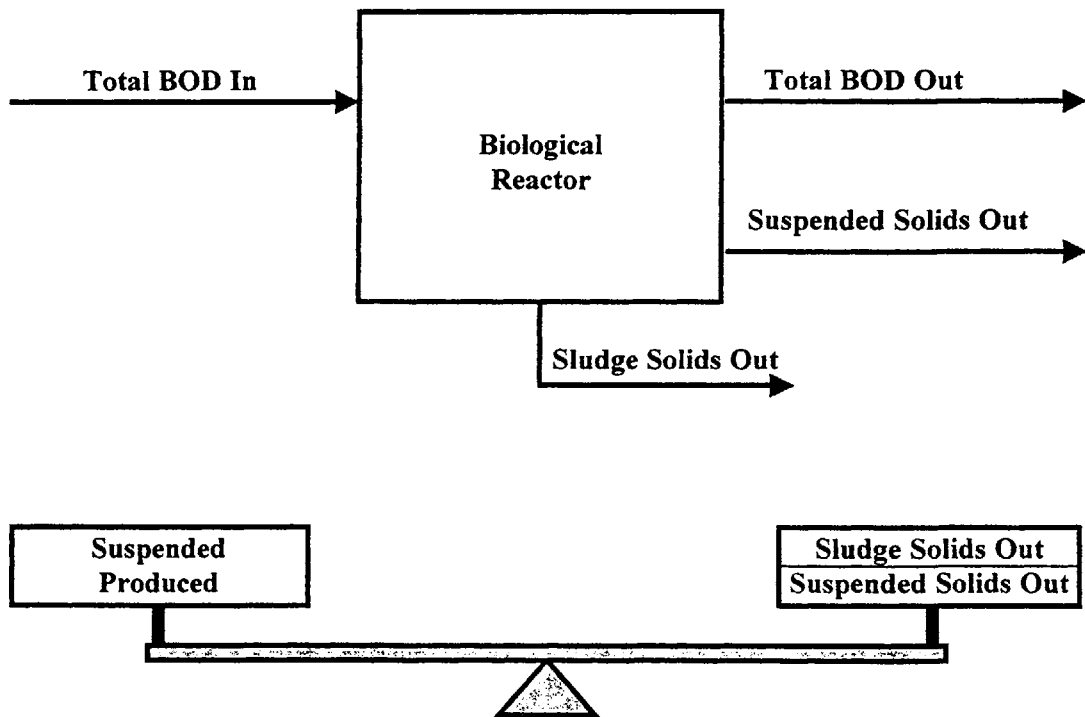
The value indicates

- (1) The sampling point/collection procedure or laboratory procedure is producing inaccurate data upon which to make process control decisions.
- (2) Or, more solids are entering the settling tank each day than are being removed. This should result in either
 - a solids buildup in the settling tank
 - a loss of solids over the effluent weir

Investigate further to determine the specific cause of the imbalance.

11.14.6.2 Mass Balance: Biological Process

Solids are produced whenever biological processes are used to remove organic matter from wastewater (see Figure 11.6). Mass balance for an aerobic biological process must take into account both the solids removed by physical settling processes and the solids produced by biological conversion of soluble organic matter to insoluble suspended matter or organisms. Research has shown that the amount of solids produced per pound of BOD₅ removed can be predicted based upon the type of process being used. Although the exact amount of solids produced can vary from plant to plant, research has developed a series of *K* factors that can be used to estimate the solids production for plants using a particular treatment process. These average factors provide a simple method to evaluate the effectiveness of a facility’s process control program. The mass balance also provides an excellent mechanism to evaluate the validity of process control and effluent monitoring data generated. Table 11.2 lists average *K* factors in pounds of solids produced per pound of BOD₅ removed for selected processes.



Solids Produced = (BOD_{in} – BOD_{out}) x Flow x 8.34 x “K” Factor

Figure 11.6 Biological process mass balance.

TABLE 11.2. Conversion Factors K .

Process	lb Solids
	lb BOD ₅ Removed
Primary	1.7
Activated Sludge with Primary	0.7
Activated Sludge without Primary	
Conventional	0.85
Step Feed	0.85
Extended Aeration	0.65
Oxidation Ditch	0.65
Contact Stabilization	1.00
Trickling Filter	1.00
Rotating Biological Contactor	1.00

11.14.6.2.1 Conversion Factor

Conversion factors depend on the activated sludge modification involved. Factors generally range from 0.5 to 1.0 lb of solids per pound of BOD removed (see Table 11.2).

11.14.6.2.2 Mass Balance Calculation

$$\text{BOD}_5 \text{ in, lb} = \text{BOD, mg/L} \times \text{Flow, MGD} \times 8.34 \quad (11.19)$$

$$\text{BOD}_5 \text{ out, lb} = \text{BOD, mg/L} \times \text{Flow, MGD} \times 8.34$$

$$\text{Solids Produced, lb/day} = [\text{BOD in, lb} - \text{BOD out, lb}] \times K$$

$$\text{TSS out, lb/day} = \text{TSS}_{\text{out}}, \text{ mg/L} \times \text{Flow, MGD} \times 8.34$$

$$\text{Waste, lb/day} = \text{Waste, mg/L} \times \text{Flow, MGD} \times 8.34$$

$$\text{Solids Removed, lb/day} = \text{TSS}_{\text{out}}, \text{ lb/day} + \text{Waste, lb/day}$$

$$\% \text{ Mass Balance} = \frac{(\text{Solids Produced} - \text{Solids Removed}) \times 100}{\text{Solids Produced}}$$

11.14.6.2.3 Explanation of Results

If the mass balance is $\pm 15\%$, the process sampling and testing and process control are within acceptable levels. If the balance is $> \pm 15\%$, investigate further to determine if the discrepancy represents a process control problem or is the result of non-representative sampling and inaccurate testing.

11.14.6.2.4 Sludge Waste Based Upon Mass Balance

The mass balance calculation predicts the amount of sludge that will be produced by a treatment process. This information can then be used to determine what, under current operating conditions, the waste rate must be to maintain the current solids levels.

$$\text{Waste Rate, MGD} = \frac{\text{Solids Produced, lb/day}}{(\text{Waste Concentration} \times 8.34)}$$

(11.20)

Example 11.12

Problem:

Given the following data, determine the mass balance of the biological process and the appropriate waste rate to maintain current operating conditions.

Process:	Extended Aeration (no primary)	
Influent	Flow	1.1 MGD
	BOD ₅	220 mg/L
	TSS	240 mg/L
Effluent	Flow	1.5 MGD
	BOD ₅	18 mg/L
	TSS	22 mg/L
Waste	Flow	24,000 gpd
	TSS	8,710 mg/L

$$\text{BOD}_5 \text{ in} = 220 \text{ mg/L} \times 1.1 \text{ MGD} \times 8.34 = 2,018 \text{ lb/day}$$

$$\text{BOD}_5 \text{ out} = 18 \text{ mg/L} \times 1.1 \text{ MGD} \times 8.34 = 165 \text{ lb/day}$$

$$\text{BOD}_5 \text{ Removed} = 2,018 \text{ lb/day} - 165 \text{ lb/day} = 1,853 \text{ lb/day}$$

$$\text{Solids Produced} = 1,853 \text{ lb/day} \times 0.65 \text{ lb/lb BOD}_5 = 1,204 \text{ lb solids/day}$$

$$\text{Solids Out, lb/day} = 22 \text{ mg/L} \times 1.1 \text{ MGD} \times 8.34 = 202 \text{ lb/day}$$

$$\text{Sludge Out, lb/day} = 8,710 \text{ mg/L} \times 0.024 \text{ MGD} \times 8.34 = 1,743 \text{ lb/day}$$

$$\text{Solids Removed, lb/day} = (202 \text{ lb/day} + 1,743 \text{ lb/day}) = 1,945 \text{ lb/day}$$

$$\text{Mass Balance} = \frac{(1,204 \text{ lb Solids/day} - 1,945 \text{ lb/day}) \times 100}{1,204 \text{ lb/day}} = 62\%$$

The mass balance indicates

- (1) The sampling point(s), collection methods, and/or laboratory testing procedures are producing non-representative results.
- (2) The process is removing significantly more solids than is required. Additional testing should be performed to isolate the specific cause of the imbalance.

To assist in the evaluation, the waste rate based upon the mass balance information can be calculated.

$$\text{Waste, GPD} = \frac{\text{Solids Produced, lb/day}}{(\text{Waste TSS, mg/L} \times 8.34)}$$

(11.21)

$$\text{Waste, GPD} = \frac{1,204 \text{ lb/day} \times 1,000,000}{8,710 \text{ mg/L} \times 8.34} = 16,575 \text{ gpd}$$

11.15 SUMMARY

After biological treatment by activated sludge, trickling filter, or RBC is completed, the liquid wastestream must be disinfected. We discuss chlorination, the most commonly used, most effective disinfection process, in Chapter 12.

11.16 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?
- 11-3 What change to the MCRT must be made to increase the F/M?
- 11-4 What change to the MCRT must be made to increase the MLTSS?
- 11-5 List four factors other than food that affect the growth characteristics of activated sludge.
- 11-6 What must be done to decrease the SVI?
- 11-7 What is the liquid mixture of microorganisms and solids removed from the bottom of the settling tank called?
- 11-8 What is the mixture of primary effluent and return sludge called?
- 11-9 What are the three things that must be balanced to make the activated sludge process perform properly?

- 11-10 What is the major purpose of an activated sludge process?
- 11-11 List three observations the operator should make as part of the daily operation of the activated sludge process.
- 11-12 A 2,200 mL sample of activated sludge is allowed to settle for 60 minutes. At the end of the 60 minutes, the sludge has settled 1,400 mL. What is the SSV_{60} of the sample?
- 11-13 An activated sludge sample has an MLSS concentration of 2,150 mg/L. The SSV_{30} of the sample is 420 mL/L. What is the sludge volume index of the sample?
- 11-14 The operator wastes 0.069 MGD of activated sludge. The WAS concentration is 8,100 mg/L. How many pounds of activated sludge solids have been removed from the process?
- 11-15 Which activated sludge process aerates the return sludge before mixing it with the influent flow?
- 11-16 A microscopic examination of the activated sludge reveals a predominance of rotifers. What process adjustment does this indicate is required?
- 11-17 Given the following data, calculate the desired pounds of mixed liquor suspended solids (MLSS) in the aeration tank.
- | | |
|---|--------------------------|
| Data: Primary effluent suspended solids | = 120 mg/L |
| Influent flow | = 2.1 MGD |
| Desired sludge age | = 5.0 days |
| Aeration tank | = 100 ft × 40 ft × 12 ft |
| Influent BOD | = 240 mg/L |
| Effluent suspended solids | = 15 mg/L |

- 11-18 List three observations that would indicate the activated sludge was becoming old.
- 11-19 What are the major differences between the conditions known as bulking, rising, and ashing sludge?
- 11-20 Why is color an unreliable process indicator?
- 11-21 List the conditions you would expect to observe when the activated sludge system is operating normally.
- 11-22 Why is selecting the same sample time and location each day important?
- 11-23 What can cause the sludge blanket to increase?
- 11-24 Describe a device used to measure sludge blanket depth.
- 11-25 What is a process sidestream? Give three examples.
- 11-26 Why is monitoring process sidestreams important when establishing control levels?
- 11-27 List three ways industrial waste contributions can impact process control levels.
- 11-28 What does BOD measure?

- 11-29 What is an advantage of the BOD test over the COD test?
- 11-30 What is the purpose of the secondary clarifier in an activated sludge process?
- 11-31 In the complete mix activated sludge process, what stage is occurring in the organism growth curve?
- 11-32 The major requirement for aerobic organisms to survive is _____.
- 11-33 What are the characteristics of facultative organisms?
- 11-34 A light chocolate brown mixed liquor color indicates what?
- 11-35 What is indicated by black aeration tank color?
- 11-36 Dark greasy aeration tank foam typically indicates what?
- 11-37 What color foam on the aeration tank indicates waste rate is too high?

Chlorination

12.1 INTRODUCTION

CHLORINE is the most commonly used substance for *disinfection* (the selective destruction of disease-causing organisms) in the United States. (Note: Do not confuse disinfection with sterilization, which is the destruction of all organisms.) The addition of chlorine or chlorine compounds to water is called *chlorination*. Chlorination may have many uses within a wastewater treatment facility. Along with its most common use (disinfection of plant effluent), it is also used in odor control and in the control of filamentous organisms in the activated sludge process. Recent concerns with the effect of spills of elemental chlorine, Cl_2 , and with the effect of chlorination on plant effluent quality (production of disinfection by-products [DBPs], such as trihalomethanes) and the environment have prompted re-evaluation of its use as a disinfection agent for wastewater treatment. Many wastewater treatment plants have substituted hypochlorites (sodium or calcium hypochlorite) for elemental chlorine to reduce the risks associated with accidental releases and to get out from under complex regulatory compliance requirements. Despite these concerns, chlorination remains, at present, the single most important process for preventing the spread of waterborne disease and the most common means of disinfection in use.

12.2 OVERVIEW OF CHLORINATION/DECHLORINATION PROCESS

12.2.1 CHLORINATION

- Elemental chlorine (Cl_2) is a yellow-greenish gas, 2.5 times heavier than air.
- The most common use of chlorine in wastewater treatment is for disinfection. Other uses include odor control and activated sludge bulking control. Chlorination takes place prior to the discharge of the final effluent to the receiving waters (see Figure 12.1).
- Chlorine may also be used for nitrogen removal, through a process called *breakpoint chlorination*. For nitrogen removal, enough chlorine is added to the wastewater to convert all the ammonium nitrogen to nitrogen gas. To do this, approximately 10 mg/L of chlorine must be added for every 1 mg/L of ammonium nitrogen in the wastewater.
- For disinfection, chlorine is fed manually or automatically into a chlorine contact tank or basin, where it contacts flowing wastewater for at least 30 minutes to destroy disease-causing microorganisms (pathogens) found in treated wastewater.
- Chlorine may be applied as a gas, a solid, or in liquid hypochlorite form.
- Chlorine is a very reactive substance. It has the potential to react with many different chemicals (including ammonia), as well as with organic matter. When chlorine is added to wastewater, several reactions occur:

- (1) Chlorine will react with any reducing agent (i.e., sulfide, nitrite, iron, and thiosulfate)

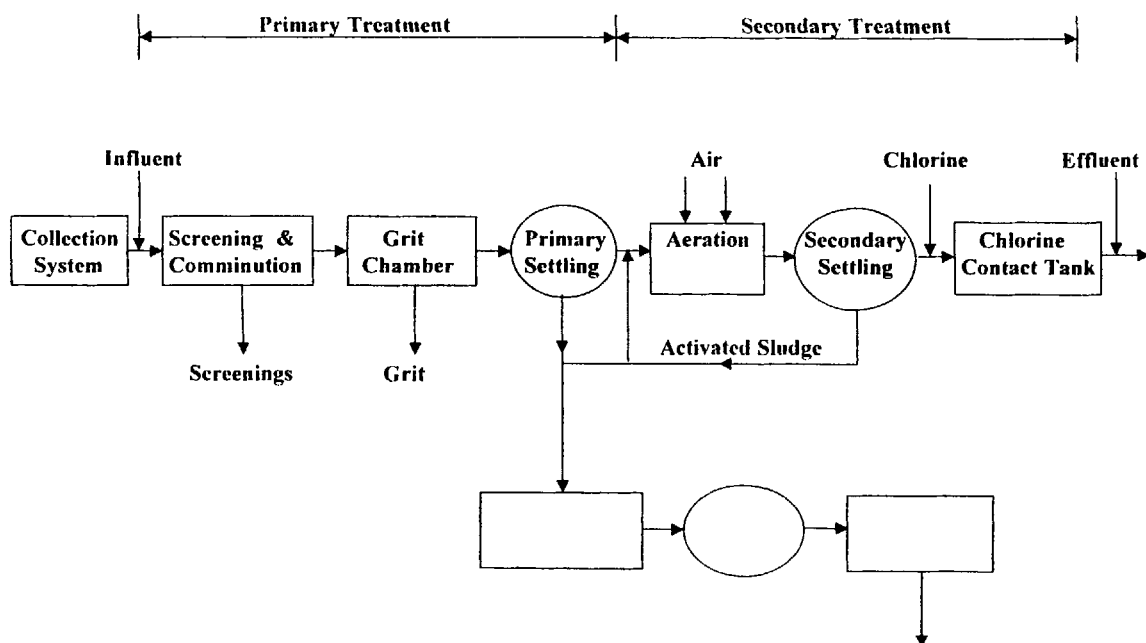


Figure 12.1 Conventional treatment process with disinfection.

present in wastewater. These reactions are known as *chlorine demand*. The chlorine used for these reactions is not available for disinfection.

- (2) Chlorine also reacts with organic compounds and ammonia compounds to form chlor-organics and chloramines. Chloramines are part of the group of chlorine compounds that have disinfecting properties and show up as part of the chlorine residual test.
- (3) After all of the chlorine demands are met, addition of more chlorine will produce a free residual chlorine. Producing a free residual chlorine in wastewater requires very large additions of chlorine.

✓ *Note:* In most wastewater treatment systems, disinfection is accomplished by means of combined residual.

12.2.2 DECHLORINATION

- Dechlorination is the removal of all traces of residual chlorine remaining after the disinfection process and prior to the discharge of the final effluent to the receiving waters.
- This is commonly accomplished by the use of sulfur compounds, such as sulfur dioxide, sodium sulfide, or sodium metabisulfite.
- Sulfur dioxide is the most popular method for dechlorination because it uses existing chlorination equipment.

12.3 OPERATOR OBSERVATIONS, PROCESS PROBLEMS, AND TROUBLESHOOTING

For proper operation, the chlorination process requires routine observation, meter readings, process control sampling and testing, and various process control calculations. Comparison of daily results with expected “normal” ranges is the key to identifying problems during the troubleshooting process and to taking the appropriate corrective actions (if required).

12.3.1 OPERATOR OBSERVATIONS

In this section, we review normal operation and performance factors. The operator should consider the following items.

- (1) *Flow Distribution*—the operator monitors the flow to ensure that it is evenly distributed between all units in service, that the flow through each individual unit is uniform, with no indication of short circuiting.
- (2) *Contact Tank*—the contact tanks or basins must be checked to ensure (1) that no excessive accumulation of scum is on the surface; (2) that no indication of solids accumulation is on the bottom; and (3) that mixing appears to be adequate.
- (3) *Chlorinator*—the operator should check (1) to ensure there is no evidence of leakage; (2) operating pressure/vacuum is within specified levels; (3) current chlorine feed setting is within expected levels; (4) in-line cylinders have sufficient chlorine to ensure continuous feed; and (5) the exhaust system is operating as designed.

12.3.1.2 Factors Affecting Performance

The operator must be familiar with those factors that affect chlorination performance. Any item that interferes with the chlorine reactions or increases the demand for chlorine can affect performance and, in turn, may produce non-disinfectant products. We discuss the main factors affecting chlorination performance in this section.

- (1) *Effluent Quality*—(1) Poor quality effluents have higher chlorine demands; (2) high concentrations of solids prevent chlorine-organism contact; and (3) incomplete nitrification can cause extremely high chlorine demand.
- (2) *Mixing*—To be effective, chlorine must be in contact with the organisms. Poor mixing results in poor chlorine distribution. Installation of baffles and using a high length-to-width ratio will improve mixing and contact.
- (3) *Contact Time*—The chlorine disinfection process is time dependent. As the contact time decreases, process effectiveness decreases. A minimum of 30 minutes of contact must be available at design flow.
- (4) *Residual Levels*—The chlorine disinfection process is total residual chlorine (TRC) dependent. The concentration of residual must be sufficient to ensure the desired reactions occur. At the design contact time, the required minimum total residual chlorine concentration is 1.0 mg/L.

12.3.2 PROCESS CONTROL SAMPLING AND TESTING

To ensure proper operation of the chlorination process, the operator must perform process control testing for the chlorination process. [Note: The process performance evaluation is based on the bacterial content (fecal coliform) of the final effluent.] Process control testing consists of performing a *total chlorine residual test* on chlorine contact effluent. The frequency of the testing is specified in the plant permit. The normal expected range of results is also specified in the plant permit.

12.3.3 TROUBLESHOOTING OPERATION PROBLEMS

The following sections present common operational problems, symptoms, causal factors, and corrective actions associated with chlorination system use in wastewater treatment.

12.3.3.1 Chlorinator

Symptoms:

- low chlorine gas pressure at the chlorinator
- no chlorine gas pressure at the chlorinator
- chlorinator will not feed any chlorine
- chlorinator system is unable to maintain sufficient water bath temperature to keep external chlorine pressure reducing valve (CPRV) open
- inability to obtain maximum feed rate from chlorinator

Causal Factors:

- insufficient number of cylinders connected to the system
- stoppage or restriction of flow between cylinders and chlorinator
- chlorine cylinders empty
- plugged, dirty or damaged pressure-reducing valve
- chlorine cylinder is hotter than chlorinator (chlorine feed apparatus)
- heating element malfunction
- inadequate chlorine gas pressure
- water pump injector clogged with deposits
- vacuum leak in joints, gaskets, tubing, etc., in chlorinator system

Corrective Actions (as applicable):

- Connect enough cylinders to system so that feed rate does not exceed recommended withdrawal rate for cylinders.
- Disconnect chlorine header system at point where cooling begins, locate stoppage, and clean with solvent.
- Repair reducing valve after shutting off cylinder valves and decreasing gas in the header system.
- Disassemble chlorinator and clean valve stem and seat.
- Precede valve with filter/sediment trap.
- Reduce temperature in cylinder area.
- Do not connect a new cylinder that has been sitting in the sun.
- Remove and replace heating element.
- Increase pressure, replace empty/flow cylinders.
- Clean injector parts using muriatic acid. Rinse parts with fresh water and place back in service.
- Disassemble vacuum relief leaks by tightening joints, replacing gaskets, and replacing tubing and/or compression nuts.

12.3.3.2 Chlorine Pressure Reducing Valve (Leaks)

Symptom:

- chlorine gas escaping from the chlorine pressure reducing valve (CPRV)

Causal Factor:

- main diaphragm of CPRV ruptured

Corrective Actions:

- disassemble valve and replace diaphragm
- inspect chlorine supply system for moisture

12.3.3.3 Chlorine Evaporator

Symptom:

- inability to maintain chlorine feed rate without icing of chlorine system

Causal Factors:

- insufficient evaporator capacity
- external CPRV cartridge is clogged

Corrective Actions:

- increase evaporator capacity
- flush and clean cartridge

12.3.3.4 Chlorine Water Supply Pump

Symptom:

- inability to maintain adequate chlorine feed rate

Causal Factor:

- malfunction or deterioration of chlorine water supply pump

Corrective Actions:

- Overhaul pump.
- If turbine pump is used, try closing valve to maintain proper discharge pressure.

12.3.3.5 Variation in Chlorine Residual in Effluent

Symptoms:

- wide variation in chlorine residual produced in the effluent
- chlorine residual too high in plant effluent to meet permit requirements
- unable to obtain residual; feed system operating properly

Causal Factors:

- chlorine flow proportion meter capacity inadequate to meet plant flow rates
- malfunctioning controls
- solids settled in chlorine contact chamber
- flow proportioning control device not zeroed or spanned correctly
- chlorine residual too high
- high chemical demand
- test interference

Corrective Actions (as applicable):

- replace with higher capacity chlorinator meter
- call manufacturer's field service technician
- clean chlorine contact tank
- re-zero and span the device in accordance with manufacturer's instructions
- install dechlorination filter
- locate and correct at source
- add sulfamic acid to samples to reduce interference

12.3.3.6 Chlorine Control Equipment

Symptom:

- Chlorine residual analyzer, recorder, controller does not control chlorine residual properly.

Causal Factors:

- electrodes fouled
- loop time is too long
- insufficient potassium iodide being added for the amount of residual being measured
- malfunctioning buffer additive system
- malfunctioning of analyzer cell
- poor mixing of chlorine at point of application
- rotameter tube range is improperly set

Corrective Actions (as applicable):

- clean electrodes
- return control loop time by
 - (1) Moving the injector closer to the point of application
 - (2) Increasing the velocity in the sample line to the analyzer
 - (3) Moving the cell closer to the sample point
 - (4) Moving the sample point closer to the point of application
- adjust potassium iodide feed to correspond with the chlorine residual being measured
- repair buffer additive system
- call authorized service personnel to repair electrical components
- install mixing device to cause turbulence at point of application
- replace rotameter with a proper range of feed rate

12.3.3.7 Coliform Count

Symptom:

- Coliform count fails to meet required standards for disinfection.

Causal Factors:

- inadequate chlorination equipment capacity
- inadequate chlorine residual control
- short circuiting in the chlorine contact chamber
- solids buildup in contact chamber
- chlorine residual is too low

Corrective Actions (as applicable):

- replace equipment as necessary to provide treatment based upon maximum flow through the plant
- use chlorine residual analyzer to monitor and control chlorine dosage automatically
- install baffling in the chlorine contact chamber
- install mixing device in chlorine contact chamber
- clean contact chamber
- increase contact time and/or increase chlorine feed rate

12.4 PROCESS CONTROL CALCULATIONS

Chlorination process control calculations include determining chlorine feed rate, chlorine dose, chlorine demand, cylinder requirements, supply on hand, and hypochlorite feed rate.

12.4.1 CHLORINE FEED RATE

$$\text{Feed Rate} = \text{Dose mg/L} \times \text{Flow, MGD} \times 8.34 \text{ lb/mg/L/MG} \quad (12.1)$$

Example 12.1

Problem:

The chlorine dose is 7.15 mg/L, and the flow rate is 3.40 MGD. What is the feed rate for chlorine in pounds per day?

Solution:

$$\text{Feed Rate} = 7.15 \text{ mg/L} \times 3.40 \text{ MGD} \times 8.34 \text{ lb/mg/L/MG} = 203 \text{ lb/day}$$

12.4.2 CHLORINE DOSE

$$\text{Dose, mg/L} = \frac{\text{Feed Rate, lb/day}}{\text{Flow, MGD} \times 8.34 \text{ lb/mg/L/MG}} \quad (12.2)$$

Example 12.2

Problem:

The scale indicates that the plant has used 320 pounds of chlorine during the past 24 hours. The flow for the same period was 5.20 MGD. What is the dose of chlorine applied to the wastewater in milligrams/liter?

Solution:

$$\text{Dose, mg/L} = \frac{320 \text{ lb/day}}{5.20 \text{ MGD} \times 8.34 \text{ lb/mg/L/MG}} = 7.4 \text{ mg/L}$$

12.4.3 CHLORINE DEMAND

$$\text{Demand, mg/L} = \text{Dose, mg/L} - \text{Residual, mg/L} \quad (12.3)$$

Example 12.3

Problem:

If the chlorine residual for Example 12.2 was 1.3 mg/L, what was the chlorine demand?

Solution:

$$\text{Demand, mg/L} = 7.4 \text{ mg/L} - 1.3 \text{ mg/L} = 6.1 \text{ mg/L}$$

12.4.4 CHLORINE CYLINDER REQUIREMENTS

A simple calculation is usually used to determine the amount of chlorine cylinders required to ensure a supply is available for specified time period.

$$\text{Cylinders} = \frac{\text{Feed Rate, lb / day} \times \text{Number of Days in Period}}{\text{Weight per Cylinder}} \quad (12.4)$$

Example 12.4

Problem:

The current feed rate is 35 lb/day. If the facility uses 150-pound cylinders, how many cylinders will be required for the month of April?

Solution:

$$\text{Cylinders} = \frac{35 \text{ lb / day} \times 30 \text{ days}}{150 \text{ lb / cylinder}} = 7 \text{ cylinders}$$

12.4.5 SUPPLY ON HAND

Operators must keep track of chlorine on hand to satisfy the requirements for a specified period of time (in days).

$$\text{Supply on hand} = \frac{\text{Avail. Full Cyls} \times \text{Weight / Cyl}}{\text{Current Feed Rate, lb / day}} \quad (12.5)$$

Example 12.5

Problem:

The treatment plant uses 60 pounds per day of chlorine. The plant has eight 150-lb cylinders. How many days supply does the plant have?

Solution:

$$\text{Supply on hand} = \frac{8 \times 150 \text{ lb / cylinder}}{60 \text{ lb / day}} = 20 \text{ days}$$

12.4.6 CHEMICAL FEED RATE: HYPOCHLORITE

When chlorinating wastewater with chlorine gas, 100% of the chlorine is available. Thus, if the chlorine demand and residual require 60 lb/day chlorine, the chlorinator setting would be just that—60 lb/24 hr.

However, if hypochlorite is used instead of chlorine to chlorinate wastewater, 100% pure chlorine is not available, because hypochlorite contains a lesser amount of chlorine. Therefore, more lb/day of hypochlorite must be fed into the system to obtain the same amount of chlorine for disinfection.

To calculate the lb/day chlorine required, we must first calculate the lb/day chlorine required, then calculate the lb/day hypochlorite needed by dividing the lb/day chlorine by the percent available chlorine.

$$\text{Hypochlorite, lb / day} = \frac{\text{Hypochlorite, lb / day}}{\frac{\% \text{ Available Cl}_2}{100}} \quad (12.6)$$

Example 12.6*Problem:*

A wastewater flow of 900,000 gpd requires a chlorine dose of 20 mg/L. If hypochlorite has 65% available chlorine, how many lb/day of hypochlorite are required?

Solution:

First, calculate the lbs/day chlorine required:

$$(\text{mg / L Cl}_2) (\text{MGD flow}) (8.34 \text{ lb / gal}) = \text{lb / day}$$

$$(20 \text{ mg / L}) (0.90 \text{ MGD}) (8.34 \text{ lb / gal}) = 150 \text{ lb / day chlorine}$$

Then calculate the lb/day hypochlorite:

$$\text{Hypochlorite, lb / day} = \frac{\text{lb / day Cl}_2}{\frac{\% \text{ Available Cl}_2}{100}} = \frac{150 \text{ lb / day Cl}_2}{0.65 \text{ Avail. Cl}_2} = 231 \text{ lb / day hypochlorite}$$

12.5 SUMMARY

Chlorine's use as a disinfectant (in whatever form) is widespread. For many treatment facilities, disinfection may be the final step before the release of effluent into the receiving body of water. However, some wastewaters and some receiving bodies require higher levels of treatment. We cover advanced wastewater treatment in the next chapter.

12.6 CHAPTER REVIEW QUESTIONS

12-1 What is the difference between disinfection and sterilization?

12-2 To be effective, enough chlorine must be added to satisfy the _____ and produce a _____ mg/L _____ for at least _____ minutes at design flow rates.

12-3 Elemental chlorine gas is _____ in color and is _____ times heavier than air.

12-4 You are currently adding 395 pounds of chlorine per day to a wastewater flow of 5.6 MGD. What is the chlorine dose in mg/L?

12-5 The chlorine dose is 8.1 mg/L. If the residual is 1.0 mg/L the chlorine demand is _____.

Advanced Wastewater Treatment

13.1 INTRODUCTION

ADVANCED wastewater treatment is defined as the method(s) and/or process(es) that remove more contaminants (suspended and dissolved substances) from wastewater than are taken out by conventional biological treatment. Put another way, advanced wastewater treatment is the application of a process or system that follows secondary treatment or that includes phosphorus removal or nitrification in conventional secondary treatment.

Advanced wastewater treatment is used to augment conventional secondary treatment because secondary treatment typically removes only between 85 and 95% of the biochemical oxygen demand (BOD) and total suspended solids (TSS) in raw sanitary sewage. Generally, this leaves 30 mg/L or less of BOD and TSS in the secondary effluent. To meet stringent water-quality standards, this level of BOD and TSS in secondary effluent may not prevent violation of water-quality standards—the plant may not make permit. Thus, advanced wastewater treatment is often used to remove additional pollutants from treated wastewater.

In addition to meeting or exceeding the requirements of water-quality standards, treatment facilities use advanced wastewater treatment for other reasons as well. For example, sometimes, conventional secondary wastewater treatment is not sufficient to protect the aquatic environment. In a stream, for example, when periodic low flow events occur, the stream may not provide the amount of dilution of effluent needed to maintain the necessary dissolved oxygen (DO) levels for aquatic organism survival.

Secondary treatment has other limitations. It does not significantly reduce the effluent concentration of nitrogen and phosphorus (important plant nutrients) in sewage. If discharged into lakes, these nutrients contribute to algal blooms and accelerated eutrophication (lake aging). Also, the nitrogen in the sewage effluent may be present mostly in the form of ammonia compounds. If in high enough concentration, ammonia compounds are toxic to aquatic organisms. Yet another problem with these compounds is that they exert a *nitrogenous* oxygen demand in the receiving water, as they convert to nitrates. This process is called nitrification (discussed in Section 13.5).

✓ *Note:* The term *tertiary treatment* is commonly used as a synonym for advanced wastewater treatment. However, these two terms do not have precisely the same meaning. Tertiary suggests a third step that is applied after primary and secondary treatment.

Advanced wastewater treatment can remove more than 99% of the pollutants from raw sewage and can produce an effluent of almost potable (drinking) water quality. However, obviously, advanced treatment is not cost-free. The cost of advanced treatment, for operation and maintenance as well as for retrofit of present conventional processes, is very high (sometimes doubling the cost of secondary treatment). Therefore, any plan to install advanced treatment technology calls for careful study—the benefit-to-cost ratio is not always big enough to justify the additional expense.

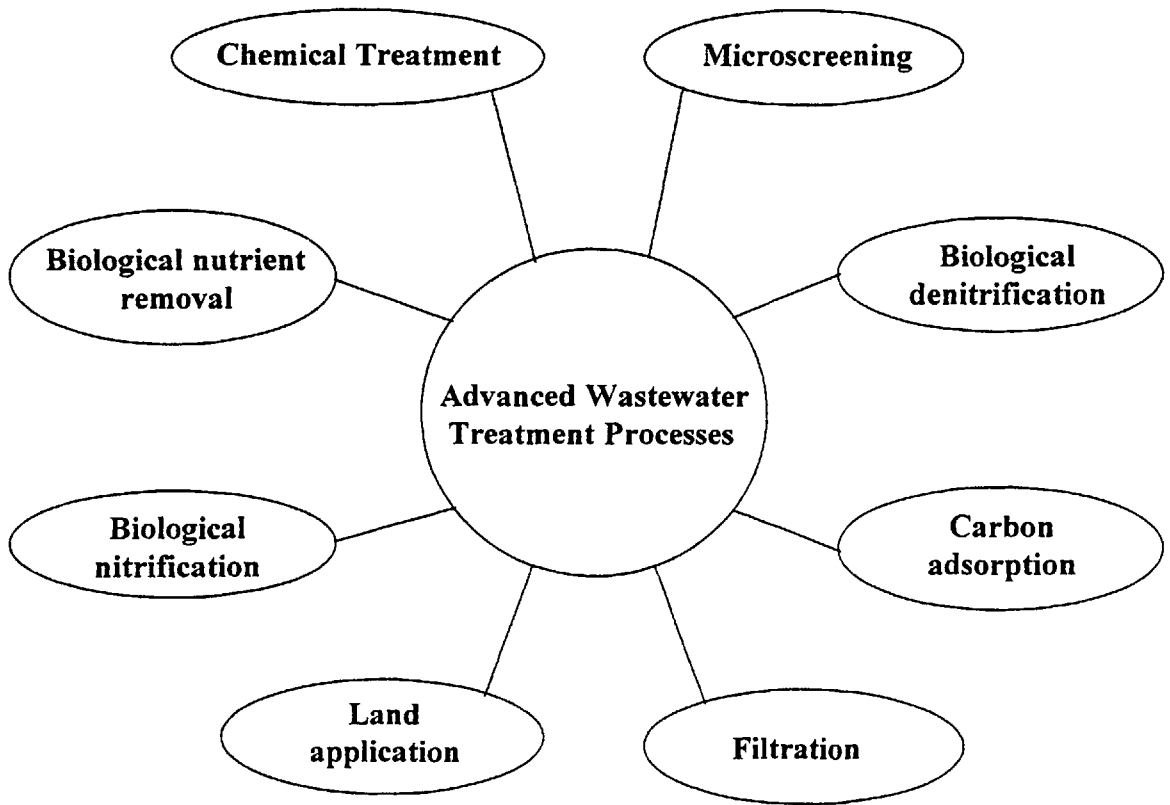


Figure 13.1 Advanced wastewater treatment processes.

Even considering the expense, application of some form of advanced treatment is not uncommon. These treatment processes can be physical, chemical, or biological. The specific process used is based upon the purpose of the treatment and the quality of the effluent desired. In this chapter, we discuss those advanced wastewater treatment processes shown in Figure 13.1.

13.2 CHEMICAL TREATMENT

The purpose of chemical treatment is to remove

- BOD_5
- total suspended solids (TSS)
- phosphorus
- heavy metals
- other substances that can be chemically converted to a settleable solid

Chemical treatment is often accomplished as an “add-on” to existing treatment systems or by means of separate facilities specifically designed for chemical additions. In each case, the basic process necessary to achieve the desired results remains the same:

- Chemicals are thoroughly mixed with the wastewater.
- The chemical reactions that occur form solids (coagulation).
- The solids are mixed to increase particle size (flocculation).
- The solids are then removed by settling and/or filtration (separation).

The specific chemical used depends on the pollutant to be removed and the characteristics of the wastewater. Chemicals may include the following:

- lime
- alum (aluminum sulfate)
- aluminum salts
- ferric or ferrous salts
- polymers
- bioadditives

13.2.1 OPERATION, OBSERVATION, AND TROUBLESHOOTING PROCEDURES

Operation and observation of performance of chemical treatment processes are dependent on the pollutant being removed and on process design.

Operational problems associated with chemical treatment processes used in advanced treatment usually revolve around problems with floc formation, settling characteristics, removal in the settling tank, and sludge (in settling tank) turning anaerobic.

To correct these problems, the operator must be able to recognize the applicable problem indicators through proper observation. In the following sections, we list common indicators/observations of operational problems, along with the applicable causal factors and corrective actions.

13.2.1.1 Poor Floc Formation and Settling Characteristics

Causal Factors:

- insufficient chemical dispersal during rapid mix
- excessive detention time in rapid mix
- improper coagulant dosage
- excessive flocculator speed

Corrective Actions (where applicable):

- increase speed of rapid mixer
- reduce detention time to 15–60 seconds
- correct dosage (determine by jar testing)
- reduce flocculator speed

13.2.1.2 Good Floc Formation, Poor Removal in Settling Tank

Causal Factors:

- excessive velocity between flocculation and settling
- settling tank operational problem

Corrective Action:

- reduce velocity to acceptable range

13.2.1.3 Settling Tank Sludge Is Turning Anaerobic

Causal Factors:

- a sludge blanket has developed in settling tank
- excessive organic carryover from secondary treatment

Corrective Actions (where applicable):

- increase sludge withdrawal to eliminate blanket
- correct secondary treatment operational problems

13.3 MICROSCREENING

Microscreening (also called *microstraining*) is an advanced treatment process used to reduce suspended solids. The microscreens are composed of specially woven steel wire fabric mounted around the perimeter of a large revolving drum. The steel wire cloth acts as a fine screen, with openings as small as 20 micrometers (or millionths of a meter)—small enough to remove microscopic organisms and debris.

The rotating drum is partially submerged in the secondary effluent, which must flow into the drum then outward through the microscreen. As the drum rotates, captured solids are carried to the top where a high-velocity water spray flushes them into a hopper or backwash tray mounted on the hollow axle of the drum. Backwash solids are recycled to plant influent for treatment. These units have found greatest application in treatment of industrial waters and final polishing filtration of wastewater effluents. Expected performance for suspended solids removal is 95 to 99%, but the typical suspended-solids removal achieved with these units is about 55%. The normal range is from 10 to 80%.

The functional design of a microscreen unit involves the following considerations:⁷ (1) The characterization of the suspended solids with respect to the concentration and degree of flocculation; (2) the selection of unit design parameter values that will not only ensure capacity to meet maximum hydraulic loadings with critical solids characteristics, but also provide desired design performance over the expected range of hydraulic and solids loadings; (3) the provision of backwash and cleaning facilities to maintain the capacity of the screen.

13.3.1 OPERATION, OBSERVATION, AND TROUBLESHOOTING PROCEDURES

Microscreen operators typically perform sampling and testing on influent and effluent TSS, and monitor screen operation to ensure proper operation. Operational problems generally consist of gradual decrease in throughput rate, leakage at ends of the drum, reduced screen capacity, hot or noisy drive systems, erratic drum rotation, and sudden increases in effluent solids.

13.3.1.1 Decrease in Throughput Rate (from Slime Growth)

Causal Factors:

- inadequate cleaning
- spray nozzles plugged

Corrective Actions (where applicable):

- increase backwash pressure (60–120 psi)
- add hypochlorite upstream of the unit
- unclog nozzles

⁷From Metcalf & Eddy, *Wastewater Engineering: Treatment, Disposal, Reuse*, 3rd ed. New York: McGraw Hill, p. 690.

13.3.1.2 Decreased Performance from Leakage at Ends of the Drum

Causal Factor:

- defective/leaking seals

Corrective Actions:

- tighten tension on sealing bands
- replace sealing bands if excessive tension is required

13.3.1.3 Screen Capacity Reduced after Shutdown Period

Causal Factor:

- Screen is fouled.

Corrective Actions:

- Clean screen prior to shut down.
- Clean screen with hypochlorite.

13.3.1.4 Drive System Is Running Hot or Noisy

Causal Factor:

- inadequate lubrication

Corrective Action:

- fill to specified level with recommended oil

13.3.1.5 Erratic Drum Rotation

Causal Factors:

- improper drive belt adjustment
- drive belts worn out

Corrective Actions:

- adjust tension to specified level
- replace drive belts

13.3.1.6 Sudden Increase in Effluent Solids

Causal Factors:

- hole in screen fabric
- screws that secure fabric are loose
- solids collection trough is overflowing

Corrective Actions (where applicable):

- repair fabric
- tighten screws
- reduce microscreen influent flow rate

13.3.1.7 Decreased Screen Capacity after High-Pressure Washing

Causal Factor:

- iron or manganese oxide film on fabric

Corrective Action:

- Clean screen with inhibited acid cleaner. Follow manufacturer's instructions.

13.4 FILTRATION

The purpose of *filtration* processes used in advanced treatment is to remove suspended solids. The specific operations associated with a filtration system are dependent on the equipment used. A general description of the process follows.

13.4.1 FILTRATION PROCESS DESCRIPTION

Wastewater flows to a filter (gravity or pressurized). The filter contains single, dual, or multimedia. Wastewater flows through the media, which removes solids. The solids remain in the filter. Backwashing the filter as needed removes trapped solids. Backwash solids are returned to the plant for treatment. Processes typically remove 95 to 99% of the suspended matter.

13.4.2 OPERATION, OBSERVATION, AND TROUBLESHOOTING PROCEDURES

Operators routinely monitor filter operation to ensure optimum performance and to detect operational problems based on indication or observation of equipment malfunction or process sub-optimal performance. We discuss operational problems typically encountered in the sections that follow.

13.4.2.1 High Effluent Turbidity

Causal Factors:

- Filter requires backwashing.
- Prior chemical treatment inadequate.

Corrective Actions (where applicable):

- Backwash unit as soon as possible.
- Adjust/control chemical dosage properly.

13.4.2.2 High Head Loss through the Filter

Causal Factor:

- Filter requires backwashing.

Corrective Action:

- Backwash unit as soon as possible.

13.4.2.3 High Head Loss through Unit Right after Backwashing

Causal Factors:

- Backwash cycle was insufficient.
- Surface scour/wash arm inoperative.

Corrective Actions (where applicable):

- Increase backwash time.
- Repair air scour or surface scrubbing arm.

13.4.2.4 Backwash Water Requirement Exceeds 5%

Causal Factors:

- excessive solids in filter influent
- excessive filter aid dosage
- surface washing/air scour not operating
- surface washing/air scour not operated long enough during backwash cycle
- excessive backwash cycle used

Corrective Actions (where applicable):

- Improve treatment prior to filtration.
- Reduce control/filter aid dose rates.
- Repair mechanical problem.
- Increase surface wash cycle time.
- Adjust backwash cycle length.

13.4.2.5 Filter Surface Clogging

Causal Factors:

- inadequate prior treatment (single media filters)
- excessive filter aid dosage (dual or mixed media filters)
- inadequate surface wash cycle
- inadequate backwash cycle

Corrective Actions (where applicable):

- Improve prior treatment.
- Replace single media with dual/mixed media.
- Reduce or eliminate filter aid.
- Provide adequate surface wash cycle.
- Provide adequate backwash cycle.

13.4.2.6 Short Filter Runs

Causal Factor:

- high head loss

Corrective Action:

- See corrective actions, Section 13.4.2.5.

13.4.2.7 Filter Effluent Turbidity Increases Rapidly

Causal Factors:

- Inadequate filter aid dosage.
- Filter aid system mechanical failure.
- Filter aid requirement has changed.

Corrective Actions (where applicable):

- Increase chemical dosage.
- Repair feed system.
- Adjust filter aid dose rate (do jar test).

13.4.2.8 Mud Ball Formation

Causal Factors:

- inadequate backwash flow rate
- inadequate surface wash

Corrective Actions (where applicable):

- Increase backwash flow to specified levels.
- Increase surface wash cycle.

13.4.2.9 Gravel Displacement

Causal Factor:

- Air is entering the underdrains during backwash cycle.

Corrective Actions:

- Control backwash volume.
- Control backwash water head.
- Replace media (severe displacement).

13.4.2.10 Medium Is Lost during Backwash Cycle

Causal Factors:

- excessive backwash flows
- excessive auxiliary scour
- air attached to filter media, causing it to float

Corrective Actions (where applicable):

- Reduce backwash flow rate.
- Stop auxiliary scour several minutes before end of backwash cycle.
- Increase backwash frequency to prevent bubble displacement and/or maintain maximum operating water depth above filter surface.

13.4.2.11 Filter Backwash Cycle Not Effective during Warm Weather

Causal Factor:

- decreased water viscosity due to higher temperatures

Corrective Action:

- Increase backwash rate until required bed expansion is achieved.

13.4.2.12 Air Binding Causes Premature Headloss Increase*Causal Factors:*

- air bubble produced by exposing an influent containing high dissolved oxygen levels to less than atmospheric pressure
- pressure drops occurring during changeover to backwash cycle

Corrective Actions (where applicable):

- Increase backwash frequency.
- Maintain maximum operating water depth.

13.5 BIOLOGICAL NITRIFICATION

Biological *nitrification* is the first basic step of *biological nitrification-denitrification* (denitrification is discussed in Section 13.6). In nitrification, the secondary effluent is introduced into another aeration tank, trickling filter, or biodisc. Because most of the carbonaceous BOD has already been removed, the microorganisms that thrive in this advanced step are the nitrifying bacteria *Nitrosomonas* and *Nitrobacter*. In nitrification, the ammonia nitrogen is converted to nitrate nitrogen, producing a *nitrified effluent*. At this point, the nitrogen has not actually been removed, only converted to a form that is not toxic to aquatic life and that does not cause an additional oxygen demand.

The nitrification process can be limited (performance affected) by alkalinity (requires 7.3 parts alkalinity to 1.0 part ammonia nitrogen); pH; dissolved oxygen availability; toxicity (ammonia or other toxic materials); and process mean cell residence time (sludge retention time). As a general rule, biological nitrification is more effective and achieves higher levels of removal during the warmer times of the year.

13.5.1 OPERATION, OBSERVATION, AND TROUBLESHOOTING PROCEDURES

Ensuring the nitrification process performs as per design requires the operator to monitor the process and to make routine adjustments. The loss of solids from settling tank, RBC, or from a trickling filter are common problems that the operator must be able to identify as well as to take proper corrective actions. In these instances, obviously, the operator needs to be familiar with activated sludge system, rotating biological contactor (RBC), or trickling filter operations.

The operator must also be familiar with other nitrification operational problems and must be able to take the proper corrective actions. We discuss typical nitrification operational problems and recommended corrective actions in the following sections.

13.5.1.1 pH Decreases with Loss of Nitrification*Causal Factors:*

- insufficient alkalinity available for process
- acid wastes in process influent

Corrective Actions (where applicable):

- If process alkalinity is less than 30 mg/L, add lime or sodium hydroxide to process influent.

- Identify source and control of acid wastes.

13.5.1.2 Incomplete Nitrification

Causal Factors:

- Process is dissolved-oxygen limited.
- Process is temperature limited.
- Influent nitrogen loading has increased.
- Low nitrifying bacteria population in process.
- Peak hourly ammonium concentrations exceed available oxygen supplies.

Corrective Actions (where applicable):

- Increase process aeration rate.
- Decrease process nitrogen loading.
- Increase nitrifying bacteria population.
- Put additional units in service.
- Modify operation to increase nitrogen removal.
- Decrease wasting or solids loss.
- Add settled raw sewage to nitrification unit to increase biological solids.
- Increase oxygen supply.
- Install flow equalization to minimize peaks.

13.5.1.3 Sludge Volume Index (SVI) of Nitrification Sludge Very High (>250)

Causal Factor:

- Nitrification is occurring in the first stage (BOD₅ removal sludge).

Corrective Actions (where applicable):

- Transfer sludge from first to second stage.
- Operate first stage at lower mean cell residence time (MCRT)/sludge retention time (SRT).

13.6 BIOLOGICAL DENITRIFICATION

Biological denitrification removes nitrogen from the wastewater. When bacteria come in contact with a nitrified element in the absence of oxygen, they reduce the nitrates to nitrogen gas, which escapes the wastewater. The denitrification process can be done in either an anoxic activated sludge system (suspended growth) or in a column system (fixed growth). The denitrification process can remove up to 85% or more of nitrogen.

After effective biological treatment, little oxygen demanding material is left in the wastewater when it reaches the denitrification process.

The denitrification reaction will only occur if an oxygen demand source exists when no dissolved oxygen is present in the wastewater. An oxygen demand source is usually added to reduce the nitrates quickly. The most common demand source added is soluble BOD or methanol. Approximately 3 mg/L of methanol is added for every 1 mg/L of nitrate-nitrogen.

Suspended growth denitrification reactors are mixed mechanically, but only enough to keep the biomass from settling without adding unwanted oxygen.

Submerged filters of different types of media may also be used to provide denitrification. A fine media downflow filter is sometimes used to provide both denitrification and effluent filtration. A

fluidized sand bed where wastewater flows upward through a media of sand or activated carbon at a rate to fluidize the bed may also be used. Denitrification bacteria grow on the media.

13.6.1 OBSERVATION, OPERATION, AND TROUBLESHOOTING PROCEDURES

In operation of a denitrification process, operators monitor performance by observing various parameters. Parameters or other indicators/observations that demonstrate process malfunction or sub-optimal performance indicate the need for various corrective actions. We discuss several of these indicators/observations of poor process performance, their causal factors, and corrective actions in the sections that follow.

13.6.1.1 Process Effluent: Sudden Increase in BOD₅

Causal Factor:

- excessive methanol or other organic matter present

Corrective Actions (as required):

- Reduce methanol addition.
- Install automated methanol control system.
- Install aerated stabilization unit for removal of excess methanol.

13.6.1.2 Sudden Increase in Effluent Nitrate Concentration

Causal Factors:

- Inadequate methanol control.
- Denitrification pH is outside 7.0–7.5 range required for process.
- Loss of solids from denitrification process due to pump failure.
- Excessive mixing introducing dissolved oxygen.

Corrective Actions (where applicable):

- Identify/correct control problem.
- Correct pH problem in nitrification process.
- Adjust pH at process influent.
- Correct denitrification sludge return pump problem.
- Increase denitrification sludge waste rate.
- Decrease denitrification sludge waste rate.
- Transfer sludge from carbonaceous units to denitrification unit.
- Reduce mixer speed.
- Remove some mixers from service.

13.6.1.3 High Head Loss (Packed Bed Nitrification)

Causal Factors:

- excessive solids in unit
- nitrogen gas accumulating in unit

Corrective Action:

- Backwash unit 1–2 minutes, then return to service.

13.6.1.4 Out of Service Packed Bed Unit Blinds on Startup

Causal Factor:

- Solids have floated to top during shut down.

Corrective Action:

- Backwash units before removing from service and immediately before placing in servicing.

13.7 CARBON ADSORPTION

The main purpose of *carbon adsorption* used in advanced treatment processes is the removal of refractory organic compounds (non-BOD₅) and soluble organic material that are difficult to eliminate by biological or physical/chemical treatment.

In the carbon adsorption process, wastewater passes through a container filled either with carbon powder or a carbon slurry. Organics adsorb onto the carbon (i.e., organic molecules are attracted to the activated carbon surface and are held there) with sufficient contact time.

A carbon system usually has several columns or basins used as contactors. Most contact chambers are either open concrete gravity-type systems or steel pressure containers applicable to either upflow or downflow operation.

With use, carbon loses its adsorptive capacity. The carbon must then be regenerated or replaced with fresh carbon. As head loss develops in carbon contactors, they are backwashed with clean effluent in much the same way the effluent filters are backwashed. Carbon used for adsorption may be in a granular form or in a powdered form.

✓ *Note:* Powdered carbon is too fine for use in columns and is usually added to the wastewater, then later removed by coagulation and settling.

13.7.1 OPERATION, OBSERVATION, AND TROUBLESHOOTING PROCEDURES

In operation of a carbon adsorption system for advanced wastewater treatment, operators are primarily interested in monitoring the system to prevent excessive head loss, to reduce levels of hydrogen sulfide in the carbon contactor, to ensure that the carbon is not fouled, and to ensure corrosion of metal parts and damage to concrete in contactors is minimal.

13.7.1.1 Excessive Head Loss

Causal Factors:

- highly turbid influent
- growth and accumulation of biological solids in unit
- excessive carbon fines due to deterioration during handling
- inlet or outlet screens plugged

Corrective Actions (where applicable):

- Backwash unit vigorously.
- Correct problem in prior treatment steps.
- Operate as an expanded upflow bed to remove solids continuously.
- Increase frequency of backwashing for downflow beds.
- Improve soluble BOD₅ removal in prior treatment steps.
- Remove carbon from unit and wash out fines.
- Replace carbon with harder carbon.

- Backflush screens.

13.7.1.2 Hydrogen Sulfide in Carbon Contactor

Causal Factors:

- low/no dissolved oxygen and/or nitrate in contactor influent
- high influent BOD₅ concentrations
- excessive detention time in carbon contactor

Corrective Actions (where applicable):

- Add air, oxygen, or sodium nitrate to unit influent.
- Improve soluble BOD₅ removal in prior treatment steps.
- Precipitate sulfides already formed with iron or chlorine.
- Reduce detention time by removing contactor(s) from service.
- Backwash units more frequently and more violently, using air scour or surface wash.

13.7.1.3 Large Decrease in COD Removed/lb of Carbon Regenerated

Causal Factor:

- Carbon is fouled and losing efficiency.

Corrective Action:

- Improve regeneration process performance.

13.7.1.4 Corrosion of Metal Parts/Damage to Concrete in Contactors

Causal Factors:

- hydrogen sulfide in carbon contactors
- holes in protective coatings exposed to dewatered carbon

Corrective Actions:

- See corrective actions in Section 13.7.1.2.
- Repair protective coatings.

13.8 LAND APPLICATION

The application of secondary effluent onto a land surface can provide an effective alternative to the expensive and complicated advanced treatment methods discussed previously and the biological nutrient removal (BNR) system discussed in Section 13.9. A high-quality polished effluent (i.e., effluent with high levels of TSS, BOD, phosphorous, and nitrogen compounds as well as refractory organics are reduced) can be obtained by the natural processes that occur as the effluent flows over the vegetated ground surface and percolates through the soil.

An additional benefit of land treatment is that it can provide the moisture and nutrients needed for vegetation growth, and it can help to recharge groundwater aquifers. In effect, land treatment of wastewater allows a direct recycling of water and nutrients for beneficial use⁸ (i.e., the sewage becomes a valuable natural resource that is not simply disposed of).

⁸From Nathanson, J. A., *Basic Environmental Technology: Water Supply, Waste Management, and Pollution Control*, 2nd ed. Upper Saddle River, NJ: Prentice Hall, p. 251.

Limitations are involved with land application of wastewater effluent. For example, the process needs large land areas. Soil type and climate are also critical factors in controlling the design and feasibility of a land treatment process.

13.8.1 TYPES/MODES OF LAND APPLICATION

Three basic types or modes of land application or treatment are commonly used: Irrigation (slow rate), overland flow, and infiltration-percolation (rapid rate). The basic objectives of these types of land applications and the conditions under which they can function vary.

In *irrigation* (also called slow rate), wastewater is sprayed or applied (usually by ridge-and-furrow surface spreading or by sprinkler systems) to the surface of the land. Wastewater enters the soil. Crops growing on the irrigation area utilize available nutrients. Soil organisms stabilize organic content of the flow. Water returns to hydrologic (water) cycle through evaporation or by entering the surface water or groundwater [see Figure 13.2(a)].

The irrigation land application method provides the best results (compared with the other two types of land application systems) with respect to advanced treatment levels of pollutant removal. Not only are suspended solids and BOD significantly reduced by filtration of the wastewater, but also biological oxidation of the organics in the top few inches of soil occurs. Nitrogen is removed primarily by crop uptake, and phosphorus is removed by adsorption within the soil.

Irrigation expected performance levels are

- BOD₅—98%
- suspended solids—98%
- nitrogen—85%
- phosphorus—95%
- metals—95%

The *overland flow* mode of land application used for water purification is accomplished by physical, chemical, and biological processes as the wastewater flows in a thin film down the relatively impermeable surface. In the process, wastewater sprayed over sloped terraces flows slowly over the surface. Soil and vegetation remove suspended solids, nutrients, and organics. A small portion of the wastewater evaporates. The remainder flows to collection channels. Collected effluent is discharged to surface waters [see Figure 13.2(b)].

Overland flow expected performance levels are

- BOD₅—92%
- suspended solids—92%
- nitrogen—70–90%
- phosphorus—40–80%
- metals—50%

In the *infiltration-percolation* (rapid rate) land application process, wastewater is sprayed/pumped to spreading basins (a.k.a. recharge basins or large ponds). Some wastewater evaporates. The remainder percolates/infiltrates into soil. Solids are removed by filtration. Water recharges the groundwater system. Most of the effluent percolates to the groundwater; very little of it is absorbed by vegetation [see Figure 13.2(c)]. The filtering and adsorption action of the soil removes most of the BOD, TSS, and phosphorous from the effluent; however, nitrogen removal is relatively poor.

Infiltration-percolation expected performance levels are

- BOD₅—85–99%
- suspended solids—98%
- nitrogen—0–50%

- phosphorus—60–95%
- metals—50–95%

13.8.2 OPERATION, OBSERVATION, AND TROUBLESHOOTING PROCEDURES

Performance levels are dependent on the land application process used. To be effective, operators must monitor the operation of the land application process employed. Experience has shown that

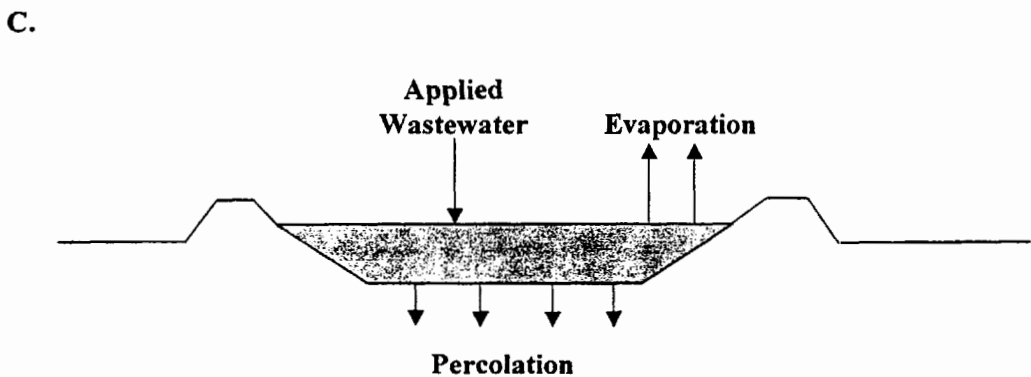
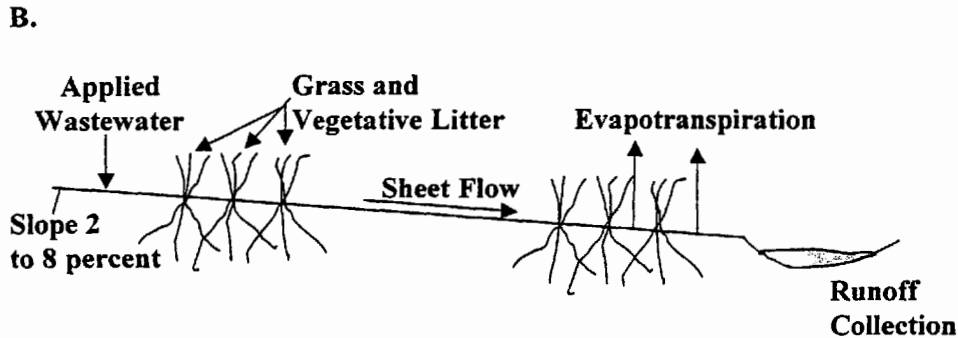
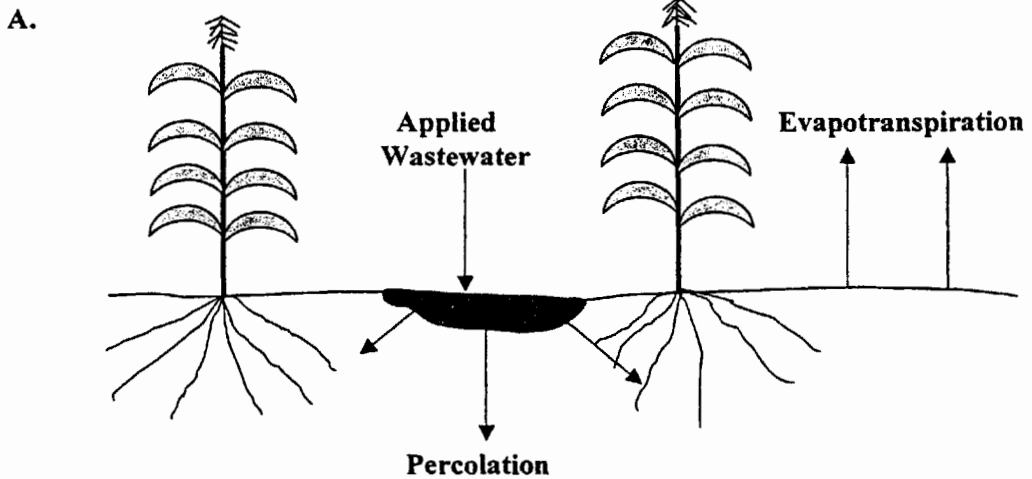


Figure 13.2 (a) Slow land treatment (irrigation); (b) overland flow; (c) rapid filtration. *Source:* Spellman, F. R. and Whiting, N., *Water Pollution Control Technology*. Rockport, MD: Government Institute, 1999.

these processes can be very effective, but problems exist when the flow contains potentially toxic materials that may become concentrated in the crops being grown on land. Along with this problem, other problems are common, including ponding, deterioration of distribution piping systems, malfunctioning sprinkler heads, waste runoff, irrigated crop die-off, poor crop growth, and too much flow rate.

13.8.2.1 In Irrigated Areas, Water Is Ponding

Causal Factors:

- excessive application rate
- inadequate drainage because of groundwater levels
- damaged drainage wells
- inadequate well withdrawal rates
- damaged drain tiles
- broken pipe in distribution system

Corrective Actions (where applicable):

- Reduce application rate to acceptable level.
- Irrigate in portions of site where groundwater is not a problem.
- Store wastewater until condition is corrected.
- Repair drainage wells.
- Increase drainage well pumping rates.
- Repair damaged drain tiles.
- Repair pipe.

13.8.2.2 Deterioration of Distribution Piping

Causal Factors:

- effluent remains in pipe for long periods
- different metals used in same line

Corrective Actions (where applicable):

- Drain pipe after each use.
- Coat steel valves.
- Install cathodic/anodic protection.

13.8.2.3 No Flow from Some Sprinkler Nozzles

Causal Factor:

- nozzles clogged

Corrective Action:

- Repair/replace screen on irrigation pump inlet.

13.8.2.4 Wastes Running Off Irrigation Area

Causal Factors:

- High sodium adsorption ratio has caused clay soil to become impermeable.

- Soil surface is sealed by solids.
- Application rate is greater than soil infiltration rate.
- Break in distribution piping.
- Soil permeability has decreased because of continuous application of wastewater.
- Rain has saturated the soil.

Corrective Actions (where applicable):

- Feed calcium and magnesium to maintain sodium adsorption ratio (SAR) to less than 9.
- Strip crop area.
- Reduce application rate to acceptable level.
- Repair system.
- Allow 2–3 day rest period between each application.
- Store wastewater until soil has drained.

13.8.2.5 Irrigated Crop Is Dead

Causal Factors:

- Too much or not enough water has been applied.
- Wastewater contains toxic materials in toxic concentrations.
- Excessive insecticide or herbicide applied.
- Inadequate drainage has flooded root zone of crop.

Corrective Actions (where applicable):

- Adjust application rate to appropriate level.
- Eliminate source of toxicity.
- Apply only as permitted/directed.

13.8.2.6 Poor Crop Growth

Causal Factors:

- Too little nitrogen (N) or phosphorus (P).
- Timing of nutrient applications does not coincide with plant nutrient need.

Corrective Actions (where applicable):

- Increase application rate to supply N and P.
- Augment N and P of wastewater with commercial fertilizer applications.
- Adjust application schedule to match crop need.

13.8.2.7 Irrigation Pump: Normal psi but Above Average Flow Rate

Causal Factors:

- Broken main, riser, or lateral.
- Leaking gasket.
- Sprinkler head or nozzle is missing.
- Too many distribution laterals are in service at one time.

Corrective Actions (where applicable):

- Locate and repair problem.

- Locate and replace defective gasket.
- Correct valving to adjust number of laterals in service.

13.8.2.8 Irrigation Pump: Above Average psi, Below Average Flow

Causal Factor:

- blockage in system

Corrective Action:

- Locate and correct blockage.

13.8.2.9 Irrigation Pump: Below Average psi and Flow Rate

Causal Factors:

- worn impeller
- partially clogged pump inlet screen

Corrective Actions (where applicable):

- Replace impeller.
- Clean screen.

13.8.2.10 Excessive Erosion Occurring

Causal Factors:

- excessive application rates
- inadequate crop coverage

Corrective Actions (where applicable):

- Reduce application rate.
- See Corrective Actions in Sections 13.8.2.5 and 13.8.2.6.

13.8.2.11 Odor Complaints

Causal Factors:

- Wastes are turning septic during transport to treatment/ irrigation site.
- Storage reservoirs are septic.

Corrective Actions (where applicable):

- Aerate or chemically treat wastes during transport.
- Install cover over discharge point; collect and treat gases before release.
- Improve pretreatment.
- Aerate storage reservoirs.

13.8.2.12 Center Pivot Irrigation Rigs Stuck in Mud

Causal Factors:

- excessive application rates
- improper rig or tires

- poor drainage

Corrective Actions:

- Reduce application rate.
- Install tire with higher flotation capabilities.

13.8.2.13 Nitrate in Groundwater Near Irrigation Site Increasing

Causal Factors:

- Nitrogen application rate does not balance with crop need.
- Application is occurring during dormant periods.
- Crop is not being properly harvested and removed.

Corrective Actions (where applicable):

- Change to crop with higher nitrogen requirement.
- Adjust schedule to apply only during active growth periods.
- Harvest and remove crop as required.

13.9 BIOLOGICAL NUTRIENT REMOVAL (BNR)

Recent experience has shown that biological nutrient removal (BNR) systems are reliable and effective in removing nitrogen and phosphorus. The process is based upon the principle that, under specific conditions, microorganisms will remove more phosphorus and nitrogen than is required for biological activity. Several patented processes are available for this purpose. Performance depends on the biological activity and the process employed.

13.10 SUMMARY

Even after the influent has traveled through all the stages of treatment and is released as effluent, treatment processes continue. The solid wastes removed from the treated waters must be treated, recycled, or disposed of. We cover solids handling in Chapter 14.

13.11 CHAPTER REVIEW QUESTIONS

13-1 Explain the purpose of advanced wastewater treatment.

13-2 Explain the difference between advanced wastewater treatment and tertiary treatment.

13-3 The specific advanced wastewater treatment used is based on what?

13-4 Another name for microscreening is _____.

13-5 The functional design of a microscreen depends upon what three considerations?

13-6 Performance of the nitrification process is affected by what?

13-7 The denitrification process typically removes up to what % nitrogen?

13-8 The oxygen demand source most commonly added to reduce nitrates quickly is?

13-9 What is the main purpose of carbon adsorption used in advanced wastewater treatment?

13-10 List two limitations to land application of wastewater.

Solids Handling

14.1 INTRODUCTION

WASTEWATER operators at larger facilities (i.e., >2.5 MGD facilities) are generally required to work either the “wet” side (liquid wastestream) or the “solid” side (with the solids, sludge, or biosolids wastestream) of treatment as operators or maintenance operators. Many operators have experience working both sides. Others work facilities where there is no distinction between either side of the treatment process.

To this point in Volume 3 of the handbook, we have concentrated exclusively on the wet or liquid side of wastewater treatment. In this chapter, we concentrate on the other side of wastewater treatment—the solids-handling side (see Figure 14.1), which completes the wastewater treatment process discussed in this handbook. This coverage includes discussion of the major solids-handling processes shown in Figure 14.2.

14.1.1 SLUDGE: BACKGROUND INFORMATION

When we speak of *sludge* or *biosolids*, we are speaking of the same substance or material; each is defined as the suspended solids removed from wastewater during sedimentation, then concentrated for further treatment and disposal or reuse. The difference between the terms *sludge* and *biosolids* is determined by the way they are managed. (*Note:* The task of disposing, treating, or reusing wastewater solids is called *sludge* or *biosolids management*.) Sludge is typically seen as wastewater solids that are “disposed” of. Biosolids is the same substance managed for reuse—commonly called beneficial reuse (e.g., for land application as a soil amendment, such as biosolids compost).

✓ *Note:* In this handbook, we use and refer to the general term *sludge* to describe wastewater solids; however, when we address beneficial use or reuse of these solids (e.g., land application), we use the term *biosolids*.

Note that even as wastewater treatment standards have become more stringent because of increasing environmental regulations, so has the volume of wastewater sludge increased.

Note also that before sludge can be disposed of or reused, it requires some form of treatment to reduce its volume, to stabilize it, and to inactivate pathogenic organisms.

Sludge forms initially as a 3–7% suspension of solids, and with each person typically generating about 4 gallons of sludge per week, the total quantity generated each day, week, month, and year is significant. Because of the volume and nature of the material, sludge management is a major factor in the design and operation of all water pollution control plants.

✓ *Note:* Wastewater solids account for more than half of the total costs in a typical secondary treatment plant.

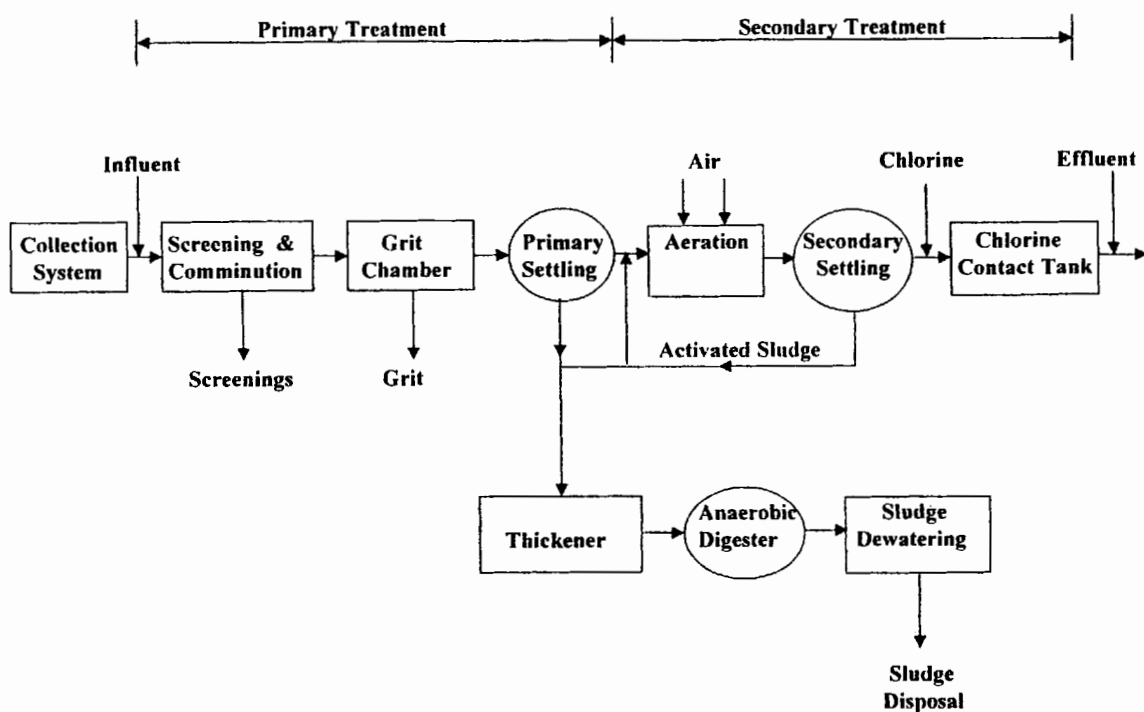


Figure 14.1 Complete conventional wastewater treatment process.

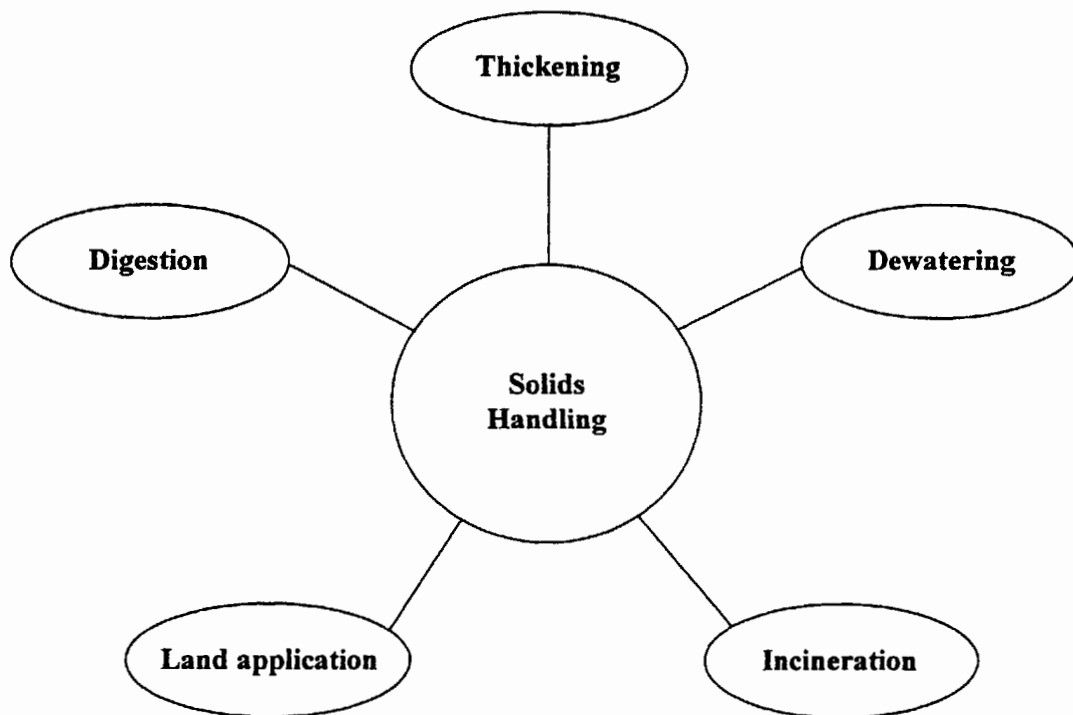


Figure 14.2 Major solids handling processes.

14.1.2 SOURCES OF SLUDGE

Wastewater sludge is generated in primary, secondary, and chemical treatment processes. In primary treatment, the solids that float or settle are removed. The floatable material makes up a portion of the solid waste known as scum. Scum is not normally considered sludge; however, it should be disposed of in an environmentally sound way. The settleable material that collects on the bottom of the clarifier is known as *primary sludge*. Primary sludge can also be referred to as raw sludge because it has not undergone decomposition. Raw primary sludge from a typical domestic facility is quite objectionable and has a high percentage of water, two characteristics that make handling difficult.

Those solids not removed in the primary clarifier are carried out of the primary unit. These solids are known as *colloidal suspended solids*. The secondary treatment system (i.e., trickling filter, activated sludge, etc.) is designed to change those colloidal solids into settleable solids that can be removed. Once in the settleable form, these solids are removed in the secondary clarifier. The sludge at the bottom of the secondary clarifier is called *secondary sludge*. Secondary sludges are light and fluffy and more difficult to process than primary sludges—in short, secondary sludges do not de-water well.

The addition of chemicals and various organic and inorganic substances prior to sedimentation and clarification may increase the solids capture and reduce the amount of solids lost in the effluent. This *chemical addition* results in the formation of heavier solids, which trap the colloidal solids or convert dissolved solids to settleable solids. The resultant solids are known as *chemical sludges*. As chemical usage increases, so does the quantity of sludge that must be handled and disposed of. Chemical sludges can be very difficult to process; they do not de-water well and contain lower percentages of solids.

14.1.3 SLUDGE CHARACTERISTICS

The composition and characteristics of sewage sludge vary widely and can change considerably with time. Notwithstanding these facts, the basic components of wastewater sludge remain the same. The only variations occur in quantity of the various components as the type of sludge and the process from which it originated changes.

The main component of all sludges is *water*. Prior to treatment, most sludges contain 95 to 99+% water (see Table 14.1). This high water content makes sludge handling and processing extremely costly in terms of both money and time. Sludge handling may represent up to 40% of the capital cost and 50% of the operation cost of a treatment plant. As a result, the importance of optimum design for handling and disposal of sludge cannot be overemphasized. The water content of the sludge is present in a number of different forms. Some forms can be removed by several sludge treatment processes, thus allowing the same flexibility in choosing the optimum sludge treatment and disposal method.

TABLE 14.1. Typical Water Content of Sludges.

Water Treatment Process	% Moisture of Sludge Generated	lb Water/lb Sludge Solids
Primary Sedimentation	95	19
Trickling Filter		
Humus—low rate	93	13.3
Humus—high rate	97	32.3
Activated Sludge	99	99

Source: USEPA's Operations Manual, Sludge Handling and Conditioning, EPA-430/9-78-002, 1978.

TABLE 14.2. Distribution of Water in an Activated Sludge.

Water Type	% Volume
Free Water	75
Floc Water	20
Capillary Water	2
Particle Water	2.5
Solids	0.5
Total	100

Source: USEPA's Operations Manual, Sludge Handling and Conditioning, EPA-430/9-78-002, 1978.

The various forms of water and their approximate percentages for a typical activated sludge are shown in Table 14.2. The forms of water associated with sludges are

- *Free water*—water that is not attached to sludge solids in any way. This can be removed by simple gravitational settling.
- *Floc water*—Water that is trapped within the floc and travels with them. Its removal is possible by mechanical de-watering.
- *Capillary water*—water that adheres to the individual particles and can be squeezed out of shape and compacted.
- *Particle water*—water that is chemically bound to the individual particles and can't be removed without incineration.

From a public health view, the second and probably more important component of sludge is the *solids matter*. Representing from 1 to 8% of the total mixture, these solids are extremely unstable. Wastewater solids can be classified into two categories based on their origin—organic and inorganic. *Organic solids* in wastewater, simply put, are materials that are or were at one time alive and that will burn or volatilize at 550°C after 15 minutes in a muffle furnace. The percent organic material within a sludge will determine how unstable it is.

The inorganic material within a sludge will determine how stable it is. The *inorganic solids* are those solids that were never alive and will not burn or volatilize at 550°C after 15 minutes in a muffle furnace. Inorganic solids are generally not subject to breakdown by biological action and are considered stable. Certain inorganic solids, however, can create problems when released to the environment, for example, heavy metals such as copper, lead, zinc, mercury, and others. These can be extremely harmful if discharged.

Organic solids may be subject to biological decomposition in either an aerobic or anaerobic environment. Decomposition of organic matter (with its production of objectionable by-products) and the possibility of toxic organic solids within the sludge compound the problems of sludge disposal.

14.1.4 SLUDGE TREATMENT: AN OVERVIEW

Release of wastewater solids without proper treatment could result in severe damage to the environment. Obviously, we must have a system to treat the volume of material removed as sludge throughout the system. Release without treatment would defeat the purpose of environmental protection. A design engineer can choose from many processes when developing sludge treatment systems. No matter what the system or combination of systems chosen, the ultimate purpose will be the same: the conversion of wastewater sludges into a form that can be handled economically and

disposed of without damage to the environment or creating nuisance conditions. Leaving either condition unmet will require further treatment. The degree of treatment will generally depend on the proposed method of disposal.

Sludge treatment processes can be classified into a number of major categories. In this handbook, we discuss the processes shown in Figure 14.2—thickening, digestion (or stabilization), de-watering, incineration, and land application. Each of these categories has then been further subdivided according to the specific processes that are used to accomplish sludge treatment.

As we stressed earlier, the importance of adequate, efficient sludge treatment cannot be overlooked when designing wastewater treatment facilities. The inadequacies of a sludge treatment system can severely affect a plant's overall performance capabilities. The inability to remove and process solids as fast as they accumulate in the process can lead to the discharge of large quantities of solids to receiving waters.

Even with proper design and capabilities in place, no system can be effective unless it is properly operated. Proper operation requires proper operator performance. Proper operator performance begins and ends with proper training.

14.2 SLUDGE THICKENING

As we pointed out earlier, the solids content of primary, activated, trickling-filter, or even mixed sludge (i.e., primary plus activated sludge) varies considerably, depending on the characteristics of the sludge. Note that the solids content is also affected by the sludge removal and pumping facilities and the method of operation. *Thickening* (or concentration) is a unit process used to increase the solids content of sludge by removing a portion of the liquid fraction. Treating watery or thin sludges (those with solids concentrations less than about 4%) is usually impractical. If a sludge can be thickened to a higher content or percent solids, and because sludge volume varies inversely with the solids concentration, doubling the solids content from 3 to 6% will cut the total sludge volume in half. Thickening can be defined as the concentration of solids to less than 15% solids.

✓ *Note:* Such a sludge is still pumpable by conventional means and has most of the characteristics of a liquid.

Thickening is usually accomplished by physical means, including gravity settling, flotation, centrifugation, and gravity belts. However, two processes are generally used for sludge thickening: gravity and dissolved air flotation. Gravity thickening is the most common sludge concentration process in use at wastewater treatment plants in the United States today. Though simple and inexpensive, it may not produce as highly concentrated sludges as the other thickening processes.

Gravity thickening is a sedimentation process similar to that which takes place in all settling tanks. In fact, gravity thickening units physically look like sedimentation tanks. Usually operated continuously with flow dependent on plant flow, gravity thickening's objective is to produce as thick a sludge as possible at minimum cost. The supernatant flow is usually returned to either the primary treatment unit or a secondary treatment process. Chemicals may be used to aid the process, thus increasing solids concentration and volume reduction. The thickened sludge is usually pumped to a blending, holding, or surge tank, or directly to a de-watering process (see Section 14.4).

In operation, a gravity sludge thickener receives sludge, and a sludge blanket develops. The blanket works to compress solids (i.e., to "squeeze" water out). Sludge concentration is controlled by blanket adjustment. Supernatant is returned for treatment. Biological activity in sludge can cause odors—chlorine is commonly added to reduce odors.

Sludge thickening by the *dissolved air flotation* process causes the sludge to float to the surface

where it is skimmed from the thickener. Sludge thickening by flotation is especially effective for light sludges, such as activated sludge, which are difficult to thicken by gravity.

In operation of dissolved air flotation thickening, secondary effluent is pressurized (40 to 80 psi) and aerated. Pressure increases gas solubility. Pressurized water is mixed with sludge (normally waste-activated sludge) prior to release into the thickener. Chemical aids (polymers) may also be added at this point. Release of pressure causes formation of small gas bubbles, which attach to the solids and lift them to the surface. Float cake forms on the surface, lifting solids above water line. Additional moisture drains from the float cake.

The performance of gravity-dissolved air-thickening processes depends on various factors, including

(1) Gravity Thickening

- type of sludge
- condition of influent sludge
- temperature
- blanket depth
- solids loading
- hydraulic loading
- solids retention time
- hydraulic detention time

(2) Dissolved Air Flotation Thickening

- bubble size
- solids loading
- sludge characteristics
- chemical selection
- chemical dose

14.2.1 OPERATION, OBSERVATION, AND TROUBLESHOOTING PROCEDURES

As with other unit treatment processes, proper operation of sludge thickeners depends on operator observation. The operator must make routine adjustment of sludge addition and withdrawal rates to achieve desired blanket thickness. Sampling and analysis of influent sludge, supernatant, and thickened sludge are also required. Sludge addition and withdrawal should be continuous if possible to achieve optimum performance. Mechanical maintenance is also required.

Expected performance ranges for gravity and dissolved air flotation thickeners follows:

- primary sludge—8–10% Solids
- waste-activated sludge—2–4% Solids
- trickling filter sludge—7–9% Solids
- combined sludges—4–9% Solids

Typical operational problems with sludge thickeners include odors, rising sludge, thickened sludge below desired solids concentration, dissolved air concentration too low, effluent flow contains excessive solids, and torque alarm conditions.

14.2.1.1 Gravity Thickener

14.2.1.1.1 Odors and Rising Sludge

Causal Factors:

- Sludge withdrawal rate is too low.

- Overflow rate is too low.
- Septicity in the thickener.

Corrective Actions (where applicable):

- Increase sludge withdrawal rate.
- Increase influent flow rate.
- Add chlorine, permanganate, or peroxide to influent.

14.2.1.1.2 Thickened Sludge Below Desired Solids Concentration

Causal Factors:

- Overflow rate is too high.
- Sludge withdrawal rate is too high.
- Short circuiting.

Corrective Actions (where applicable):

- Decrease influent sludge flow rate.
- Decrease pump rate for sludge withdrawal.
- Identify cause and correct.

14.2.1.1.3 Torque Alarm Activated

Causal Factors:

- heavy sludge accumulation
- collector mechanism jammed

Corrective Actions (where applicable):

- Agitate sludge blanket to decrease density.
- Increase sludge withdrawal rate.
- Attempt to locate and remove obstacle.
- De-water tank and remove obstacle.

14.2.1.2 Dissolved Air Flotation Thickener

14.2.1.2.1 Float Solids Concentration Too Low

Causal Factors:

- Skimmer speed is too high.
- Unit is overloaded.
- Insufficient polymer dose.
- Excessive air-to-solids ratio.
- Low dissolved air levels.

Corrective Actions (where applicable):

- Adjust skimmer speed to permit concentration to occur.
- Stop sludge flow through unit/purge with recycle flow.
- Determine proper chemical dose and adjust.
- Reduce air flow to pressurization tank.

- Identify malfunction and correct.

14.2.1.2.2 Dissolved Air Concentration Too Low

Causal Factor:

- mechanical malfunction

Corrective Action:

- identify cause and correct

14.2.1.2.3 Effluent (Subnatant) Flow Contains Excessive Solids

Causal Factors:

- Unit is overloaded.
- Chemical dose is too low.
- Skimmer is not operating.
- Low solids:air ratio.
- Solids buildup in thickener.

Corrective Actions (where applicable):

- Turn off sludge flow.
- Purge unit with recycle.
- Determine proper chemical dose and blow.
- Turn skimmer on.
- Adjust skimmer speed.
- Increase air flow to pressurization system.
- Remove sludge from tank.

14.2.2 PROCESS CALCULATIONS (GRAVITY/DISSOLVED AIR FLOTATION)

Sludge thickening calculations are based on the concept that the solids in the primary or secondary sludge are equal to the solids in the thickened sludge. Assuming a negligible amount of solids are lost in the thickener overflow, the solids are the same. Note that the water is removed to thicken the sludge and results in a higher percent solids.

14.2.2.1 Estimating Daily Sludge Production

The calculation for estimation of the required sludge pumping rate provides a method to establish an initial pumping rate or to evaluate the adequacy of the current pump rate.

$$\text{Est. Pump Rate} = \frac{(\text{Influent TSS Conc.} - \text{Eff. TSS Conc.}) \times \text{Flow} \times 8.34}{\% \text{ Solids in Sludge} \times 8.34 \times 1,440 \text{ min/day}} \quad (14.1)$$

Example 14.1

Problem:

The sludge withdrawn from the primary settling tank contains 1.5% solids. The unit influent contains 280 mg/L TSS, and the effluent contains 141 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:

$$\text{Sludge Rate, gpm} = \frac{(280 \text{ mg/L} - 141 \text{ mg/L}) \times 5.55 \text{ MGD} \times 8.34}{0.015 \times 8.34 \times 1,440 \text{ min/day}} = 36 \text{ gpm}$$

14.2.2.2 Surface Loading Rate, gal/ft²/day

Surface loading rate (surface settling rate) is hydraulic loading—the amount of sludge applied per square foot of gravity thickener.

$$\text{Surface Loading, gal/day/ft}^2 = \frac{\text{Sludge Applied to the Thickener, gpd}}{\text{Thickener Area, ft}^2} \quad (14.2)$$

Example 14.2

Problem:

The 70-foot diameter gravity thickener receives 32,000 gpd of sludge. What is the surface loading in gallons per square foot per day?

Solution:

$$\text{Surface Loading} = \frac{32,000 \text{ gpd}}{0.785 \times 70 \text{ ft} \times 70 \text{ ft}} = 8.32 \text{ gpd/ft}^2$$

14.2.2.3 Solids Loading Rate, lb/ft²/day

The solids loading rate is the pounds of solids per day being applied to 1 square foot of tank surface area. The calculation uses the surface area of the bottom of the tank. It assumes the floor of the tank is flat and has the same dimensions as the surface.

$$\text{Solids Loading Rate, lb/day/ft}^2 = \frac{\% \text{ Sludge Solids} \times \text{Sludge Flow, gpd} \times 8.34 \text{ lb/gal}}{\text{Thickener Area, ft}^2} \quad (14.3)$$

Example 14.3

Problem:

The thickener influent contains 1.6% solids. The influent flow rate is 39,000 gpd. The thickener is 50 ft in diameter and 10 ft deep. What is the solid loading in pounds per day?

Solution:

$$\text{Solids Loading Rate, lb/day/ft}^2 = \frac{0.016 \times 39,000 \text{ gpd} \times 8.34 \text{ lb/gal}}{0.785 \times 50 \text{ ft} \times 50 \text{ ft}} = 2.7 \text{ lb/ft}^2$$

14.2.2.4 Concentration Factor

The concentration factor represents the increase in concentration resulting from the thickener.

$$CF = \frac{\text{Thickened Sludge Concentration, \%}}{\text{Influent Sludge Concentration, \%}} \quad (14.4)$$

Example 14.4

Problem:

The influent sludge contains 3.5% solids. The thickened sludge solids concentration is 7.7%. What is the concentration factor?

Solution:

$$CF = \frac{7.7\%}{3.5\%} = 2.2$$

14.2.2.5 Air-to-Solids Ratio

This is the ratio between the pounds of solids entering the thickener and the pounds of air being applied.

$$\text{Air:Solids Ratio} = \frac{\text{Air Flow ft}^3 / \text{min} \times 0.075 \text{ lb / ft}^3}{\text{Sludge Flow, gpm} \times \% \text{ Solids} \times 8.34 \text{ lb / gal}} \quad (14.5)$$

Example 14.5

Problem:

The sludge pumped to the thickener is 0.85% solids. The air flow is 13 cfm. What is the air-to-solids ratio if the current sludge flow rate entering the unit is 50 gpm?

Solution:

$$\text{Air:Solids Ratio} = \frac{13 \text{ cfm} \times 0.075 \text{ lb / ft}^3}{50 \text{ gpm} \times 0.0085 \times 8.34 \text{ lb / gal}} = 0.28$$

14.2.2.6 Recycle Flow in Percent

The amount of recycle flow expressed as a percent.

$$\text{Recycle, \%} = \frac{\text{Recycle Flow Rate, gpm} \times 100}{\text{Sludge Flow, gpm}} = 175\% \quad (14.6)$$

Example 14.6

Problem:

The sludge flow to the thickener is 80 gpm. The recycle flow rate is 140 gpm. What is the % recycle?

Solution:

$$\% \text{ Recycle} = \frac{140 \text{ gpm} \times 100}{80 \text{ gpm}} = 175\%$$

14.3 SLUDGE DIGESTION

A major problem in designing wastewater treatment plants is the disposal of sludges into the environment without causing damage or nuisance. Untreated sludge is even more difficult to dispose of. Untreated raw sludges must be stabilized to minimize disposal problems. In most cases, the term *stabilization* is considered synonymous with digestion.

Sludge digestion is a process in which biochemical decomposition of the organic solids occurs; in the decomposition process, the organics are converted into simpler and more stable substances. Digestion also reduces the total mass or weight of sludge solids, destroys pathogens, and makes it easier to dry or de-water the sludge. Well-digested sludge has the appearance and characteristics of a rich potting soil.

Sludge may be digested under aerobic or anaerobic conditions. Most large municipal sewage treatment plants use anaerobic digestion; aerobic digestion finds application primarily in small, package-activated sludge treatment systems.

14.3.1 AEROBIC DIGESTION

The purpose of *aerobic digestion* is to stabilize organic matter, to reduce volume, and to eliminate pathogenic organisms. Aerobic digestion is similar to the activated sludge process. Sludge is aerated for 20 days or more. Volatile solids are reduced by biological activity.

14.3.1.1 Operation, Observation, and Troubleshooting Procedures

Aerobic digestion is the separate aeration of primary sludge, waste biological sludge, or a blend of these two in an open or closed tank. A separate sedimentation tank may be used following aerobic digestion, or a one-tank, batch-type system where the sludge is aerated, mixed, settled, and decanted in the same tank may be used.

The aerobic digestion process is an extension of the extended aeration process. The volatile material in the wastes is digested to a reasonable maximum of up to 45% destruction of volatile solids. The decomposition of solids and regrowth of organisms is maintained until the available energy in active cells and the storage of waste materials are sufficiently low and stable enough for disposal.

Aerobic digestion reduces the volume of sludge solids and reduces odors or other nuisances that may be a hindrance to final disposal.

The operator monitors the aerobic digester to determine if operating parameters are within acceptable limits. Normal operating levels are shown in Table 14.3.

TABLE 14.3. Aerobic Digester Normal Operating Levels.

Parameter	Normal Levels
Detention Time, days	>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%

14.3.1.2 Operational Problems

The principal problem associated with the operation of an aerobic digester is pH control.

14.3.1.2.1 Digester pH Drops

Causal Factors:

- normal biological activity
- low influent alkalinity

Corrective Action:

- Add alkalinity (lime, bicarbonate, etc.).

14.3.1.3 Process Control Calculations

14.3.1.3.1 Volatile Solids Loading, lb/ft³/day

Volatile solids (organic matter) loading for the aerobic digester is expressed in pounds of volatile solids entering the digester per day per cubic foot of digester capacity.

$$\text{Volatile Solids Loading} = \frac{\text{Volatile Solids Added, lb/day}}{\text{Digester Volume, ft}^3} \quad (14.7)$$

Example 14.7

Problem:

The aerobic digester is 20 ft in diameter and has an operating depth of 20 ft. The sludge added to the digester daily contains 1,500 lb of volatile solids. What is the volatile solids loading in pounds per day per cubic foot?

Solution:

$$\text{Vol. Solids Loading, lb/day/ft}^3 = \frac{1,500 \text{ lb/day}}{0.785 \times 20 \text{ ft} \times 20 \text{ ft} \times 20 \text{ ft}} = 0.24 \text{ lb/day/ft}^3$$

14.3.1.3.2 Digestion Time, Days

The theoretical time the sludge remains in the aerobic digester:

$$\text{Digestion Time, Days} = \frac{\text{Digester volume, gallons}}{\text{Sludge Added, gpd}} \quad (14.8)$$

Example 14.8

Problem:

The digester volume is 240,000 gal. Sludge is added to the digester at the rate of 15,000 gpd. What is the digestion time in days?

Solution:

$$\text{Digestion Time, Days} = \frac{240,000 \text{ gal}}{15,000 \text{ gpd}} = 16 \text{ days}$$

14.3.1.3.3 pH Adjustment

In many instances, 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 required by the digester.

$$\text{Chem. Required, lb} = \frac{\text{Chem. Used in Lab Test, mg} \times \text{Dig. Vol.} \times 3.785}{\text{Sample Vol., L} \times 454 \text{ g/lb} \times 1,000 \text{ mg/g}} \quad (14.9)$$

Example 14.9

Problem:

240 mg of lime will increase the pH of a 1-L sample of the aerobic digester contents to pH 7.1. The digester volume is 240,000 gal. How many pounds of lime will be required to increase the digester pH to 7.3?

Solution:

$$\text{Chem. Required, lb} = \frac{240 \text{ mg} \times 240,000 \text{ gal} \times 3.785 \text{ L/gal}}{1 \text{ L} \times 454 \text{ g/lb} \times 1,000 \text{ mg/g}} = 480 \text{ lb}$$

14.3.2 ANAEROBIC DIGESTION

The purpose of *anaerobic digestion* is the same as aerobic digestion: to stabilize organic matter, to reduce volume, and to eliminate pathogenic organisms.

Equipment used in anaerobic digestion includes an anaerobic digester of either the floating or fixed cover type. These include sludge pumps for sludge addition and withdrawal, as well as heating equipment such as heat exchangers, heaters and pumps, and mixing equipment for recirculation. Typical ancillaries include gas storage, cleaning equipment, and safety equipment such as vacuum relief and pressure relief devices, flame traps, and explosion-proof electrical equipment.

In the anaerobic process, sludge enters the sealed digester where organic matter decomposes anaerobically. Anaerobic digestion is a two-stage process:

- (1) Sugars, starches, and carbohydrates are converted to volatile acids, carbon dioxide, and hydrogen sulfide.
- (2) Volatile acids are converted to methane gas.

14.3.2.1 Operation, Observation, and Troubleshooting Procedures

During operation of an anaerobic digester, the operator monitors various performance factors. These performance factors include the following:

- % volatile matter in raw sludge

- digester temperature
- mixing
- volatile acids/alkalinity ratio
- feed rate
- % solids in raw sludge
- single stage or two stage operation
- pH

Along with monitoring performance factors, the operator also performs various operational tasks and adjustments.

- (1) Sludge additions are commonly made by controlling sludge pumping to achieve the desired organic loading and optimum performance. In this process, the operator pumps sludge frequently (several times per day). Generally, the best practice is to pump small amounts at frequent intervals.
- (2) The operator controls supernatant withdrawal for maximum sludge retention time. Samples are collected at all drawoff points, and the level with the best quality is selected.
- (3) Sludge is withdrawn only when necessary. At least 25% seed is left behind.
- (4) pH is adjusted as required to maintain 6.8 to 7.2 by adjusting feed rate, withdrawing sludge, or adding alkalinity.
- (5) If heated, digester temperature must be controlled. Temperature adjustment is limited to no more than 1°F per day. Normal temperature range is 90 to 95°F.
- (6) If mixers are installed, mixing must be adequate to ensure organisms are exposed to food material.
- (7) Safety (primarily because of highly explosive methane content) is a major concern in the operation of anaerobic digesters. Routinely inspect and maintain the gas collection system, condensate/flame traps, pressure relief valves, and vacuum relief valves.

Process control testing is also an important part of the operator's task and observation functions in maintaining optimal anaerobic digester operation. Process control testing includes sampling and analyzing:

- (1) Supernatant
 - pH
 - volatile acids
 - alkalinity
 - BOD or COD
 - total solids
 - temperature
- (2) Sludge (In and Out)
 - % solids
 - % volatile matter

Tables 14.4, 14.5, and 14.6 list important parameter settings for raw sludge solids, volatile acids/alkalinity ratio, and normal operating ranges, respectively.

14.3.2.1.1 Operational Problems

In operating an anaerobic digester, the operator must monitor gas production, pH level, the volatile acids/alkalinity ratio, and other indicators of operational problems.

TABLE 14.4. Raw Sludge Solids Ranges: Impact.

Raw Sludge Solids	Impact
< 4% Solids	Loss of alkalinity Decreased sludge retention time Increased heating requirements Increased Vol. acid/Alkalinity Ratio
4–8% Solids	Normal Operation
> 8% Solids	Poor Mixing Organic Overloading Increased Vol. Acid: Alkalinity Ratio

14.3.2.1.1.1 DIGESTER GAS PRODUCTION REDUCED, pH DROPS BELOW 6.8, AND VOLATILE ACIDS/ALKALINITY RATIO INCREASES

Causal Factors:

- digester souring
- organic overloading
- inadequate mixing
- low alkalinity
- hydraulic overloading
- toxicity
- loss of digestion capacity

Corrective Actions (where applicable):

- Add alkalinity (digested sludge, lime, etc.).
- Improve temperature control.
- Improve mixing.
- Eliminate toxicity.
- Clean digester.

14.3.2.1.1.2 GRAY FOAM OOZING FROM DIGESTER

Causal Factors:

- rapid gasification
- foam-producing organisms present
- foam-producing chemical present

Corrective Actions:

- Reduce mixing.
- Reduce feed rate.
- Mix slowly by hand.
- Clean all contaminated equipment.

TABLE 14.5. Volatile Acids/Alkalinity Ratio.

Operating condition	V.A./alkalinity ratio
Optimum	less than or equal to 0.1
Acceptable range	0.1–0.3
% Carbon dioxide in gas increases	less than or equal to 0.5
pH decreases	less than or equal to 0.8

TABLE 14.6. Anaerobic Digester: Normal Operating Ranges.

Parameter	Normal Range
Sludge Retention Time	
Heated	30–60 days
Unheated	180+ days
Volatile solids loading	0.04–0.1 lb V.M./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	Less than or equal to 0.1
Volatile solids reduction	40–60%
Moisture reduction	40–60%

14.3.3 PROCESS CONTROL CALCULATIONS

Key anaerobic digestion process control calculations are covered in the sections that follow.

14.3.3.1 Required Seed Volume in Gallons

$$\text{Seed Volume (Gallons)} = \text{Digester Volume, gal} \times \% \text{ Seed} \tag{14.10}$$

Example 14.10

Problem:

The new digester requires a 25% seed to achieve normal operation within the allotted time. If the digester volume is 280,000 gallons, how many gallons of seed material will be required?

Solution:

$$\text{Seed Volume} = 280,000 \times 0.25 = 70,000 \text{ gal}$$

14.3.3.2 Volatile Acids to Alkalinity Ratio

The volatile acids to alkalinity ratio can be used to control anaerobic digester.

$$\text{Ratio} = \frac{\text{Volatile Acids Concentration}}{\text{Alkalinity Concentration}} \tag{14.11}$$

Example 14.11

Problem:

The digester contains 240 mg/L volatile acids and 1,840 mg/alkalinity. What is the volatile acids/alkalinity ratio?

Solution:

$$\text{Ratio} = \frac{240 \text{ mg/L}}{1,840 \text{ mg/L}} = 0.13$$

✓ *Note:* Increases in the ratio normally indicate a potential change in the operating condition of the digester.

14.3.3.3 Sludge Retention Time

The length of time the sludge remains in the digester.

$$\text{SRT} = \frac{\text{Digester Volume in Gallons}}{\text{Sludge volume added per day, gpd}} \quad (14.12)$$

Example 14.12

Problem:

Sludge is added to a 520,000 gallon digester at the rate of 12,600 gallons per day. What is the sludge retention time?

Solution:

$$\text{SRT} = \frac{520,000 \text{ gal}}{12,600 \text{ gpd}} = 41.3 \text{ days}$$

14.3.3.4 Estimated Gas Production in Cubic Feet/Day

The rate of gas production is normally expressed as the volume of gas (ft³) produced per pound of volatile matter destroyed. The total cubic feet of gas a digester will produce per day can be calculated by

$$\text{Gas Production, ft}^3/\text{day} =$$

$$\text{Vol. Matter In, lb/day} \times \% \text{ Vol. Mat. Reduct.} \times \text{Prod. Rate ft}^3/\text{lb} \quad (14.13)$$

✓ *Note:* Multiplying the volatile matter added to the digester per day by the % volatile matter reduction (in decimal percent) gives the amount of volatile matter being destroyed by the digestion process per day.

Example 14.13

Problem:

The digester reduces 11,500 lb of volatile matter per day. Currently, the volatile matter reduction achieved by the digester is 55%. The rate of gas production is 11.2 cubic feet of gas per pound of volatile matter destroyed.

Solution:

$$\text{Gas Prod.} = 11,500 \text{ lb/day} \times 0.55 \times 11.2 \text{ ft}^3/\text{lb} = 70,840 \text{ ft}^3/\text{day}$$

14.3.3.5 Volatile Matter Reduction, Percent

Because of the changes occurring during sludge digestion, the calculation used to determine percent volatile matter reduction is more complicated.

$$\% \text{ Reduction} = \frac{(\% \text{ Volatile Matter}_{\text{in}} - \% \text{ Volatile Matter}_{\text{out}}) \times 100}{[\% \text{ Volatile Matter}_{\text{in}} - (\% \text{ Volatile Matter}_{\text{in}} \times \% \text{ Volatile Matter}_{\text{out}})]} \tag{14.14}$$

Example 14.14

Problem:

Using the digester data provided here, determine the % volatile matter reduction for the digester: raw sludge volatile matter, 71%; digested sludge volatile matter, 54%.

Solution:

$$\% \text{ Volatile Matter Reduction} = \frac{0.71 - 0.54}{[0.71 - (0.71 \times 0.54)]} = 52\%$$

14.3.3.6 Percent Moisture Reduction in Digested Sludge

$$\% \text{ Moisture Reduction} = \frac{(\% \text{ Moisture}_{\text{in}} - \% \text{ Moisture}_{\text{out}}) \times 100}{[\% \text{ Moisture}_{\text{in}} - (\% \text{ Moisture}_{\text{in}} \times \% \text{ Moisture}_{\text{out}})]} \tag{14.15}$$

✓ *Note:* % Moisture = 100% – Percent Solids

Example 14.15

Problem:

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

Raw Sludge	% Solids	9%
	% Moisture	91% (100% – 9%)
Digested Sludge	% Solids	15%
	% Moisture	85% (100% – 15%)

$$\% \text{ Moisture Reduction} = \frac{(0.91 - 0.85) \times 100}{[0.91 - (0.91 \times 0.85)]} = 44\%$$

14.4 SLUDGE DE-WATERING

The process of removing enough water from a liquid sludge to change its consistency to that of a

damp solid is called *sludge de-watering*. Although the process is also called *sludge drying*, the “dry” or de-watered sludge may still contain a significant amount of water, often as much as 70%. But at moisture contents of 70% or less, the sludge no longer behaves as a liquid and can be handled manually or mechanically.

Several methods are available to de-water sludge. The actual processes used to remove water from sludges and change their form from a liquid to a damp solid are best described by the particular types of de-watering techniques/devices used. The commonly used techniques/devices include the following:

- drying beds
- vacuum filtration
- centrifuges
- filter presses

Note that an ideal de-watering operation would capture all of the sludge solids at minimum cost and the resultant dry sludge solids 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.

14.4.1 DRYING BEDS

The simplest method of de-watering sludge is the drying bed. Sludge drying beds consist of perforated or open-joint drainage systems in a support medium (i.e., gravel), covered by a filter medium (sand, wire mesh, extruded plastic). Beds are separated into workable sections by concrete, wood, or other materials. Drying beds may be open to the weather or enclosed. They may rely entirely on natural drainage and evaporation processes or may use vacuum to assist the process.

The digested sludge is spread on an open bed of sand and is allowed to remain there until it dries; drying takes place by a combination of evaporation and gravity drainage. When the sludge reaches the desired percent solids, the de-watered sludge is removed from the bed and transported to the point of disposal/reuse.

14.4.1.1 Performance Factors

In sludge drying beds, various factors affect the length of time required to achieve the desired solids concentrations. The major factors and their impact on drying bed performance include the following:

- *Climate*—Drying beds in cold or moist climates will require significantly longer drying time to achieve an adequate level of percent solids concentrations in the de-watered sludge.
- *Depth of applied sludge*—The depth of the sludge drawn onto the bed has a major impact on the required drying time. Deeper sludge layers require longer drying times. Under ideal conditions, a well-digested sludge drawn to a depth of approximately eight inches will require approximately three weeks to reach the desired 40 to 60% solids.
- *Type of sludge applied*—The quality and solids concentration of the drying media will affect the time requirements.
- *Bed cover*—Covered drying beds prevent re-wetting of the sludge during storm events. In most cases, this reduces the average drying time required to reach the desired solids levels.

14.4.1.2 Operation, Observation, and Troubleshooting Procedures

Although drying beds involve two natural processes—drainage and evaporation—that normally work well enough on their own, a certain amount of preparation and operator attention is still required

to maintain optimum drying performance. For example, in the preparation stage, all debris is removed from the raked and leveled media surface. Then, all openings to the bed are sealed.

After the bed is properly prepared, the sludge lines are opened, and sludge is allowed to flow slowly onto the media. The bed is filled to desired operating level (8–12 inches). The sludge line is closed and flushed, and the bed drain is opened. Water begins to drain. The sludge remains on the media until the desired % solids (40–60%) is achieved. Later, the sludge is removed. In most operations, manual removal is required to prevent damage to the underdrain system. The sludge is disposed of in an approved landfill or by land application as a soil conditioner.

14.4.1.2.1 Operational Problems

In the operation of a sludge drying bed, the operator observes the operation and looks for various indicators of operational problems and makes process adjustments as required.

14.4.1.2.1.1 SLUDGE TAKES A LONG TIME TO DE-WATER

Causal Factors:

- Applied sludge is too deep.
- Sludge was applied to a dirty bed.
- The drain system is plugged or broken.
- Insufficient design capacity.
- Inclement weather/poor drying conditions.

Corrective Actions (where applicable):

- Allow bed to dry to minimum acceptable % solids and remove.
- Use described procedure below to determine appropriate sludge depth.
 - (1) Clean bed and apply smaller depth of sludge (i.e., 6–8 inches).
 - (2) Measure the decrease in depth (draw down) at the end of 3 days of drying.
 - (3) Use a sludge depth equal to twice the three-day drawdown depth for future applications.
- After sludge has dried, remove sludge and 0.5–1.0 inches of sand. Add clean sand.
- Allow sludge to dry to minimum allowable % solids and remove.
- Use external water source (with back flow prevention) to slowly flush underdrains.
- Repair/replace underdrains as required.
- Prevent damage to underdrains by draining during freezing weather.
- Use polymer to increase bed performance.
- Cover or enclose the beds.

14.4.1.2.1.2 INFLUENT SLUDGE IS VERY THIN

Causal Factor:

- “Coning” is occurring in the digester.

Corrective Action:

- Reduce rate of sludge withdrawal.

14.4.1.2.1.3 SLUDGE FEED LINES PLUG FREQUENTLY

Causal Factor:

- Solids and/or grit is accumulating in the lines.

Corrective Actions:

- Open lines fully at the start of each withdrawal cycle.
- Flush lines at the end of each withdrawal cycle.

14.4.1.2.1.4 FLIES BREEDING IN THE DRYING SLUDGE

Causal Factors:

- inadequately digested sludge
- natural insect reproduction

Corrective Actions:

- Break sludge crust, and apply a larvicide (borax).
- Use insecticide (if approved) to remove adult insects.
- Remove sludge as soon as possible.

14.4.1.2.1.5 OBJECTIONABLE ODORS WHEN SLUDGE IS APPLIED TO BED

Causal Factor:

- Raw or partially digested sludge is being applied to the bed.

Corrective Actions:

- Add lime to the sludge to control odors and potential insect and rodent problems.
- Remove the sludge as quickly as possible.
- Identify and correct the digester problem.

14.4.2 CENTRIFUGATION

Centrifuges of various types have been used for de-watering municipal sludges for at least 30 years. The most common system employed is the continuous feed, solid bowl, conveyor type centrifuge. The centrifuge uses centrifugal force to speed up the sedimentation process, thus forcing water out of the sludge solids particles. Inside the unit, the solids and liquids flow in opposite directions, earning the name “countercurrent.”

14.4.2.1 Operation, Observation, and Troubleshooting Procedures

In the operation of the continuous feed, solid bowl, conveyor type centrifuge (recall that this is the most common type currently used) and other commonly used centrifuges, solid/liquid separation occurs as a result of rotating the liquid at high speeds to cause separation by gravity.

In the solid bowl type, the solid bowl has a rotating unit with a bowl and a conveyor (see Figure 14.3). The unit has a conical section at one end that acts as a drainage device. The conveyor screw pushes the sludge solids to outlet ports and the cake to a discharge hopper. The sludge slurry enters the rotating bowl through a feed pipe leading into the hollow shaft of the rotating screw conveyor. The sludge is distributed through ports into a pool inside the rotating bowl. As the liquid sludge flows through the hollow shaft toward the overflow device, the fine solids settle to the wall of the rotating bowl. The screw conveyor pushes the solids to the conical section, where the solids are forced out of the water and the water drains back in the pool.

Expected % solids for centrifuge de-watered sludges is in the range of 10–50%. The expected performance is dependent on the type of sludge being de-watered, as shown in Table 14.7.

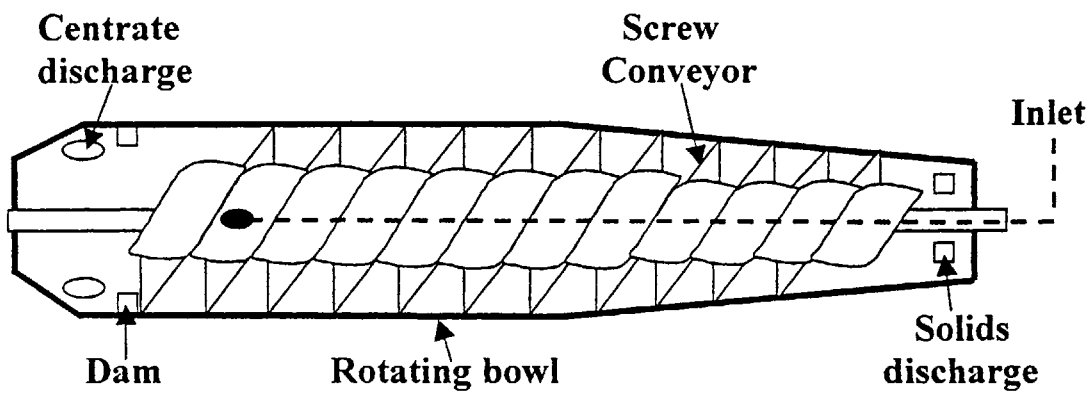


Figure 14.3 Centrifuge.

Centrifuge operation is dependent upon various performance factors:

- bowl design: length/diameter ratio; bowl angle; flow pattern
- bowl speed
- pool volume
- conveyor design
- relative conveyor speed
- type/condition of sludge
- type and amount of chemical conditioning
- operating pool depth
- relative conveyor speed (if adjustable)

Centrifuge operators often find that the operation of centrifuges can be simple, clean, and efficient. In most cases, chemical conditioning is required to achieve optimum concentrations. Operators soon discover that centrifuges are noise-makers; units run at very high speed and produce high-level noise, which can cause loss of hearing with prolonged exposure. Therefore, when working in an area where a centrifuge is in operation, special care must be taken to provide hearing protection.

Actual operation of a centrifugation unit requires the operator to control and adjust chemical feed rates; to observe unit operation and performance; to control and monitor centrate returned to treatment system; and to perform required maintenance as outlined in the manufacturer’s technical manual.

The centrifuge operator must be trained to observe and recognize (as with other unit processes) operational problems that may occur with centrifuge operation. We cover several typical indicators and/or observations of centrifuge problems, along with causal factors and suggested corrective actions (troubleshooting procedures) in the following sections.

TABLE 14.7. Expected % Solids for Centrifuge De-watered Sludges.

Type of Sludge	% Solids
Raw Sludge	25–35%
Anaerobic Digestion	15–30%
Activated Sludge	8–10%
Heat Treated	30–50%

14.4.2.1.1 Poor Centrate Clarity

Causal Factors:

- feed rate too high
- wrong plate dam position
- worn conveyor flights
- speed too high
- high feed sludge solids concentration
- improper chemical conditioning

Corrective Actions (where applicable):

- Adjust sludge feed rate.
- Increase pool depth.
- Repair/replace conveyor.
- Change pulley setting to obtain lower speed.
- Dilute sludge feed.
- Adjust chemical dosage.

14.4.2.1.2 Solids Cake Not Dry Enough

Causal Factors:

- feed rate too high
- wrong plate dam position
- speed too low
- excessive chemical conditioning
- influent too warm

Corrective Actions (where applicable):

- Reduce sludge feed rate.
- Decrease pool depth to increase dryness.
- Change pulley setting to obtain higher speed.
- Adjust chemical dosage.
- Reduce influent temperature.

14.4.2.1.3 Torque Control Keeps Tripping

Causal Factors:

- Feed rate is too high.
- Feed solids concentration too high.
- Foreign material (i.e., tramp iron) in machine.
- Gear unit is misaligned.
- Gear unit has mechanical problem.

Corrective Actions (where applicable):

- Reduce flows.
- Dilute flows.
- Remove conveyor/clear foreign materials.

- Correct gear unit alignment.
- Repair gear unit.

14.4.2.1.4 Excess Vibration

Causal Factors:

- Improper lubrication.
- Improper adjustment of vibration isolators.
- Discharge funnels are contacting centrifuge.
- Portion of conveyor flights may be plugged (causing an imbalance).
- Gear box improperly aligned.
- Pillow box bearings are damaged.
- Bowl is out of balance.
- Parts not tightly assembled.
- Uneven wear on conveyor.

Corrective Actions (where applicable):

- Lubricate according to manufacturer's instructions.
- Adjust isolators.
- Reposition slip joints at funnels.
- Flush centrifuge.
- Align gear box.
- Replace bearings.
- Return rotating parts to factory for re-balancing.
- Tighten parts.
- Resurface and re-balance.

14.4.2.1.5 Sudden Increase in Power Consumption

Causal Factors:

- contact between bowl exterior and accumulated solids in case
- effluent pipe plugged

Corrective Actions (where applicable):

- Apply hard surfacing to areas with wear.
- Clear solids discharge.

14.4.2.1.6 Gradual Increase in Power Consumption

Causal Factor:

- conveyor blade wear

Corrective Action:

- Replace blades.

14.4.2.1.7 Spasmodic Surging of Solids Discharge

Causal Factors:

- Pool depth too low.

- Conveyor helix is rough.
- Feed pipe too near drainage deck.
- Excessive vibration.

Corrective Actions (where applicable):

- Increase pool depth.
- Refinish conveyor blades area.
- Move feed pipe to effluent end (if adjustable).
- See Section 14.4.2.1.4.

14.4.2.1.8 Centrifuge Shuts Down or Will Not Start

Causal Factors:

- Blown fuses.
- Overload relay is tripped.
- Motor overheated/thermal protectors tripped.
- Torque control is tripped.
- Vibration switch is tripped.

Corrective Actions (where applicable):

- Replace fuses.
- Flush centrifuge, and reset relay.
- Flush centrifuge, reset thermal protectors.
- See Section 14.4.2.1.3.
- See Section 14.4.2.1.4.

14.4.3 VACUUM FILTRATION

The *rotary vacuum filter* is a device used to separate solid material from liquid. Capable of excellent solids capture and high-quality supernatant/filtrate, solids concentrations of 15 to 40% can be achieved.

14.4.3.1 Types of Rotary Vacuum Filters

The three principal types of rotary vacuum filters are rotary drum, coil, and belt.

The *rotary drum* filter consists of a cylindrical drum rotating partially submerged in a vat or pan of conditioned sludge (see Figure 14.4). The drum is divided length-wise into a number of sections that are connected through internal piping to ports in the valve body (plate) at the hub. This plate rotates in contact with a fixed valve plate with similar parts, which are connected to a vacuum supply, a compressed air supply, and an atmosphere vent. As the drum rotates, each section is thus connected to the appropriate service.

The *coil type* vacuum filter uses two layers of stainless steel coils arranged in corduroy fashion around the drum. After a de-watering cycle, the two layers of springs leave the drum bed and are separated from each other so that the cake is lifted off the lower layer and is discharged from the upper layer. The coils are then washed and reapplied to the drum. The coil filter is used successfully for all types of sludges; however, sludges with extremely fine particles or ones that are resistant to flocculation de-water poorly with this system.

The media on a *belt filter* leaves the drum surface at the end of the drying zone and passes over a small diameter discharge roll to aid cake discharge. Washing of the media occurs next. Then the media are returned to the drum and to the vat for another cycle. This type of filter normally has a

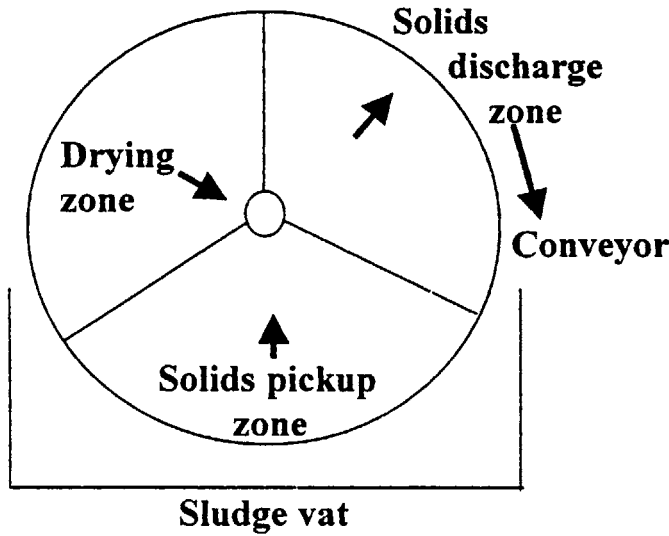


Figure 14.4 Vacuum filter.

small-diameter curved bar between the point where the belt leaves the drum and the discharge roll. This bar primarily aids in maintaining belt dimensional stability.

14.4.3.1.1 Filter Media

Drum and belt vacuum filters use natural or synthetic fiber materials. On the drum filter, the cloth is stretched and secured to the surface of the drum. In the belt filter, the cloth is stretched over the drum and through the pulley system. The installation of a blanket requires several days. The cloth will (with proper care) last several hundred to several thousand hours. The life of the blanket depends on the cloth selected, the conditioning chemical, backwash frequency, and cleaning (i.e., acid bath) frequency.

14.4.3.1.2 Filter Drum

The filter drum is a maze of pipe work running from a metal screen and wooden skeleton and connecting to a rotating valve port at each end of the drum. The drum is equipped with a variable speed drive to turn the drum from $\frac{1}{8}$ to 1 rpm. Normally, solids pickup is indirectly related to the drum speed. The drum is partially submerged in a vat containing the conditioned sludge. Normally, submergence is limited to $\frac{1}{5}$ or less of filter surface at a time.

14.4.3.1.3 Chemical Conditioning

Sludges de-watered using vacuum filtration are normally chemically conditioned just prior to filtration. Sludge conditioning increases the percentage of solids captured by the filter and improves the de-watering characteristics of the sludge. However, conditioned sludge must be filtered as quickly as possible after chemical addition to obtain these desirable results.

14.4.4 OPERATION, OBSERVATION, AND TROUBLESHOOTING PROCEDURES

In operation, chemically treated sludge is picked up by the rotating drum. A vacuum is applied to the inside of the drum to draw the sludge onto the outside of the drum cover. This porous outside cover or filter medium allows the filtrate or liquid to pass through into the drum and the filter cake

(de-watered sludge) to stay on the medium. In the cake release/discharge mode, slight air pressure is applied to the drum interior. De-watered solids are lifted from medium and scraped off by a scraper blade. Solids drop onto a conveyor for transport to further treatment or disposal. The filtrate water is returned to the plant for treatment.

While in operation, the operator observes drum speed, sludge pickup, filter cake thickness/appearance, chemical feed rates, sludge depth in vat, and overall equipment operation. Sampling and testing are routinely performed on influent sludge solids concentration, filtrate BOD₅ and solids, and sludge cake solids concentration. We cover the indicators/observations of vacuum filter operational problems and causal factors, along with recommended corrective actions in the following sections.

14.4.4.1 High Solids in Filtrate

Causal Factors:

- improper coagulant dosage
- filter media blinding

Corrective Actions (where applicable):

- Adjust coagulant dosage.
- Recalibrate coagulant feeder.
- Clean synthetic cloth with steam and detergent.
- Clean steel coil with acid bath.
- Clean cloth with water or replace cloth.

14.4.4.2 Thin Filter Cake and Poor De-watering

Causal Factors:

- filter media binding
- improper chemical dosage
- inadequate vacuum
- drum speed too high
- drum submergence too low

Corrective Actions (where applicable):

- Clean synthetic cloth with steam and detergent.
- Clean steel coils with acid bath.
- Clean cloth with water or replace cloth.
- Adjust coagulant dosage.
- Recalibrate coagulant feeder.
- Repair vacuum system.
- Reduce drum speed.
- Increase drum submergence.

14.4.4.3 Vacuum Pump Stops

Causal Factors:

- Power to drive motor is off.
- Lack of seal water.
- Broken drive belt.

Corrective Action (where applicable):

- Reset heater, breaker, etc.; restart.
- Start seal water flow.
- Replace drive belt.

14.4.4.4 Drum Stops Rotating*Causal Factor:*

- Power to drive motor is off.

Corrective Action:

- Reset heater, breaker, etc.; restart.

14.4.4.5 Receiver Vibrating*Causal Factors:*

- Filtrate pump is clogged.
- Loose bolts and gasket around inspection plate.
- Worn ball check valve in filtrate pump.
- Air leaks in suction line.
- Dirty drum face.
- Seal strips are missing.

Corrective Actions (where applicable):

- Clear pump.
- Tighten bolts and gasket.
- Replace ball check.
- Seal leaks.
- Clean face with pressure hose.
- Replace missing seal strips.

14.4.4.6 High Vat Level*Causal Factors:*

- Improper chemical conditioning.
- Feed rate is too high.
- Drum speed is too slow.
- Filtrate pump is off or clogged.
- Drain line plugged.
- Vacuum pump stopped.
- Seal strips are missing.

Corrective Actions:

- Change coagulant dosage.
- Reduce feed rate.
- Increase drum speed.
- Turn on or clean pump.
- Clean drain line.
- Replace seal strips.

14.4.4.7 Low Vat Level

Causal Factors:

- Feed rate is too low.
- Vat drain valve is open.

Corrective Actions (where applicable):

- Increase feed rate.
- Close vat drain valve.

14.4.4.8 Vacuum Pump Drawing High Amperage

Causal Factors:

- Filtrate pump is clogged.
- Improper chemical conditioning.
- High vat level.
- Cooling water flow to vacuum pump is too high.

Corrective Actions (where applicable):

- Clear pump clog.
- Adjust coagulant dosage.
- See Section 14.4.4.6.
- Decrease cooling water flow rate.

14.4.4.9 Scale Buildup on Vacuum Pump Seals

Causal Factor:

- hard, unstable water

Corrective Action:

- Add sequestering agent.

14.4.5 PRESSURE FILTRATION

Pressure filtration differs from vacuum filtration in that the liquid is forced through the filter media by a positive pressure instead of a vacuum. Several types of presses are available, but the most commonly used types are plate and frame presses and belt presses.

The *plate and frame press* consists of vertical plates that are held in a frame and that are pressed together between a fixed and moving end. A cloth filter medium is mounted on the face of each individual plate. The press is closed, and sludge is pumped into the press at pressures up to 225 psi and passes through feed holes in the trays along the length of the press. Filter presses usually require a precoat material, such as incinerator ash or diatomaceous earth to aid in solids retention on the cloth and to allow easier release of the cake.

Performance factors for plate and frame presses include feed sludge characteristics, type and amount of chemical conditioning, operating pressures, and the type and amount of precoat.

Belt filter presses generally avoid the sludge pick-up problems occasionally experienced with rotary vacuum filters. The sludge is gravity thickened, chemically conditioned with polymer, then pressure de-watered in the filter press to increase the solids content of either digested or undigested sludge. The influent mixture of sludge and polymer is fed to the moving porous belt on the filter

press. De-watering occurs as the sludge moves through a series of rollers that squeeze the sludge to the belt or squeeze the sludge between two belts (see Figure 14.5). The cake is discharged from the belt by a scraper mechanism and the water is returned to the plant for treatment.

Performance factors for the belt press include sludge feed rate, belt speed, belt tension, belt permeability, chemical dosage, and chemical selection.

14.4.5.1 Operation, Observation, and Troubleshooting Procedures

Most plate and filter press operations are partially/fully automated. Operation consists of observation, maintenance, and sampling and testing.

Operation of belt filter presses consists of preparation of conditioning chemicals, chemical feed rate adjustments, sludge feed rate adjustments, belt alignment, belt speed and belt tension adjustments, sampling and testing, and maintenance.

14.4.5.1.1 Operational Problems

We include common operation problems, causal factors, and recommended corrective actions for the plate press and belt filter press in the following sections.

14.4.5.1.1.1 PLATE PRESS: PLATES FAIL TO SEAL

Causal Factors:

- poor alignment
- inadequate shimming

Corrective Actions (where applicable):

- Realign plates.
- Adjust shimming of stay bosses.

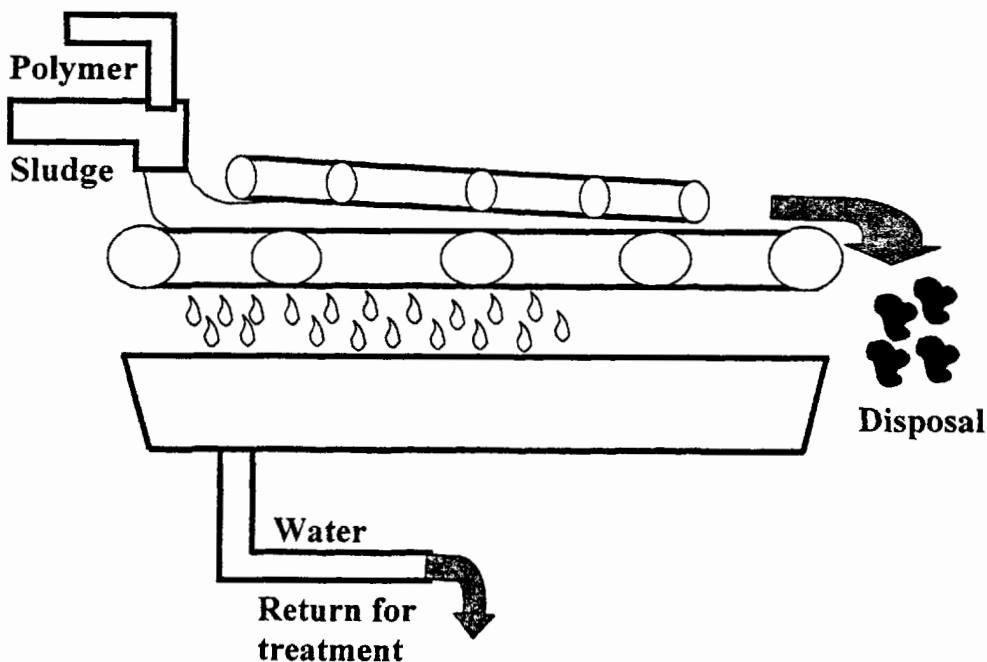


Figure 14.5 Belt filter press.

14.4.5.1.1.2 PLATE PRESS: CAKE DISCHARGE DIFFICULT

Causal Factors:

- inadequate precoat
- improper conditioning

Corrective Actions (where applicable):

- Increase precoat, feed at 25–40 psig.
- Change conditioner type or dosage (use filter leaf test to determine).

14.4.5.1.1.3 PLATE PRESS: FILTER CYCLE TIMES EXCESSIVE

Causal Factors:

- improper conditioning
- feed solids too low

Corrective Actions (where applicable):

- Change chemical dosage.
- Improve thickening operation.

14.4.5.1.1.4 PLATE PRESS: FILTER CAKE STICKS TO CONVEYORS

Causal Factor:

- improper conditioning chemical/dosage

Corrective Action:

- Increase inorganic conditioner dose.

14.4.5.1.1.5 PLATE PRESS: PRECOAT PRESSURES GRADUALLY INCREASE

Causal Factors:

- improper sludge conditioning
- improper precoat feed
- filter media plugged
- calcium buildup in media

Corrective Actions (where applicable):

- Change chemical dosage.
- Decrease feed for a few cycles, then optimize.
- Wash filter media.
- Wash media with inhibited hydrochloric acid.

14.4.5.1.1.6 PLATE PRESS: FREQUENT MEDIA BINDING

Causal Factors:

- inadequate precoat
- initial feed rate too high (no precoat)

Corrective Actions (where applicable):

- Increase precoat.
- Reduce feed rate/develop initial cake slowly.

14.4.5.1.1.7 PLATE PRESS: EXCESSIVE MOISTURE IN CAKE

Causal Factors:

- improper conditioning
- filter cycle too short

Corrective Actions (where applicable):

- Change chemical dosage.
- Lengthen filter cycle.

14.4.5.1.1.8 PLATE PRESS: SLUDGE BLOWING OUT OF PRESS

Causal Factor:

- obstruction between plates

Corrective Action:

- Shut down feed pump, hit press closure drive, restart feed pump, clean after cycle.

14.4.5.1.1.9 PLATE PRESS: LEAKS AROUND LOWER FACES OF PLATES

Causal Factor:

- wet cake soiling media on lower faces

Corrective Action:

- See Section 14.4.5.1.1.7.

14.4.5.1.1.10 BELT PRESS: FILTER CAKE DISCHARGE IS DIFFICULT

Causal Factors:

- wrong conditioning chemical selected
- improper chemical dosage
- changing sludge characteristics
- wrong application point

Corrective Actions (where applicable):

- Change conditioning chemical.
- Adjust chemical dosage.
- Change chemical and/or dosage.
- Adjust application point.

14.4.5.1.1.11 BELT PRESS: SLUDGE LEAKING FROM BELT EDGES

Causal Factors:

- Excessive belt tension.
- Belt speed too low.
- Excessive sludge feed rate.

Corrective Actions (where applicable):

- Reduce belt tension.
- Increase belt speed.
- Reduce sludge feed rate.

14.4.5.1.1.12 BELT PRESS: EXCESSIVE MOISTURE IN FILTER CAKE

Causal Factors:

- improper belt speed/drainage time
- wrong conditioning chemical
- improper chemical dosage
- inadequate belt washing
- wrong belt weave/material

Corrective Actions (where applicable):

- Adjust belt speed.
- Change conditioning chemical.
- Adjust chemical dosage.
- Clear spray nozzles/adjust sprays.
- Replace belt.

14.4.5.1.1.13 BELT PRESS: EXCESSIVE BELT WEAR ALONG EDGES

Causal Factors:

- roller misalignment
- improper belt tension
- tension/alignment control system

Corrective Actions (where applicable):

- Correct roller alignment.
- Correct tension.
- Repair tracking and alignment system controls.

14.4.5.1.1.14 BELT PRESS: BELT SHIFTS OR SEIZES

Causal Factors:

- uneven sludge distribution
- inadequate/uneven belt washing

Corrective Actions:

- Adjust feed for uniform sludge distribution.
- Clean and adjust belt washing sprays.

14.5 SLUDGE INCINERATION

Wastewater sludge can be incinerated, converting the organic solids into mostly water vapor and carbon dioxide and leaving behind an inert ash residue; the process provides the highest levels of moisture, organic matter, pathogenic organism, and volume reduction of any sludge treatment process (more than 90% volume reduction). However, because of high construction costs as well as operation and environmental concerns, incineration of wastewater sludge is not widely practiced.

14.5.1 PROCESS DESCRIPTION

The incineration process first dries, then burns the sludge. The process involves the following steps:

- (1) The temperature of the sludge feed is raised to 212°F.
- (2) Water evaporates from the sludge.
- (3) The temperature of the water vapor and air mixture increases.
- (4) The temperature of the dried sludge volatile solids raises to the ignition point.

✓ *Note:* Incineration will achieve maximum reductions if sufficient fuel, air, time, temperature, and turbulence are provided.

14.5.2 INCINERATION PROCESSES

The two incineration processes in use today are the multiple hearth furnace and the fluidized bed reactor.

14.5.2.1 Multiple Hearth Furnace

The *multiple hearth furnace* consists of a circular steel shell surrounding a number of hearths. Scrappers (rabble arms) are connected to a central rotating shaft. Units range from 4.5 to 21.5 feet in diameter and have from four to 11 hearths.

In operation, de-watered sludge solids 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 generated by burning on lower hearths. The dry solids pass to the lower hearths. The high temperature on the lower hearths ignites the solids. Burning continues to completion. Ash materials discharge to lower cooling hearths where they are discharged for disposal. Internal equipment is continuously cooled by air flowing inside center column and rabble arms.

14.5.2.2 Fluidized Bed Furnace

The *fluidized bed* incinerator consists of a vertical circular steel shell (reactor) with a grid to support a sand bed and an air system to provide warm air to the bottom of the sand bed. The evaporation and incineration process takes place within the super-heated sand bed layer.

In operation, air is pumped to the bottom of the unit. The air flow expands (fluidizes) the sand bed inside. The fluidized bed is heated to its operating temperature (1,200–1,500°F). Auxiliary fuel is added when needed to maintain operating temperature. The sludge solids are injected into the heated sand bed. Moisture immediately evaporates. Organic matter ignites and reduces to ash. Residues are ground to fine ash by the sand movement. Fine ash particles flow up and out of unit with exhaust gases. Ash particles are removed using common air pollution control processes. Oxygen analyzers in the exhaust gas stack control the air flow rate.

✓ *Note:* Because these systems retain a high amount of heat in the sand, the system can be operated as little as four hours per day with little or no reheating.

14.5.3 OPERATION, OBSERVATION, AND TROUBLESHOOTING PROCEDURES

The operator of an incinerator monitors various performance factors to ensure optimal operation. These performance factors include feed sludge volatile content, feed sludge moisture content, operating temperature, sludge feed rate, fuel feed rate, and air feed rate.

✓ *Note:* To ensure that the volatile material is ignited, the sludge must be heated between 1,400 and 1,700°F.

In ensuring operating parameters are in the correct range, the operator monitors and adjusts sludge feed rate, air flow, and auxiliary fuel feed rate.

All maintenance conducted on an incinerator should be in accordance with manufacturer's recommendations.

14.5.3.1 Operational Problems

The operator of a multiple hearth or fluidized bed incinerator must be able to recognize operational problems using various indicators or through observation. We discuss these indicators/observations, causal factors, and recommended corrective actions in the following sections.

14.5.3.1.1 Multiple Hearth: Incinerator Temperature Too High

Causal Factors:

- excessive fuel feed rate
- greasy solids
- thermocouple burned out

Corrective Actions (where applicable):

- Decrease fuel feed rate.
- Reduce sludge feed rate.
- Increase air feed rate.
- Replace thermocouple.

14.5.3.1.2 Multiple Hearth: Furnace Temperature Too Low

Causal Factors:

- Moisture content of the sludge has increased.
- Fuel system malfunction.
- Excessive air feed rate.
- Flame out.

Corrective Actions (where applicable):

- Increase fuel feed rate until de-watering operation improves.
- Establish proper fuel feed rate.
- Decrease air feed rate.
- Increase sludge feed rate.
- Relight furnace.

14.5.3.1.3 Multiple Hearth: Oxygen Content of Stack Gas Too High

Causal Factors:

- Sludge feed rate is too low.
- Sludge feed system blockage.
- Air feed rate is too high.

Corrective Actions (where applicable):

- Increase sludge feed rate.
- Clear any feed system blockages.
- Decrease air feed rate.

14.5.3.1.4 Multiple Hearth: Oxygen Content of Stack Gas Too Low

Causal Factors:

- Volatile or grease content of the sludge has increased.
- Air feed rate is too low.

Corrective Actions (where applicable):

- Increase air feed rate.
- Decrease sludge feed rate.
- Increase air feed rate.

14.5.3.1.5 Multiple Hearth: Furnace Refractories Deteriorated

Causal Factor:

- rapid startup/shutdown of furnace

Corrective Actions:

- Repair furnace refractories.
- Follow specified startup/shutdown procedures.

14.5.3.1.6 Multiple Hearth: Unusually High Cooling Effect

Causal Factor:

- air leak

Corrective Action:

- Locate and repair leak.

14.5.3.1.7 Multiple Hearth: Short Hearth Life

Causal Factor:

- uneven firing

Corrective Action:

- Fire hearths equally on both sides.

14.5.3.1.8 Multiple Hearth: Center Shaft Shear Pin Failure

Causal Factors:

- Rabble arm is dragging on hearth.
- Debris is caught under the arm.

Corrective Actions (where applicable):

- Adjust rabble arm to eliminate rubbing.
- Remove debris.

14.5.3.1.9 Multiple Hearth: Scrubber Temperature Too High

Causal Factor:

- low water flow to scrubber

Corrective Action:

- Adjust water flow to proper level.

14.5.3.1.10 Multiple Hearth: Stack Gas Temperatures Too Low

Causal Factors:

- inadequate fuel feed supply
- excessive sludge feed rate

Corrective Actions (where applicable):

- Increase fuel feed rate.
- Decrease sludge feed rate.

14.5.3.1.11 Multiple Hearth: Stack Gas Temperatures Too High

Causal Factors:

- Sludge has higher volatile content (heat value).
- Excessive fuel feed rate.

Corrective Actions (where applicable):

- Increase air feed rate.
- Decrease sludge feed rate.
- Decrease fuel feed rate.

14.5.3.1.12 Multiple Hearth: Furnace Burners Slagging Up

Causal Factor:

- burner design

Corrective Action:

- Replace burners with newer designs that reduce slagging.

14.5.3.1.13 Multiple Hearth: Rabble Arms Dropping

Causal Factors:

- excessive hearth temperatures
- loss of cooling air

Corrective Actions (where applicable):

- Maintain temperatures within proper range.
- Discontinue injection of scum into the hearth.
- Repair cooling air system immediately.

14.5.3.1.14 Multiple Hearth: Excessive Air Pollutants in Stack Gas

Causal Factors:

- incomplete combustion—insufficient air
- air pollution control malfunction

Corrective Actions (where applicable):

- Raise air to fuel ratio.
- Repair/replace broken equipment.

14.5.3.1.15 Multiple Hearth: Flashing or Explosions

Causal Factor:

- scum or grease additions

Corrective Action:

- Remove scum/grease before incineration.

14.5.3.1.16 Fluidized Bed: Bed Temperature Falling

Causal Factors:

- inadequate fuel supply
- excessive sludge feed rate
- excessive sludge moisture levels
- excessive air flow

Corrective Actions (where applicable):

- Increase fuel supply.
- Repair fuel system malfunction.
- Decrease sludge feed rate.
- Correct sludge de-watering process problem.
- Decrease air flow rate.

14.5.3.1.17 Fluidized Bed: Low (<3%) Oxygen in Exhaust Gas

Causal Factors:

- low air flow rate
- fuel feed rate too high

Corrective Actions (where applicable):

- Increase blower air feed rate.
- Reduce fuel feed rate.

14.5.3.1.18 Fluidized Bed: Excessive (>6%) Oxygen in Exhaust Gas

Causal Factor:

- Sludge feed rate is too low.

Corrective Actions (where applicable):

- Increase sludge feed rate.
- Adjust fuel feed rate to maintain steady bed temperature.

14.5.3.1.19 Fluidized Bed: Erratic Bed Depth on Control Panel

Causal Factor:

- bed pressure taps plugged with solids

Corrective Actions (where applicable):

- Tap a metal rod into pressure tap pipe when the unit is not in operation.
- Apply compressed air to pressure tap while the unit is in operation (follow manufacturer's safety guidelines).

14.5.3.1.20 Fluidized Bed: Preheat Burner Fails and Alarm Sounds

Causal Factors:

- Pilot flame is not receiving fuel.
- Pilot flame is not receiving spark.
- Defective pressure regulator(s).
- Pilot flame ignites but flame scanner malfunctions.

Corrective Actions (where applicable):

- Correct fuel system problem.
- Replace defective part.
- Replace defective regulator(s).
- Clear scanner sight glass.
- Replace defective scanner.

14.5.3.1.21 Fluidized Bed: Bed Temperature Too High

Causal Factors:

- Bed gun fuel feed rate is too high.
- Grease or high organic content in sludge (high heat value).

Corrective Actions (where applicable):

- Reduce bed gun fuel feed rate.
- Increase air flow rate.
- Decrease sludge fuel rate.

14.5.3.1.22 Fluidized Bed: Bed Temperature Reads Off Scale

Causal Factor:

- thermocouple burned out

Corrective Action:

- Replace thermocouple.

14.5.3.1.23 Fluidized Bed: Scrubber Inlet Shows High Temperature

Causal Factors:

- No water flowing in scrubber.
- Spray nozzles are plugged.
- Ash water not recirculating.

Corrective Actions (where applicable):

- Open valves to provide water.
- Correct system malfunction to provide required pressure.
- Clear nozzles and strainers.
- Repair/replace recirculation pump.
- Unclog scrubber discharge line.

14.5.3.1.24 Fluidized Bed: Poor Bed Fluidization

Causal Factor:

- sand leakage through support plate during shut down

Corrective Actions (where applicable):

- Clear wind box.
- Clean wind box at least once per month.

14.6 LAND APPLICATION OF SLUDGE (BIOSOLIDS)⁹

Land application of treated sludge or biosolids has become not only a necessity (because of the banning of ocean dumping in the U.S. in 1992 and the shortage of landfill space since then), but also quite popular as a beneficial reuse practice (i.e., disposed of in an environmentally sound manner by recycling nutrients and soil conditioners). Biosolids are being applied throughout the U.S. to agricultural and forest lands.

Many readers may be surprised to discover that the present trend in wastewater treatment toward land application of biosolids is not a new development, but the revival of an old (rather, an ancient) option. For example, sludge was applied in the U.S. for generations—before the advent of cheap, plentiful chemical fertilizers in the 1950s, when the practice became virtually obsolete. Again, the banning of ocean dumping and other environmental concerns has caused the re-birth of an ancient practice—a beneficial reuse practice that not only lowers disposal costs, but also returns valuable nutrients to farm and forest lands.

For use in land applications, the biosolids must meet certain conditions. Biosolids must comply with state and federal biosolids management/disposal regulations and must also be free of materials dangerous to human health (i.e., toxicity, pathogenic organisms, etc.) and/or dangerous to the environment (i.e., toxicity, pesticides, heavy metals, etc.).

Biosolids are land applied by direct injection or by application and incorporation (plowing in).

⁹Adapted from Outwater, A. B., *Reuse of Sludge and Minor Wastewater Residuals*. Boca Raton, FL: Lewis Publishers, p. 67, 1994.

14.6.1 PROCESS CONTROL: SAMPLING AND TESTING

Land application of biosolids requires precise control to avoid problems. The quantity and the quality of biosolids applied must be accurately determined. For this reason, the operator's process control activities include biosolids sampling/testing functions.

Biosolids sampling and testing includes determination of % solids, heavy metals, organic pesticides and herbicide, alkalinity, total organic carbon (TOC), organic nitrogen, and ammonia nitrogen.

14.6.2 PROCESS CONTROL: CALCULATIONS

Process control calculations include determining disposal cost, plant available nitrogen (PAN), application rate (dry tons and wet tons/acre), metals loading rates, maximum allowable applications based upon metals loading, and site life based on metals loading.

14.6.2.1 Disposal Cost

The cost of disposal of biosolids can be determined by

$$\text{Cost} = \text{Wet Tons Biosolids Produced / Year} \times \% \text{ Solids} \times \text{Cost / dry ton} \quad (14.16)$$

Example 14.16

Problem:

The treatment system produces 1,925 wet tons of biosolids for disposal each year. The biosolids are 18% solids. A contractor disposes of the biosolids for \$28.00 per dry ton. What is the annual cost for sludge disposal?

Solution:

$$\text{Cost} = 1,925 \text{ wet tons / year} \times 0.18 \times \$28.00 / \text{dry ton} = \$9,702$$

14.6.2.2 Plant Available Nitrogen (PAN)

One factor considered when land applying biosolids is the amount of nitrogen in the biosolids available to the plants grown on the site. This includes ammonia nitrogen and organic nitrogen. The organic nitrogen must be mineralized for plant consumption. Only a portion of the organic nitrogen is mineralized per year. The mineralization factor (f_1) is assumed to be 0.20. The amount of ammonia nitrogen available is directly related to the time elapsed between applying the biosolids and incorporating (plowing) the sludge into the soil. We provide volatilization rates based upon this example below.

$$\text{PAN, lb / dry ton} = [(\text{Org. Nit., mg / kg} \times f_1) + (\text{Amm. Nit., mg / kg} \times V_1)] \times 0.002 \text{ lb / dry ton} \quad (14.17)$$

where

f_1 = Mineral rate for organic nitrogen (assume 0.20)

V_1 = Volatilization rate ammonia nitrogen

$V_1 = 1.00$ if biosolids are injected

$V_1 = 0.85$ if biosolids are plowed in within 24 hours

$V_1 = 0.70$ if biosolids are plowed in within 7 days

Example 14.17*Problem:*

The biosolids contain 21,000 mg/kg of organic nitrogen and 10,500 mg/kg of ammonia nitrogen. The biosolids are incorporated into the soil within 24 hours after application. What is the plant available nitrogen (PAN) per dry ton of solids?

Solution:

$$\begin{aligned}\text{PAN, lb/dry ton} &= [(21,000 \text{ mg/kg} \times 0.20) + (10,500 \times 0.85)] \times 0.002 \\ &= 26.3 \text{ lb PAN/dry ton}\end{aligned}$$

14.6.2.3 Application Rate Based on Crop Nitrogen Requirement

In most cases, the application rate of domestic biosolids to crop lands will be controlled by the amount of nitrogen the crop requires. The biosolids application rate based upon the nitrogen requirement is determined by the following:

- (1) Using an agriculture handbook to determine the nitrogen requirement of the crop to be grown
- (2) Determining the amount of sludge in dry tons required to provide this much nitrogen

$$\text{Dry tons/acre} = \frac{\text{Plant Nitrogen Requirement, lb/acre}}{\text{Plant Available Nitrogen, lb/dry ton}} \quad (14.18)$$

Example 14.18*Problem:*

The crop to be planted on the land application site requires 150 lb of nitrogen per acre. What is the required biosolids application rate if the PAN of the biosolids is 30 lb/dry ton?

Solution:

$$\text{Dry tons/acre} = \frac{150 \text{ lb nitrogen/acre}}{30 \text{ lb/dry ton}} = 5 \text{ dry tons per acre}$$

14.6.2.4 Metals Loading

When biosolids are land applied, metals concentrations are closely monitored and their loading on land application sites are calculated.

$$\text{Loading, lb/acre} = \text{Metal Conc., mg/kg} \times 0.002 \text{ lb/dry ton} \times \text{Appl. Rate, dry tons/acre} \quad (14.19)$$

Example 14.19*Problem:*

The biosolids contain 14 mg/kg of lead. Biosolids are currently being applied to the site at a rate of 11 dry tons per acre. What is the metals loading rate for lead in pounds per acre?

Solution:

$$\text{Loading Rate, lb/acre} = 14 \text{ mg/kg} \times 0.002 \text{ lb/dry ton} \times 11 \text{ dry tons} = 0.31 \text{ lb/acre}$$

14.6.2.5 Maximum Allowable Applications Based Upon Metals Loading

If metals are present, they may limit the total number of applications a site can receive. Metals loadings are normally expressed in terms of the maximum total amount of metal that can be applied to a site during its use.

$$\text{Applications} = \frac{\text{Max. Allowable Cumulative Load for the Metal, lb/Ac}}{\text{Metal Loading, lb/acre/application}} \quad (14.20)$$

Example 14.20

Problem:

The maximum allowable cumulative lead loading is 48.0 lbs/acre. Based upon the current loading of 0.35 lbs/acre, how many applications of biosolids can be made to this site?

Solution:

$$\text{Applications} = \frac{48.0 \text{ lb/acre}}{0.35 \text{ lb/acre}} = 137 \text{ applications}$$

14.6.2.6 Site Life Based On Metals Loading

The maximum number of applications based upon metals loading and the number of applications per year can be used to determine the maximum site life.

$$\text{Site Life, years} = \frac{\text{Maximum Allowable Applications}}{\text{Number of Applications Planned Per Year}} \quad (14.21)$$

Example 14.21

Problem:

Biosolids is currently applied to a site twice annually. Based upon the lead content of the biosolids, the maximum number of applications is determined to be 135 applications. Based upon the lead loading and the application rate, how many years can this site be used?

Solution:

$$\text{Site Life} = \frac{135 \text{ applications}}{2 \text{ applications/year}} = 68 \text{ years}$$

✓ *Note:* When more than one metal is present, the calculations must be performed for each metal. The site life would then be the lowest value generated by these calculations.

14.7 SUMMARY

Wastewater treatment requires mastering many physical tasks, as well as the mental ability to

perform the mathematical calculations necessary for proper operation. However, the need to perform treatment tasks and the information operators need for actions on those physical tasks are determined by sampling, testing, and analysis—the topics covered in Chapter 15.

14.8 CHAPTER REVIEW QUESTIONS

- 14-1 Before sludge can be disposed of or reused as biosolids, it requires some form of treatment to _____.
- 14-2 Define free water.
- 14-3 What is the difference between organic and inorganic solids?
- 14-4 Define sludge thickening.
- 14-5 List the major factors that affect drying bed performance.
- 14-6 What are the major advantages of incinerating sludge?
- 14-7 The sludge pump operates 30 minutes every 3 hours. The pump delivers 70 gpm. If the sludge is 5.5% solids and has a volatile matter content of 69%, how many pounds of volatile solids are removed from the settling tank each day?
- 14-8 The digester has a volume of 72,000 gallons. Sludge is added to the digester at the rate of 2,800 gallons per day. What is the sludge retention time in days?
- 14-9 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 reduction in gas production?
- 14-10 The supernatant contains 344 mg/L volatile acids and 1,830 mg/L of alkalinity. What is the volatile acids alkalinity ratio?

Wastewater Sampling and Analysis

15.1 INTRODUCTION

WASTEWATER operators have a twofold function in wastewater treatment plant operations: (1) keep the plant running and (2) make permit. To accomplish this, the operator does more than simply turn valves, push switches, lubricate equipment, read gauges and record data. The wastewater operator also collects samples and typically performs analysis on these samples. Sampling and performing sample analysis are important, not only because they are required to satisfy various local, state, and federal compliance stipulations, but because they help to gauge the performance of the treatment process. Results from such samples indicate how the plant is performing. From these sampling results, the operator determines what adjustments (if any) should be made to optimize the treatment process.

✓ *Note:* Anyone who is to perform the vital task of sampling should remember the important axiom: “The result of any test can be no better than the sample on which it is performed.”

15.1.1 TYPES OF SAMPLES

Wastewater operators take two types of samples: grab samples and composite samples. A *grab sample* (or catch sample) is a discreet sample collected at one time and location. It must be used for any parameter whose concentration can change quickly (i.e., dissolved oxygen, pH, temperature, total residual chlorine). Note that a grab sample is representative of the parameter *only* at the instant the sample was collected.

A *composite sample* (time-composite sample) is a series of grab samples taken at specified time intervals and in proportion to flow. A composite sample is representative of the average concentration of the parameter over a specified time period.

15.1.2 SAMPLE CONTAINERS

Sample containers may be specified for a particular test. If no container is specified, borosilicate glass or plastic containers may be used. Sample containers should be clean and free of soap or chemical residues.

15.1.3 PRESERVATION METHODS

Preservation methods, at best, only retard changes that inevitably continue after sample collection. Changes that take place in a sample are either biological or chemical. Preservation methods employed (when permitted) for a particular sample are specified for individual parameters.

15.1.4 SAMPLING CALCULATIONS

15.1.4.1 Composite Sample Volumes

Composite samples consist of discreet sample portions collected at specified intervals in proportion to the flow rate at the time of collection.

$$\text{Sample Volume} = \frac{\text{Plant Flow}_T, \text{MGD} \times \text{Total Required Sample, mL}}{\text{No. of Samples Collected} \times \text{Ave. Daily Flow, MGD}} \tag{15.1}$$

where

Sample_T = Sample volume to collect at time *T*

15.1.4.2 Proportioning Factor

Sample volume_T can also be calculated using a proportioning factor (PF).

$$\text{PF} = \frac{\text{Total Sample Volume Required, mL}}{\text{No. of Samples Collected} \times \text{Ave. Daily Flow, MGD}} \tag{15.2}$$
$$\text{Sample Volume}_T = \text{Flow}_T, \text{MGD} \times \text{PG}$$

Example 15.1

Problem:

Use the data in the chart to determine the required volume of sample to be collected at 11 A.M.

No. of Samples in Composite	5 samples (1/hour)
Total Required Sample Volume	4,000 mL
Average Daily Flow	0.95 MGD
Flow @ 10 A.M.	0.69 MGD
Flow @ 11 A.M.	0.94 MGD
Flow @ 12 P.M.	1.05 MGD
Flow @ 1 P.M.	0.83 MGD
Flow @ 2 P.M.	0.68 MGD

Solution:

$$\text{Sample Volume}_{11 \text{ A.M.}} = \frac{0.94 \text{ MGD} \times 4,000 \text{ mL}}{5 \text{ samples} \times 0.95 \text{ MGD}} = 792 \text{ mL}$$

What is the proportioning factor (PF) for this sampling activity?

$$\text{Proportioning Factor (PF)} = \frac{4,000 \text{ mL}}{5 \times 0.95 \text{ MGD}} = 842 \text{ mL / MGD}$$

Using the proportioning factor, what volume of sample should be collected at 12 P.M.?

$$\text{Sample Volume}_{12 \text{ P.M.}} = 1.05 \text{ MGD} \times 842 \text{ mL / MGD} = 884.1 \text{ mL}$$

15.2 SAMPLING AND ANALYSIS

In the following sections, we describe sampling and analysis techniques used for phosphorus, nitrogen, alkalinity, and hardness testing. We selected these four testing procedures because they represent the types of sampling analysis procedures typically performed by wastewater operators at the advanced level.

✓ *Note:* In the procedures described herein, no attempt should be made to perform the tests for the various forms of phosphorous, and nitrogen and for alkalinity or hardness using only the summary information provided within these sections. Refer to the appropriate reference cited in the Federal Regulations for a complete discussion of each procedure.

15.2.1 PHOSPHORUS ANALYSIS

Phosphorus normally exists in wastewater in the following forms of phosphate.

- *Orthophosphates* (reactive phosphorus)—Composed of phosphate, hydrogen phosphate and di-hydrogen phosphate can be determined by colorimetric procedures without acid hydrolysis or digestion.
- *Condensed Phosphates* (acid hydrolyzable phosphorus)—Composed of pyro, meta, and other polyphosphates that exist as long chain molecules and can be converted to orthophosphates by acid hydrolysis. A small amount may be measured during colorimetric procedures for orthophosphate.
- *Organic Phosphates*—Phosphate that is chemically part of the organic matter in wastewater and must be converted to orthophosphates.

Each of these phosphates can exist in suspended or dissolved forms, which can be determined by filtering a sample, then performing the appropriate pretreatment and testing procedures. The National Pollutant Discharge Elimination System (NPDES) permit (for each state) normally expresses effluent limitations in total or total reactive phosphorus; we discuss only those methods.

The approved method for determination of orthophosphate (reactive phosphorus) or total phosphorus specified in the current Federal regulation *Guidelines Establishing Test Procedures for the Analysis of Pollutants* Federal Register 40-CFR-136 is the manual, single reagent, ascorbic acid reduction procedure. The regulation also designates the use of the persulfate digestion procedure, followed by manual, single reagent, ascorbic acid reduction for total phosphorus.

A complete listing of the various forms of phosphorus and the required pretreatment and analysis methods is shown in Table 15.1.

TABLE 15.1. Forms of Phosphorus.

Sample Containing Phosphorus	
Test Method	Test Results
Direct Ascorbic Test	Orthophosphate
Persulfate Digestion	Condensed Phosphate followed by Ascorbic Acid
Filtration followed by Ascorbic Acid	Dissolved Orthophosphate
Filtration followed by Acid Hydrolysis and Ascorbic Acid	Dissolved Condensed Phosphate
Filtration followed by Persulfate Digestion and Ascorbic Acid	Dissolved Total Phosphate

15.2.1.1 Sampling and Preservation

Samples used for determination of phosphorus can be either grab or composite.

Procedure:

- Do not store low concentration samples in plastic bottles.
- Do not use commercial detergents to clean any equipment used to collect, store, or analyze phosphorus samples.
- Rinse all sampling containers with hot diluted (1 + 1) hydrochloric acid, then rinse three times with distilled water.

15.2.1.2 Preservation

If the sample is to be analyzed for each of the phosphorus forms, split prior to preservation.

Procedure:

- Filter one portion of the sample immediately. After filtering, divide the filtered sample into two portions.
- Cool one portion to 4°C. Acidify the second portion to a pH <2.0 using concentrated sulfuric acid, then cool to 4°C.
- Acidify the unfiltered portion to a pH <2.0 using concentrated sulfuric acid, and cool to 4°C.
- If total phosphorus is the only determination to be made, acidify the sample to a pH <2.0 using concentrated sulfuric acid, and cool to 4°C.
- Acidified and cooled samples may be held for up to 4 weeks.
- Preserved orthophosphate samples should be run within 48 hours.

15.2.1.3 Pretreatment

To measure total phosphorus using the approved test method, samples must be digested using the *persulfate digestion procedure*. Other, more rigorous digestion methods exist, but are not required under the current federal regulations.

15.2.1.4 Persulfate Digestion

Persulfate digestion is the least vigorous digestion method and the least demanding in procedure and technique. In this procedure, a sample of wastewater is heated in the presence of ammonium persulfate in an acid solution until the polyphosphates and organically bound phosphates are converted to orthophosphate. The orthophosphate is then determined using the single reagent ascorbic acid method.

15.2.1.4.1 Persulfate Digestion Procedure

The persulfate digestion procedure requires the following chemicals:

- phenolphthalein indicator, aqueous
- sulfuric acid solution
- ammonium persulfate, crystals
- sodium hydroxide, 1 N
- distilled water

✓ *Note:* With the exception of distilled water (of course), the other solutions listed above must be used/handled with extreme caution, either because they are poisonous or corrosive—check applicable Material Safety Data Sheet (MSDS).

All glassware used for phosphorus testing must be acid washed with hot, dilute (1 + 1) hydrochloric acid and rinsed with distilled water. To avoid potential contamination, glassware used for phosphorus testing should not be used for any other purpose. Equipment used includes the following:

- 125 mL Erlenmeyer flasks
- 50 mL graduated cylinder
- 100 mL graduated cylinder
- 5 mL measuring pipettes
- hot plate, autoclave, or pressure cooker
- glass scoop (0.4-gram capacity)

Procedure:

- (1) Measure 50 mL of sample or an appropriate volume of sample diluted to 50 mL with distilled water.
- (2) Pour the sample or diluted sample into a 125 mL Erlenmeyer flask.
- (3) Add two drops phenolphthalein indicator.
- (4) If a red color develops, add sulfuric solution until the color disappears.
- (5) Add 1 mL of sulfuric acid solution and 0.4 g ammonium persulfate.
- (6) Digest the sample by either boiling the treated sample gently for 30–40 minutes or until total volume is 10 mL or autoclaving the treated sample at 15–20 psig for 30 minutes.
- (7) Cool the sample to room temperature.
- (8) If a hot plate was used, dilute the sample to 30 mL.
- (9) Add one drop phenolphthalein, and neutralize to a faint pink color with 1 N sodium hydroxide.
- (10) Dilute the neutralized, digested sample to 100 mL with distilled water.

✓ *Note:* If a precipitate forms at this point, do not filter the sample. Mix the sample thoroughly before withdrawing portions for subsequent procedures.

- (11) Test the digested sample using the single reagent, ascorbic acid method for orthophosphate.

15.2.1.4.2 Single Reagent Ascorbic Acid Method: Orthophosphate

✓ *Note:* Although the federal regulations cite three ascorbic acid methods (manual or automated single reagent and manual two reagent) we discuss only the manual single reagent procedure in the handbook. The remaining methods are beyond the scope of this handbook because of their complexity.

In the single reagent ascorbic acid method for orthophosphate determination, ammonium molybdate and potassium antimonyl tartrate will react with orthophosphates in acidic solution to form phosphomolybdic acid. The phosphomolybdic acid is then reduced by ascorbic acid to form an intense molybdenum blue color.

A combined reagent consisting of the following chemicals is used:

- sulfuric acid solution, 5 N
- potassium antimonyl tartrate solution

- ammonium molybdate solution
- ascorbic acid solution, 0.01 M

✓ *Note:* The combined reagent has a useful life of only four hours and must be prepared fresh daily.

Stock phosphate solution, 1.00 mL = 50 micrograms phosphorus (P)

Standard phosphate solution, 1.00 mL = 2.50 micrograms phosphorus (P)

All glassware used for phosphorus testing must be acid washed with hot, diluted (1 + 1) hydrochloric acid and rinsed with distilled water. To avoid potential contamination, glassware used for phosphorus testing should not be used for any other purpose.

The equipment used in the single reagent ascorbic acid orthophosphate determination method includes the following:

- 125 mL Erlenmeyer flasks
- 50 mL graduated cylinder
- 100 mL graduated cylinder
- 10 mL measuring pipettes
- 5 mL measuring pipettes
- glass cuvettes, 2.5 cm (1 inch) diameter
- spectrophotometer: Infrared phototube for use at 880 nm
Light path of at least 2.5 cm (1 inch)

15.2.1.4.3 Orthophosphate Standard Curve

✓ *Note:* Standards must be treated in the same manner as samples.

If only orthophosphates are to be performed, the volumes of standard solution selected may be placed in 125 mL Erlenmeyer flasks and diluted to 50 mL with distilled water. If the persulfate digestion is used to determine total phosphorus, the volumes of standard solution selected must be placed in the 125 mL Erlenmeyer flasks and digested as described in the persulfate digestion procedure detailed in Section 15.2.1.4.1.

A 50-mL aliquot of the digested standard is used for the preparation of the standard curve.

On preparing a standard curve (see Figure 15.1), select a series of standard phosphorus solution volumes. For samples with a concentration in the range of 0.3 to 2.0 mg/L, prepare standard solutions by pipetting appropriate volumes of 15–100 micrograms into 125-mL digestion flasks and dilute to 50 mL with distilled water.

Place 50 mL of distilled water in a 125-mL digestion flask, and proceed with the persulfate digestion and the single reagent, ascorbic acid procedures outlined below.

Procedure:

- (1) Measure 50.0 mL of sample or an appropriate portion of sample diluted to 50 mL of sample into a dry, acid cleaned, 125-mL Erlenmeyer flask.

✓ *Note:* The sample may be a digested, hydrolyzed, undigested, or filtered sample, depending on the form of phosphorus being determined.

- (2) Add one drop of phenolphthalein indicator. If a red color develops, add 5 N sulfuric acid until the color just disappears.

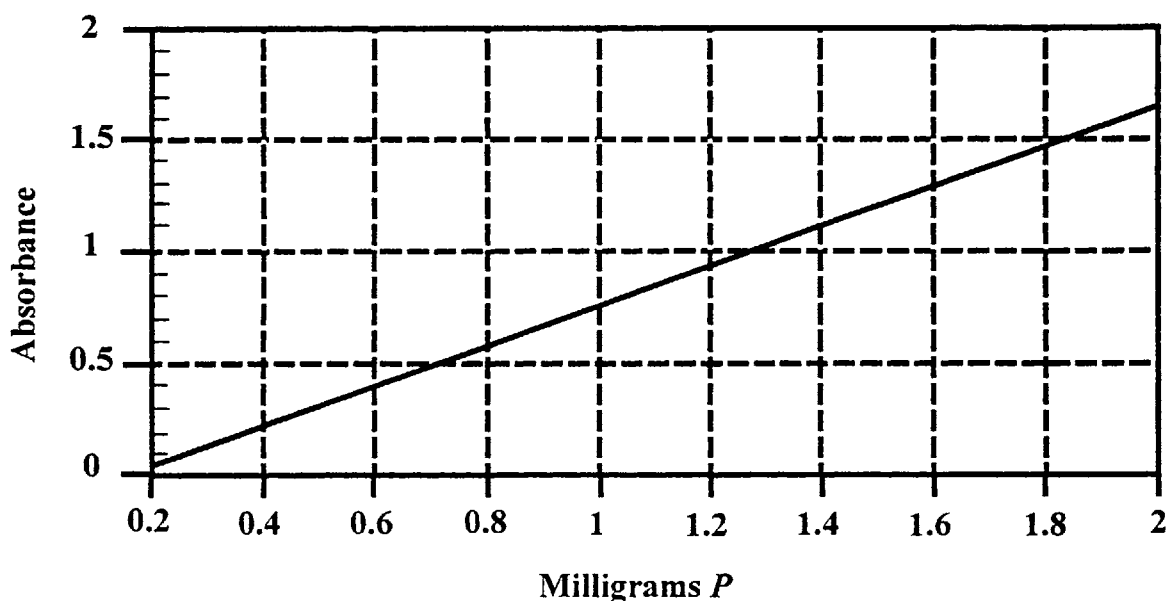


Figure 15.1 Orthophosphate standard curve (ascorbic acid method).

- (3) Add 8.0 mL of combined reagent, and mix thoroughly.
- (4) Allow 10 minutes for color development.

✓ *Note:* The color developed must be measured within 30 minutes of the addition of the combined reagent.

- (5) Measure absorbance (A) at 880 nm using a distilled water reagent blank to set the instrument to 0.0 A.

✓ *Note:* In highly colored or turbid samples, prepare a sample blank by adding all reagents to the sample except the ascorbic acid and antimonyl potassium tartrate. Subtract the absorbance of the sample blank from the absorbance of the samples.

Calculations:

- (1) Read the mg of phosphorus from the standard curve (see Figure 15.1).
- (2) Use the following formula to calculate the milligrams of phosphorus per liter (mg P/L):

$$\text{mg/L phosphorus} = \frac{\text{mg phosphorus from graph} \times 1,000}{\text{mL of actual sample}} \quad (15.3)$$

Interferences:

Several chemicals may interfere with this test procedure causing invalid or inconclusive results. We list examples below:

- Arsenates can produce a blue color similar to that produced by phosphates in the determination.
- Chromium (hexavalent) and nitrite give low results in the test. The change is dependent upon the concentration of chromium or nitrite:

- 3% @ 1.0–10.0 mg/L
- 15% @ above 10.0 mg/L
- Arsenic concentrations as low as 0.10 mg/L interfere with the test procedure.
- Sulfide concentrations >1.0 mg/L interfere with the test.
- Silicate concentrations >10.0 mg/L interfere with the test procedure.

Sensitivity:

The sensitivity procedure is suitable for orthophosphate concentrations of 0.01 to 6 mg/L PO_4^{-3} . If the samples to be tested have an expected phosphorus concentration higher than 6 mg/L, a suitable dilution must be prepared prior to color development.

The minimum detectable concentration of phosphorus by this test procedure is 0.01 mg/L P. The limits of the test procedure are dependent upon the length of the light path used in the determination:

0.5 cm	0.30–2.0 mg/L P
1.0 cm	0.15–1.30 mg/L P
5.0 cm	0.01–0.25 mg/L P

15.2.2 NITROGEN TESTING

In the following sections, we briefly describe sampling and testing procedures for ammonia, total Kjeldahl, organic, nitrite nitrogen, and nitrate nitrogen. Again, no attempt should be made to perform the tests for the various forms of nitrogen using only the summary information provided with this handbook. Refer to the appropriate reference in the federal regulations for a complete discussion of each procedure.

Approved methods for determination of the various forms of nitrogen found in wastewater and required preliminary treatment steps are shown in Table 15.2.

15.2.2.1 Ammonia Nitrogen Determination

Samples for determination of *ammonia nitrogen* can be either grab or composite. The most reliable results are obtained using freshly collected samples. Note that residual chlorine must be removed from the samples immediately after collection to prevent reaction with ammonia. This dechlorination can be accomplished by using sodium thiosulfate solution, sodium arsenite solution, sodium sulfite solution, or phenylarsine oxide solution.

After dechlorination, preserve samples (if the samples must be held) by acidifying the sample to a pH <2.0 by adding concentrated sulfuric acid (approximately 0.8 milliliters per liter of sample). Acidified samples can be held for up to 28 days when refrigerated at 4°C or less.

TABLE 15.2. Summary of Nitrogen Analysis Methods.

Nitrogen Form	Method	Preliminary Treatment
Ammonia	Acidimetric Titration Nesslerization (colorimetric)	Distillation
	Specific Ion Electrode	
Total Kjeldahl	Acidimetric Titration Nesslerization (colorimetric)	Digestion and Nitrogen Distillation
	Specific Ion Electrode	
Nitrite Nitrogen	Diazotization with Manual/Auto Colorimetric Measurement	None Required
	Single Step Diazotization	
Nitrate Nitrogen	Brucine Sulfate Cadmium Reduction	None Required

15.2.2.1.1 Preliminary Distillation Procedure

In determining wastewater ammonia, to reduce interference, ammonia nitrogen concentrations must include a preliminary distillation step. The preliminary distillation step can be eliminated only if there is documentation showing there is no statistically significant difference between the results of direct ammonia determinations and determinations made after distillation. Direct ammonia determinations should only be used with the Nesslerization and specific ion electrode procedures.

Procedure Preparation:

In the preliminary distillation procedure, the sample pH is raised to 9.5, and the ammonia is removed by distillation. The ammonia is then absorbed in an acid solution (boric acid, indicating boric acid, or 0.04 N sulfuric acid). The process separates the ammonia nitrogen from other wastewater components that could cause interference with the test methods.

The chemicals used in this procedure include the following (*Note:* Keep in mind that many of the chemical solutions listed are poisonous or corrosive—check the applicable MSDS):

- ammonia-free distilled water
- borate buffer solution
- sodium hydroxide solution, 6 N
- dechlorination solutions: phenylarsine oxide solution, sodium arsenite solution, sodium sulfite solution, or sodium thiosulfate solution
- sodium hydroxide, 1 N
- sulfuric acid, 1 N
- absorbing solutions: boric acid solution, indicating boric acid solution, or sulfuric acid solution 0.04

The equipment used in this procedure includes distillation apparatus consisting of the following:

- 800 to 2,000 mL borosilicate glass flask
- appropriate connecting bulb
- vertical condenser (pyrex, block tin, or aluminum)
- heating source capable of consistent, even temperature production
- 500 mL Erlenmeyer flasks

A micro distillation unit may be substituted for the above when Nesslerization of specific ion electrode ammonia methods is used.

✓ *Note:* Whenever glassware connections are made, all connections should be ground glass or Teflon-wrapped materials.

Distillation Procedure:

The first step in the distillation procedure is to prepare the distillation apparatus:

- (1) Place glass beads, 500 mL of ammonia-free distilled water, and 25 mL of borate buffer in the distillation flask.
- (2) Add enough 6 N sodium hydroxide to adjust solution pH to 9.5.
- (3) Attach the flask to the distillation unit.
- (4) Distill until no trace of ammonia is evident when Nessler's reagent or mixed indicator (methyl red-methylene blue) is added to aliquots of the distillate.
- (5) Leave the distillation unit assembled until ready to attach the distillation flask containing the sample.

The next step requires measuring 500 mL of dechlorinated sample or an aliquot of sample diluted to 500 mL with ammonia-free distilled water into a distillation flask. Then neutralize to approximately a pH of 7 with sodium hydroxide (1 N) or sulfuric acid (1 N). Add 25 mL of borate buffer solution to the sample. Adjust sample pH to 9.5 with 6 N sodium hydroxide. Then measure 50 mL of absorbing solution into a 500 mL Erlenmeyer flask.

Select the appropriate absorbing solution based upon the method selected:

Method	Absorbing Solution
Titrimetric	Indicating boric acid
Nesslerization	Boric acid
Specific Ion Electrode	0.04 N sulfuric acid

Proceed as follows:

- (1) Place the absorbing flask under the condenser outlet with the outlet tube below the surface of the solution.
- (2) Place sample flask on the distillation apparatus, and adjust heat to provide a distillation rate of 6–10 mL/min.
- (3) After 250–300 mL of distillate have been collected, lower the collection flask until the outlet is above the absorbing solution, and distill 2–3 minutes longer.
- (4) Remove the heat source, and allow the distillation flask to cool.
- (5) Dilute the contents of the collection flask to 500 mL with ammonia-free distilled water.
- (6) Proceed to determine the ammonia concentration using the appropriate approved method.

15.2.2.2 Nesslerization

The reaction of ammonia and Nessler reagent will produce a color that ranges from pale yellow to brown, depending upon the amount of ammonia nitrogen present. The *Nesslerization procedure* is applicable to samples or sample dilutions with ammonia nitrogen levels between 0.4 mg/L and 5 mg/L.

A standard curve (see Figure 15.2) must be prepared that defines the relationship between observed values of % transmittance at the specified wavelength and known concentrations of ammonia nitrogen. To ensure the accuracy of the standard curve, all standards and blanks used to prepare the curve must be prepared in exactly the same way the samples will be prepared.

Procedure Preparation:

- ✓ *Note:* Keep in mind that at least one standard and one blank must be used each time the test is performed.

The chemicals used in this procedure include the following:

- stock ammonium solution, 1 mL = 1 mg N
- standard ammonium solution, 1 mL = 0.01 mg N
- Nessler reagent (care and caution must be used; check MSDS)

The equipment used includes:

- spectrophotometer (light path of 1 cm or more), (400–500 nm), or filter photometer (light path of 1 cm), Violet filter (T 400–425 nm)
- pH meter equipped with a high pH electrode

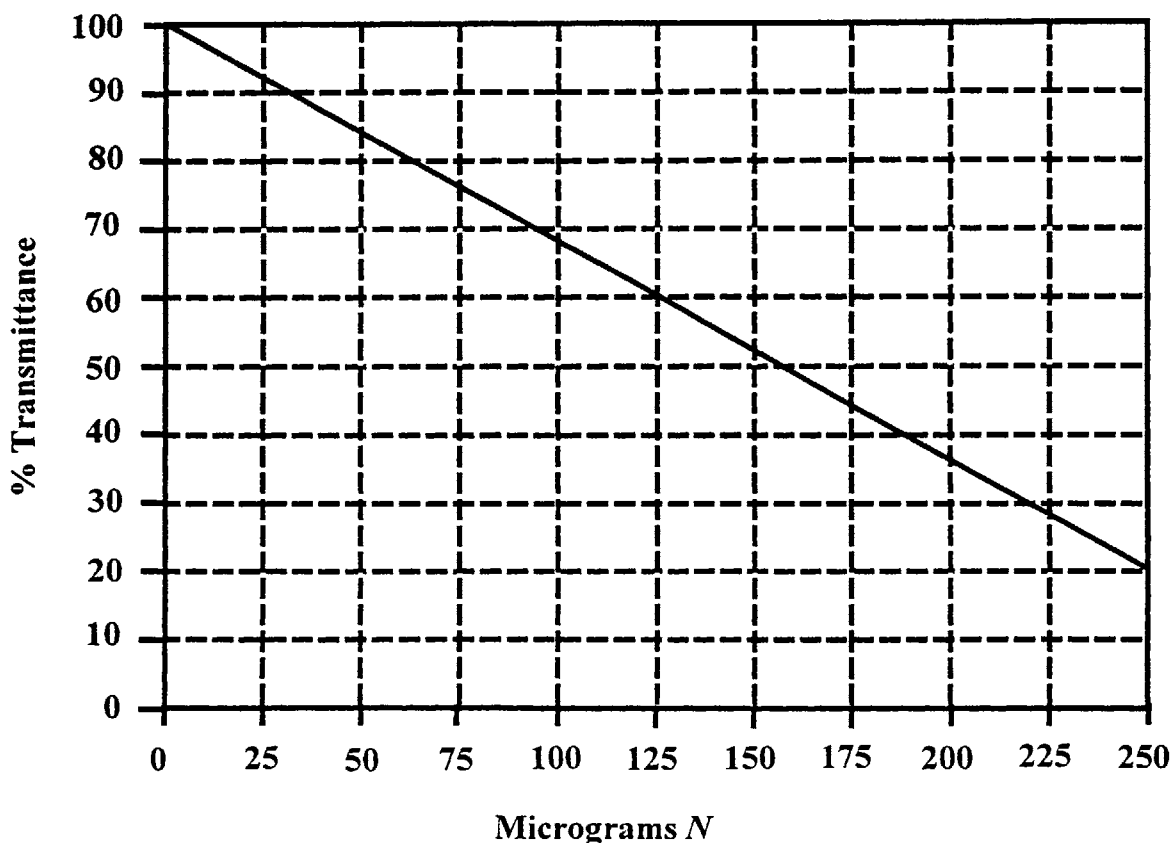


Figure 15.2 Ammonia nitrogen standard curve (nesslerization method).

- beakers, 200–250 mL
- Erlenmeyer flask, 125 mL
- cuvettes, optically matched (for use in colorimeter-spectrophotometer)

Test Procedure:

- (1) Pipet 50 mL of distillate or a suitable aliquot of distillate (diluted to 50 mL) into a 125-mL Erlenmeyer flask.
 - (2) Neutralize the boric acid absorbing solution by adding 2 mL Nessler reagent or adding sodium hydroxide followed by addition of 1 mL of Nessler reagent.
 - (3) Cap the Erlenmeyer flasks with clean rubber stoppers, and mix thoroughly.
 - (4) Allow 10-minute color development (sample, blank and standards must be maintained at same temperature and have the same color development time).
- ✓ If ammonia nitrogen is extremely low, allow 30 minute development.
- (5) Measure % transmittance of the sample using the distilled water blank to set the instrument at 100% T for the selected wavelength.
- ✓ The wavelength selected is dependent on the ammonia concentration and must be determined experimentally. Once selected, the wavelength must remain constant for standards and samples.

- (6) Read the ammonia nitrogen in micrograms from the standard curve (see Figure 15.2) and calculate ammonia nitrogen concentration in mg/L using the formula below.

$$\text{NH}_3 - \text{N, mg/L} = \frac{A}{\text{Samples Volume, mL}} \times \frac{B}{C} \quad (15.4)$$

where

A = Micrograms of N from standard curve (Figure 15.2)

B = Volume of distillate collected

C = Volume of distillate used for Nesslerization

Sample Volume = Original sample placed in distillation flask

Interferences:

When performing this test, certain interferences are likely. For example, urea and cyanate may hydrolyze slightly (5–7%) at pH = 9.5 and may increase results slightly. Also, residual chlorine will interfere if not removed.

Sensitivity:

In regards to sensitivity, with careful preparation of the Nessler reagent, 1 microgram per 50 mL may be detected; however, results at this level are extremely erratic. Note that the method is normally used for ammonia nitrogen concentrations of 0.4–5.0 mg/L.

15.2.2.3 Acidimetric Titration

In the *acidimetric procedure* (applicable to samples with ammonia nitrogen concentrations greater than 5 mg/L), the ammonium nitrogen distilled into an indicating boric acid absorbent solution is titrated to the pale lavender endpoint of methyl red-methylene blue mixed indicator with a strong acid titrant. The volume of acid used for the titration represents the concentration of ammonia nitrogen in the sample.

Chemicals used in this procedure include the following (again, these substances are hazardous and must be handled with caution; check MSDS):

- indicating boric acid solution
- methyl red-methylene blue mixed indicator
- sulfuric acid standard solution, 0.02 N (1 mL = 280 microgram N)

Equipment used includes the following:

- Erlenmeyer flasks, 500 mL
- burette, 50 mL
- magnetic stirrer and stir bars (optional)

Procedure:

- (1) Distill the sample as described previously using indicating boric acid absorbent solution.

(2) Select an appropriate aliquot of distillate based upon expected ammonia concentration.

Ammonia Nitrogen, mg/L	Distillate, mL
5–10	250
10–20	100
20–50	50
50–100	25

(3) Measure the selected aliquot of distillate into a 500-mL Erlenmeyer flask.

(4) Titrate with 0.02 N standard sulfuric acid titrant until the indicator turns a pale lavender.

(5) Repeat the entire procedure using an ammonia-free distilled water blank.

(6) Ammonia nitrogen calculations are made using the formula below.

$$\text{Ammonia Nitrogen, mg/L} = \frac{(A - B) \times 280}{\text{mL sample}} \quad (15.5)$$

where

A = Titrant for sample

B = Titrant for blank

mL sample = mL sample titrated

✓ *Note:* Interference from volatile alkaline substances may cause variations in results.

15.2.2.4 Specific Ion Electrode Method for Ammonia Nitrogen

In the *specific ion electrode method*, an electrode, a filling solution, and a membrane that separates the filling solution from the liquid being tested is used. The membrane allows ammonia to enter and react with the filling solution. The reaction produces a current that is measured by the electrode.

Chemicals used include the following:

- sodium hydroxide, 10 M
- stock ammonium solution (1 mL = 1 mg N)
- electrode filling solution

Equipment used includes the following:

- ammonia-specific ion electrode
- electrometer: pH meter capable of reading relative millivolt potential or specific ion meter
- magnetic stirrer with TFE stirring bars
- beakers, 150–250 mL (must be thermally insulated from stirrer)

When using a pH meter with a millivolt display, a calibration curve (ammonia electrode standard curve, not shown here) must be prepared using standards containing 0.1, 1, 10, 100, or 1,000 mg/L of ammonia nitrogen. Because the electrode measures relative millivolt production, the normal procedure is to set the millivolt reading for the 10 mg/L concentration to zero and determine the remaining standards' millivolt production relative to this value. The results are then plotted on semi-log graph paper.

The standard reference or calibration curve should be checked daily by means of a standard ammonium solution that has been processed in the same manner as the samples to be tested.

Electrode Procedure:

The procedure is dependent on the meter and electrode system chosen for the determination, and, thus, can't be described in detail in this discussion. However, we provide an overview of a general procedure for the electrode method as follows:

- (1) Test the electrode and membrane daily to confirm proper operation. This should include determination of the slope of the calibration curve (58 ± 1 millivolt at 25°C).
- (2) Maintain samples and standards at the same temperature.
- (3) Adjust pH to 11 or higher just prior to analysis.
- (4) Stir constantly during the analysis.
- (5) Read results directly from the curve.

Interferences:

Several interferences are possible. Results may be greatly affected by temperature variations. For instance, a 1°C temperature change may produce a $\pm 2\%$ error in the measurement. Additionally, volatile amines interfere with operation of the electrode. High concentrations of ionic substances can also interfere, because of their effects on the solubility of ammonia. Ammonia forms complexes with certain metallic ions, causing lower test results. If mercury is suspected, it should be removed by complexing with iodide. Water vapor may also interfere if it passes through the membrane and dilutes the internal filling solution, a problem normally eliminated by adjusting the pH with 10 N sodium hydroxide. Finally, the presence of wetting agents (such as those found in commercial detergents) can result in water passing through the membrane.

Sensitivity:

Sensitivity may also vary. The specific ion electrode method has acceptable accuracy to 1 mg/L ammonia nitrogen. Below 1 mg/L, membrane response is very slow. Determinations below this level require special precautions and procedures. Results can be reproduced to within $\pm 2\%$ if the meter is recalibrated hourly during use. Reproducibility of results is dependent on temperature variations, meter drift, and electronic noise.

15.2.2.5 Total Kjeldahl Nitrogen (TKN)

Organic nitrogen is determined by the *Kjeldahl method*. The aqueous sample is first boiled to drive off the ammonia, and then is digested. During the digestion, the organic nitrogen is converted to ammonia. Total Kjeldahl nitrogen (TKN) is determined in the same manner as organic nitrogen (the method selected should be based upon the anticipated TKN concentration), except that the ammonia is not driven off before the digestion step. Kjeldahl nitrogen is, therefore, the total of the organic and ammonia nitrogen.¹⁰

Either grab or composite samples may be used for TKN (organic nitrogen) determinations. The most accurate results will be obtained on freshly collected samples.

If samples must be stored prior to analyses, the sample may be preserved by addition of 0.8 mg/L of concentrated sulfuric acid (sufficient to reach pH 12), plus refrigeration at or below 4°C .

Chemicals used in TKN analysis include the following (these chemicals should be handled with extreme caution—check MSDS):

¹⁰From Metcalf & Eddy, *Wastewater Engineering: Treatment, Disposal, Reuse*, 3rd ed. New York: McGraw-Hill, p. 85, 1991.

- Kjeldahl digestion reagent consisting of sulfuric acid, concentrated; potassium sulfate; and mercuric oxide, red
- phenolphthalein indicator solution
- sodium hydroxide-sodium thiosulfate reagent
- borate buffer solution
- sodium hydroxide 6 N
- copper sulfate solution (optional)
- reagents for distillation and measurement of ammonia nitrogen

Equipment used includes the following:

- heating unit capable of heating a 250-mL sample from 25°C to boiling within 5 minutes
- fume hood or exhaust fume ejector
- Kjeldahl flasks, 500 to 1,000 mL, with ground glass joint
- Kjeldahl flasks, 100 mL, with ground glass joint
- graduated cylinders, 100 mL
- equipment for distillation and measurement of ammonia nitrogen

Macro Kjeldahl Digestion Procedure:

- (1) Select and measure an appropriate volume of sample and place it in a 500–800 mL Kjeldahl flask.

TKN, mg/L	Sample Volume, milliliters
0–1	500 ¹¹
1–10	250
10–20	100
20–50	50
50–100	25

- (2) Dilute (if necessary) to 300 mL with ammonia-free distilled water.
- (3) *Carefully* add 50 mL of digestion reagent to the sample.
- (4) If large amounts of organic matter are present, add an additional 50 mL of reagent per gram of organic matter (estimated from volatile solids).
- (5) Mix the contents of the flask thoroughly. (*Note:* Incomplete mixing can cause bumping during the digestion and may result in glassware breakage or loss of sample.)
- (6) Add several glass beads or ceramic chips to the flask.
- (7) Place the flask on a digestion apparatus, and heat the solution to boiling. Continue boiling until dense white fumes (SO₂) form.
- (8) When the fumes clear out of the flask, a clear (colorless or pale yellow color) liquid should remain in the flask.
- (9) Continue the digestion for an additional 30 minutes after the fumes have cleared from the flask.
- (10) Cool the flask. Dilute the digestate to 300 mL with ammonia-free distilled water.
- (11) Add 0.5 mL phenolphthalein indicator to the flask.
- (12) Tilt the digestion flask, and *carefully* add a sufficient amount of sodium hydroxide-thiosulfate reagent to form alkaline layer (approximately 50 mL per 50 mL of digestion reagent).
- (13) Connect the Kjeldahl flask to a distillation apparatus, mix thoroughly, and distill approximately 200 mL of distillate into the appropriate absorbing solution.
- (14) Determine the total Kjeldahl nitrogen using the Nesslerization, acidimetric, or electrode methods for ammonia determination.

¹¹Must use an 80-mL Kjeldahl Flask.

✓ *Note:* When the spectrophotometric method is used, the blank and all standards must be treated by the digestion procedure.

Semi-Micro Procedure:

Select and measure an appropriate volume of sample, and place it in a 100-mL Kjeldahl flask.

TKN, mg/L	Sample Volume, milliliters
4–40	50
8–80	25
20–200	10
40–400	5

- (1) Dilute (if necessary) to 50 mL with ammonia-free distilled water.
- (2) *Carefully* add 10 mL of digestion reagent to the sample.
- (3) Mix the contents of the flask thoroughly. (*Note:* Incomplete mixing can cause bumping during digestion and may result in glassware breakage or loss of sample.)
- (4) Add several glass beads or ceramic chips to the flask.
- (5) Place the flask on a digestion apparatus, and heat the solution to boiling.
- (6) Continue boiling until dense white fumes form.
- (7) When the fumes clear out of the flask, a clear (colorless or pale yellow) liquid should remain in the flask.
- (8) Continue the digestion for an additional 30 minutes after the fumes have cleared from the flask.
- (9) Cool the flask. Dilute to no more than 30 mL with ammonia-free water.
- (10) Add one or two drops of phenolphthalein indicator to the flask.
- (11) Tilt the digestion flask, and *carefully* add a sufficient amount of sodium hydroxide-thiosulfate reagent to form alkaline layer (approximately 10 mL per 10 mL of digestion reagent).
- (12) Mix the flask contents thoroughly.
- (13) Connect the flask to a steam distillation apparatus, and distill 30–40 mL of distillate into the appropriate absorbing solution.
- (14) Determine the total Kjeldahl nitrogen using the Nesslerization, acidimetric, or electrode methods for ammonia determination.

✓ *Note:* When the spectrophotometric method is used, the blank and all standards must be treated by the digestion procedure.

Interferences:

In performing the TKN procedure (macro or semi-micro), certain forms of organic nitrogen-interferences (i.e., azides, azines, azos, hydrazones, nitros, nitriles, semi-carbozones, and oximes) are not recovered. Because the TKN determination is based upon the analysis of ammonia measurement, the analyst must also consider the interferences noted for the ammonia nitrogen methods previously discussed in Section 15.2.2. Ammonia sensitivity is also directly related to limits noted for the ammonia nitrogen tests specified in Section 15.2.2.

15.2.2.6 Organic Nitrogen

Organic nitrogen is the difference between the total Kjeldahl nitrogen (TKN) and the ammonia nitrogen concentration of the sample.

$$\text{Organic Nitrogen} = \text{TKN} - \text{Ammonia Nitrogen} \quad (15.6)$$

The organic nitrogen concentration can also be determined by performing the digestion procedure on the contents remaining in the distillation flask after the preliminary distillation step for removal of ammonia is completed.

15.2.2.7 Nitrite Nitrogen

The determination of *nitrite nitrogen* is a colorimetric test procedure. The approved procedure is diazotization with manual or automatic colorimetric measurement. An approved national alternate single-step adaptation of this method has been developed by the Hach Company.

Samples should be tested immediately after collection. If significant turbidity or suspended solids are present in the samples, filter through a 9.45- μm pore size membrane filter.

For composite samples or short-term storage of grab samples, refrigeration at 4°C is advised. The maximum holding time for nitrite nitrogen samples is 48 hours.

Chemicals used in nitrite nitrogen determination include the following (these chemicals should be handled with caution; check MSDS):

- Nitrite-free water—this must be used in mixing all other test reagents.
- Stock nitrite solution, 1 mL $\approx$ 0.250 mg N.

✓ *Note:* This reagent should be standardized regularly against standard potassium permanganate and either standard sodium oxalate or standard ferrous ammonium sulfate.

- Intermediate nitrite sol., 1 mL = 0.050 mg N (prepare daily).
- Standard nitrate sol., 1 mL = 0.0005 mg N (prepare daily).
- Hydrochloric acid, 1 + 3.
- Sulfanilamide reagent.
- N-(1-naphthyl)-ethylenediamine dihydrochloride solution.
- Hach NitriVer-3 powder pillows, for 10-mL sample (alt. method).
- Hach NitriVer-3 powder pillows, for 25-mL sample (alt. method).

Equipment used in the nitrite nitrogen determination includes colorimetric equipment, consisting of the following:

- spectrophotometer—light path 1 cm or longer, at 543 nm
—or—
- filter photometer—light path 1 cm or longer, equipped with green filter having maximum transmittance near 540 nm
- colorimeter—direct reading, light path 1 cm or longer operating at or near 543 nm
- pipettes, measuring 5 mL
- safety pipettes, 1 mL
- beakers, 100 mL
- cuvettes, colorimetric, optically matched
- sample containers for direct reading colorimeters, 10 and 25 mL

15.2.2.7.1 Standard Diazotization Procedure for Nitrite Nitrogen

The first step in performing the standard diazotization procedure for nitrite nitrogen is to prepare a standard calibration. The standard curve preparation procedure includes the following steps:

- (1) Prepare nitrite standards by placing 0, 0.1, 0.2, 0.4, 0.7, 1.0, 1.4, 1.7, 2.0, and 2.5 mL of standard nitrite solution in 50-mL volumetric flasks.
- (2) Dilute each to 50 mL using nitrite-free distilled water. The prepared standards will correspond to 0, 0.001 mg/L, 0.002 mg/L, 0.004 mg/L, 0.007 mg/L, 0.010 mg/L, 0.014 mg/L, 0.017 mg/L, 0.020 mg, and 0.025 mg/L of nitrite nitrogen ($\text{NO}_2^- \text{N}$).
- (3) Prepare the standard curve by processing prepared standards in accordance with test procedure. All standards and blanks must be subjected to all procedural steps used for analysis of samples.

Test Procedure:

- (1) If the expected nitrite nitrogen level is greater than the range of the calibration curve, dilute the sample with nitrite-free water.
- (2) Measure 50 mL of clear sample or diluted sample into a 100-mL beaker.
- (3) If the sample pH is >7.0 , neutralize the sample to 7.0 with 1 + 3 HCl.
- (4) Add 1 mL of the sulfanilamide reagent, and mix thoroughly.
- (5) Allow the reagent, and sample to stand for 2 to 8 minutes, then add 1 mL of N-(1-naphthyl)-ethylenediamine dihydrochloride solution to the sample, and mix immediately.
- (6) Develop for at least 10 minutes, but no longer than 2 hours.
- (7) Measure and record the absorbance at 543 nm.
- (8) Read the mg/L of nitrite nitrogen from the standard curve.

15.2.2.7.2 Nationally Approved Alternate Procedure

The nationally approved alternate test procedure for nitrite nitrogen is accepted for use at any wastewater treatment facility in the U.S. The method and chemicals were developed for use with several direct reading colorimeters available from the Hach Company. The method is applicable to nitrite nitrogen concentrations from 0.001 mg/L to 0.180 mg/L. The reagents are available in powder pillows for use with 10- and 25-mL sample sizes. The powder pillows can also be used with other colorimeters and spectrophotometers. In these cases, a standard curve must be developed and used to determine nitrite nitrogen concentration. When the Hach equipment is used (i.e., Hach DR100 described in the procedure shown here), the nitrite nitrogen concentration can be read directly from the instrument.

✓ *Note:* When using a direct reading colorimeter and the nationally approved alternate method, follow the instructions provided with the instrument.

Procedure (Using Hach DR-100):

- (1) If the expected nitrite nitrogen level is greater than the range of the direct reading colorimeter, dilute the sample with nitrite-free water.
- (2) Measure 10 mL of clear sample or diluted sample into the 2.5-cm sample cell.
- (3) Add the contents of one NitriVer 3 Nitrite Reagent Powder Pillow to one sample cell.
- (4) Cap the sample cell, and shake the sample for one minute.
- (5) Allow the color to develop for at least 10 minutes, but no more than 15 minutes.
- (6) Following the manufacturer's instruction for colorimeter use, determine the nitrite concentration (direct reading colorimeter), or measure the sample absorbance and determine nitrite concentration from standard curve.

For undiluted samples, results of the test are read directly from the standard curve or colorimeter. For diluted samples, the following equation is used:

$$\text{NO}_2 - \text{N, mg/L} = C \times \frac{V}{S} \quad (15.7)$$

where

C = Concentration from curve or instrument readout

V = Total volume of dilution in milliliters

S = Volume of sample in the dilution in milliliters

Interference can be expected if free chlorine and trichloramines are present in sample; they produce a false red or orange color. Because of chemical incompatibility, however, it is unlikely that nitrite, free chlorine, and trichloramines will exist simultaneously in a sample.

Interferences:

Interference is more likely to be the result of antimony, gold, bismuth, iron, lead, mercury, silver, chloroplatinate, and metavanadate precipitate under test conditions. Also, cupric iron can cause low results. Colored ions that change the color of the sample can also cause interference.

15.2.2.8 Nitrate Nitrogen Testing

The determination of *nitrate nitrogen* is one of the more difficult analyses plant personnel may be required to perform. The procedures are complex, and a high probability that interferences will be present exists. The nitrate concentration ranges covered by the approved methods are very limited. The approved methods for determination of nitrate nitrogen in wastewater samples are

- Brucine Sulfate Method
- Cadmium Reduction Method

The choice of the method used for nitrate nitrogen determination depends largely on the capabilities of the laboratory and the operator, the concentration of the samples, and the expected interferences in the sample.

To ensure accuracy, analysis of nitrate nitrogen samples should be performed immediately after the sample is collected.

If the sample must be preserved, it should be stored at or below 4°C. If the cadmium reduction method is used, the sample must be preserved by acidification at a pH <2 using concentrated sulfuric acid. The acidified sample must then be refrigerated at or below 4°C. The maximum holding time for refrigerated samples is 48 hours. The maximum holding time for refrigerated acidified samples is 28 days.

Because of the limited range of concentrations covered by the two approved methods, an initial screening using a non-approved method (such as the nitrate electrode) may be helpful. If such a procedure is used, be sure to consult the electrode manufacturer's instruction manual for appropriate guidance and procedures.

15.2.2.8.1 Brucine Sulfate Method for Nitrate Nitrogen

When nitrate nitrogen reacts with brucine, it produces a yellow color directly related to the concentration of the nitrate. The reaction to produce the colored substance is heat and development-time sensitive. To minimize impact, the reagent addition sequence and the precise times for

incubation at the required temperatures are specified. The incubation times and acid concentrations have been selected to produce maximum color intensity and stability.

Chemicals used for the Brucine Sulfate Method include the following (these chemicals should be handled with extreme caution—check applicable MSDS):

- stock nitrate solution, 1 mL = 0.1 mg N
- standard nitrate solution, 1 mL = 0.001 mg N
- sodium arsenite solution
- brucine sulfanilic acid solution
- sulfuric acid solution
- sodium chlorine solution

Test equipment includes the following:

- spectrophotometer minimum light path of 1 inch, 410 nm
- safety pipet
- wire test tube racks
- stirred boiling water bath
- reaction tubes—2.5 cm diameter by 15 cm length, borosilicate glass

✓ *Note:* Optically matched 2.5-cm cuvettes of the appropriate length are recommended, because they minimize the safety hazards associated with transfer of hot reactive liquids and eliminate the need to determine individual tube reagent blanks.

In formulating the calibration curve, a series of nitrate standards covering the recommended range of nitrate nitrogen concentration for the test (0.1 to 1.0 mg/L) must be prepared.

✓ *Note:* If matched tubes are not used, a “reagent blank” must be determined for each tube. The “reagent blank” absorbance must be subtracted from the actual absorbance to determine the “final” absorbance for each standard.

Test Procedure:

- (1) If the sample contains residual chlorine, add one drop (0.05 mL) sodium arsenite solution for every 0.1 mg/L of chlorine. Add one extra drop to a 50-mL sample.
- (2) Place reaction tubes in a wire rack. Each tube must be surrounded by empty spaces. Each test must include a reagent blank and two standards for comparison with standard curve.
- (3) Add 10 mL of sample or an aliquot diluted to 10 mL to each sample tube.
- (4) Add 10 mL of distilled water to a reaction tube (reagent blank).
- (5) Add 10 mL of standard solution (different concentrations) to two reaction tubes.
- (6) Place the rack and reaction tubes in a cool water bath.
- (7) Add 2 mL sodium chloride solution to each tube, and mix by swirling.
- (8) Add 10 mL sulfuric acid solution to each tube, and mix by swirling.
- (9) Allow the reaction tubes to cool to room temperature.
- (10) If any turbidity is present, or if unmatched cuvettes are being used, determine the “sample blank” absorbance of each tube at 410 nm.
- (11) Place tubes back in the cool water bath, and add 0.5 mL brucine sulfate-sulfanilic acid reagent. Mix by swirling.
- (12) Place rack in a well-stirred boiling water bath, and incubate at 95°C or higher for *exactly* 20 minutes.

- (13) Remove the reaction tubes from boiling water bath, and place in the cool water bath.
- (14) Cool the tubes to room temperature.
- (15) Remove tubes from cool water bath, dry each tube, and determine absorbance at 410 nm.

✓ *Note:* If unmatched tubes are used, the “reagent blanks” for each tube should be determined. Subtract the absorbance of the “reagent blank” from the actual absorbance to determine the “final” absorbance for the blank, samples, and standards.

In determining mg/L nitrate nitrogen, Equation (15.8) may be used.

$$\text{mg/L Nitrate Nitrogen} = \frac{\text{Microgram NO}_3 - \text{N (Graph)}}{\text{mL sample in reaction tube}} \quad (15.8)$$

Interferences:

All strong oxidizing and reducing agents cause interference in this analysis method. Iron and manganese concentrations greater than 1 mg/L cause a positive interference. Nitrite concentrations greater than 0.5 will also interfere.

✓ *Note:* This method should be used for nitrate nitrogen concentrations of 0.1–1.0 mg/L. Concentrations greater than 2.0 mg/L give highly variable results, and method sensitivity is very poor at concentrations less than 0.1 mg/L. Samples in excess of 2.0 mg/L nitrate nitrogen may be diluted prior to analysis by this method.

15.2.2.8.2 Cadmium Reduction Method

In the *Cadmium Reduction Method*, nitrate ions are reduced to nitrite when passed through a column containing cadmium granules coated with copper. The total nitrite concentration (sample nitrite + nitrite from nitrate conversion) is then determined using the procedure described previously for nitrite analysis. This result is referred to as the nitrate-nitrite nitrogen concentration and is determined by subtracting the nitrite concentration of the unreduced sample from the nitrate-nitrite concentration.

Chemicals used for the Cadmium Reduction Method include the following (many of these chemicals should be handled with extreme caution—check MSDS):

- nitrate-free distilled water
- ammonium chloride-EDTA solution
- dilute ammonium chloride-EDTA solution
- copper-coated cadmium granules
- hydrochloric acid, 6 N
- sodium hydroxide, 1 N
- sulfanilamide reagent
- N-(1-naphthyl) ethylenediamine dihydrochloride solution
- stock nitrate solution, 1 mL = 0.1 mg
- standard nitrate solution, 1 mL–0.1 micrograms

Equipment used includes the following:

- Reduction column—The reduction column can be purchased or constructed. Instructions for constructing a column using a 100-mL volumetric pipette can be found in *Standard Methods*.
- Spectrophotometer—Light path of at least 1 cm operating at 543 nm.

Reduction Column Preparation/Activation:

- (1) Pack glass wool in the bottom of the reduction column.
- (2) Fill column with distilled water.
- (3) Pour in enough copper-coated cadmium filings to produce a column 18.5 cm in length.
- (4) Maintain the water level above the copper-cadmium granules to prevent air bubbles from being trapped in the column.
- (5) Wash the column with 200 mL of diluted ammonium chloride-EDTA solution.
- (6) After preparation and when the column will not be used for several hours (3 hours or more), cover the copper-cadmium granules in the column with diluted ammonium chloride-EDTA solution.

✓ *Note:* Do not let the copper-cadmium granules dry out.

- (7) Activate the column before using by washing with 100 mL of a mixture containing 25 mL of a 1.0 mg/L nitrate N standard and 75 mL of dilute ammonium chloride-EDTA solution. The flow rate of the activating mixture through the column should be at 7 to 10 mL/minute.

✓ *Note:* If the column becomes inactive (reduced color development for reference standards), the cadmium must be removed from the column and reactivated.

Sample Pretreatment:

- (1) For samples containing excessive turbidity or suspended solids, filter the samples through a 0.45- μ m pore size membrane filter or a glass fiber filter.
- (2) For samples containing residual chlorine, remove by adding sodium thiosulfate solution.
- (3) For samples with a pH outside of the range of 8.0 to 9.0, adjust the pH to the desired range using 6 N HCl or 1 N NaOH.
- (4) For samples containing significant amounts of oil and grease, remove oil and grease with an organic solvent (i.e., Freon or hexane).

Procedure:

✓ *Note:* The cadmium reduction method is applicable for samples or sample dilutions with nitrate nitrogen levels between 0.01 and 1.0 mg/L. However, the method is best applied to nitrate nitrogen concentrations of <0.1 mg/L.

- (1) Prepare a standard curve (concentration versus absorbance) by diluting appropriate standard solution volumes to 25 mL with nitrate-free water treating each standard to all remaining procedural steps.
- (2) Place 25 mL of sample in a 125-mL Erlenmeyer flask.
- (3) Add 75 mL of dilute ammonium chloride-EDTA solution, and mix by swirling.
- (4) Pour the mixed sample into a cadmium reduction column.
- (5) Allow the sample mixture to pass through the column at a flow rate of 7 to 10 mL/min.
- (6) Place a 100-mL graduated cylinder under the column to collect the effluent.
- (7) Discard any sample liquid remaining in the 125-mL flask, and shake dry.
- (8) After collecting 25 mL of the column effluent in the graduated cylinder, replace the cylinder with the 125-mL Erlenmeyer.
- (9) Collect the remaining volume.

- (10) Discard the 25 mL of column effluent collected in the graduated cylinder, rinse the cylinder with nitrite-free distilled water, and shake dry.
 - (11) When the flow from the column has ceased, measure exactly 50 mL of sample into the clean graduated cylinder.
 - (12) Discard any sample remaining in the 125-mL Erlenmeyer flask, and shake dry.
 - (13) Pour the 50 mL of sample back into the 125-mL Erlenmeyer flask.
 - (14) This process can be repeated using additional samples or standards without washing the column.
 - (15) Repeat the process using a nitrate-free distilled water blank. At least one nitrate reference standard should be passed through the reduction column with each series of samples.
 - (16) Determine the nitrite nitrogen concentration in the reduced sample:
 - Begin determination within 15 minutes after reduction has been completed.
 - Add 2.0 mL of sulfanilamide to the 50 mL of reduced sample, reagent blank, and standards, and swirl to mix.
 - Allow reaction to continue for 2–8 minutes.
 - Add 2.0 mL N-(1-naphthyl)-ethylenediamine solution, and mix immediately.
 - Allow color to develop for at least 10 minutes.
 - Read absorbance at 543 nm within 2 hours.
- ✓ *Note:* If the nitrate-nitrite nitrogen concentration is higher than 1 mg/L N, use the remaining reduced portion of the sample to prepare a dilution and retest.
- Repeat procedure using an unreduced 50-mL portion of sample to determine the nitrite-nitrogen concentration of the sample.

✓ *Note:* The national alternate test method for nitrite nitrogen can also be used.

Computation of nitrate-nitrite nitrogen concentrations (with dilution factors applied as needed) is made directly from the standard curve. If the nitrite nitrogen in the sample is determined separately, the nitrate nitrogen concentration can be determined by subtraction.

$$\text{Nitrate Nitrogen, mg/L} = \text{Nitrate - Nitrite Nitrogen, mg/L} - \text{Nitrite Nitrogen, mg/L} \quad (15.9)$$

Interferences:

Suspended matter in samples can restrict flow through the reduction column. Iron, copper, and other metals may interfere with the test (addition of EDTA normally eliminates these interferences). The presence of residual chlorine may oxidize the column (dechlorination eliminates this problem). Significant amounts of oil and grease in samples can coat the surface of the copper-cadmium granules and reduce the efficiency of the column.

15.2.3 ALKALINITY

Simply put, *alkalinity* is the acid-neutralizing capability of the wastewater. The alkalinity concentration of the wastewater is a critical factor in certain treatment processes.

The approved method for determination of alkalinity in wastewater is a titrimetric method using a pH meter or a color endpoint indicator.

Samples may be either grab or composite (though most representative information is obtained through the use of grab samples). Samples should be preserved by refrigeration at or below 4°C; they can be held up to 14 days.

Chemicals used in alkalinity analysis include the following (handle these chemicals with care and caution—check the MSDS):

- sodium carbonate solution 0.05 N
- standard sulfuric or hydrochloric acid 0.1 N
- standard sulfuric or hydrochloric acid 0.02 N
- bromocresol green indicator
- mixed bromocresol green-methyl red indicator
- metacresol purple indicator
- phenolphthalein indicator
- sodium thiosulfate

Equipment used:

- titration vessel
- burette, 50 mL, 25 mL, 10 mL
- flasks, volumetric, 1,000 mL, 200 mL, 100 mL
- magnetic stirrer
- pH meter and electrodes

15.2.3.1 Sample Size Selection Criteria

The sample size selected for the alkalinity determination should meet the following criteria:

- (1) The sample volume is sufficient to ensure the volume of titrant required will allow good volumetric precision.
- (2) The sample volume is small enough to produce sharp, clearly defined endpoints.
- (3) For samples with anticipated calcium carbonate alkalinity $<1,000$ mg/L, a sample volume that will contain <50 mg equivalent calcium carbonate alkalinity should be selected. A 0.02 N standard acid titrant should then be used.
- (4) For samples with anticipated calcium carbonate alkalinity $>1,000$, a sample volume that will contain <250 mg equivalent calcium carbonate alkalinity should be selected. A 0.1 N standard acid titrant should then be used.

15.2.3.2 Test Procedure—pH Meter Endpoint

- (1) Standardize the pH meter using pH buffers that will bracket the test endpoint ($\text{pH} = 4.5$).
- (2) Select the appropriate sample size and titrant normally.
- (3) Add magnetic stir bar, and begin gentle stirring.
- (4) Record the start volume from the burette.
- (5) Add titrant slowly until the pH is approximately 5.0.
- (6) Continue adding titrant slowly, allowing the pH to return to equilibrium after each addition until pH is 4.5.
- (7) Record the final burette volume.

15.2.3.3 Low Level Test Procedure—pH Meter Endpoint

- (1) Standardize the pH meter using pH buffers that will bracket the test endpoint ($\text{pH} = 4.5$).
- (2) Select the appropriate sample size (100–200 mL) and titrant normally (0.02 N).
- (3) Add magnetic stir bar and begin gentle stirring.

- (4) Use a 10-mL microburette.
- (5) Record the titrant start volume.
- (6) Add titrant slowly until the sample pH levels are 4.3–4.7.
- (7) Record burette volume.
- (8) Slowly add titrant until the sample pH changes by exactly 0.3 pH units.
- (9) Record the burette volume.

15.2.3.4 Test Procedure—Color Endpoint

- (1) Select the appropriate sample size and titrant normality.
- (2) Add magnetic stir bar, and begin gentle stirring.
- (3) Record the start volume from the burette.
- (4) Add five drops (0.2 mL) of mixed bromocresol green-methyl red indicator.
- (5) Add titrant slowly until a slight color change (green to gray) is noted.
- (6) Continue adding titrant slowly, allowing the reactions to return to equilibrium between additions, until the solution changes from green to light pink.
- (7) Record the final burette volume.

15.2.3.5 Alkalinity Calculation

Alkalinity can be calculated using the following formula:

$$\text{Alkalinity, mg Calcium Carbonate / Liter} = \frac{A \times N \times 50,000}{\text{mL sample}} \quad (15.10)$$

where

A = mL of standard acid used

N = normality of standard acid

Alkalinity—low level (<20 mg/L) can be calculated using the following formula:

$$\text{Alkalinity, mg Calcium Carbonate / Liter} = \frac{(2B - C) \times N \times 50,000}{\text{mL sample}} \quad (15.11)$$

where

B = mL of standard acid used to reach pH 4.4–4.5

C = total mL of standard acid used in the titration

N = normality of standard acid

In test reports, the results of the alkalinity analysis should be reported as follows: “The alkalinity to pH _____ equals _____ milligrams calcium carbonate/liter.”

Interferences:

Soaps, oily matter, suspended solids, or precipitates may interfere with the pH electrode response. Allow sufficient time for electrodes to come to equilibrium after each addition of acid.

Sensitivity:

The standard procedure for alkalinity determination is acceptable for concentrations of >20 mg/L calcium carbonate equivalence. For levels of <20 mg/L, the low level alkalinity procedure must be used.

15.2.4 HARDNESS

Hardness is a measure of the amount of calcium and magnesium metallic cations present in the wastewater. The amount of hardness present will have an impact on the exhibited toxicity of certain wastewater components. Many of the more recent NPDES permits require plant discharge hardness to be monitored and reported.

The approved method of determination of hardness uses a colorimetric titration. When certain dyes are added to alkaline ($\text{pH } 10.0 \pm 0.1$) samples containing calcium and magnesium, a wine red color occurs. Ethylenediaminetetraacetic acid (EDTA) and its sodium salt reacts with calcium and magnesium to form a soluble material known as a chelate. When EDTA is added, it removes the calcium and magnesium, and the color of the dye changes to blue.

Samples may be either grab or composite. Samples should be preserved by adjusting the sample $\text{pH} \leq 2.0$ with concentrated nitric or sulfuric acid. Preserved samples may be held up to 6 months.

15.2.4.1 Sample Pretreatment

Wastewater samples must be digested using either nitric acid-hydrochloric acid digestion or nitric acid-perchloric acid digestion prior to hardness determination.

15.2.4.1.1 Nitric Acid-Hydrochloric Acid Digestion

Equipment used in nitric acid-hydrochloric acid digestion includes the following:

- hot plate
- Erlenmeyer flask, 125 mL (acid washed)
- Griffin beakers, 150 mL (acid washed)

Chemicals used include the following (care and caution required when handling these chemicals—refer to applicable MSDS):

- nitric acid, concentrated
- hydrochloric acid, 1 + 1

Procedure:

- (1) Mix and pipette an appropriate volume of well-mixed, acid-preserved sample to a flask or beaker.
- (2) If not already acidified, acidify to methyl orange endpoint with concentrated sulfuric acid.
- (3) Add 5 mL of concentrated nitric acid and a few boiling chips.
- (4) Place on the hot plate, and bring to a slow boil.
- (5) Evaporate to a volume of 15–20 mL.
- (6) Add 5 mL concentrated nitric acid and 10 mL of concentrated sulfuric acid.
- (7) Evaporate on a hot plate until dense white fumes of sulfur trioxide appear.

✓ *Note:* Do not allow the sample to evaporate to dryness during the digestion process.

- (8) If solution does not clear, add 10 mL of concentrated nitric acid, and repeat evaporation to sulfur trioxide fumes.
- (9) Heat to remove all nitric acid before continuing (all nitric acid is removed when solution is clear and no brownish fumes are noted).
- (10) Cool and dilute to approximately 50 mL with distilled water.
- (11) Heat to almost boiling to dissolve soluble salts.
- (12) Filter (if required), then proceed to hardness procedure.

15.2.4.1.2 Nitric Acid-Perchloric Acid Digestion

✓ *Note:* Because of the potential for explosion and other potential safety hazards, use of this method is not recommended. If test results indicate the nitric acid-sulfuric acid digestion is insufficient, consult the appropriate edition of the references cited in the federal regulations for information on this procedure.

15.2.4.2 Sample Testing

Chemicals used in sample hardness testing include the following (care and caution are required when handling these chemicals—refer to the applicable MSDS):

- buffer solution
- inhibitor solution I
- inhibitor solution II
- magnesium 1.2-cyclohexanediaminetetraacetate
- eriochrome black T indicator
- calmagite indicator
- standard EDTA titrant 0.01 N
- standard calcium solution (1 mL = 1 mg calcium carbonate)
- sodium hydroxide 0.1 N

Equipment used includes the following:

- graduated cylinder, 50 mL, 100 mL
- burette, 50 mL, 25 mL, 10 mL
- porcelain casserole or similar titration vessel
- magnetic stirrer

The sample size selected for the hardness determination should permit the volume of titrant used to be <15 mL and should permit completion of the titration in <5 minutes from the addition of the buffer.

15.2.4.2.1 EDTA Standardization

To ensure accurate hardness determination, the EDTA must be standardized against a known concentration of calcium carbonate on a routine basis.

- (1) Using a volumetric pipette, measure 25 mL of standard calcium carbonate solution (1.0 mL = 1.00 mg calcium carbonate) into a porcelain casserole or similar titration vessel.
- (2) Dilute to approximately 50 mL and add 1–2 mL of buffer solution.
- (3) Add one or two drops or appropriate amount of powdered indicator, and titrate with standard EDTA until the last reddish tinge disappears.

(4) Calculate the EDTA calcium carbonate equivalence (B):

$$B = \frac{\text{mL Calcium Carbonate solution titrated}}{\text{mL EDTA titrant used}} \quad (15.12)$$

15.2.4.2.2 Test Procedure

- (1) Measure 25.0 mL (or appropriate volume) of sample.
- (2) Dilute to 50 mL with distilled water.
- (3) Place in a porcelain casserole or similar titration vessel.
- (4) Add 1–2 mL of buffer solution.
- (5) Add inhibitor solution (if required).
- (6) Add one or two drops of indicator solution or an appropriate amount of powder indicator.
- (7) Record burette start volume.
- (8) Add standard EDTA solution until the last reddish tinge disappears.

✓ *Note:* The lack of a clear endpoint color change may indicate the need to add inhibitor solution or to prepare fresh indicator. The endpoint determination should be made using daylight or daylight fluorescent lighting. Incandescent bulbs may cause a reddish tinge in the sample.

- (9) Record the burette final volume.

15.2.4.2.3 Low Level Test Procedure

- (1) Use significantly larger sample volume (100–1,000 mL).
- (2) Add proportionately larger volumes of buffer and indicator.
- (3) Proceed with titration as described previously with the following modifications:
 - Use a 10-mL microburette.
 - Add titrant slowly.
 - Run a blank titration using distilled, redistilled, or deionized water.
 - Subtract blank titrant volume from titrant sample.

15.2.4.2.4 Calculation

Hardness (EDTA) as mg/L calcium carbonate can be calculated using the following formula:

$$\text{Hardness (EDTA), mg/L calcium carbonate} = \frac{A \times B \times 1,000}{\text{mL sample}} \quad (15.13)$$

where

A = mL EDTA used in titration

B = mg calcium carbonate equivalent to 1.00 mL EDTA titrant

Interferences:

Some metal ions may cause indistinct or fading endpoints or interfere with the hardness determination. Addition of specified inhibitor solutions (I or II) will correct the problem up to specified contaminant concentration levels. Suspended or colloidal matter may also interfere with the endpoint.

Several metals (barium, cadmium, lead, manganese, strontium, and zinc) may titrate as hardness. Use of inhibitor II will reduce or eliminate this.

If interferences cannot be eliminated, the calcium and magnesium content of the sample should be determined separately, and the hardness should be determined by calculation.

Sensitivity:

The standard procedure for hardness is acceptable for concentrations >5 mg/L calcium carbonate equivalence. For levels <5 mg/L, the low level alkalinity procedure should be used.

15.3 SUMMARY

Careful and accurate sampling, testing, and analysis of the test results are essential for proper, effective wastewater treatment. As you advance in operator training, the tasks you are required to perform become more complex, and they demand more time, skill, and attention on your part. The licensing examinations, of course, are in place to test your abilities—your skill and knowledge, especially. We provide a sample examination for your own testing purposes in Chapter 16.

15.4 CHAPTER REVIEW QUESTIONS

- 15-1 What pretreatment must be performed prior to testing a sample for total phosphorus?
- 15-2 The mass of phosphorus read from the standard curve for a 40-mL sample dilution is 0.21 mg. What is the concentration of phosphorus in the sample?
- 15-3 What preservation procedures are acceptable for samples collected to be measured for ammonia nitrogen?
- 15-4 The difference between the total Kjeldahl nitrogen (TKN) and the ammonia nitrogen concentration of a sample is _____.
- 15-5 What form of nitrogen is actually measured when determining the nitrate nitrogen concentration by the cadmium reduction method?
- 15-6 Using the data provided, what is the ammonia nitrogen concentration in milligrams per liter?
- | | |
|-----------------------|---------|
| Sample volume | 200 mL |
| Sample titrant volume | 27.8 mL |
| Blank titrant volume | 0.2 mL |

15-7 Using the bench data for the Nesslerization determination of ammonia nitrogen, what is the ammonia nitrogen concentration in milligrams per liter?

Ammonia nitrogen mass (from graph)	170 micrograms
Distillate collected	200 mL
Distillate used for test	25 mL
Original sample volume	50 mL

15-8 Define hardness.

15-9 A 30-mL sample requires 18 mL of 0.02 N sulfuric acid to reach a pH of 4.5. What is the sample calcium carbonate alkalinity in milligrams per liter?

15-10 A 200-mL sample of treated effluent requires 3.4 mL of 0.02 N sulfuric acid to reach a pH of 4.3. An additional 0.4 mL of 0.02 N acid is required to reduce the sample pH to 4.0. What is the sample calcium carbonate alkalinity in milligrams per liter?

Final Review Exam

16.1 INTRODUCTION

NOW that you have read each chapter and have completed the chapter review questions, test your overall knowledge of the material contained in Volume 3 by completing the final review examination. For the questions you have difficulty answering or that you answer incorrectly (we provide answers and solutions in Appendix B), review the sections containing the pertinent subject matter. Successful review and completion and study of all the material presented in Volumes 1, 2, and 3 of the handbook series should prepare you for the certification or licensure examination at the highest level.

Unlike the actual state certification/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 this chapter requires, in most cases, a written response to each question. In our experience, students studying for exams do best when they write out the “correct” answer only (for retention purposes). When studying for exams, viewing only the correct answer instead of several different choices (e.g., multiple choice questions, where wrong answers might be confused and retained as the correct answer) is best. We find that enough doubt on possible other answers remains to cause the test-taker to sometimes select the wrong answer on the licensure exam. We are interested, obviously, in only retaining correct answers.

Good luck!

16.2 FINAL REVIEW EXAM

- 16-1 A pump will pump a 10-ft $\times$ 10-ft $\times$ 8-ft well dry in 7 minutes. What is the pump output in gal/min?
- 16-2 After every storm, the plant influent rate doubles for several hours. The influent total suspended solids concentration also increases significantly, and the volatile suspended solids concentration decreases. The most likely cause for these conditions is _____.
- 16-3 After the distributor passes, small pools or puddles of wastewater can be seen in several places on the surface of the media in the trickling filter. The most likely cause for this condition is _____.

- 16-4 Based upon the data provided, what adjustment to the primary settling tank sludge withdrawal program is required?
- | | |
|-----------------------------|--|
| Sludge pump cycle | 20 minutes/hours |
| Pump rate | 50 gpm |
| Sludge Solids Concentration | |
| • 2 minutes— | 10.9% |
| • 10 minutes— | 7.1% |
| • 20 minutes— | 3.8% |
| Blanket Depth | 1.50 feet and steady for the past week |
- 16-5 Failure to remove large solids in preliminary treatment can cause operational problems that include _____.
- 16-6 The surface of the media in an RBC is covered with a dull, white, chalky growth. Based on this information, the RBC has recently received flows with high concentrations of _____.
- 16-7 The drive motor of your comminutor is operating, but the comminutor blades are not. The most likely cause of this problem is _____.
- 16-8 The grit removed from the plant's aerated channels has a gray color and develops a foul odor on standing. How would you correct this problem?
- 16-9 The main pump in the collection system pump station is not operating. The circuit breaker for the pump will not reset. What is the likely cause of this situation?
- 16-10 The grit in the primary sludge is causing excessive wear on primary treatment sludge pumps. The plant uses an aerated grit channel. What action should be taken to correct this problem?
- 16-11 A dye is added to the primary settling tank influent. In 15 minutes, the dye appears in the tank effluent. After 35 minutes, most of the dye has passed through the tanks. In 45 minutes, the dye is completely gone. Based upon this information and the data provided below, this indicates that _____.
- Data:
- | | |
|---------------------------------|-----------|
| Influent flow rate | 2.60 MGD |
| Unit diameter | 50 feet |
| Operating depth | 16 feet |
| Design hydraulic detention time | 2.0 hours |

- 16-12 If the aeration tank influent BOD₅ increases while the mixed liquor suspended solids, mixed liquor volatile solids, and the return and waste rates remain constant, the impact on F:M ratio is _____.
- 16-13 When the mean cell residence time (MCRT) increases, the mixed liquor suspended solids (MLSS) concentration in the aeration tank _____.
- 16-14 The predominant organism in a conventional activated sludge system is the stalked ciliate. There is a small amount of crisp, white foam on the surface aeration tank. The MCRT is 9.5 days. What action is needed (if any)?
- 16-15 The hydraulic and organic loading to the aeration tank remains constant. When the waste rate is increased, the mean cell residence time (MCRT) will _____.
- 16-16 There are large clumps of solids on the surface of the final settling tank of the activated sludge process. The SSV₃₀ is 470 mL/L, and the aeration MLSS is 3,340 mg/L. The liquid above the solids in the settleometer is clear. The return activated sludge has a strong rotten egg odor. What action should you take?
- 16-17 What is the purpose of the secondary clarifier in an activated sludge process?
- 16-18 What does BOD measure?
- 16-19 A black aeration tank color indicates what?
- 16-20 A dark, greasy aeration tank foam indicates what?
- 16-21 White foam on the aeration tank indicates what?
- 16-22 What might indicate the waste rate is too low?

- 16-23 Typical dissolved oxygen values for activated sludge are _____.
- 16-24 What changes to the MLVSS concentration would the operator make when the temperature decreases from 25°C to 15°C?
- 16-25 To increase the MLVSS, we must decrease the _____.
- 16-26 To increase the F/M, we must _____ the MCRT.
- 16-27 To increase the MCRT, we _____ the waste rate.
- 16-28 To increase the MLTSS, we _____ the MCRT.
- 16-29 If the MCRT is increased in a well-operated activated sludge facility, what would be expected to happen to the 30-minute setting?
- 16-30 To increase the F/M, we must _____ the waste rate.
- 16-31 What change must be made in the MCRT to prevent the mixed liquor concentration from changing when one aeration tank is taken out of service?
- 16-32 In the activated sludge process, a light chocolate brown foam in the aeration tank indicates _____.
- 16-33 The plant adds 320 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?
- 16-34 The plant currently uses 48 pounds per day of chlorine. Assuming the chlorine usage will increase by 10% during the next year, how many 1-ton cylinders of chlorine will be needed for the year (365 days)?
- 16-35 What is the difference between disinfection and sterilization?

- 16-36 Elemental chlorine gas is _____ in color and is _____ times heavier than air.
- 16-37 The sludge pump operates 30 minutes every 3 hours. The pump delivers 80 gpm. If the sludge is 5.5% solids and has a volatile matter content of 66%, how many pounds of volatile solids are removed from the settling tank each day?
- 16-38 The aerobic digester has a volume of 52,000 gal. The lab test indicates that 42 mg of lime were required to increase the pH of a 1-L sample of digested sludge from 6.1 to the desired 7.2. How many pounds of lime must be added to the digester to increase the pH of the unit to 7.3?
- 16-39 The digester has a volume of 72,000 gal. Sludge is added to the digester at the rate of 2,800 gal per day. What is the sludge retention time in days?
- 16-40 What is the normal operating temperature of a heated digester?
- 16-41 The supernatant contains 340 mg/L volatile acids and 1,830 mg/L of alkalinity. What is the volatile acids alkalinity ratio?
- 16-42 The digester is 50 ft in diameter and has a depth of 22 ft. Sludge is pumped to the digester at the rate of 5,000 gal per day. What is the sludge retention time?
- 16-43 The raw sludge pumped to the digester contains 70% volatile matter. The digested sludge removed from the digester contains 48% volatile matter. What is the % volatile matter reduction?
- 16-44 Give three reasons for treating wastewater.
- 16-45 When organic matter is decomposed aerobically, what materials are produced?

- 16-46 The settling tank is 150 ft in diameter, and the flow to the unit is 4.8 MGD. What is the surface loading rate in gal/day/ft²?
- 16-47 Name three materials or pollutants that are not removed by the natural purification process.
- 16-48 The 125-ft diameter secondary settling tank consists of a cylindrical section 20 ft deep and a cone-shaped bottom that has a depth of 10 ft. What is the total volume of secondary settling tank in cubic feet?
- 16-49 A lab test indicates that a 500-g sample of sludge contains 25 g of solids. What is the percentage of solids in the sludge sample?
- 16-50 The operator withdraws 5,434 gal of solids from the digester. How many pounds of solids have been removed?
- 16-51 The plant has three grit channels in service. Each channel is 2 ft wide and has a water depth of 3 ft. What is the velocity in the channel when the flow rate is 8 MGD?
- 16-52 The ferric chloride stock solution contains 28% (by weight) ferric chloride (specific gravity 1.56). The working solution used by the plant is 5.5% (by weight) ferric chloride (specific gravity 1.11). How many gallons of stock ferric chloride solution must be used to prepare 5,000 gal of working solution?
- 16-53 What factors must be considered when using chemical additions?
- 16-54 The channel is 3.5 ft wide and has a liquid depth of 2.2 ft. The velocity of the flow in the channel is 3.0 fps. What is the flow rate in MGD?

- 16-55 The head behind a 90° V-notch weir is 4.0 inches. What is the head in feet?
- 16-56 What is the purpose of primary treatment?
- 16-57 Name three parts of the trickling filter, and give the purpose of each part.
- 16-58 What makes the RBC process similar to the trickling filter?
- 16-59 Define cross-connection.
- 16-60 Define mixed liquor.
- 16-61 What is the primary goal of any troubleshooting effort?
- 16-62 During the week, a total of 280 gal of screenings were removed from the wastewater screens. What was the average screening removal in cu ft/day?
- 16-63 Why is removing grit from the wastewater treatment system important?
- 16-64 A treatment plant removes 14 cu ft of grit in one day. If the plant flow is 10 MGD, what is this removal expressed as cu ft/MG?
- 16-65 The monthly average grit removal is 2.4 cu ft/MG. If the average daily flow for the month is 4,400,000 gpd, how many cu yd must be available for grit disposal if the disposal pit is to have a 90-day capacity?

- 16-66 What is an average detention time in a primary clarifier?
- 16-67 A sedimentation tank is 90 ft long and 25 ft wide. If the flow to the tank is 2,220,000 gpd, what is the surface overflow rate in gpd/sq ft?
- 16-68 A trickling filter 80 ft in diameter treats a primary effluent flow of 600,000 gpd. If the recirculated flow to the trickling filter is 100,000 gpd, what is the hydraulic loading rate in gpd/sq ft on the trickling filter?
- 16-69 If 115 mg/L suspended solids are removed by a trickling filter, how many lb/day suspended solids are removed when the flow is 3,250,000 gpd?
- 16-70 An RBC treats a primary effluent flow of 2.80 MGD. If the media surface area is 650,000 sq ft, what is the hydraulic loading rate in gpd/sq ft on the RBC?
- 16-71 An RBC has a media surface area of 700,000 sq ft and receives a flow of 1,700,000 gpd. If the soluble BOD concentration of the primary effluent is 140 mg/L, what is the organic loading in lb/day/1,000 ft on the RBC?
- 16-72 List three factors other than food that affect the growth characteristics of activated sludge.
- 16-73 What is the purpose of the activated sludge process?
- 16-74 A 2,400-mL sample of activated sludge is allowed to settle for 60 minutes. At the end of the 60 minutes, the sludge has settled 1,400 mL. What is the SSV_{60} of the sample?
- 16-75 The major requirement for aerobic organisms to be active is _____.
- 16-76 What is the purpose of advanced wastewater treatment?

- 16-77 The oxygen demand source most commonly added to reduce nitrates quickly is _____.
- 16-78 Define sludge thickening.
- 16-79 The digester has a volume of 75,000 gal. Sludge is added to the digester at the rate of 2,700 gal per day. What is the sludge retention time in days?
- 16-80 A 35-mL sample requires 19 mL of 0.02 N sulfuric acid to reach a pH of 4.6. What is the sample calcium carbonate alkalinity in mg/L?
- 16-81 In advanced wastewater treatment application, list one use of chemical oxidation.
- 16-82 The term "available chlorine" technically refers to _____.
- 16-83 Nitrite nitrogen is relatively unimportant in wastewater studies because _____.
- 16-84 List four objectives of aerobic sludge digestion.
- 16-85 A secondary clarifier in an activated sludge plant has excessive pin floc visible. What is the problem?
- 16-86 What is the advantage of using mechanical or diffused aeration equipment to provide oxygen?
- 16-87 Microscopic examination reveals a predominance of rotifers. What process adjustment does this indicate is required?
- 16-88 What problems may occur if solids remain in a sedimentation basin too long?

- 16-89 The velocity for grit channels is usually_____.
- 16-90 What is short-circuiting?
- 16-91 Why is the seeded BOD test required for some samples?
- 16-92 The label of hypochlorite solution states that the specific gravity of the solution is 1.1480. What is the weight of 1 gal of the hypochlorite solution?
- 16-93 Describe the appearance of the slime when the RBC is operating properly.
- 16-94 What is the slime that grows on a trickling filter called?
- 16-95 Describe the process occurring in an RBC process.
- 16-96 The plant effluent contains 26 mg/L BOD. The effluent flow rate is 8.00 MGD. How many kilograms per day of BOD₅ are being discharged?
- 16-97 The main action of a mixed media filter is _____.
- 16-98 A composite sample will give a(n) _____.
- 16-99 The plant effluent contains 30 mg/L solids. The effluent flow rate is 3.20 MGD. How many pounds per day of solids are discharged?
- 16-100 Define mean cell residence time (MCRT).

Answers to Chapter Review Questions

Chapter 2 Review Questions:

- 2-1 Connection between a storm drain and a sanitary collection system; or a connection between two sections of a collection system to handle anticipated overloads of one system; or a connection between drinking (potable) water and an unsafe water supply or sanitary collection system.
- 2-2 The amount of organic matter that can be biologically oxidized under controlled conditions (5 days @ 20°C in the dark).
- 2-3 A device used to measure wastewater flow.
- 2-4 Organisms that can survive and function in the presence or absence of free elemental oxygen.
- 2-5 Extraneous flows in sewers. Infiltration: Water entering the collection system through cracks, joints, or breaks. Inflow: Water discharged into sewer pipes or service connections from such sources as facility foundation drains, roof leaders, cellar and yard area drain, cooling water from air conditioner, and other clean-water discharges from commercial and industrial establishments.
- 2-6 Solids that join together to form larger particles that will settle better.
- 2-7 Combination of return activated sludge and wastewater in the aeration tank.
- 2-8 Any discernible, defined, and discrete conveyance from which pollutants are or may be discharged.
- 2-9 The amber-colored liquid above the sludge layer in a digester.
- 2-10 Readings taken at 30–60 minutes are used to calculate the settled sludge volume (SSV) and the sludge volume index (SVI).

Matching Exercise Answers:

(1) <i>y</i>	(6) <i>n</i>	(11) <i>j</i>	(16) <i>x</i>	(21) <i>w</i>
(2) <i>i</i>	(7) <i>c</i>	(12) <i>e</i>	(17) <i>h</i>	(22) <i>o</i>
(3) <i>l</i>	(8) <i>m</i>	(13) <i>k</i>	(18) <i>f</i>	(23) <i>s</i>
(4) <i>v</i>	(9) <i>q</i>	(14) <i>r</i>	(19) <i>g</i>	(24) <i>b</i>
(5) <i>d</i>	(10) <i>a</i>	(15) <i>u</i>	(20) <i>p</i>	(25) <i>t</i>

Chapter 3 Review Questions:

- 3-1 A systematic approach to solving problems.
- 3-2 When it is not possible to use a lock.
- 3-3 Every situation varies somewhat, and, therefore, the troubleshooting process also varies.

- 3-4 To identify and correct the problem that is causing the poor performance and/or non-compliance.
- 3-5 To provide a step-by-step procedure to assist in the troubleshooting effort.

Chapter 4 Review Questions:

$$4-1 \quad \frac{40 \text{ in}}{12 \text{ in/ft}} = 3.3 \text{ ft}$$

$$4-2 \quad 5,450 \text{ gal} \times 8.34 \text{ lb/gal} = 45,453 \text{ lb}$$

$$4-3 \quad 1,990 \text{ ft}^3 \times 7.48 \text{ gal/ft}^3 = 14,885 \text{ gal}$$

$$4-4 \quad 38 \text{ mg/L} \times 3.89 \text{ MGD} \times 8.34 \text{ lb/MG/mg/L} = 1,233 \text{ lb/day}$$

$$4-5 \quad 26 \text{ mg/L} \times 7.25 \text{ MGD} \times 3.785 \text{ kg/mg/L} = 713 \text{ kg/day}$$

$$4-6 \quad \frac{3,540 \text{ lb/day}}{3,524 \text{ mg/L} \times 8.34 \text{ lb/MG/L}} = 0.120 \text{ MG}$$

$$4-7 \quad \frac{255 \text{ mg/L} \times 0.80 \text{ MGD} \times 8.34 \text{ lb/MG/mg/L}}{0.17 \text{ lb BOD}_5/\text{person}} = 10,008 \text{ people}$$

$$4-8 \quad \text{BOD} = 0.21 \text{ lb/cap} \cdot \text{d}$$

$$\text{SS} = 0.28 \text{ lb/cap} \cdot \text{d}$$

$$\begin{aligned} \text{Per Capita BOD, mg/L Concentration} &= \frac{0.21 \text{ lb/capita} \cdot \text{d} \times 10^6 \text{ gal/Mgal}}{[8.34 \text{ lb/Mgal} \cdot (\text{mg/L})] \times 110 \text{ gal/capita} \cdot \text{d}} \\ &= 229 \text{ mg/L} \end{aligned}$$

$$\begin{aligned} \text{Per Capita SS, mg/L Concentration} &= \frac{0.28 \text{ lb/capita} \cdot \text{d} \times 10^6 \text{ gal/Mgal}}{[8.34 \text{ lb/Mgal} \cdot (\text{mg/L})] \times 110 \text{ gal/capita} \cdot \text{d}} \\ &= 305 \text{ mg/L} \end{aligned}$$

$$4-9 \quad 8.34 \text{ lb/gal} \times 1.1540 = 9.62 \text{ lb/gal}$$

$$4-10 \quad 8.5 \text{ lb/gal}$$

$$4-11 \quad \frac{45 \text{ lb/cu ft}}{62.4 \text{ lb/cu ft}} = 0.72 \text{ lb/cu ft}$$

$$4-12 \quad (1.3)(8.34 \text{ lb/gal}) = 11.7 \text{ lb/gal}$$

$$4-13 \quad \frac{(30 \text{ ft})(1,800 \text{ gpm})(8.34 \text{ lb/gal})}{33,000 \text{ ft-lb/min/hp}} = 13.6 \text{ hp}$$

$$4-14 \quad \text{Brake hp (25 mhp)} \frac{(80)}{100} = 20 \text{ bhp}$$

$$\text{Water hp (20 bhp)} \frac{(75)}{100} = 15 \text{ whp}$$

$$4-15 \quad \frac{40 \text{ whp}}{0.80} = 50 \text{ bhp}$$

Chapter 5 Review Question:

- 5-1 A plan is necessary both to prevent industrial contamination of the influent to the plant and to be able to determine (hopefully) the source of the discharge.

Chapter 6 Review Questions:

- 6-1 Because unit processes are designed for specific flow levels and process adjustments are based upon current levels of flow and are commonly controlled by flow rate adjustments.
- 6-2 $(2.5 \text{ ft})(1.5 \text{ ft})(0.8 \text{ fps}) = 3 \text{ cfs}$
- 6-3 $(2.5 \text{ ft})(1.25 \text{ ft})(1.6 \text{ ft/sec})(7.48 \text{ gal/cu ft})(60 \text{ sec/min}) = 2,244 \text{ gpm}$
- 6-4 $(3 \text{ ft})(0.83 \text{ ft})(1 \text{ fps}) = 2.5 \text{ cfs}$
- 6-5 The Parshall flume is preferred. Weirs are not frequently used anymore because solids may collect behind the weir, causing odor and inaccurate flow measurements. Parshall flumes are now widely used for measuring wastewater flow, because they have no obstructions.

Chapter 7 Review Questions:

- 7-1 To protect plant equipment and to remove materials that are not affected by treatment.
- 7-2 To remove large solids (rags, sticks, rocks, etc.).
- 7-3 $60 \text{ gpd} \div 7.48 \text{ gal/cu ft} = 8.0 \text{ cu ft/day}$
- 7-4
$$\frac{275 \text{ gal/wk}}{(7.48 \text{ gal/cu ft})(7 \text{ days/wk})} = \frac{275}{52.4} = 5.3 \text{ cu ft/day}$$
- 7-5
$$\frac{\frac{40 \text{ gal}}{7.48 \text{ gal/cu ft}}}{2.2 \text{ MGD}} = 2.4 \text{ cu ft/MG}$$
- 7-6 By the amount of water flowing through the channel, by the depth of the water in the channel, by the width of the channel, or by cumulative width of channels in service.
- 7-7
$$V, \text{ fps} = \frac{9.0 \text{ MGD} \times 1.55 \text{ cfs/MGD}}{3 \text{ channels} \times (2 \text{ ft}) \times (3 \text{ ft})} = 0.78 \text{ fps}$$
- 7-8 Reduce odors, freshen septic wastes, reduce BOD₅, prevent corrosion, improve settling and flotation.
- 7-9 To prevent excessive wear grit caused to pumps and to prevent it from taking up valuable space in downstream unit processes.
- 7-10 1.4 ft/s
- 7-11
$$\frac{4.0 \text{ MGD}}{1 \text{ d}} \times \frac{1 \text{ d}}{24 \text{ hr}} \times \frac{80 \text{ hr}}{1} = 13.3 \text{ MG}$$

$$\frac{4 \text{ ft} \times 5 \text{ ft} \times 2 \text{ ft}}{13.3 \text{ MG}} = 3.0 \text{ ft}^3/\text{MG}$$
- 7-12 Flow rate in channels.
- 7-13 Slow the wastewater so that the heavy inorganic material will settle out.

$$7-14 \quad \frac{30 \text{ ft}}{33 \text{ sec}} = 0.9 \text{ ft/sec}$$

$$7-15 \quad (2.8 \text{ ft})(1.3 \text{ ft})(x \text{ fps}) = \frac{(1,100 \text{ gpm})}{(7.48 \text{ gpd/cu ft})(60 \text{ sec/min})}$$

$$3.64(x) = \frac{(1,100 \text{ gpm})}{449}$$

$$x = \frac{2.45}{3.78}$$

$$x = 0.65 \text{ fps}$$

$$7-16 \quad \frac{12 \text{ cu ft/day}}{9 \text{ MGD}} = 1.3 \text{ cu ft/MG}$$

$$7-17 \quad \frac{(2.6 \text{ cu ft})(3.8 \text{ MGD})}{\text{MG}} = 9.9 \text{ cu ft} \times 30 \text{ d}$$

$$= 296.4 \text{ cu ft} = 11 \text{ cu yd in a month}$$

$$7-18 \quad \frac{(2.3 \text{ cu ft})(4.25 \text{ MG})(90 \text{ days})}{\text{MG}} = \frac{880 \text{ cu ft}}{27} = 32.6 \text{ cu yd}$$

Chapter 8 Review Questions:

8-1 To reduce settleable and floatable solids.

8-2 Settleable solids: 90–95%

Suspended solids: 40–60%

BOD₅: 25–30%

$$8-3 \quad \text{V.M lb/day} = 70 \text{ gpm} \times \frac{20 \text{ min}}{3 \text{ hr}} \times \frac{24 \text{ hr}}{\text{day}} \times \frac{5.5\%}{100} \times \frac{66\%}{100} \times \frac{8.34 \text{ lb}}{\text{gal}} = 3,391 \text{ lb/day}$$

$$8-4 \quad \frac{0.785 \times 70 \text{ ft} \times 70 \text{ ft} \times 10 \text{ ft} \times 7.48 \text{ gal/ft}^3 \times 24 \text{ hr/day}}{2.8 \text{ MGD} \times 1,000,000 \text{ gal/MG}} = 2.5 \text{ hr}$$

✓ *Note:* 1–3 hours is recommended; obviously, 2.5 hours falls within this range.

$$\frac{2.8 \text{ MGD} \times 1,000,000 \text{ gal/MG}}{0.785 \times 70 \text{ ft} \times 70 \text{ ft}} = 728 \text{ gpd/ft}^2$$

$$\frac{2.8 \text{ MGD} \times 1,000,000 \text{ gal/MG}}{3.14 \times 70} = 12,739 \text{ gpd/ft}$$

8-5 90 to 95% of the settleable solids.

8-6 1–3 hours.

$$8-7 \quad \text{Surface} = 90 \text{ ft} \times 20 \text{ ft} = 1,800 \text{ ft}^2$$

$$\text{Surface Overflow Rate} = \frac{1,500,000 \text{ gpd}}{1,800 \text{ ft}^2} = 833 \text{ gpd/ft}^2$$

$$8-8 \quad \text{WOR} = \frac{1,500,000 \text{ gpd}}{70 \text{ ft}} = 21,429 \text{ gpd/ft}$$

$$8-9 \quad \text{Tank Vol} = 90 \text{ ft} \times 20 \text{ ft} \times 12 \text{ ft} \times 7.48 \text{ gal/ft}^3 = 161,568 \text{ gal}$$

$$\text{Detention time} = 3 \times 161,568 \text{ gal} \times \frac{1 \text{ d}}{5,000,000} \times \frac{24 \text{ hr}}{1 \text{ d}} \times \frac{60 \text{ min}}{1 \text{ hr}} = 140 \text{ min}$$

$$\text{SOR} = \frac{5,000,000 \text{ gpd}}{3 \times 90 \text{ ft} \times 20 \text{ ft}} = 926 \text{ gpd/ft}^2$$

$$\text{WOR} = \frac{5,000,000 \text{ gpd}}{3 \times 86 \text{ ft}} = 19,380 \text{ gpd/ft}$$

$$8-10 \quad 2.8 \text{ hours.}$$

$$8-11 \quad \frac{1,750,000 \text{ gpd}}{24 \text{ hr}} = 72,917 \text{ gph}$$

$$\frac{160,000 \text{ gpd}}{72,917 \text{ gph}} = 2.2 \text{ hr}$$

$$8-12 \quad \frac{4,300,000 \text{ gpd}}{24 \text{ hr}} = 179,167 \text{ gph}$$

$$\frac{(0.785) (80 \text{ ft}) (80 \text{ ft}) (10 \text{ ft}) (7.48 \text{ gal/cu ft})}{179,167 \text{ gph}} = 2.1 \text{ hr}$$

$$8-13 \quad \frac{1,400,000 \text{ gpd}}{120 \text{ ft}} = 11,667 \text{ gpd/ft}$$

$$8-14 \quad \frac{2,650,000 \text{ gpd}}{(0.785) (70 \text{ ft}) (70 \text{ ft})} = 689 \text{ gpd/sq ft}$$

$$8-15 \quad \frac{2,190,000 \text{ gpd}}{(80 \text{ ft}) (30 \text{ ft})} = 913 \text{ gpd/sq ft}$$

$$8-16 \quad (120 \text{ mg/L}) (5.14 \text{ MGD}) (8.34 \text{ lb/gal}) = 5,144 \text{ lb/day SS}$$

$$8-17 \quad 300 \text{ mg/L} - 120 \text{ mg/L} = 180 \text{ mg/L}$$

$$(180 \text{ mg/L}) (0.95 \text{ MGD}) (8.34 \text{ lb/gal}) = 1,426 \text{ lb/day SS}$$

Chapter 9 Review Questions:

- 9-1 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 underdrains with the treated wastewater.
- 9-2 The total mass of organisms attached to the media. Similar to solids inventory in the activated sludge process, it is sometimes referred to as zoogloal slime.
- 9-3 A complex population of organisms that form a "slime growth" on the trickling filter media and break down the organic matter in wastewater. These slimes consist of living organisms feeding on the wastes in the wastewater, dead organisms, silt, and other debris.
- 9-4 The practice of operating two or more trickling filters in series. The effluent of one filter is used as the influent of the next. This practice can produce a higher quality effluent by removing additional BOD₅ or COD.

- 9-5 Clogging the media so water does not drain through the media. Corrective actions include flushing media, raking media, dosing with chlorine, increasing recirculation, flooding for 24 hours, or drying for several hours.
- 9-6 Mixing part of the treated effluent with the untreated wastes. Requires pumps, flow meter, and additional piping.
- 9-7 Causes include poor housekeeping, intermittent wet-dry conditions, and/or warm weather. Corrective actions include improving housekeeping, increasing recirculation, applying low level residual chlorine, and/or using a flood filter.
- 9-8 Reduce recirculation, reduce heat loss by covering, or erect wind screens.
- 9-9 Check filter influent for aerobic conditions; inspect underdrains and vents for clogging. Correction: add forced air ventilation, increase recirculation, or add masking agent.
- 9-10
$$\frac{720,000 \text{ gpd}}{(0.785) (70 \text{ ft}) (70 \text{ ft})} = 187 \text{ gpd/sq ft}$$
- 9-11
$$\frac{1,200,000 \text{ gpd}}{(0.785) (90 \text{ ft}) (90 \text{ ft})} = 189 \text{ gpd/sq ft}$$
- 9-12
$$\text{Volume} = (0.785) (80 \text{ ft}) (80 \text{ ft}) (6 \text{ ft}) = 30,144 \text{ cu ft}$$

$$\frac{(200 \text{ mg/L}) (1.1 \text{ MGD}) (8.34 \text{ lb/gal})}{30 \quad 1000 - \text{cu ft}} = 61.2 \text{ lb BOD/d/1,000 cu ft}$$
- 9-13
$$\text{Volume} = (0.785) (60 \text{ ft}) (60 \text{ ft}) (6 \text{ ft}) = 16,956 \text{ cu ft}$$

$$\frac{(185 \text{ mg/L}) (0.9 \text{ MGD}) (8.34 \text{ lb/gal})}{16.9 \quad 100 - \text{cu ft}} = 82.2 \text{ lb BOD/d/1,000 cu ft}$$
- 9-14
$$(120 \text{ mg/L}) (3.15 \text{ MGD}) (8.34 \text{ lb/gal}) = 3,153 \text{ lb/day SS Rem.}$$
- 9-15
$$(169 \text{ mg/L BOD Rem.}) (2.75 \text{ MGD}) (8.34 \text{ lb/gal}) = 3,876 \text{ lb/day BOD removed}$$

Chapter 10 Review Questions:

- 10-1 A series of plastic disks placed side by side on a shaft. The disks are suspended in a channel of wastewater and rotate through the wastewater.
- 10-2 The biological growth is attached to a media.
- 10-3 Nitrification is occurring in the later stages of the process.
- 10-4 Sulfur will cause slime to become white and chalky in appearance.
- 10-5
$$\frac{2,650,000 \text{ gpd}}{700,000 \text{ sq ft}} = 3.8 \text{ gpd/sq ft}$$
- 10-6
$$\frac{1,500,000 \text{ gpd}}{400,000 \text{ sq ft}} = 3.8 \text{ gpd/sq ft}$$
- 10-7
$$(240 \text{ mg/L SS}) (0.5) = 120 \text{ mg/L particulate BOD}$$
- 10-8
$$216 \text{ mg/L total BOD} = (230 \text{ mg/L}) (0.6) + X \text{ mg/L Sol. BOD}$$

$$X = 78 \text{ mg/L Sol. BOD}$$
- 10-9
$$\frac{(140 \text{ mg/L}) (4.10 \text{ MGD}) (8.34 \text{ lb/gal})}{850 \quad 1000 - \text{sq ft}} = 5.6 \text{ lb/day/1,000 sq ft}$$

$$10-10 \quad \frac{(120 \text{ mg/L})(2.48 \text{ MGD})(8.34 \text{ lb/gal})}{620 \quad 1000 - \text{sq ft}} = 4.0 \text{ lb/day/1,000 sq ft}$$

$$10-11 \quad \frac{(146 \text{ mg/L})(1.68 \text{ MGD})(8.34 \text{ lb/gal})}{650 \quad 1000 - \text{sq ft}} = 3.1 \text{ lb/day/1,000 sq ft}$$

10-12 First determine mg/L soluble BOD:
 $185 \text{ mg/L total BOD} = (202 \text{ mg/L})(0.7) + X \text{ mg/L Sol. BOD}$

$$X = 44 \text{ mg/L Sol. BOD}$$

Then calculate lb/day soluble BOD:

$$(44 \text{ mg/L})(2.5 \text{ MGD})(8.34 \text{ lb/gal}) = 917 \text{ lb/day}$$

Chapter 11 Review Questions:

11-1 Decrease; decrease; decrease; increase; increase.

11-2 (1) Provides needed oxygen for microorganisms.

(2) Provides mixing required to put the food and microorganisms together.

11-3 Decrease MCRT.

11-4 Increase MCRT.

11-5 Temperature, pH, toxicity, waste rate, and aeration tank configuration.

11-6 Decrease waste rate.

11-7 Activated sludge.

11-8 Mixed liquor.

11-9 Food, oxygen, and organisms.

11-10 To remove BOD.

11-11 Settling tank capacity, aeration rates, process control tests, aeration tank color, foam, and odors.

$$11-12 \quad \frac{1,400 \times 1,000}{2,200 \text{ mL}} = 636$$

$$11-13 \quad \frac{420 \text{ mL/L} \times 1,000}{2,150 \text{ mg/L}} = 195$$

$$11-14 \quad \text{Waste lb/day} = 8,100 \text{ mg/L} \times 0.069 \text{ MGD} \times 8.34 \\ = 4,661 \text{ lb/day}$$

11-15 Contact stabilization.

11-16 Waste rate should be increased slightly.

11-17 lb (MLSS under aeration)

$$= Q (\text{MGD}) \times \text{Prim. effluent SS (mg/L)} \times 8.34 \times \text{sludge age (days)}$$

$$= 2.1 \text{ MGD} \times 120 \text{ mg/L} \times 8.34 \times 5 \text{ days}$$

$$= 10,508 \text{ lb MLSS}$$

11-18 Thick, greasy, brown or tan foam, dark brown sludge color, ash or pin floc in effluent, possibly rising sludge in settling tank.

- 11-19 (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 where discrete settling occurred.
- 11-20 Color could be the result of outside factors, such as stormwater or industrial waste.
- 11-21 Chocolate brown, musty odor, uniform blanket settling, light, crisp white foam, low solids in effluent, very clear effluent.
- 11-22 Helps to eliminate variations that are not the result of changes in the sludge settling characteristics.
- 11-23 Increased flow, increased temperature, sludge bulking, decreased sludge age, increased organic loading.
- 11-24 The most widely used device consists of a 15–20 ft long clear plastic pipe marked at 6-inch intervals; the pipe is equipped with a ball valve at the bottom.
- 11-25 Flows produced in other treatment processes that must be returned to the wastewater treatment system prior to disposal. Examples: Anaerobic digester supernatant, thickener supernatant, aerobic digester supernatant liquids removed from sludge de-watering, heat treatment supernatant, and chlorine oxidation supernatant.
- 11-26 To determine the quantity and strength of the sidestreams for their effects on the treatment process.
- 11-27 Organic overloading, insufficient nutrients, toxic materials.
- 11-28 The effect of organic material in wastewater.
- 11-29 BOD test shows the actual impact of the wastewater.
- 11-30 To separate and return biosolids to the aeration tank.
- 11-31 Declining.
- 11-32 Must be in presence of dissolved oxygen.
- 11-33 Can function with or without dissolved oxygen. Prefer to use dissolved oxygen as oxygen source but can use chemically combined oxygen, such as sulfate or nitrates.
- 11-34 A well-operated activated sludge process.
- 11-35 Low dissolved oxygen concentration.
- 11-36 High mixed liquor concentration.
- 11-37 White foam.

Chapter 12 Review Questions:

- 12-1 Disinfection is selective destruction of disease-causing organisms. Sterilization is the destruction of all organisms.
- 12-2 demand; 1.0; residual; 30.
- 12-3 yellow-green; 2.5.
- 12-4
$$\text{Dose, mg/L} = \frac{395 \text{ lb/day}}{[5.6 \text{ MGD} \times 8.34]} = 8.5 \text{ mg/L}$$
- 12-5 7.1

Chapter 13 Review Questions:

- 13-1 To remove additional pollutants from treated wastewater.

- 13-2 Tertiary suggests a third step that is applied after primary and secondary treatment, while advanced treatment may be integrated into conventional treatment.
- 13-3 On the purpose of the treatment and quality of the effluent desired.
- 13-4 Microstraining.
- 13-5 (1) Characterization of SS with respect to the concentration and degree of flocculation.
 (2) Selection of design parameters that will ensure capacity to meet maximum hydraulic loading with critical solids characteristics but also provide desired design performance over the expected range of hydraulic and solid loading.
 (3) The provision of backwash and cleaning facilities to maintain the capacity of the screen.
- 13-6 Alkalinity, pH, dissolved oxygen, toxicity, and/or process mean cell residence time.
- 13-7 85%.
- 13-8 Methanol.
- 13-9 Removal of refractory organic compounds and soluble organic material that is difficult to remove by biological or physical/chemical treatment.
- 13-10 Large land area required. Soil and climate sensitive.

Chapter 14 Review Questions:

- 14-1 Reduces its volume; stabilizes it; inactivates pathogenic organisms.
- 14-2 Water not attached to sludge solids in any way.
- 14-3 Organic solids are materials that are or at one time were alive and will burn or volatilize at 550°C after 15 minutes in a muffle furnace.
 Inorganic solids are solids that were never alive and will not burn or volatilize at 550°C after 15 minutes in a muffle furnace.
- 14-4 A unit process used to increase the solids content of sludge by removing a portion of the liquid fraction.
- 14-5 Climate; depth of applied sludge; type of sludge; and bed cover.
- 14-6 Provides the highest level of moisture, organic matter, pathogenic organisms, and volume reduction.
- 14-7 $30 \text{ min/cyc} \times 24 \text{ hr} / 3 \text{ hr/cyc.} \times 70 \text{ gpm} \times 8.34 \text{ lb/gal} \times 0.055 \times 0.69 = 5,317 \text{ lb/day}$
- 14-8 $\frac{72,000 \text{ gal}}{2,800 \text{ gpd}} = 26 \text{ days}$
- 14-9 90–95°F; no more than 1°F each day
- 14-10 $\frac{344 \text{ mg/L}}{1,830 \text{ mg/L}} = 0.19$

Chapter 15 Review Questions:

- 15-1 Samples must be digested.
- 15-2 $= \frac{0.21 \text{ mg}}{40 \text{ mL}}$
 $= 0.005 \text{ mg/L phosphorus} \times 1,000 \text{ mL/L} = 5.25 \text{ mg/L}$
- 15-3 After dechlorination, samples are preserved by acidifying them to a pH <2.0 by adding concentrated sulfuric acid (approximately 0.8 mL/L of sample).

15-4 Organic nitrogen.

15-5 Nitrate-nitrogen.

$$15-6 \quad \frac{27.6 \times 280}{200} = 38.6 \text{ mg/L}$$

$$15-7 \quad \frac{170 \text{ mg}}{50 \text{ mL}} \times \frac{200}{25} = 27.2 \text{ mg/L}$$

15-8 The measure of the amount of calcium and magnesium metallic cation present in the wastewater.

$$15-8 \quad \frac{18 \text{ mL} \times 0.02 \times 50,000}{30 \text{ mL}} = 600 \text{ mg/L}$$

$$15-9 \quad = \frac{(2 \times 3.4 - 3.8) \times 0.02 \times 50,000}{200 \text{ mL}}$$
$$= 15.0 \text{ mg/L}$$

Answers to Final Review Examination: Chapter 16

16-1 $10 \text{ ft} \times 10 \text{ ft} \times 8 \text{ ft} = 800 \text{ ft}^3$

$800 \text{ ft}^3 \times 7.48 = 5,984 \text{ gal}$

$\frac{5,984 \text{ gal}}{7 \text{ min}} = 854.9 \text{ gal/min}$

16-2 Severe infiltration/inflow (I/I).

16-3 Ponding.

16-4 No adjustment required.

16-5 Downstream treatment processes.

16-6 Sulfur.

16-7 The coupling is broken.

16-8 Increase the air flow to the channels.

16-9 Pipe clogged or closed valve in the discharge line.

16-10 Decrease the grit channel aeration rate.

16-11 A short-circuiting problem has occurred.

16-12 Will increase.

16-13 Increase.

16-14 Do nothing; the process is within expected levels.

16-15 Decrease.

16-16 Increase the return rate.

16-17 To separate and return biosolids to the aeration tank.

16-18 The effect of organic matter on wastewater.

16-19 Low dissolved oxygen level.

16-20 High mixed liquor concentration.

16-21 Waste rate too high.

16-22 Dark greasy foam on the aeration tank.

16-23 Between 1.5 and 2.5 mg/L.

16-24 Increase the MLVSS concentration.

16-25 Waste rate.

16-26 Decrease.

16-27 Decrease.

16-28 Decrease.

16-29 Increase.

- 16-30 Increase.
- 16-31 Decrease MCRT.
- 16-32 A well-operated activated sludge process.
- 16-33 $320 \text{ lb HTH/day} \times 0.45 \text{ Avail. chlorine} = 144 \text{ lb chlorine/day}$
- 16-34 $\frac{48 \text{ lb/day} \times 1.10 \times 365 \text{ days}}{2,000 \text{ lb containers}} = 10 (9.6) \text{ containers}$
- 16-35 Disinfection destroys pathogenic organisms. Sterilization destroys all organisms.
- 16-36 Yellow green; 2.5.
- 16-37 $30 \text{ min/cyc.} \times 24 \text{ hr/3 hr/cyc.} \times 80 \text{ gpm} \times 8.34 \text{ lb/gal} \times 0.055 \times 0.66 = 5,813 \text{ lb/day}$
- 16-38 $\frac{42 \text{ mg} \times 52,000 \text{ gal} \times 3.785 \text{ L/gal}}{1 \text{ L} \times 454 \text{ g/lb} \times 1,000 \text{ mg/g}} = 18 \text{ lb}$
- 16-39 $\frac{72,000 \text{ gal}}{2,800 \text{ gpd}} = 26 \text{ days}$
- 16-40 90–95°F.
- 16-41 $\frac{340 \text{ mg/L}}{1,830 \text{ mg/L}} = 0.19$
- 16-42 $\frac{0.785 \times 50 \text{ ft} \times 50 \text{ ft} \times 22 \text{ ft} \times 7.5 \text{ gal/ft}^3}{5,000 \text{ gpd}} = 64.8 \text{ days}$
- 16-43 $\frac{(0.70 - 0.48) \times 100}{[0.70 - (0.70 \times 0.48)]} = 60.4\%$
- 16-44 Prevent disease; protect aquatic organisms; protect water quality.
- 16-45 Carbon dioxide, water, more organisms, stable solids.
- 16-46 $\frac{4.8 \text{ MGD} \times 1,000,000 \text{ gal/ MGD}}{0.785 \times 150 \text{ ft} \times 150 \text{ ft}} = 272 \text{ gpd/ft}^2$
- 16-47 Toxic matter, inorganic dissolved solids, pathogenic organisms.
- 16-48 $0.785 \times 125 \text{ ft} \times 125 \text{ ft} \times 20 \text{ ft} = 245,312 \text{ ft}^3$
- $0.262 \times 125 \text{ ft} \times 125 \text{ ft} \times 10 \text{ ft} = \frac{40,938 \text{ ft}^3}{286,250 \text{ ft}^3}$
- 16-49 $\frac{25 \text{ g} \times 100}{500 \text{ g}} = 5\%$
- 16-50 $5,434 \text{ gal} \times 8.34 \text{ lb/gal} = 45,320 \text{ lb}$
- 16-51 $\frac{8.0 \text{ MGD} \times 1.55 \text{ cfs/ MGD}}{3 \text{ channels} \times 2 \text{ ft} \times 3 \text{ ft}} = 0.69 \text{ fps}$
- 16-52 $\frac{5,000 \text{ gal} \times 1.11 \times 0.055}{1.56 \times 0.28} = 699 \text{ gal}$
- 16-53 Purpose for adding chemical; chemical properties of the selected chemical; where chemicals are being added.
- 16-54 $Q, \text{ MGD} = \frac{3.0 \text{ fps} \times 3.5 \text{ ft} \times 2.2 \text{ ft}}{1.55 \text{ cfs/ MGD}} = 14.9 \text{ MGD}$

$$16-55 \quad \text{Head} = \frac{4.0 \text{ in}}{12 \text{ in/ft}} = 0.33 \text{ ft}$$

16-56 To remove settleable and floatable solids.

16-57 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 and provide ventilation.

16-58 The use of fixed film biological organisms.

16-59 Connection between a storm drain and a sanitary collection system; or a connection between two sections of a collection system to handle anticipated overloads of one system; or a connection between (potable) water and an unsafe water supply or sanitary collection system.

16-60 Combination of return-activated sludge and wastewater in the aeration tank.

16-61 To identify and correct the problem that is causing the poor performance and/or non-compliance.

$$16-62 \quad \frac{280 \text{ gal/wk}}{(7.48 \text{ gal/cu ft})(7 \text{ days/wk})} = 5.3 \text{ cu ft/day}$$

16-63 To prevent the excessive wear grit causes to pumps and to prevent it from taking up valuable space in downstream unit processes.

$$16-64 \quad \frac{14 \text{ cu ft/day}}{10 \text{ MGD}} = 1.4 \text{ cu ft/MG}$$

$$16-65 \quad \frac{(2.4 \text{ cu ft})(4.4 \text{ MG})(90 \text{ days})}{\text{MG}} = 950 \text{ cu ft required}$$

$$= \frac{950}{27} = 35 \text{ cu yd required}$$

16-66 1–3 hours.

$$16-67 \quad \frac{2,220,000 \text{ gpd}}{(90 \text{ ft})(25 \text{ ft})} = 987 \text{ gpd/sq ft}$$

$$16-68 \quad \frac{700,000 \text{ gpd}}{(0.785)(80 \text{ ft})(80 \text{ ft})} = 139 \text{ gpd/sq ft}$$

$$16-69 \quad (115 \text{ mg/L})(3.250 \text{ MGD})(8.34 \text{ lb/gal}) = 3,117 \text{ lb/day BOD removed}$$

$$16-70 \quad \frac{2,800,000 \text{ gpd}}{650,000 \text{ sq ft}} = 4.3 \text{ gpd/sq ft}$$

$$16-71 \quad \frac{(140 \text{ mg/L})(1.70 \text{ MGD})(8.34 \text{ lb/gal})}{700 \quad 1,000 \text{ sq ft}} = 2.8 \text{ lb/day/1,000 sq ft}$$

16-72 Temperature, pH, toxicity, waste rate, aeration tank configuration.

16-73 To remove BOD.

$$16-74 \quad \frac{1,400 \text{ mL} \times 1,000}{2,400 \text{ mL}} = 583$$

16-75 Must be in presence of dissolved oxygen.

- 16-76 To remove additional pollutants from treated wastewater.
- 16-77 Methanol.
- 16-78 A unit process used to increase the solids content of sludge by removing a portion of the liquid fraction.
- 16-79 $\frac{75,000 \text{ gal}}{2,700 \text{ gpd}} = 28 \text{ days}$
- 16-80 $\frac{19 \text{ mL} \times 0.02 \times 50,000}{35 \text{ mL}} = 543 \text{ mg/L}$
- 16-81 Removal of ammonia.
- 16-82 The total oxidizing power of the chlorine compound.
- 16-83 It seldom exceeds 1 mg/L.
- 16-84 Oxidize sludge organics to stable end products
—Reduce mass of sludge.
—Reduce volume of sludge.
—Condition sludge for further solids handling.
- 16-85 Turbulence in the aeration tank is too great.
- 16-86 Eliminates wide diurnal and seasonal variations in dissolved oxygen (especially in ponds).
- 16-87 Increase waste rate.
- 16-88 Solids will become septic, gasify, and be resuspended. This will cause a decrease in the effluent quality.
- 16-89 1 ft/sec
- 16-90 A condition that allows the flow to pass through the unit quickly.
- 16-91 Either because the microorganisms have been killed or are absent.
- 16-92 $8.34 \text{ lb/gal} \times 1.1480 = 9.6 \text{ lb/gal}$
- 16-93 Gray-shaggy.
- 16-94 The zoogloal mass.
- 16-95 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.
- 16-96 $26 \text{ mg/L} \times 8.00 \text{ MGD} \times 3.785 \text{ kg/MG/mg/L} = 787 \text{ kg/day}$
- 16-97 Straining.
- 16-98 Representative long-term sample.
- 16-99 $30 \text{ mg/L} \times 3.20 \text{ MGD} \times 8.34 \text{ lb/MG/mg/L} = 801 \text{ lb/day}$
- 16-100 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.

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 ² H]
Cone	(1/3) (π) (Radius, ft) ² (Height, ft) [0.33 R ² H]
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, %	$\text{In} - \text{Out} \times 100$

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