Wisconsin Department of Natural Resources
Wastewater Operator Certification

Biological Treatment: Suspended Growth Processes Study Guide

Subclass A1

August 2015
Wisconsin Department of Natural Resources
Operator Certification Program
PO Box 7921, Madison, WI 53707

http://.dnr.wi.gov

Preface

The Biological Treatment: Suspended Growth Processes Study Guide is an important resource for preparing for the certification exam and is arranged by chapters and sections. Each section consists of key knowledges with important informational concepts you need to know for the certification exam. This study guide also serves as a wastewater treatment plant operations primer that can be used as a reference on the subject.

In preparing for the exams:
1. Study the material! Read every key knowledge until the concept is fully understood and known to memory.

2. Learn with others! Take classes in this type of wastewater operations to improve your understanding and knowledge of the subject.

3. Learn even more! For an even greater understanding and knowledge of the subjects, read and review the references listed at the end of the study guide.

Knowledge of the study guide material will be tested using a multiple choice format. Every test question and answer comes directly from one of the key knowledges.

Choosing a test date:
Before choosing a test date, consider the time you have to thoroughly study the guides and the training opportunities available. A listing of wastewater training opportunities and exam dates is available at http://dnr.wi.gov by searching for the keywords “Operator Certification”.

Acknowledgements

The Biological Treatment: Suspended Growth Processes Study Guide was the result of a collaborative effort of yearlong monthly meetings of wastewater operators, trainers, consultants, the Wisconsin Wastewater Operator Association (WWOA) and the Wisconsin Department of Natural Resources (WDNR). This study guide was developed as the result of the knowledge and collective work of following workgroup members:

Chris Marx, Chilton WWTP, Chilton, WI
Matt Schmidt, Green Bay Metro, Green Bay, WI
Joe Flanagan, Blanchardville WWTP, Blanchardville, WI
Gary Hanson, AECom, Sheboygan, WI
Doug Nelson, Ruekert and Mielke, Madison, WI
Jim Shaw, ITT Sanitaire, Madison, WI
Dan Tomaro, Wastewater Training Solutions, Oregon, WI
Curtis Nickels, Wisconsin Department of Natural Resources, Plymouth, WI
Hannah Fass, Wisconsin Department of Natural Resources, Madison, WI
Amy Garbe, Wisconsin Department of Natural Resources, Madison, WI
Danielle Luke, Wisconsin Department of Natural Resources, Madison, WI
Jack Saltes, Wisconsin Department of Natural Resources, Madison, WI

Table of Contents

Chapter 1 - Theory and Principles

Section 1.1 - Definitions

1.1.1 Define activated sludge.

Activated sludge is a mixture of sludge particles (floc), bacteria, fungi, protozoa, and rotifers maintained in suspension by aeration and mixing.

1.1.2 Define aerobic (oxic) [O2].

Aerobic is a condition in which free and dissolved oxygen (DO) is available in an aqueous environment.

1.1.3 Define anaerobic [Ø].

Anaerobic is a condition in which free, dissolved, and combined oxygen is unavailable in an aqueous environment.

1.1.4 Define anoxic [NO2, NO3, SO4].

Anoxic is a condition in which oxygen is only available in a combined form such as nitrate (NO3-), nitrite (NO2-), or sulfate (SO4) in an aqueous environment.

1.1.5 Define denitrification.

Denitrification is a biological process where bacteria convert nitrate (NO3-) and nitrite (NO2-) to nitrogen gas (N2) under anoxic conditions.

1.1.6 Define floc.

Floc is clusters of microorganisms and solid particles that form in the activated sludge process and settle in the final clarifier.

1.1.7 Define food to microorganism ratio (F:M or F/M).

F:M is the amount of food (biochemical oxygen demand (BOD)) provided to the microorganisms (mixed liquor volatile suspended solids (MLVSS) or mixed liquor suspend solids (MLSS)) in the aeration basins.

F:M is determined by dividing the pounds of influent BOD by the pounds of MLVSS or MLSS under aeration.

1.1.8 Define hydraulic retention time (HRT).

HRT is the period of time that wastewater remains in a tank. This is important because treatment processes require sufficient time for the wastewater to be treated.

1.1.9 Define marbling.

Marbling is the variegated, marble stone like appearance on a quiescent part of an aeration basin as a result of good floc (solids) and water separation. This is usually indicative of a good sludge age.

Figure 1.1.9.1

1.1.10 Define mixed liquor suspended solids (MLSS).

The amount of suspended solids in an aeration tank, expressed in milligrams per liter (mg/L). MLSS consists mostly of microorganisms and non-biodegradable suspended matter. Total pounds of MLSS in an aeration tank can be calculated by multiplying the concentration of MLSS (mg/L) in the aeration tank by the tank volume in million gallons (MG), and then multiplying the product by 8.34.

1.1.11 Define mixed liquor volatile suspended solids (MLVSS).

MLVSS is the amount of organic or volatile suspended solids in an aeration tank, expressed in mg/L. This volatile portion is used as a measure of the microorganisms present in the aeration tank. Total pounds of MLVSS in an aeration tank can be calculated by multiplying the concentration of MLVSS (mg/L) in the aeration tank by the tank volume (MG), and then multiplying the product by 8.34.

1.1.12 Define nitrification.

Nitrification is a biological process where nitrifying bacteria convert nitrogen in the form of ammonia (NH3) into nitrite (NO2-) and nitrate (NO3-) under aerobic conditions.

1.1.13 Define organic loading and organic overload.

Organic loading is the amount of biodegradable material that exerts an oxygen demand on the biological treatment process. The organic strength of the wastewater is usually measured as BOD in mg/L.

An organic overload is an event which significantly increases the organic loading (BOD) to the aeration basin above normal influent organic loading conditions.

1.1.14 Define protozoa.

Protozoa are single celled microscopic organisms that require oxygen and food (bacteria) for growth and reproduction. Protoza include amoeba, flagellates and ciliates.

1.1.15 Define return activated sludge (RAS).

RAS is the settled activated sludge (biomass) that is collected in a final clarifier and returned to the secondary treatment process to mix with incoming wastewater. This returns a concentrated population of microorganisms back into the aeration basin.

1.1.16 Define secondary treatment.

Secondary treatment is a term to describe the biological treatment of wastewater. Activated sludge is a type of secondary treatment.

Secondary treatment provides a high level of removal of biodegradable organic pollutants to protect receiving water quality that clarification alone cannot provide.

1.1.17 Define sludge age.

Sludge age is the theoretical length of time a particle of activated sludge stays in the treatment plant and is measured in days. In an activated sludge plant, sludge age is the amount (lbs) of MLSS divided by the suspended solids, or excess cell mass, withdrawn from the system per day (lbs/day of waste activated sludge (WAS)).

1.1.18 Define sludge blanket.

The sludge blanket is the layer of solids on the bottom of the clarifier.

1.1.19 Define sludge volume index (SVI).

SVI is a numerical expression of the settling characteristics of activated sludge in the final clarifier. SVI is expressed as the ratio of the volume in milliliters of activated sludge settled from a 1,000 mL sample in 30 minutes divided by the concentration of mixed liquor in milligrams per liter multiplied by 1,000. A good settling sludge (textbook value) is 100, but can commonly be between 80 and 150.

1.1.20 Define treatment facility overflow (TFO).

A TFO is a release of wastewater, other than through permitted outfalls, from a wastewater facility into a water of the state or the land surface. All TFOs must be reported to the Department of Natural Resources within 24 hours of the occurrence.

1.1.21 Define waste activated sludge (WAS).

WAS is the activated sludge (excess biomass or cell mass) removed from the secondary treatment process. For most treatment plants, this will be a portion of the RAS flow stream.

Section 1.2 - Microbiological Principles

1.2.1 Describe the activated sludge process.

Activated sludge is a biological process that utilizes microorganisms to convert organic and certain inorganic matter from wastewater into cell mass. The activated sludge is then separated from the liquid by clarification. The settled sludge is either returned (recycled activated sludge (RAS)) or wasted (wasted activated sludge (WAS)). Activated sludge is commonly used as a wastewater treatment process because it is an effective and versatile treatment process and capable of a high degree of treatment.

1.2.2 Describe the role microorganisms have in the activated sludge process.

The principle role microorganisms have in the activated sludge process is to convert dissolved and particulate organic matter, measured as biochemical oxygen demand (BOD), into cell mass. In a conventional activated sludge process, microorganisms use oxygen to break down organic matter (food) for their growth and survival. Over time and as wastewater moves through the aeration basin, food (BOD) decreases with a resultant increase in cell mass (mixed liquor suspended solids (MLSS) concentration).

1.2.3 Describe the environmental factors that influence the health and growth of microorganisms.

The activated sludge wastewater treatment process must operate under proper environmental conditions to support a healthy, growing population of microorganisms. The operator must monitor the activated sludge process to ensure the right environmental conditions are being provided for the microorganisms. Efficient wastewater treatment plant performance will then be achieved.

A. Food
Incoming wastewater to a treatment plant provides the food that microorganisms need for their growth and reproduction. This food is mostly organic material. The more soluble the organic material is, the more easily microorganisms can use it. Since the amount and type of organic loading in the treatment plant affects the growth of the microorganisms, influent total BOD and soluble BOD are measurements an operator can make to determine the amount and type of incoming food for the microorganisms.

B. Flow
Incoming wastewater must flow through a treatment plant at a rate that allows microorganisms sufficient time to consume the incoming food and to settle properly. High flows can shorten the time necessary for the full treatment of wastewater. Extremely high flows can wash microorganisms out of the plant through the final clarifier.

C. Oxygen
Conventional activated sludge is an aerobic process. Many bacteria in the activated sludge process need free oxygen (O2) to convert food into energy for their growth. For optimal

performance, it is very important for an operator to be sure enough oxygen is being provided in the aeration tanks for the microorganisms (typically 1.0 to 3.0 mg/L). Aeration basin dissolved oxygen (DO) concentrations (mg/L) are measured continuously in many plants to ensure adequate oxygen is available.

D. Temperature

All biological and chemical reactions are affected by temperature. Microorganisms' growth and reaction rates are slow at cold temperatures and much faster at warmer temperatures. Most microorganisms do best under moderate temperatures (10ºC to 25ºC). Aeration basin temperatures should be routinely measured and recorded.

E. pH

Biological and chemical reactions are affected by pH. Most microorganisms do well in a pH environment between 6.0 and 9.0. Acidic (low pH) or alkaline (high pH) conditions can adversely affect microorganism growth and survival. Operators measure both influent pH and aeration basin pH to ensure proper plant pH conditions.

F. Nutrients

Microorganisms need trace nutrients such as nitrogen, phosphorus, and some metals for their metabolism. Most incoming wastewater to a treatment plant, especially domestic wastewater, contains an abundance of these trace nutrients. The ratio of BOD to nitrogen (N) to phosphorus (P) should be at least 100:5:1. Influent wastewater can be measured to determine this nutrient ratio.

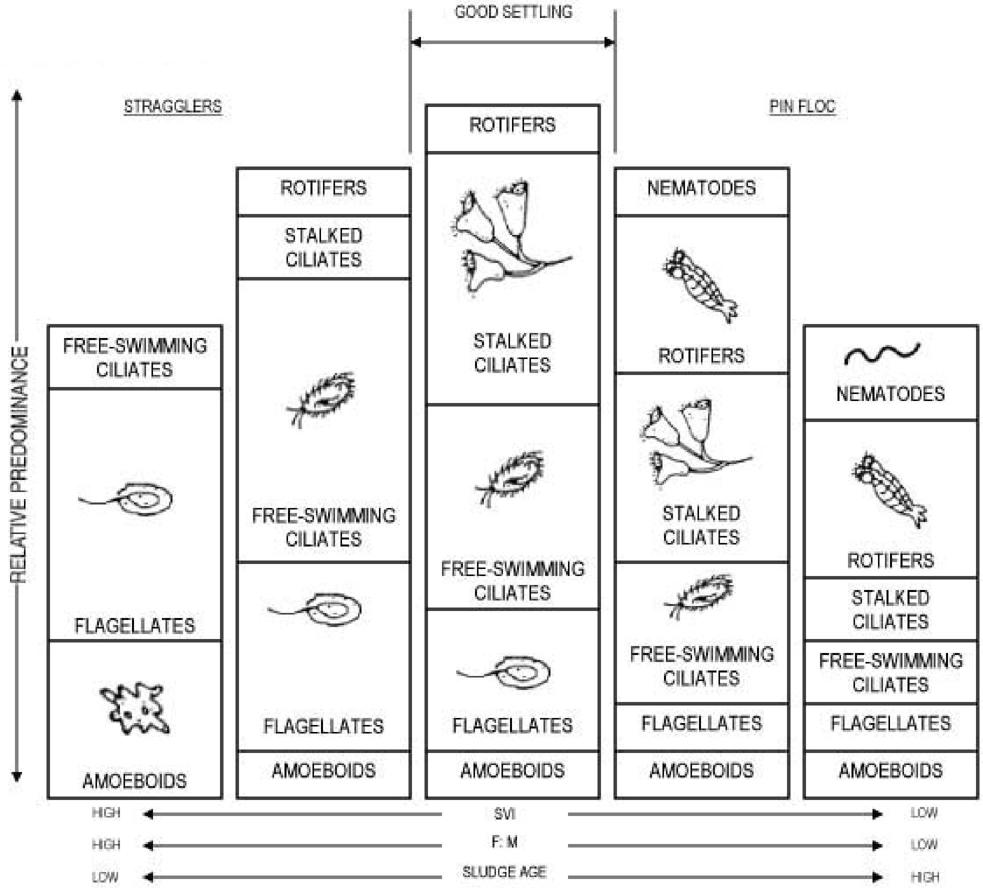
G. Toxicity

Incoming wastewater to a treatment plant may at times contain materials or compounds that are toxic to microorganisms. Depending on the concentration of toxic material, microorganisms could be destroyed or their metabolic rates affected, thus impairing the wastewater treatment plant efficiency.

1.2.4 Describe the types of protozoa and organisms commonly found in activated sludge and observable under a microscope.

Protozoa are single-celled microscopic organisms, several hundred times larger than bacteria. It is the protozoa we observe under a microscope since bacteria are actually too small to see. There are four types of protozoa commonly found in activated sludge systems. They are identified by their method of movement within the wastewater environment. The four types are: amoebae, ciliates (free-swimming and stalked), flagellates, and suctoreans. Rotifers are multi-celled (metazoa) organisms also commonly found in activated sludge systems. The relative predominance of these protozoa is commonly associated with the age of the activated sludge.

Figure 1.2.4.1



Source: CSU Sacramento, Operation of Wastewater Treatment Plants (Vol II, 6th ed.)

1.2.5 Describe the conditions that favor the growth of filamentous organisms in the activated sludge process.

The growth of filamentous organisms can occur due to the following conditions:

A. Low DO
B. Low food to mircoorganism (F/M) ratio
C. Low pH
D. High sulfides
E. Nutrient deficiency
F. Excessive grease

1.2.6 Describe the environmental conditions necessary to support the growth of nitrifying bacteria.

Nitrifying bacteria convert ammonia to nitrate. They work best under the following environmental conditions:

A. DO greater than 1.0 mg/L
B. pH between 7.0 and 8.5
C. Alkalinity greater than 50 mg/L
D. Temperature between 50ºF and 85ºF (10ºC to 30ºC)

1.2.7 Describe the environmental conditions needed for the growth of denitrifying bacteria.

Denitrifying bacteria convert nitrite and nitrate to nitrogen gas. They work best under the following environmental conditions:

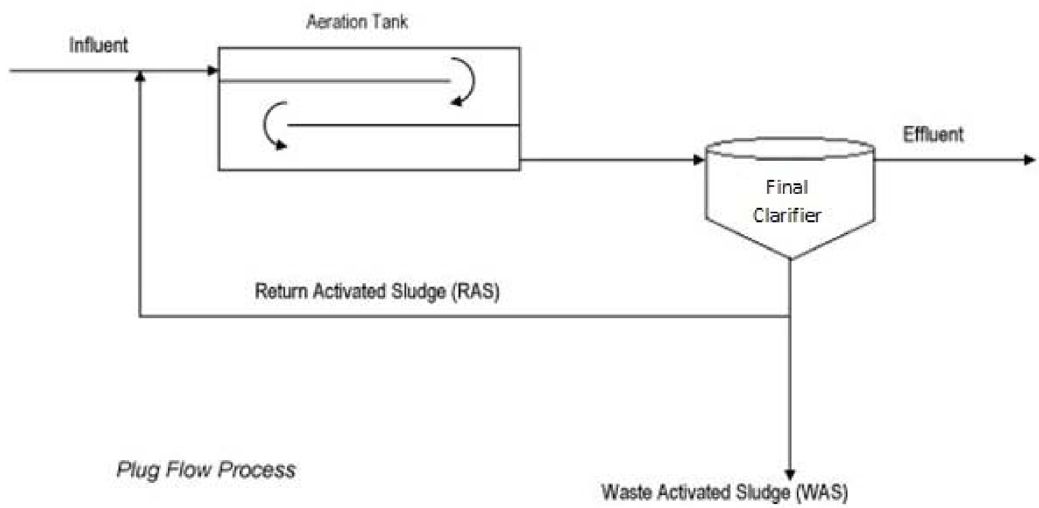
A. DO less than 0.2 mg/L
B. pH between 7.0 and 8.5
C. Adequate organic matter (BOD)
D. Temperature between 50ºF and 85ºF (10ºC to 30ºC)

Section 1.3 - Process Variations

1.3.1 Describe conventional plug-flow activated sludge process.

Conventional plug-flow activated sludge is a process in which influent and returned activated sludge (RAS) enters at the head of the aeration tank and travels through the tank at a constant rate to the point of discharge. The sludge age is generally less than 15 days, usually best between 3 and 10 days.

Figure 1.3.1.1

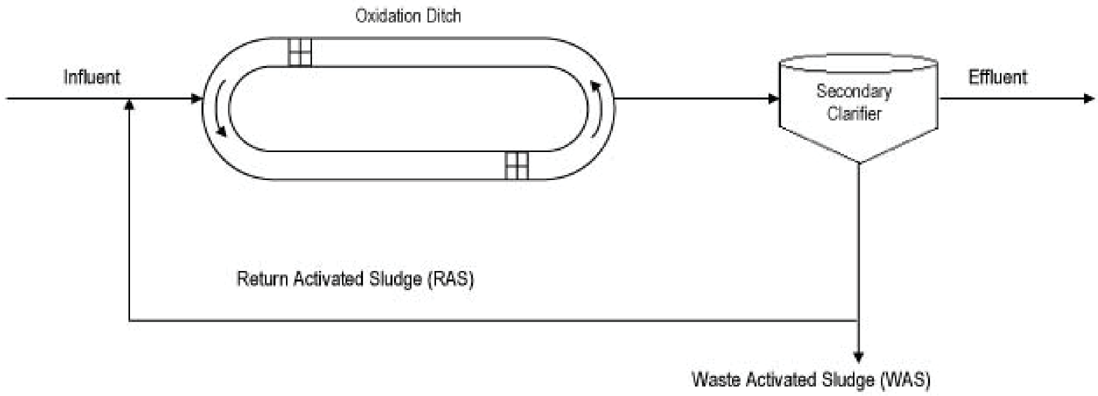


Source: Amy Garbe (WDNR) and Operation of Municipal Wastewater Treatment Plants, Water Environment Federation (WEF) (Vol. II, 6th ed.)

1.3.2 Describe the extended aeration activated sludge process.

Extended aeration uses conventional plug flow patterns, however, the aeration tanks are larger to provide for over 15 hours of hydraulic retention times (HRT). The sludge age is typically greater than 15 days, usually best between 15 and 30 days. This results in a highly treated effluent, and less wasted activated sludge (WAS) produced. The oxidation ditch is a variation of the extended aeration process.

Figure 1.3.2.1



Oxidation Ditch Process

Source: Amy Garbe (WDNR) and Operation of Municipal Wastewater Treatment Plants, Water Environment Federation (WEF) (Vol. II, 6th ed.)

1.3.3 Describe other variations of the activated sludge process.

A. Step-feed

In the step-feed process, primary effluent is added at two or more points along the length of the aeration tank (see figure 1.3.3.1). This configuration spreads out the organic load and evens out the oxygen uptake rate throughout the length of the basin. This configuration also allows for better control in handling shock loads and lower mixed liquor suspended solids (MLSS) to the final clarifiers.

B. Contact stabilization

A two-tank process of activated sludge treatment (see figure 1.3.3.2). The first tank (contact tank) has a short detention time, followed by clarification. The settled sludge is pumped to a second tank (re-aeration tank) with a much longer detention time. The advantages of contact stabilization are less total tank volume required than that needed for conventional processes, and it reduces the potential loss of MLSS through washout. Contact stabilization may be applicable when stringent effluent limits are not required.

C. Complete mix

An activated sludge process where the contents of the entire aeration tank are rapidly mixed to provide a uniform distribution of food (biochemical oxygen demand (BOD)), microorganisms, and dissolved oxygen (DO) (see figure 1.3.3.3). An advantage is the ability to handle surges in loading. This process is used when a high quality effluent is not required. Complete mix is most commonly used in industrial activated sludge plants.

D. Sequencing batch reactors (SBRs)

The SBR is a modification of the activated sludge process that treats wastewater in batches as opposed to a continual or flow-through basis (see figure 1.3.3.4). In most facilities, the use of an SBR requires at least two reactor vessels so that wastewater can be accepted at all times.

There are a great number of variations based on proprietary mechanisms and processes in SBR treatment, but all systems have a sequence of at least four steps that need to occur for the proper operation of the systems. The four treatment steps need to include:

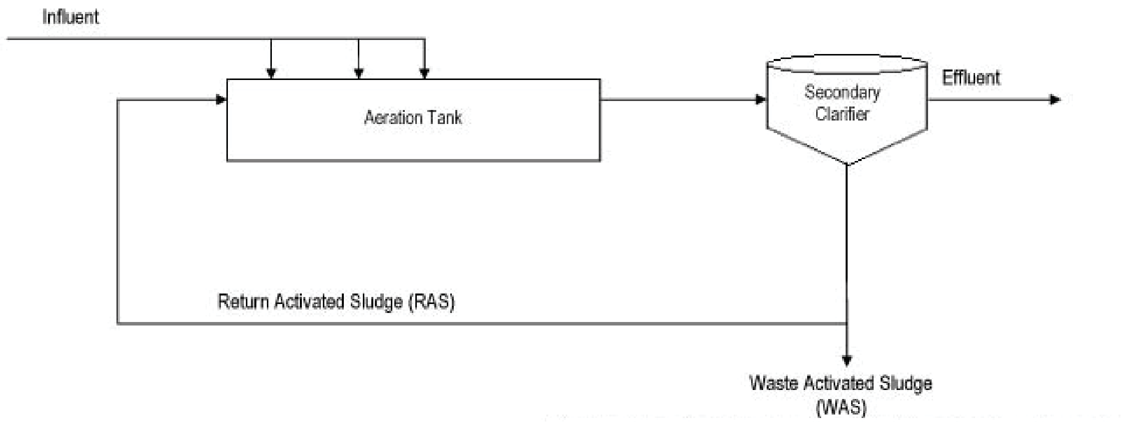
1. Fill
2. React
3. Settle
4. Decant and sludge waste

SBRs that remove nutrients may have additional steps in the sequence. SBRs provide secondary treatment within a smaller footprint because final clairfiers are not used in the process, but the process requires a more sophisticated control system.

E. Others

There are many other variations of the activated sludge process, some proprietary, and the reader can read the references at the end of this study guide for other variations of the activated sludge process.

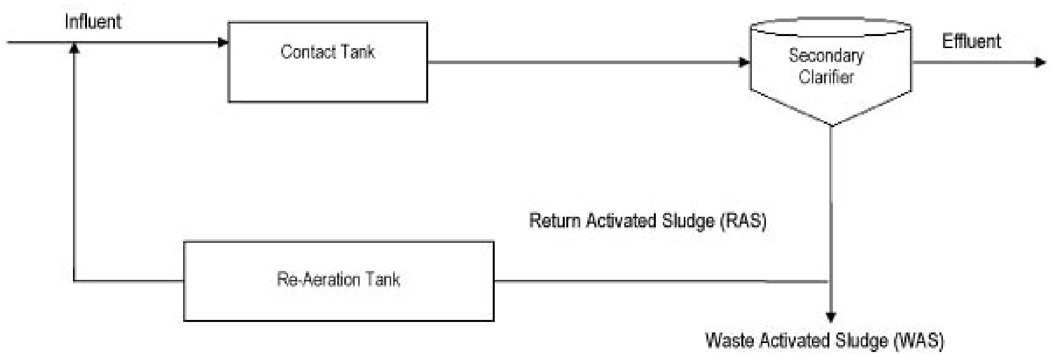
Figure 1.3.3.1



Step Feed Process

Source: Amy Garbe (WDNR) and Operation of Municipal Wastewater Treatment Plants, Water Environment Federation (WEF) (Vol. II, 6th ed.)

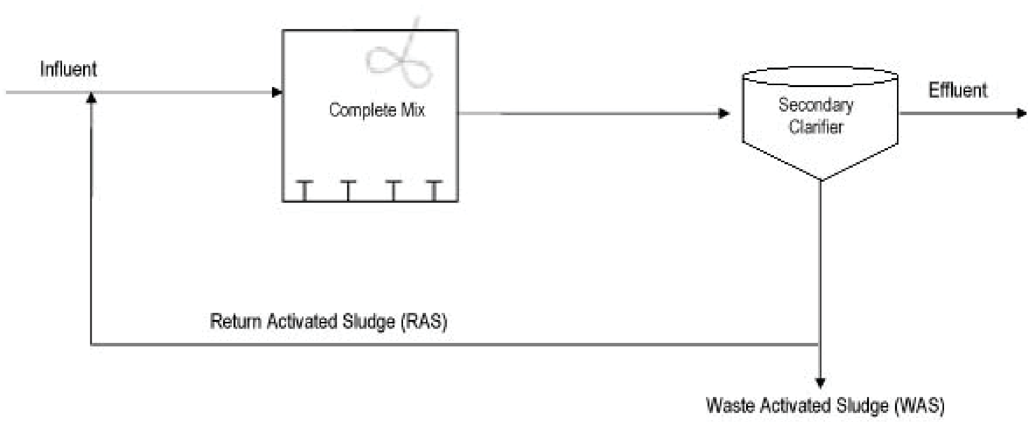
Figure 1.3.3.2



Contact Stabilization Process

Source: Amy Garbe (WDNR) and Operation of Municipal Wastewater Treatment Plants, Water Environment Federation (WEF) (Vol. II, 6th ed.)

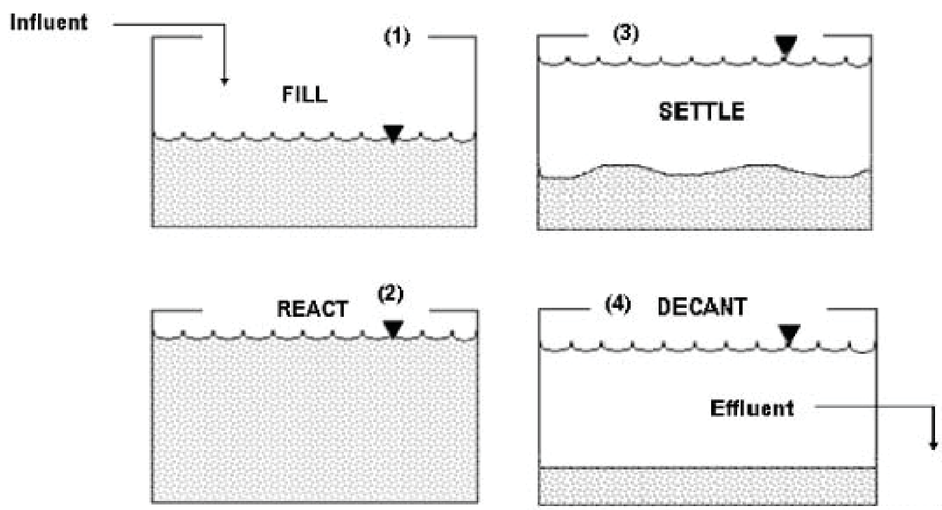
Figure 1.3.3.3



Complete Mix Process

Source: Amy Garbe (WDNR) and Operation of Municipal Wastewater Treatment Plants, Water Environment Federation (WEF) (Vol. II, 6th ed.)

Figure 1.3.3.4



Sequencing Batch Reactor Process

Source: Amy Garbe (WDNR) and Operation of Municipal Wastewater Treatment Plants, Water Environment Federation (WEF) (Vol. II, 6th ed.)

Chapter 2 - Operation and Maintenance

Section 2.1 - Definitions

2.1.1 Describe a diffused aeration system.

Diffused aeration is a method of introducing air at the maximum possible submergence. Oxygen is transferred into the liquid as the bubbles rise through the water to the surface. Because the retention time of the air bubbles is maximized, oxygen transfer is greater. The most common types of diffusers generate fine or coarse bubbles.

The major factors that influence energy consumption in a diffused aeration system are:

A. Type of aeration equipment
1. Fine bubble diffuser
2. Coarse bubble diffuser

B. Placement of diffusers on tank floor
1. Full tank floor coverage
2. Non-full tank floor coverage (i.e. side tank wall(s) or center of tank placement)

C. System operating pressure

D. Oxygen transfer efficiency (OTE) (following ASCE standard test protocol). OTE is a function of bubble size and diffuser placement.

E. Diffuser maintenance requirements

The most efficient system is a combination of fine bubble diffusers, full floor coverage diffuser placement, and an annual cleaning requirement.

A coarse bubble system placed in full floor coverage has low maintenance requirements but OTE is approximately half of a fine bubble diffuser.

A fine bubble diffuser system used in non-full floor coverage placement (side roll or center roll) is not any more efficient than a typical coarse bubble diffuser, but may require more maintenance than the coarse bubble diffuser.

[NOTE: A diffused aeration system consumes approximately half of all the power consumed in a wastewater treatment plant. Energy cost is based on air flow and system operating pressure.]

2.1.2 Define diffusers.

A diffuser is a perforated membrane, porous disc, or other device used for discharging air into the aeration basins.

2.1.3 Describe a mechanical aeration system.

Mechanical aeration is a method that forces oxygen and surface water down into the liquid with a mechanical mixing device. The most common types of mechanical aerators utilize paddles or discs, spray, or turbine mechanisms.

2.1.4 Define variable frequency drive (VFD).

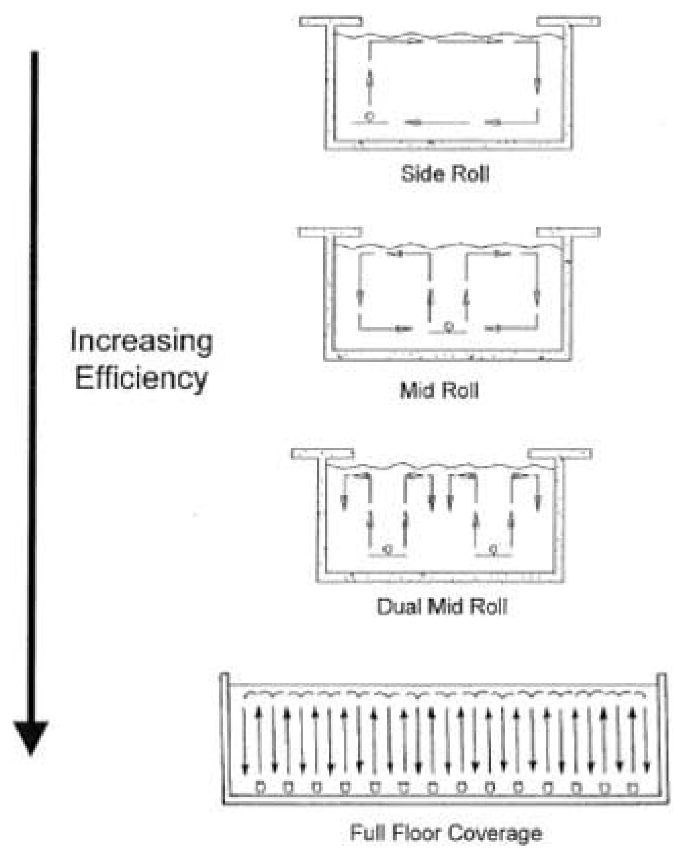
A VFD is a system for regulating the rotational speed of an alternating current (AC) electric motor by controlling the frequency of the electric power supplied to the motor.

Section 2.2 - Methods

2.2.1 Diagram full floor coverage, side roll, and center roll placement of diffusers.

Figure 2.2.1.1

Aeration Layout Efficiency Diagram



Source: Jim Shaw, Shaw Water Treatment and Sanitaire

Figure 2.2.1.2

2.2.2 Discuss the transfer of oxygen into wastewater.

In the activated sludge process, oxygen is transferred into wastewater by two methods: a diffused aeration system or a mechanical aeration system. Transfer efficiency depends on the contact time between the bubble and the liquid, the size of the bubble, and the turbulence of the liquid. Longer contact time, smaller bubbles, and more turbulence of the liquid creates greater transfer efficiencies.

2.2.3 Describe the common process control methods for wasting sludge from activated sludge process.

A. Constant mixed liquor suspended solids (MLSS)
Provided the influent loadings are constant, the operator maintains a relatively constant solids inventory (MLSS level) in the aeration basins for a desired level of treatment. The range of MLSS is typically between 1,000 and 4,000 mg/L.

B. Food to microorganism ratio (F/M)
For microbiological health and effective treatment, the microorganisms (MLSS) under aeration should be maintained at a certain level for the amount of food (influent biochemical oxygen demand (BOD)) coming into the plant. This is known as the F/M ratio. For conventional activated sludge, the F/M ratio is usually between 0.2 and 0.5. For extended

aeration systems, such as package plants and oxidation ditches, the F/M ratio should be between 0.03 and 0.10.

C. Sludge age
Activated sludge is recycled back through the aeration basins by returning settled sludge (recycled activated sludge (RAS)) in the final clarifiers and thus remains in the activated sludge system for a number of days. For effective treatment, a certain sludge age is desired for the type of activated sludge system. For conventional activated sludge, a sludge age of 3 to 10 days is typical. For extended aeration activated sludge, older sludge ages of 15 to 30 days are common.

All three process control methods are regulated by wasting sludge. It is the key to controlling the activated sludge process. The operator should monitor MLSS, F/M ratio, and sludge age to waste accordingly and thus ensure optimal operations and process stability.

2.2.4 Discuss the relationship between sludge age and F/M ratio.

F/M ratio and sludge age are inversely related (1 divided by the sludge age approximates the F/M ratio). The older the sludge, the lower the F/M ratio; conversely, the younger the sludge, the higher the F/M ratio.

2.2.5 Explain how solids are generated in an aeration basin, and the consequences to the operation if excess solids are not removed (wasted).

Solids are generated by microorganism growth and reproduction. The influent BOD supplies the food for the growth and reproduction. As microorganisms' populations multiply, excess solids (microorganisms) must be removed (wasted). If excess solids are not removed, the MLSS and sludge age will increase and process efficiency will be lowered. Sludge settling rates are affected. Eventually, if excess solids do not get wasted, they can overflow the clarifier weirs and into the receiving water.

2.2.6 Describe the affect of waste activated sludge (WAS) concentration on desired wasting rates.

The concentration of WAS has a direct bearing on how much to waste and the volume wasted. On a volume basis, a thicker WAS (high WAS concentration) will require less amount of wasting than a thinner WAS (low WAS concentration).

2.2.7 Discuss the importance of wasting sludge on a regular basis.

Wasting sludge is the most important operational process control of the activated sludge process. By wasting sludge on a consistent basis, preferably daily, the biomass within the aeration tank will remain healthy and at a consistent MLSS level.

2.2.8 Discuss factors that influence the flow rates of RAS.

A. Clarifier sludge blanket
Solids settle and concentrate in the final clarifiers forming a sludge blanket. The sludge blanket can increase or decrease depending on the RAS flow rate. The proper RAS flow rate allows for a desired sludge blanket.

B. RAS concentration
Varying the RAS flow rate will affect the concentration and detention time of clarified solids. Adjusting the RAS pumping rate allows the return of more or less concentrated solids while also increasing or decreasing the depth of the sludge blanket. RAS flow rates can be paced off influent flow rates.

C. Final clarifier solids loading rate (SLR)
The rate at which the activated sludge is returned from the final clarifiers to the aeration basins, along with the influent flow, affects the flow of solids into the clarifiers. Aeration basin MLSS must have sufficient time to settle and be returned or wasted in the activated sludge system. Clarifiers are designed for certain solids loading rates that should not be exceeded.

D. Denitrification
When RAS flow rates are too low, thick sludge blankets in the final clarifier can result. The operator will see gas bubbles (from nitrogen gas) and rising or floating sludge clumps on the clarifier surface.

2.2.9 Discuss the methods of controlling dissolved oxygen (DO) levels in diffused air systems.

A. By controlling air valves
B. By controlling the blower output such as using variable frequency drives (VFD)
C. By increasing or decreasing the number of blowers in operation
D. Cleaning or replacing diffusers
E. Changing the number of diffusers
F. Process control (ex: MLSS levels)

2.2.10 Discuss the methods of controlling DO levels in mechanical aeration systems.

A. Increasing or decreasing the aerator speed by using VFDs
B. Increasing or decreasing the aerator submergence by adjusting the tank water level
C. Increasing or decreasing the number of aerators in operation
D. Process control (ex: MLSS levels)

[NOTE: Throttling air valves with a positive displacement blower will not reduce air flow output but will raise operating pressure of the blower with high electric cost as the result. Throttling an inlet air valve on a centrifugal blower will reduce air discharge flow.]

2.2.11 Discuss the factors that most influence energy consumption in a diffused aeration system.

A diffused aeration system consumes approximately half of the power consumed in a wastewater treatment plant.

A. Equipment
1. Type of aeration system diffusers (ultra-fine bubble, fine bubble, or coarse bubble)
2. Diffuser placement on the tank floor (full floor coverage, side placement, or center placement)
3. System operating pressure
4. Oxygen transfer efficiency (OTE) (following ASCE standard test)

B. Operations
   1. Diffuser maintenance
   2. MLSS
   3. Excess process DO

The most efficient aeration system is a combination of fine bubble and high OTE with the diffusers placed in full floor coverage with a mid-range system pressure (6 to 8 psi) and annual cleaning. A coarse bubble diffuser system placed in full floor coverage has low maintenance requirements but a much lower OTE (about half of fine bubble diffusers). Fine bubble diffusers used in a side roll or center roll placement are not any more efficient than a similarly placed coarse bubble diffuser and may require more maintenance.

2.2.12 Outline the startup procedures for the activated sludge portion of a treatment plant. Prior to any startup activity for new equipment, installation service and training of the plant staff by a qualified person must have been completed.

A. Inspect all ground water relief valves operation and insure they are: clean, seat properly, and operate freely
B. Inspect aeration basin for debris and remove
C. Check blowers for proper oil level, lubrication, and rotation
D. Fill aeration basin with clean water 6 inches above diffusers and piping; check air system for level and leaks; tighten, adjust, and repair
E. Inspect final clarifiers for debris and remove
F. Check final clarifiers for proper oil level, lubrication, and rotation
G. Turn on and rotate final clarifier sludge collector at least 2 complete rotations checking for proper operation
H. Check RAS and WAS pumps for proper oil level, lubrication, and rotation
I. Start filling the aeration basin at a low flow rate, directing flow away from the air piping and diffusers to minimize potential damage to the aeration system
J. Start blowers and add seed sludge if available after diffusers are submerged
K. Allow flow from aeration basin to overflow into clarifier
L. Start sludge collector mechanism when water level reaches the bottom of the weirs
M. Open isolation valves (suction and discharge) at the RAS and WAS pumps, purge air from pumps and turn on the pumps
N. Turn on power to RAS and WAS flow meters
O. Allow the MLSS to reach the target level before beginning to waste

2.2.13 List the steps that might be taken to speed up the formation of sufficient MLSS when starting or restarting an activated sludge plant.

A. Obtain seed activated or return sludge without filamentous organisms from a nearby plant
B. Returned sludge from the final clarifier should be recirculated at a medium to high rate to build up solids
C. Limit wasting any sludge until a targeted MLSS is established

2.2.14 List the strategies for dealing with extreme weekly or seasonal fluctuations in loading rates.

A. Weekly

If loadings can be anticipated, adjust MLSS as needed. If the loading is from industry, consideration should be given to flow equalization at the plant and/or the industry. In addition, consideration should be given to a pretreatment system at the source to minimize loading rates.

B. Seasonal
Seasonal loading changes most likely occur where there is a large population fluctuation (a large tourist community or a school). Another seasonal loading change could occur from industries, such as a connected vegetable packing cannery. Adjust MLSS or add/remove tankages from service.

2.2.15 List the operational modifications an operator of an activated sludge system must make to change-over from summer to winter operations.

A. Increase the MLSS concentration
B. Winterize equipment and tankage to prevent freezing problems

Section 2.3 - Equipment

2.3.1 List the basic components of an activated sludge system.

A. Aeration tank
B. Blowers and diffusers or mechanical aerators
C. Clarifiers
D. Waste activated sludge (WAS) and recycle activated sludge (RAS) pumps

2.3.2 Describe the purpose of the aeration system.

The aeration system in the activated sludge provides oxygen to the microorganisms and mixes the contents of the aeration basins. The mixing brings the wastewater pollutants into contact with the microorganisms to treat the wastewater and reduce the pollutants.

2.3.3 Discuss the types of blowers used in activated sludge aeration systems.

A. Centrifugal
A blower consisting of an impeller fixed on a rotating shaft and enclosed in a casing having an inlet and a discharge connection. A centrifugal blower output will vary depending on output pressure. The primary drawback of a centrifugal blower is that they cannot achieve the high compression ratio of positive displacement blowers without multiple stages.

B. Positive displacement (PD)
A PD blower forces air to move by trapping a fixed amount, then displacing that trapped volume into the discharge pipe. PD blowers will produce the same flow at a given speed no matter the discharge pressure. This type of blower operating against a closed discharge valve will continue to produce flow until the pressure causes the line to burst or the pump is severely damaged. A relief or safety valve on the discharge side of the PD blower is a necessary component.

2.3.4 Discuss the types of diffusers used in activated sludge systems.

A. Fine bubble aeration diffuser

A fine bubble aeration diffuser is a device through which air is pumped and divided into very small bubbles that are used to introduce and dissolve oxygen (DO) into the liquid. Fine bubble diffusers are normally disks or tubes that use membranes or ceramic materials to create the bubbles and gentle mixing action. Fine bubble diffused aeration utilizes full floor coverage in order to be effective and energy efficient.

B. Coarse bubble aeration diffuser
A coarse bubble aeration diffuser is a device through which air is pumped and divided into large bubbles that are transferred and dissolved into the liquid. Coarse bubble diffusers normally discharge air at a high rate and are installed to induce a spiral or cross roll mixing pattern. Coarse bubble diffusers are typically installed in a non-clogging application.

2.3.5 Compare the performance of fine bubble to coarse bubble diffused air systems.

A grid of fine bubble diffusers on the floor of an aeration basin has a much higher oxygen transfer efficiency (OTE) and will require less air volume than coarse bubble diffusers. This represents energy savings for blower operation. Fine bubble diffusers require more maintenance (cleaning) than coarse bubble diffusers.

2.3.6 Discuss the use of variable frequency drives (VFD) in activated sludge systems.

The ability to adjust motor speed with a VFD enables closer matching of motor output to changing process load requirements and often results in energy savings. VFDs are commonly used in many applications in an activated sludge system such as with blowers, aerators, RAS and WAS pumps. Maintenance costs may also be lower, since lower operating speeds can result in longer life for bearings and motors.

2.3.7 List the advantages of VFDs.

A. Match performance to demand
B. Eliminate need to store pressure
C. Constant line pressure
D. Constant tank level
E. Energy savings
F. Reduced voltage starting ("soft start", ramp time 1 to 4 sec)
G. Motor protection in controller
H. Phase converter
I. Installation easy and fast

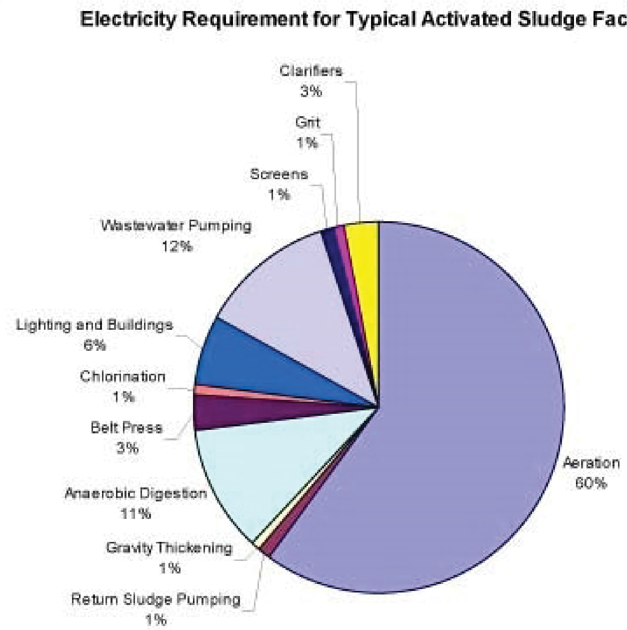
2.3.8 Describe air lift pumps and their use in small activated sludge plants.

Air lift pumps are mostly used in small activated sludge plants to return and waste sludge from the system. They operate on the principle of water and air displacement. Air lift pumps are prone to plugging, especially at low return flow rates. Operators should closely monitor these pumps to ensure sludge is being returned at all times.

2.3.9 Discuss energy usage in an activated sludge process.

The aeration system of an activated sludge uses the largest percentage (60% or more) of the energy in the treatment process. Wastewater pumping is another large energy user (12%) at a wastewater plant. Energy usage can be reduced with cost savings by having energy-efficient aeration systems, blowers, motors, and pumps.

Figure 2.3.9.1



Source: Joseph Cantwell, Focus on Energy (2009)

Section 2.4 - Preventative Maintenance

2.4.1 List the maintenance considerations for a diffused aeration system.

A. Centrifugal blowers
1. Unusual noise or vibrations
2. Lubrication of blowers and motors
3. Check and lubricate couplings
4. Check discharge pressure and temperature
5. Check filters and obstructions
6. Check amperage meter

B. Positive displacement blowers
1. Unusual noise or vibrations
2. Lubrication of blowers and motors
3. Check and lubricate couplings
4. Check and exercise pressure relief valve
5. Check discharge pressure and temperature
6. Check filters and obstructions
7. Check blower seals
8. Check drive belt alignment and tension

All maintenance and repairs should be documented. Consult the O&M manual for all maintenance needs.

2.4.2 List the maintenance considerations for a mechanical aeration system.

A. Consult the O&M manual for the lubrication needs of the motor, gear box, shaft, and others
B. Inspect aerators
C. Check for unusual vibration

All maintenance and repairs should be documented.

2.4.3 List the maintenance considerations for diffusers.

A. Check surface aeration patterns for uneven distribution
B. Check air line pressure reading
C. Check and purge moisture as needed
D. Drain, inspect, and clean the aeration tanks annually

All maintenance and repairs should be documented. Consult the O&M manual for additional maintenance needs.

2.4.4 Compare the maintenance requirements of fine bubble to coarse bubble diffuser systems.

A. Course bubble aeration systems
  1. Aeration basins should be drained annually
  2. Remove excess settled solids that have accumulated
  3. Clean diffusers and piping assemblies as needed
  4. Inspect all hardware and components
  5. Repair, replace, and tighten components as needed
  6. Refill aeration tank following startup procedures

B. Fine bubble aeration systems
  1. Aeration basins should be drained annually
  2. Drain aeration basin and leave air on
  3. Remove excess settled solids that have accumulated
  4. With air on, hose off and wash each diffuser with clean water
  5. With air off, if needed scrub each diffuser with either a soft bristle brush or rag
  6. Turn air back on and repeat hosing procedure for each diffuser
  7. Inspect all hardware and components
  8. Repair, replace, or tighten components as needed
  9. Refill aeration tank following startup procedures

2.4.5 Discuss the importance of routine preventative maintenance of aeration basins and clarifiers.

Aeration basins and clarifiers should be emptied on a regular basis to:

A. Perform a detailed inspection of the structure, valves, and control gates
B. Clean out grit and settled solids
C. Maintain equipment and piping

When emptying aeration basins and clarifiers, an operator should be aware of structural and operational effects. Notify the Department of Natural Resources of scheduled maintenance activities as given in the standard conditions of the Wisconsin Pollution Discharge Elimination System (WPDES) permit.

Chapter 3 - Monitoring, Process Control, and Troubleshooting

Section 3.1 - Definitions

3.1.1 Define 30-minute settling test.

A sample of mixed liquor is taken as it exits the aeration tank. It is mixed, and then allowed to settle for 30 minutes in a 1,000 mL beaker or cylinder. This test shows the sludge settling characteristics and the clarity of the water on top of the sludge. It reflects the performance of the final clarifier and can be used to help diagnose clarifier settling problems.

3.1.2 Define bulking.

An activated sludge that does not settle well and may overflow the weirs of the final clarifiers resulting in excess suspended solids in the effluent is described as bulking. It is usually caused by filamentous organisms.

3.1.3 Define filaments.

Filamentous organisms are a group of thread-like organisms, when in excess, can impair the settling of activated sludge and create a bulking condition in the final clarifier.

3.1.4 Define hydraulic load.

Hydraulic load is the flow entering the plant, measured in million gallons per day (MGD).

3.1.5 Define pin floc.

Very fine floc particles with poor settling characteristics, usually indicative of an old sludge (high mixed liquor suspended solids (MLSS) levels).

3.1.6 Define short-circuiting.

Short-circuiting is an uneven flow distribution in a wastewater tank. Density currents occur in some parts of a tank and the wastewater travel time (detention time) is less than in other parts of the tank.

3.1.7 Define straggler floc.

Straggler floc is a small, light, and fluffy floc particles with poor settling characteristics, usually indicative of a younger sludge and/or low MLSS levels.

Section 3.2 - Sampling and Testing

3.2.1 Explain the difference between mixed liquor suspended solids (MLSS) and mixed liquor volatile suspended solids (MLVSS).

MLSS represents all the suspended solids in the mixture (inorganic and organic). MLVSS represents only the organic amount known as the volatile portion. It is this fraction that is considered the alive and active portion of the suspended solids for treatment. The normal range of volatile portion in a mixed liquor sample is usually between 60 and 80%.

3.2.2 List common indicator organisms one would see when looking under a microscope at a sample of activated sludge.

A. Amoeba
B. Flagellates
C. Free swimming ciliate
D. Crawling ciliate
E. Single stalked ciliate
F. Community stalked ciliate
G. Rotifer
H. Filamentous organism

Figure 3.2.2.1

Source: Auralene Glymph, Microbiologist

3.2.3 Describe the importance of using a microscope for monitoring the activated sludge process.

A microscope is used to examine the microorganism population and determine the relative health and age of the activated sludge system. The microscope, when regularly used, can tell the operator a lot about the activated sludge system and can greatly aid an operator in running the plant. It is one of the most important process control tools an operator can use.

Protozoa in the activated sludge process are single-celled microscopic organisms, several hundred times larger than bacteria. It is easier to see protozoa under the microscope since bacteria are very small and difficult to see. Protozoa (i.e. amoeba, flagellates, and ciliates) and Metazoa (rotifers, nematodes, and waterbear) are indicator organisms in the activated sludge process. Microscope magnifications are usually 10x, 20x, 40x, and 100x. For most wastewater organisms, an operator will most likely be using 10x and 40x. Oil immersion is used at 100x to provide a very clear image of the organism at such a high power. In wastewater treatment systems, stains are used to help differentiate types of filamentous bacteria.

All activated sludge plants should have a good microscope in their laboratory. The operator of an activated sludge plant is highly advised to take classes and training on the proper use of a microscope and in protozoa, metazoa, and filamentous organism identification.

3.2.4 List and discuss the process control equipment used for monitoring an activated sludge plant.

A. Dissolved oxygen (DO) meter
A DO meter is used to monitor aeration basin dissolved oxygen levels. Many plants have in-line DO sensors to automatically control DO levels. If manual measurements are made, they should be taken in each aeration basin using a field DO probe.

B. Settleometer
Used to monitor sludge settling characteristics in 30 minutes. A 1,000 mL beaker or cylinder is most commonly used. The MLSS sample for this test should be collected just before it goes to the final clarifier.

C. Sludge blanket finder
Used to measure the depth of settled sludge in the bottom of a clarifier. A clear core sampler (Sludge Judge®) or an electronic device is most commonly used. Samples are usually collected before and after the scraper mechanism both near the well, midway, and near the sidewall. When and where the sludge depth is measured, be consistent each day.

D. Microscope
A microscope is used to observe the population and health of microorgansims living in an activated sludge system. The settled MLSS sample used for the 30-minute settling test can be used for the microscopic observation sample.

E. pH/temperature meter
A pH/temperature meter is used to measure pHs and temperatures of wastewater entering the plant and the aeration basins.

F. Flow meters
Flow meters are used to measure influent, sidestream, recycle activated sludge (RAS), waste activated sludge (WAS), and effluent flows.

3.2.5 List common process control tests used for operating an activated sludge treatment plant.

A. Sight and smell
B. DO, pH, and temperature
C. 30 minute settling test and settling curve
D. Sludge volume index (SVI)
E. Sludge age
F. Food to microorganism (F:M) ratio
G. RAS flow and concentration
H. WAS flow and concentration

I. MLSS and MLVSS
J. Clarifier sludge depths
K. Microscope

There is no one process control test that is best, although MLSS is the most common and widely used.

The best process control test(s) for operating an activated sludge plant is a variety of tests.

3.2.6 Discuss the following tests in monitoring activated sludge operations:

A. Soluble biochemical oxygen demand (BOD)
(Standard Method 5210B) This is the measure of the oxygen demand (as BOD mg/L) of soluble forms of organic matter that remains in the wastewater after it has been filtered in the standard total suspended solids (TSS) test as BOD (mg/L).

B. Carbonaceous biochemical oxygen demand (CBOD)
(Standard Method 5210B) This test is used to measure the oxygen demand of carbonaceous material in a wastewater sample as CBOD (mg/L). This test includes the use of a nitrogenous demand inhibitor to exclude the oxygen demand of ammonia and organic nitrogen.

C. Chemical oxygen demand (COD)
(Standard Method 5220) This test is used to rapidly measure the oxygen demand of both organic and inorganic matter by using a chemical oxidant as COD (mg/L).

3.2.7 Discuss real time in-line monitoring in the operations of an activated sludge treatment plant.

Real time in-line monitoring allows for better process control and energy efficiency of the activated sludge process. Instrumentation and monitoring equipment are installed directly in the tankages for automatic and continuous readings. Process adjustments and timely operational changes can then be made, if needed, that keep the activated sludge process stable and optimally running.

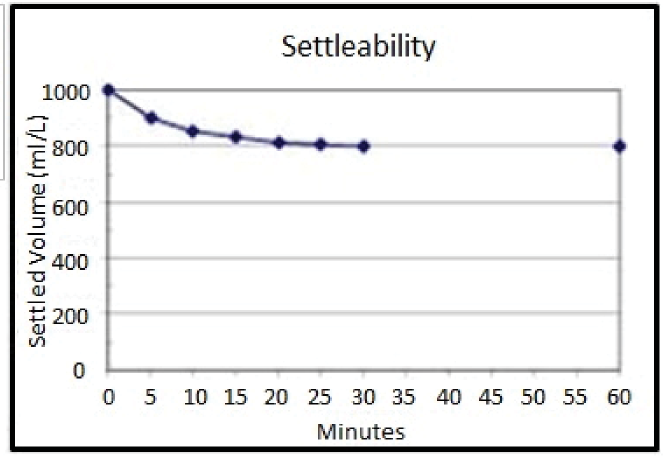
Sampling and in-line testing of various pollutants of interest (such as pH, ammonia, orthophosphorus, etc) allows for a rapid assessment of the treatment occuring in various stages of the plant and troubleshooting any treatment problems or variability. Pacing blower output from in-line aeration basin DO sensors provides for greater energy efficiency by delivering oxygen based on the incoming waste load. RAS flow rates can be adjusted based on influent flow rates to help maintain a more consistent sludge blanket in the clarifiers and more consistant MLSS concentrations in the aeration basin. The use of and placement of in-line monitoring probes and sensors is dependent upon treatment objectives.

3.2.8 Graph a settleability curve and discuss its meaning.

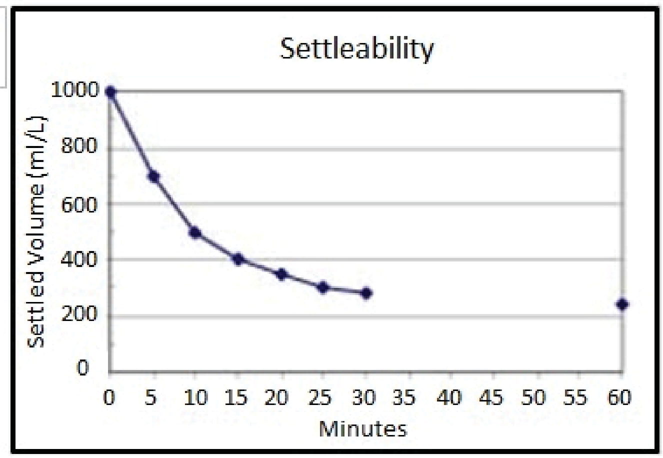
A settleability curve can be graphed using the results of the 30-minute settling test. The shape of the settling curve indicates the settling characteristics of the activated sludge. It shows how the sludge settles and is helpful in assessing settling problems.

Figure 3.2.8.1

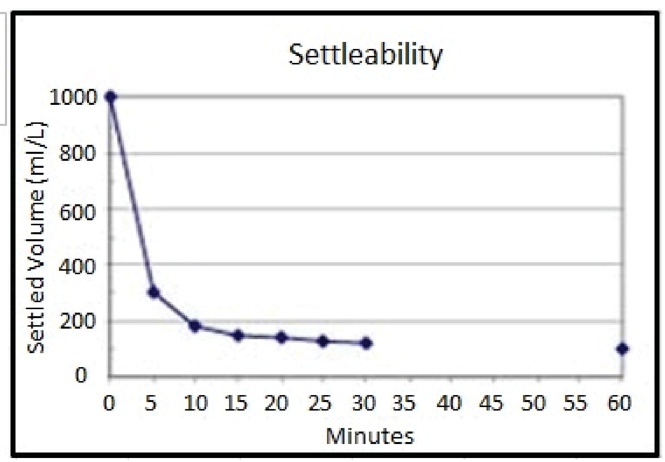
This graph indicates a young sludge that may settle poorly, possibly due to excessive filamentous organisms, slime bulking, or just too many solids in the system (hindered settling).



This graph shows a good settling sludge.



This graph is characteristic of old, fast settling and grainy sludge, often described as 'settles like a rock'.



Section 3.3 - Data Understanding and Interpretation

3.3.1 Describe the characteristics of healthy acitvated sludge.

The color of healthy activated sludge is tan to brown. It would have an earthy odor. During a 30-minute settling test, the settled sludge volume would be 200 to 300 mL/L. The sludge volume index (SVI) would be 80 to 150. The supernatant would be clear with little or no floc particles. Sludge age for conventional systems would be 3 to 10 days and 15 to 30 days for extended aeration systems. A healthy sludge has good floc (solids) and water separation with a resultant observed marbling appearance in the quiescent part of the aeration basin (see key knowledge 1.1.9).

3.3.2 Discuss the characteristics of young and old activated sludge.

A. Young sludge
Young sludge consists of sludge which has not yet reached a high enough sludge age to be most effective in a particular activated sludge process. Billowing, whitish foam is an indicator that the sludge age is too low. Young sludge will often have poor settling characteristics in the clarifier and can leave straggler floc in the clarifier effluent. Young sludge is often associated with a high food to microorganism (F/M) ratio. To correct for young sludge, it is necessary to decrease wasting rates. This will increase the amount of solids under aeration, reduce the F/M ratio, and increase the sludge age.

B. Old sludge
Old sludge consists of sludge in which the sludge age is too high to be most effective in a particular activated sludge process. Dark brown foam and a somewhat greasy or scummy appearance is an indicator of old sludge. Settling in the clarifier is rapid, but pin floc can be present in the effluent and the effluent is hazy. Old sludge is often associated with a low F/M ratio. To correct for old sludge, it is necessary to increase wasting rates and return less sludge to the aeration basin. This will reduce the amount of solids under aeration, increase the F/M ratio, and decrease the sludge age.

3.3.3 Describe the visual observations an operator can make to support process control data indicating the following conditions:

A. Filamentous bulking sludge
The sludge blanket in the final clarifier will be near the surface, often with solids going over the weirs. Confirm by microscopic examination.

B. Nocardia filaments present
Thick, greasy, dark tan foam on aeration basins and possibly on final clarifiers. Confirm by microscopic examination.

C. Return rates too low
Thin mixed liquor suspended solids (MLSS) and a sludge blanket build up of solids. Rising clumps of sludge or gas bubbles may occur in the final clarifier.

D. Return rates too high
No sludge blanket in the final clarifier and a thin returned activated sludge (RAS).

3.3.4 Explain why some activated sludge plants must meet ammonia nitrogen limits.

Ammonia is toxic to fish and aquatic life and its toxicity is temperature and pH dependent. The actual limits for ammonia nitrogen are calculated based on stream flow, stream temperature, stream pH, and the type of fishery classification.

3.3.5 List three factors that affect dissolved oxygen (DO) in aeration basins, and explain how they affect plant operation.

A. Biochemical oxygen demand (BOD) loading
An increase in influent BOD (food) will increase oxygen demand and more aeration may be required to treat the incoming BOD.

B. Temperature
An increase in wastewater temperature lowers the solubility of oxygen in water thus requiring more air. This usually happens during summer operations.

C. Toxicity
A loss of viable bacteria in the aeration basin may result in higher than normal DO because dead bacteria will be unable to consume the oxygen supplied. The source of the toxicity should be identified and eliminated and the mixed liquor may need to be wasted from the plant to remove the dead bacteria. Seeding may be necessary.

Section 3.4 - Sidestreams and Recycle Flows

3.4.1 Discuss the possible impact of sidestreams or recycle flows back to the activated sludge process.

Sidestreams or recycle flows usually come from solids handling treatment or dewatering processes, such as decanting digesters or sludge storage tanks. Sidestreams may be high in biochemical oxygen demand (BOD), total suspended solids (TSS), ammonia, phosphorus, and sulfides or very low in temperature. It is best to return sidestreams slowly and regularly so microorganisms adjust and acclimate to this loading. If permit limits phosphorus or ammonia, it is critical to know the loading from sidestreams. Sidestreams can upset a treatment plant or result in a pass-through of pollutants to the effluent, resulting in permit violations. If permit limits phosphorus or ammonia, sometimes it is necessary to separately treat the sidestream.

3.4.2 List common sidestreams within a treatment plant.

The most common sidestreams are from:

A. Thickening and dewatering process
1. Gravity belt thickening filtrate
2. Centrifuge centrate
3. Gravity thickening supernatant
4. Dissolved air flotation subnatant
5. Rotary drum thickening filtrate
6. Belt filter press filtrate
7. Sludge drying bed underdrain
8. Plate and frame filtrate
9. Reed bed filtrate

B. Stabilization and storage
1. Aerobic digester decant

2. Anaerobic digestion supernatant
3. Biosolids storage decant
4. Tertiary sand filter backwash

3.4.3 Discuss the acceptance of septage and holding tank waste at an activated sludge plant.

By their nature, septage and holding tank wastes can be very high in BOD, TSS, ammonia, phosphorus, and sulfides (see figure 3.4.3.1). They may also be high in organic acids and fats, oil, and grease (FOG). Plants that accept these wastes should control the amount of these wastes accepted into the plant by knowing the strength and volume and how much the plant can handle during a day or week without stressing the microorganisms. Large slug loads can impact the microorganisms that may not be accustomed to such waste. Septage or holding tank waste can also create unfavorable environmental conditions. Discharging septage or holding waste should be at a location that allows removal of grit and screenings and blending slowly into the plant influent. Some larger plants have septage receiving stations and provide preliminary treatment and regulate the flow into the plant. While receiving septage or holding tank waste at a treatment plant can be a good revenue source for a community, it must be done so at a volume and flow rate as to not upset the plant and at a reasonable cost of treatment. Hauled-in wastes should also be regularly sampled and monitored.

Figure 3.4.3.1

Range of Wastewater Characteristics
All units [mg/L], except for standard pH units

Parameter	Domestic Sewage[1]	Septage[2]	Holding Tank[2]
BOD	100-400	565-5,800	225-800
TSS	100-350	2,220-14,700	60-700
Ammonia	12-50	116-428	18-310
Phosphorus	4-15	24-186	8-28
pH		1.5-12.6	

1 Metcalf & Eddy (1972)
2 Madison Metro Sewage District Data (2006)

Section 3.5 - Performance Limiting Factors

3.5.1 Discuss the importance of fat, oil, and grease (FOG) control.

FOG has many negative effects on treatment plant equipment and operations. FOG clogs pipes, valves and pumps, builds up in pump station wet wells, and treatment plant basins. Foaming filamentous organisms, such as Microthrix and Nocardia, thrive on surface floating fat and grease as a food source where it is readily available to them for prolific growth and resultant foaming.

The best control of FOG is eliminating it at its sources. A sewer use ordinance with a FOG limit (50 to 100 mg/L) and a strong Grease Control and Inspection Program are critical to controlling the amount of FOG entering the sanitary sewers and treatment plant. Good housekeeping practices and regularly manitained grease traps and interceptors at restaurants and institutions are a must along with ongoing information and education (I&E) mailings to residents and businesses.

3.5.2 List and discuss the strategies an operator can use to deal with unintended high strength or toxic discharges of industrial waste.

Industrial wastes are most commonly regulated through a municipality's Sewer Use Ordinance and it should be enforced if necessary. Some industries are regulated by the DNR Pretreatment Standards.

Pollutants entering a treatment plant by an industry cannot pass through or cause interference in the treatment process as a requirement of all commercial and industrial dischargers. Influents of special concern are slug loads or wastes that:

A. Have a high biochemical oxygen demand (BOD) or chemical oxygen demand (COD)
B. Have a low or high pH
C. Are toxic
D. Impair floc settling (surfactants)

If an operator notices a waste coming into the plant that will affect treatment, the operator should try and isolate the incoming waste in any unused tankage if available. Bypassing a high strength or toxic waste around a biological treatment unit may become necessary to save some viable bacteria for treatment after the discharge of concern has passed. This will allow the operator to regain treatment more quickly once things return to normal. Locating the source of the waste is imperative. Operators should proactively communicate and work with the industries in their community as much as they can so plant upsets are avoided.

3.5.3 Discuss the differences and importance of hydraulic residence time (HRT) and sludge age.

HRT refers to the wastewater liquid within the treatment plant. HRT is the amount of time it takes a particle of water, upon entering the plant to leave the plant. Think of it as a car entering and then exiting a freeway mostly straight, with some curves and hills. In activated sludge plants, HRT is measured in hours, usually between 20 and 30 hours, under normal flow conditions.

Sludge age refers to the wastewater solids within the treatment plant. Sludge age is the amount of time a particle of activated sludge remains in the treatment plant, settling in the clarifier, and returning to the aeration basin. This cycle happens many times before that sludge particle is wasted out of the system. Think of it as a car in a roundabout, going around and around, and eventually exiting. Sludge age is thus measured in days, usually 3 to 30 days, depending on the type of activated sludge plant and wasting rate.

Both the HRT and sludge age are very important for proper wastewater treatment and the removal of pollutants to occur.

3.5.4 Discuss the operational problems related to hydraulic overloads from inflow and infiltration (I/I) and suggest what an operator might be able to do to maintain and maximize performance during high flow periods.

During wet weather peak flows, an operator is faced with protecting equipment and unit processes while trying to maintain treatment. The loss of solids through the final clarifiers is the most common problem from wet weather peak flow events. The key factor that controls the peak flow capacity of activated sludge systems is solids separation.

Keys to optimum solids separation are:

A. Mixed liquor settleability
The key to optimizing settleability is maintaining the proper environmental conditions that favor the growth and health of good large floc-forming bacteria that settle well (not filamentous organisms) through operating the treatment plant with regular and consistent process.

B. Optimize clarifier performance
Be sure weirs are level and flow over them is evenly distributed. If there is more than one clarifier, the flow distribution from the aeration basins to each clarifier should be evenly distributed. Return activated sludge (RAS) rates should be set to minimize sludge blankets to less than a foot. If clarifier short-circuiting is occurring, which is usually worse during high flow periods, clarifier baffles can be considered.

C. Reduce clarifier solids loading rate (SLR)
SLR is affected by the incoming flow and RAS flow rate. Some ways to reduce the SLR to the final clarifier(s) is to:

1. Bring any extra, unused tankages online if they are available, such as another clarifier or aeration basin

2. Take some aeration basin(s) offline and store solids in them until flows subside

3. Operate the aeration basins in a step-feed configuration to reduce solids at the end of the aeration basins and thus the solids entering the final clarifier

4. Adjust the RAS rate to balance the lowest possible sludge blanket at the lowest SLR.

The best long term strategy for maintaining wastewater treatment during wet weather periods is to reduce the amount of I/I of clearwater entering into the sewer system. An ongoing collection system Capacity, Management, Operation and Maintenance (CMOM) program should be developed and implemented.

Many of the concepts presented in this key knowledge were derived from a series of articles written by Bill Marten, Wastewater Process and Operations Engineer, Triad Engineering Inc, in the Wisconsin Wastewater Operators Association's (WWOA) The Clarifier (2005- 2006). For complete details on ways to maximize secondary treatment wet weather capacity, the reader is referred to these six articles.

Section 3.6 - Corrective Actions

3.6.1 List common operational problems that can occur in the activated sludge process.

A. Aeration basin low dissolved oxygen (DO)
B. Clarifier settling
C. Foaming
D. Loss of nitrification

There are many other operational problems that can occur in the activated sludge process. For detailed and comprehensive troubleshooting guides, see the references at the end of this study guide.

3.6.2 List and discuss possible causes and corrective actions for low DO in an aeration basin.

Figure 3.6.2.1

Problem	Cause	Corrective Action
Low dissolved oxygen (DO)	DO meter or probes	Check the calibration of DO monitoring equipment; clean probes and monitoring equipment regularly to ensure accurate DO measurements
	Inadequate air supply	Increase air supply (see key knowledges 2.2.9 and 2.2.10)
	Excessive organic loading	Reduce influent loading through enforcement of sewer use ordinance; a pretreatment program; equalization basins or bringing additional aeration basins on-line if available

3.6.3 List and discuss the possible causes and corrective actions for foaming problems.

Figure 3.6.3.1

Problem	Cause	Corrective Action
Foaming	Young sludge (white billowing foam)	Increase sludge age
	Filamentous foaming organisms (Nocardia, Microthrix)	Adjust environmental conditions. Adjust food to microorganism (F/M) ratio, sludge age and DO. Reducing incoming fats, oils, and grease (FOG) is one of the most important factors to control surface filamentous forming organisms
	Industrial and chemical discharges (surfactants, phosphates, etc…)	Enforce sewer use ordinance

3.6.4 For plants that have ammonia limits, list and discuss possible causes of incomplete or lack of nitrification and corrective actions.

Figure 3.6.4.1

Problem	Cause	Corrective Action
Incomplete or lack of nitrification	Improper environmental conditions	Nitrifying bacteria are very sensitive to environmental factors, such as very low DO, alkalinity, and temperatures; an older sludge (>8 days) is usually needed for their growth; adjust these environmental conditions, as you can, to support the growth of nitrifying bacteria (see key knowledge 1.2.6)

Chapter 4 - Safety and Regulations

Section 4.1 - Definitions

4.1.1 Define personal protective equipment (PPE).

PPEs are the protective clothing and other devices designed to protect an individual while in potentially hazardous areas or performing potentially hazardous operations. Examples of PPE include gloves, hard hat, steel toed boots, safety glasses, and other appropriate clothing.

Section 4.2 - Personal Safety

4.2.1 List various safety considerations that are important when working in an activated sludge plant.

A. Falling into tanks, especially aeration tanks where currents can pull an operator under the water surface
B. Noise
C. Exposure to waterborne and bloodborne pathogens
D. Rotating equipment
E. Electrical hazards
F. Slippery surfaces
G. Confined spaces
H. Compressed air
I. Chemicals and chemical equipment

Operators should follow all federal and state safety requirements. Safety programs and emergency procedures should be in place and followed at all times.

4.2.2 Discuss procedures for entering treatment tanks or vessels.

Owners of wastewater treatment facilities should clearly define all confined spaces. Operators should know all confined space areas and follow all confined space entry procedures.

4.2.3 Describe the applicable safety program and requirements municipal wastewater treatment plants must follow.

Wisconsin Department of Safety and Professional Services - SPS 332 - Public Employee Safety and Health must be followed. Some of the important safety requirements are confined space, excavation, hearing conservation, blood borne pathogens, CPR/First Aid, Safety Data Sheets (SDS), electrical, fall protection, hazardous materials, as well as others. Non-public entities follow OSHA CFR 29 part 1910.

4.2.4 Discuss the importance of floatation devices at a wastewater treatment plant.

Sampling from basins, channels, and other treatment processes puts an operator at risk of falling into the wastewater. Basins that are aerated can be the most dangerous because the aeration process makes it extremely difficult to stay afloat in waters saturated with high concentrations of air. For this reason, an operator should never extend beyond the protection of the guardrails. OSHA highly recommends ring buoys with at least 90 ft of line be provided and readily available for emergencies and strategically placed around all process basins. OSHA also recommends any operator working over or near water where a risk of drowning is present be provided with a life jacket or buoyant work vest.

Section 4.3 - Chemical

4.3.1 Discuss the importance of maintaining chemical delivery, storage, and usage records.

Some chemicals used in an activated sludge treatment plant are hazardous materials and must be identified. Safety Data Sheets (SDS) are required to be kept on-site and readily available. In the event of a spill, the Department of Natural Resources must be contacted.

4.3.2 Discuss preventative spill measures and procedures when handling hazardous chemicals.

Storage tanks must have secondary containment that equals the volume of the storage tank. During unloading of delivery vehicles, place containment pails under potential leak points and when uncoupling fill lines. Inspect and maintain fill lines and valves. Inspect storage tanks and hardware for integrity. Pay attention to what you are doing!

Provide on-site containment equipment such as absorbent booms, sandbags, etc. and seal the yard and storm drains to prevent off-site loss of chemical.

4.3.3 Discuss what should be done in the event of a chemical spill.

A. Any spill of hazardous material should be reported to the Department of Natural Resources within 24 hours and to the local emergency response agencies
B. Contact CHEMTREX for further spill response and cleanup advice

4.3.4 Discuss the proper procedure for entering a chemical storage tank.

Contract any tank inspection and repairs to trained specialists for such work. FOLLOW ALL CONFINED SPACE ENTRY PROCEDURES.

Section 4.4 - Regulations

4.4.1 There are no key knowledges for this section at this time.

Chapter 5 - Calculations

Section 5.1 - Flows and Loadings

5.1.1 Given data, calculate the biochemical oxygen demand (BOD) (lbs) entering the treatment plant each day.

GIVEN:
[MGD = million gallons per day]

Influent flow = 0.845 MGD
Influent BOD = 320 mg/L

FORMULA AND SOLUTION:

Influent BOD (lbs/day) = influent flow (MGD) × influent BOD (mg/L) × 8.34
= 0.845 MGD × 320 mg/L × 8.34
= 2,255 lbs/day

5.1.2 Given data, calculate the BOD (lbs) being treated and removed.

GIVEN:

Influent flow = 1.2 MGD
Influent BOD = 240 mg/L
Effluent flow = 1.2 MGD
Effluent BOD = 10 mg/L

FORMULAS AND SOLUTION:

Influent BOD (lbs/day) = influent flow (MGD) × influent BOD conc. (mg/L) × 8.34
= 1.2 MGD × 240 mg/L × 8.34
= 2,402 lbs of BOD/day

Effluent BOD (lbs/day) = effluent flow (MGD) × effluent BOD cons. (mg/L) × 8.34
= 1.2 MGD × 10 mg/L × 8.34
= 100 lbs of BOD/day

BOD removed (lbs) = influent BOD (lbs) - effluent BOD (lbs)
= 2,402 lbs of BOD/day - 100 lbs of BOD/day
= 2,302 lbs of BOD/day removed (96% removal)

Section 5.2 - Sludge Age

5.2.1 Given treatment plant data, calculate the sludge age (days).

GIVEN:
[MLSS = mixed liquor suspended solids]
[MG = million gallons]
[WAS = wasted activated sludge]
[MGD = million gallons per day]

MLSS = 2,400 mg/L
Aeration basin volume = 35,000 gals = 0.0350 MG
WAS concentration = 3,500 mg/L
WAS flow = 0.001 MGD

FORMULAS AND SOLUTION:

MLSS (lbs) = aeration basin vol. (MG) × MLSS (mg/L) × 8.34
= 0.035 MG × 2,400 mg/L × 8.34
= 701 lbs of MLSS under aeration

WAS (lbs) = WAS flow (MGD) × WAS cons. (mg/L) × 8.34
= 0.001 MGD × 3,500 mg/L × 8.34
= 29 lbs of WAS/day
Sludge age (days) = MLSS (lbs under aeration) ÷ WAS (lbs/day)
= 701 lbs ÷ 29 lbs/day
= 24 days

Section 5.3 - Food to Microorganism Ratio

5.3.1 Given treatment plant data, calculate the food to microorganism (F/M) ratio.

GIVEN:
[MGD = million gallons per day]
[BOD = biochemical oxygen demand]
[MG = million gallons]
[MLSS = mixed liquor suspended solids]

Influent flow = 0.275 MGD
Influent BOD = 230 mg/L
Aeration basin volume = 0.432 MG
Aeration basin MLSS = 1,750 mg/L

FORMULAS AND SOLUTION:

Influent BOD (lbs) = influent flow (MGD) × influent BOD (mg/L) × 8.34
= 0.275 MGD × 230 mg/L × 8.34
= 528 lbs of BOD

MLSS (lbs) = aeration basin vol. (MG) × MLSS (mg/L) × 8.34
= 0.432 MG × 1,750 mg/L × 8.34
= 6,305 lbs of MLSS under aeration

F/M ratio = influent BOD (lbs) ÷ MLSS under aeration (lbs)
= 528 lbs ÷ 6,305 lbs
= 0.08 F/M

5.3.2 Given the treatment plant data, calculate the F/M ratio and its significance.

GIVEN:

Influent BOD = 40 lbs
Aeration basin MLSS = 4,000 lbs

FORMULA AND SOLUTION:

F/M ratio = incoming BOD (lbs) ÷ MLSS under aeration (lbs)
= 40 lbs BOD ÷ 4,000 lbs MLSS
= 0.01

This is a very low F/M ratio for extended aeration and indicates that there are too many solids (MLSS) under aeration for the amount of food (BOD) coming in.

Section 5.4 - Sludge Volume Index

5.4.1 Given treatment data, calculate the sludge volume index (SVI).

GIVEN:
[MLSS = mixed liquor suspended solids]

30-minute settling test = 250 mL/L
MLSS = 2,500 mg/L

FORMULA AND SOLUTION:

SVI = [settled volume in 30 mins (mL/L) ÷ MLSS (mg/L)] × 1,000
= [250 mL/L ÷ 2,500 mg/L] × 1,000
= 100

5.4.2 Given treatment plant data, calculate the SVI and discuss possible causes.

GIVEN:

30-minute settling test = 800 mL/L
MLSS = 4,000 mg/L

FORMULA AND SOLUTION:

SVI = [settled volume in 30 mins (mL/L) ÷ MLSS (mg/L)] × 1,000
= [800 mL/L÷ 4,000 mg/L] × 1,000
= 200

Possible causes for high SVI:
A. Filamentous organisms
B. Young, poor settling sludge
C. Too high a MLSS

Section 5.5 - Wasting Rates

5.5.1 Given data, calculate how many gallons of sludge to waste to achieve a desired sludge age.

GIVEN:
[MLSS = mixed liquor suspended solids]
[WAS = wasted activated sludge]
[MG = million gallons]
[gpd = gallons per day]

Aeration basin volume = 90,000 gals
MLSS = 1,800 mg/L
WAS concentration = 5,000 mg/L
Desired sludge age = 9 days

FORMULAS AND SOLUTIONS:

MLSS under aeration (lbs) = aeration basin vol. (MG) × MLSS (mg/L) × 8.34
= 0.09 MG × 1,800 mg/L × 8.34
=1,351 lbs of MLSS

Sludge age (days) = MLSS under aeration (lbs) ÷ sludge wasted (lbs/day)
REARRANGING THIS:
Sludge to waste (lbs/day) = MLSS under aeration (lbs) ÷ desired sludge age (days)
= 1,351 lbs ÷ 9 days
= 150 lbs/day

Sludge to waste (gpd) = (sludge to waste (lbs) ÷ [WAS conc. (mg/L) × 8.34]) × 1,000,000
= [150 lbs ÷ (5,000 mg/L × 8.34)] × 1,000,000
= 3,600 gpd

5.5.2 Given data, calculate how much sludge (gals) to waste to achieve a desired MLSS level.

GIVEN:
[MLSS = mixed liquor suspended solids]
[WAS = wasted activated sludge]

Aeration basin volume = 250,000 gals
Current MLSS = 2,200 mg/L
Desired MLSS = 2,000 mg/L
WAS concentration = 4,000 mg/L

FORMULAS AND SOLUTION:

Current MLSS (lbs) = basin volume (MG) × MLSS (mg/L) × 8.34
= 0.250 MG × 2,200 mg/L × 8.34
=4,587 lbs
Desired MLSS (lbs) = basin volume (MG) × MLSS (mg/L) × 8.34
= 0.250 MG × 2,000 mg/L × 8.34
= 4,170 lbs

Sludge to be wasted (lbs) = current MLSS (lbs) - desired MLSS (lbs)
= 4,587 lbs - 4,170 lbs
= 417 lbs
Sludge to be wasted (gals) = [sludge to waste (lbs) ÷ (WAS conc. (mg/L) × 8.34)] × 1,000,000
= [417 lbs ÷ (4,000 mg/L × 8.34)] × 1,000,000
= 12,500 gals

References and Resources

1. **UW WATER LIBRARY**

   Most of the resources listed on this page can be borrowed through the UW Water Library as part of a partnership between the UW Water Library, the Wisconsin Wastewater Operator Association (WWOA), Central States Water Environmental Association (CSWEA), and the Wisconsin Department of Natural Resources. Instructions for borrowing materials from the UW Water Library can be found by visiting the website provided below, clicking on 'WISCONSIN RESIDENTS', and then clicking on 'HOW TO BORROW MATERIALS'.

   www.aqua.wisc.edu/waterlibrary

2. **OPERATION OF MUNICIPAL WASTEWATER TREATMENT PLANTS**

   Water Environmental Federation (WEF). (2008). Operation of Municipal Wastewater Treatment Plants: Manual of Practice No. 11 (6th ed., Vols. I, II, III). New York, New York: McGraw-Hill.

   www.wef.org

3. **OPERATION OF WASTEWATER TREATMENT PLANTS**

   Office of Water Programs, California State University, Sacramento. (2008). Operation of Wastewater Treatment Plants (7th ed.). Sacramento, CA: University Enterprises, Inc., California State University.

   www.owp.csus.edu

4. **WASTEWATER MICROBIOLOGY: A HANDBOOK FOR OPERATORS**

   Glymph, T. (2005). Wastewater Microbiology: A Handbook for Operators. Denver, CO: American Water Works Association.

   www.awwa.org

5. **MAXIMIZING SECONDARY TREATMENT WET WEATHER CAPACITY**

   Marten, B. (2005-2006, February-February). Maximizing Secondary Treatment Wet Weather Capacity. The Clarifier, vol. 159-164.

   www.wwoa.org

6. **BASIC ACTIVATED SLUDGE PROCESS CONTROL: PROBLEM-RELATED OPERATIONS-BASED EDUCATION (PROBE)**

   Water Environment Federation (WEF). (1994). Basic Activated Sludge Control Process Control: Problem-Related Operations-Based Education (PROBE). Alexandria, VA: Water Environment Federation.

   www.wef.org

7. **AERATION: A WASTEWATER TREATMENT PROCESS**

   Water Pollution Control Federation, American Society of Civil Engineers. (1988). Aeration: A Wastewater Treatment Process. Alexandria, VA: Water Pollution Control Federation.

   www.wef.org

8. **WISCONSIN ADMINISTRATIVE CODE SPS 332 PUBLIC EMPOLYEE SAFETY AND HEALTH**

Wisconsin Administrative Code SPS 332 Public Employee Safety and Health (2014)

http://docs.legis.wisconsin.gov

9. **OSHA CFR 29 PART 1910**

Occupational Safety & Health Administration (OSHA). (2012). Regulations (Standards-29 CFR 1910.1200)

www.osha.gov