Wisconsin Department of Natural Resources
Wastewater Operator Certification

Introduction To Activated Sludge Study Guide

December 2010 Edition

Subclass C

Wisconsin Department of Natural Resources
Bureau of Science Services, Operator Certification Program
P.O. Box 7921, Madison, WI 53707

http://dnr.wi.gov

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PRINTED ON RECYCLED PAPER

Printed on 12/11/12

Preface

This operator's study guide represents the results of an ambitious program. Operators of wastewater facilities, regulators, educators and local officials, jointly prepared the objectives and exam questions for this subclass.

How to use this study guide with references

In preparation for the exams you should:

1. Read all of the key knowledge's for each objective.

2. Use the resources listed at the end of the study guide for additional information.

3. Review all key knowledge's until you fully understand them and know them by memory.

It is advisable that the operator take classroom or online training in this process before attempting the certification exam.

Choosing A Test Date

Before you choose a test date, consider the training opportunities available in your area. A listing of training opportunities and exam dates is available on the internet at http://dnr.wi.gov, keyword search "operator certification". It can also be found in the annual DNR "Certified Operator" or by contacting your DNR regional operator certification coordinator.

Acknowledgements

This Study Guide is the result of the efforts of the following workgroup individuals:

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Chapter 1 - Theory and Principles

Section 1.1 - Definitions

1.1.1 Define activated sludge.

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

1.1.2 Define secondary treatment.

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.

1.1.3 Define clarification.

A process to reduce the concentration of suspended matter in water. In the activated sludge treatment process, the removal of suspended solids from wastewater is usually through gravity separation in a clarifier.

1.1.4 Define waste activated sludge (WAS).

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 Return Activated Sludge (RAS) flow stream.

1.1.5 Define return activated sludge (RAS).

The settled activated sludge (biomass) that is collected in a secondary 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.

1.1.6 Define sludge volume index (SVI).

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 80-150.

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

Food to microorganism ratio (F:M or F/M) is the amount of food (BOD5) provided to the microorganisms (MLVSS or MLSS) in the aeration basins.

F/M is determined by dividing the pounds of influent BOD5 by the pounds of mixed liquor volatile suspended solids or mixed liquor suspended solids under aeration.

1.1.8 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 (MG), and then multiplying the product by 8.34 (lbs/gal).

1.1.9 Define mixed liquor volatile suspended solids (MLVSS).

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 (lbs/gal).

1.1.10 Define sludge age.

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

1.1.11 Define nitrification.

A biological process where nitrifying bacteria convert nitrogen in the form of ammonia (NH_3) into nitrite (NO_2^-) and nitrate (NO_3^-) under aerobic conditions.

1.1.12 Define denitrification.

A biological process where bacteria convert nitrate (NO_3^-) and nitrite (NO_2^-) to nitrogen gas (N_2) under anoxic conditions.

1.1.13 Define floc.

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

1.1.14 Define sludge blanket.

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

1.1.15 Define aerobic (oxic) [O_2].

A condition in which free and dissolved oxygen is available in an aqueous environment.

1.1.16 Define Anoxic [NO_2, NO_3, SO_4].

A condition in which oxygen is only available in a combined form such as nitrate (NO_3^-), nitrite (NO_2^-), or sulfate (SO_4) in an aqueous environment.

1.1.17 Define Anaerobic [Ø].

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

1.1.18 Define Protozoa.

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

1.1.19 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 biochemical oxygen demand (BOD) in milligrams per liter (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.

1.1.20 Define weir(s).

A weir is a level control structure (often v-notched) in a final clarifier used to provide a uniform effluent flow.

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 (RAS) or wasted (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 (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 1.0-3.0 mg/L). Aeration basin dissolved oxygen concentrations (milligrams per liter) 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 (10-25ºC). 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 6.0-9.0. 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 sewage, contains an abundance of these trace nutrients. The ratio of BOD5 to nitrogen (N) to phosphorus (P) should be at least 100:5:1. Influent wastewater can be measured to determine this nutrient ratio.

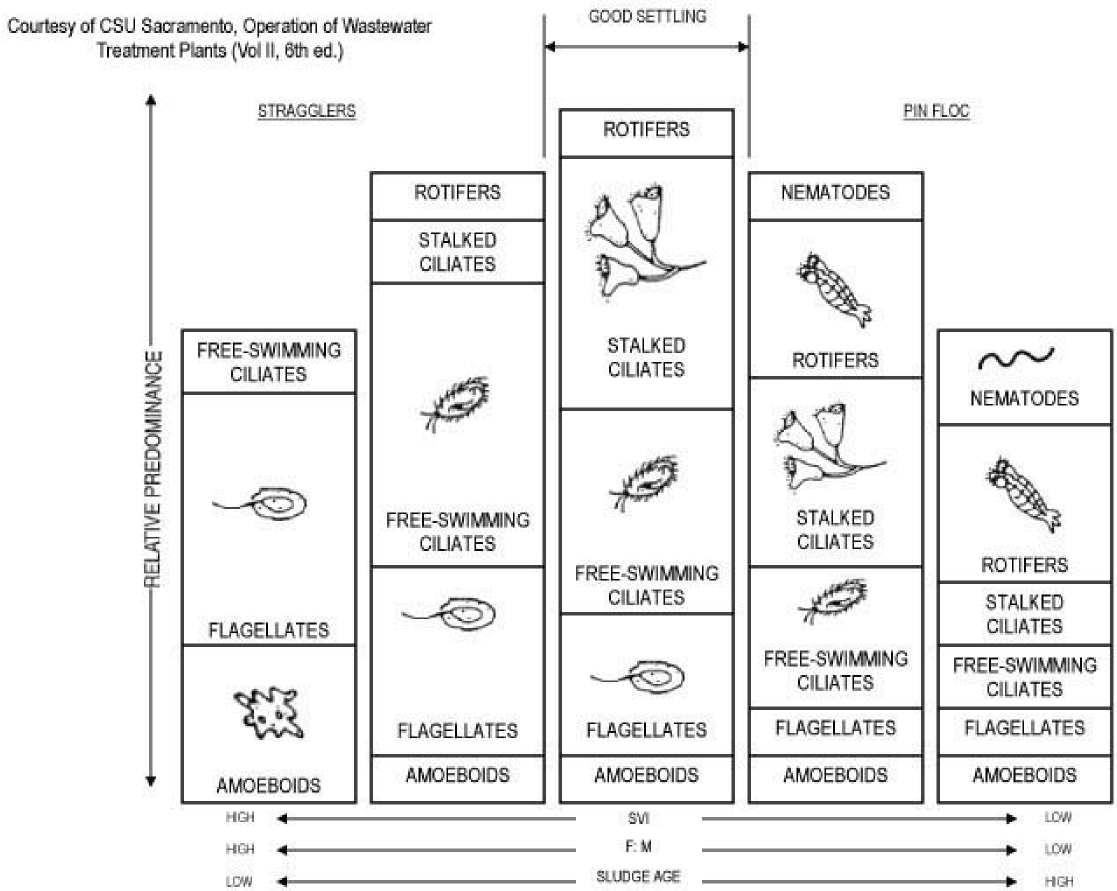
G. Toxicity
Incoming wastewater to a treatment plant may at times contain materials or compounds that are toxic to microorganisms. Depending on the concentration of toxic material, microorganisms could be destroyed or their metabolic rates affected, thus impairing the wastewater treatment plant efficiency.

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



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 dissolved oxygen
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. Dissolved oxygen greater than 1.0 mg/L

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

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

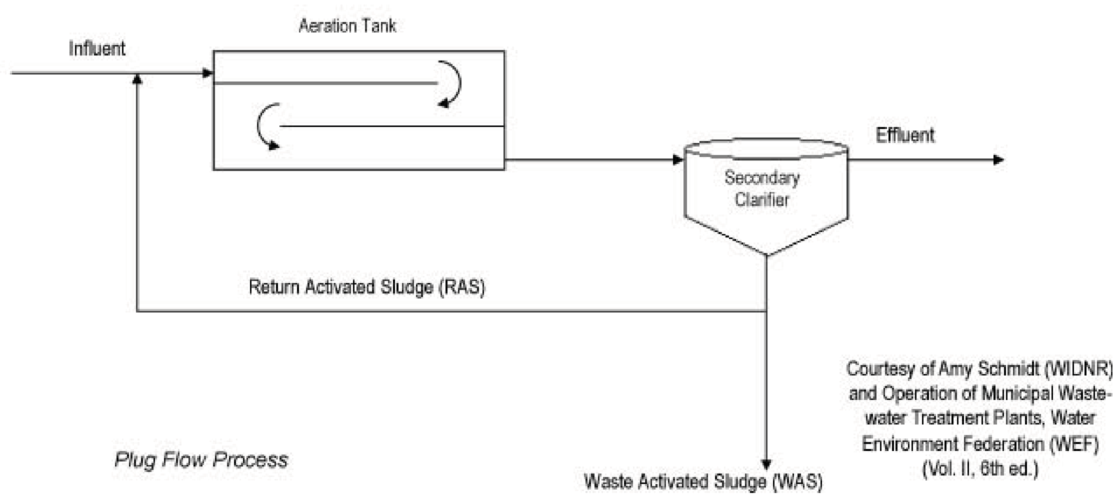
Denitrifying bacteria convert nitrite and nitrate to nitrogen gas. They work best under the following environmental conditions:
A. Dissolved oxygen less than 0.2 mg/L
B. pH between 7.0 and 8.5
C. Adequate organic matter (BOD)
D. Temperature between 50-85 ºF (10-30 ºC)

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 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 3-10 days.

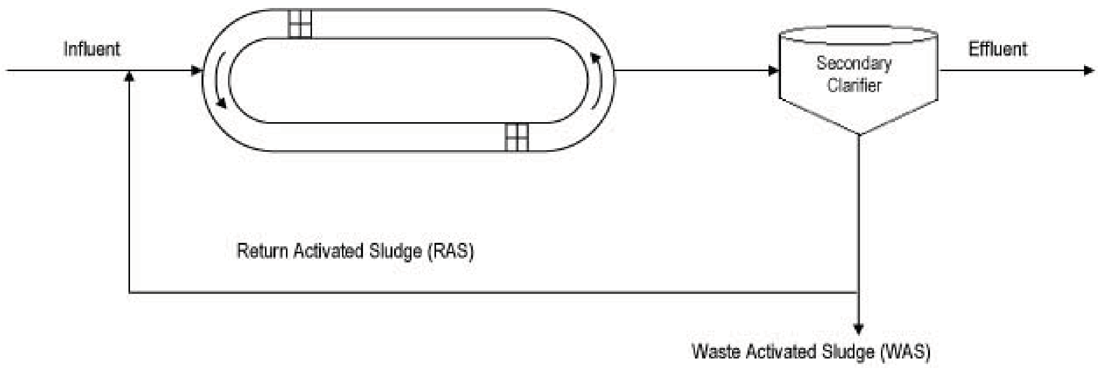
Figure 1.3.1.1



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 15-30 days. This results in a highly treated effluent, and less WAS produced. The oxidation ditch is a variation of the extended aeration process.

Figure 1.3.2.1



Oxidation Ditch Process

Courtesy of Amy Schmidt (WIDNR) 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 MLSS to the secondary 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 (BOD), microorganisms, and dissolved oxygen (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 Sequencing Batch Reactor (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.

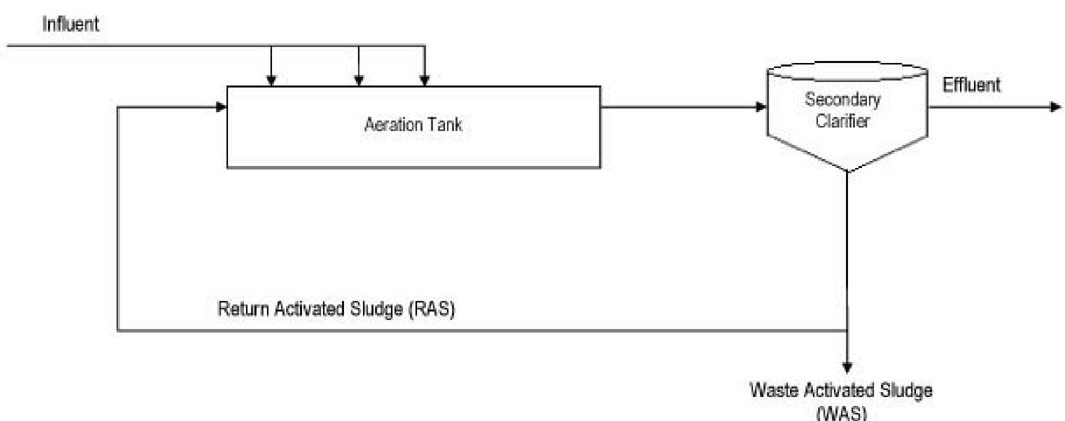
There are a great number of variations based on proprietary mechanisms and processes in SBR treatment, but all systems have a sequence of at least four steps that need to occur for the proper operation of the systems. The four treatment steps need to include:

1. Fill
2. React
3. Settle
4. Decant/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 is referred to the references at the end of this study guide.

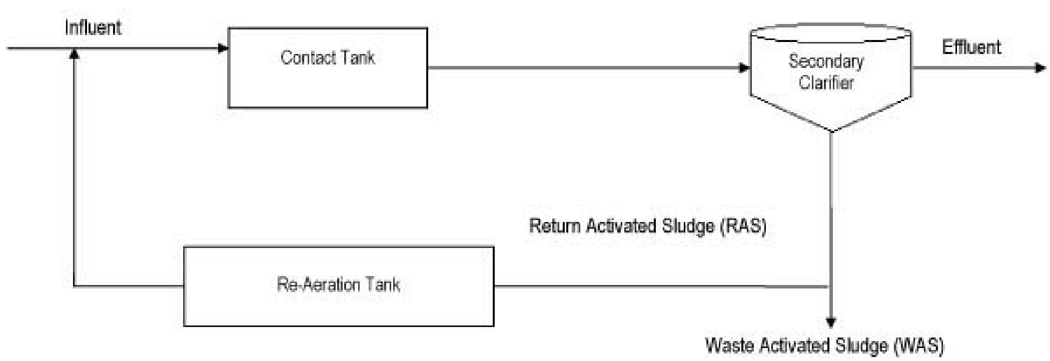
Figure 1.3.3.1



Step Feed Process

Courtesy of Amy Schmidt (WIDNR) and Operation of Municipal Wastewater Treatment Plants, Water Environment Federation (WEF) (Vol. II, 6th ed.)

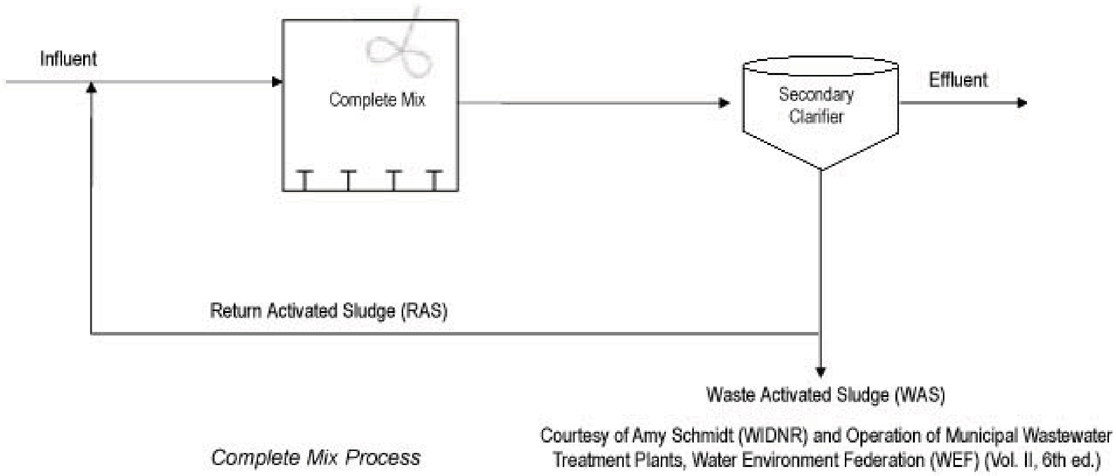
Figure 1.3.3.2



Contact Stabilization Process

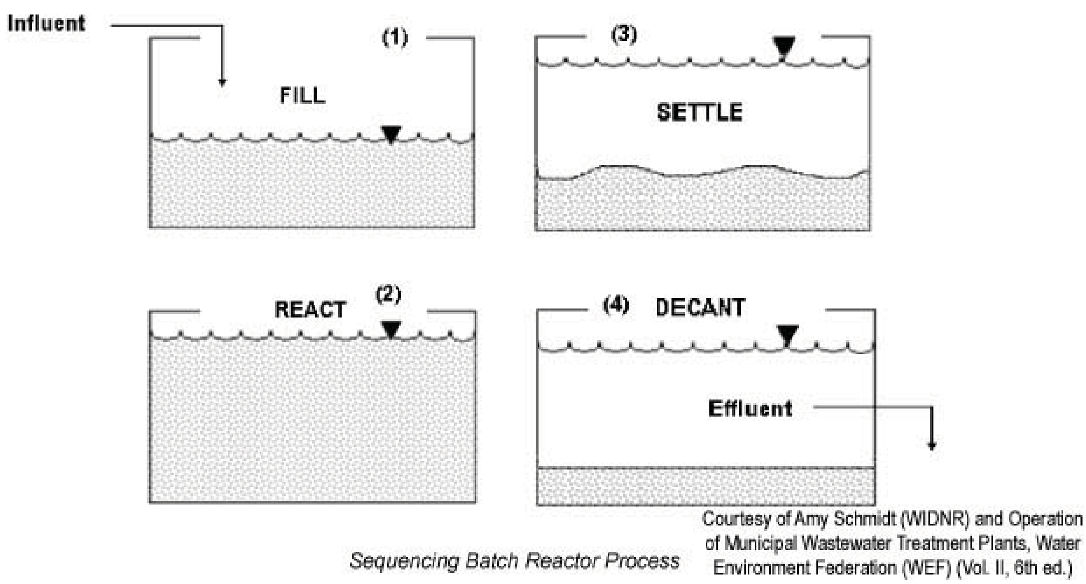
Courtesy of Amy Schmidt (WIDNR) and Operation of Municipal Wastewater Treatment Plants, Water Environment Federation (WEF) (Vol. II, 6th ed.)

Figure 1.3.3.3



Complete Mix Process

Figure 1.3.3.4



Sequencing Batch Reactor Process

Chapter 2 - Operation and Maintenance

Section 2.1 - Definitions

2.1.1 Define diffusers.

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

2.1.2 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 (following ASCE standard test protocol). Oxygen transfer efficiency 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 (oxygen transfer efficiency) is approximately 1/2 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 1/2 of all the power consumed in a wastewater treatment plant. Energy cost is based on air flow and system operating pressure.

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).

Variable Frequency Drive (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 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.

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

A. Constant MLSS (Mixed Liquor Suspended Solids)
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 1000-4000 mg/L.

B. Food To Microorganism Ratio (F/M Ratio)
For microbiological health and effective treatment, the microorganisms (mixed liquor suspended solids) under aeration should be maintained at a certain level for the amount of food (influent BOD) coming into the plant. This is known as the food to microorganism ratio. For conventional activated sludge, the F/M ratio is usually between 0.2-0.5. For extended aeration systems, such as package plants and oxidation ditches, the F/M ratio should be between 0.03-0.10.

C. Sludge Age
Activated sludge is recycled back through the aeration basins by returning settled sludge 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 3-10 days is typical. For extended aeration activated sludge, older sludge ages of 15-30 days are common. 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.

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.

2.2.3 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 mixed liquor suspended solids (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.

2.2.4 Describe the affect of waste activated sludge 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 waste activated sludge (high WAS concentration) will require less amount of wasting than a thinner waste activated sludge (low WAS concentration).

2.2.5 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.

2.2.6 Discuss factors that influence the flow rates of return activated sludge (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, effects the flow of solids into the clarifiers. Aeration basin mixed liquor suspended solids 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/floating sludge clumps on the clarifier surface.

2.2.7 Discuss the methods of controlling dissolved oxygen levels in diffused air systems.

A. By controlling air valves
B. By controlling the blower output such as using VFDs
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)

2.2.8 Discuss the methods of controlling dissolved oxygen levels in mechanical aeration systems.

A. By increasing or decreasing the aerator speed by using VFDs
B. By increasing or decreasing the aerator submergence by adjusting the tank water level
C. By 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.]

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. WAS/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
A positive displacement (PD) blower forces air to move by trapping a fixed amount, then displacing that trapped volume into the discharge pipe. Positive displacement 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 device through which air is pumped and divided into very small bubbles that are used to introduce and dissolve oxygen 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 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 Discuss the use of variable frequency drives (VFDs) 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. VFD's are commonly used in many applications in an activated sludge system such as with blowers, aerators, return (RAS) and waste (WAS) activated sludge pumps. Maintenance costs may also be lower, since lower operating speeds can result in longer life for bearings and motors.

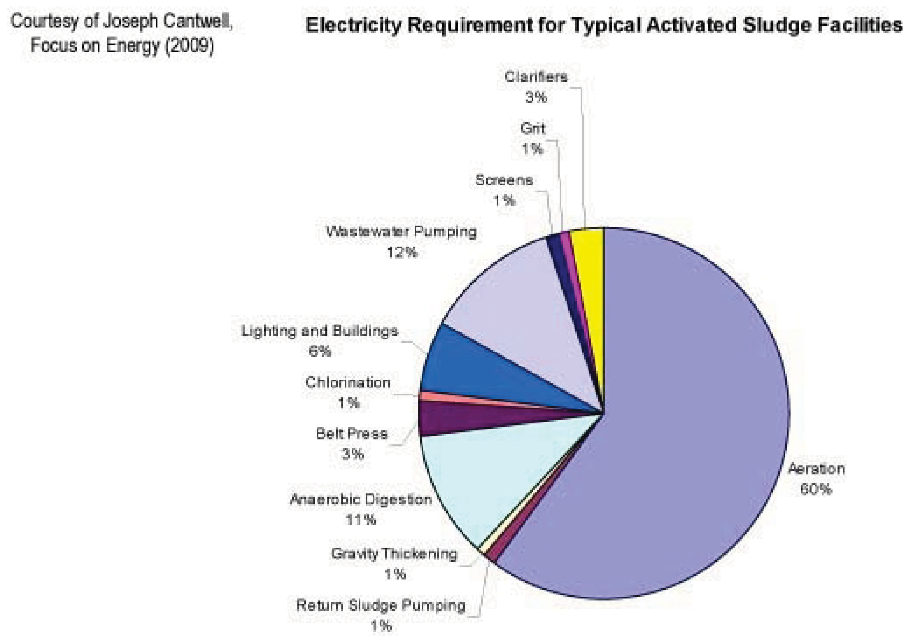
2.3.6 Describe air-lift pumps and their use in small activated sludge plants.

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/air displacement. Air-lift pumps are prone to plugging, especially at low return flow rates. Operators should closely monitor these pumps often to ensure sludge is being returned at all times.

2.3.7 Discuss energy usage in an activated sludge process.

The aeration system of an activated sludge uses the largest percentage (60%+) 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 2.3.7.1



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.

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.

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, and 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 WIDNR of scheduled maintenance activities as given in the standard conditions of the WPDES permit.

2.4.6 List the items to include in a maintenance schedule for final clarifiers.

An operator should consult the O&M Manual for the preventative maintenance schedule. Daily observations should be performed such as checking for oil leaks, unusual vibrations or noises, scum collection, weirs, and floating solids. All maintenance and repairs should be documented.

2.4.7 List what to look for when inspecting clarifier weirs.

Clarifier weirs should be inspected daily for:

A. Level weirs- even flow uniformly across the weirs
B. Algae or debris plugging v-notches
C. Condition of the weirs
D. Effluent quality

Chapter 3 - Monitoring, Process Control, and Troubleshooting

Section 3.1 - Definitions

3.1.1 Define filaments.

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

3.1.2 Define pin floc.

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

3.1.3 Define straggler floc.

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

3.1.4 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. It is usually caused by filamentous organisms.

3.1.5 Define slime bulking.

Nutrient deficiency causes stressful conditions for bacteria. Nutrient deficient bacteria are unable to produce proper cell walls and as reaction to stress will produce excess amounts of a slimey, fat (lipid) layer instead of a normal cell wall. Excess organic acids can also cause stress on bacteria and can increase slime bulking. Slime bulking affects sludge settling.

3.1.6 Define hydraulic load.

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

3.1.7 Define washout.

Washout is the loss of biomass from the final clarifiers due to high flows.

3.1.8 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.

3.1.9 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 1000 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 secondary clarifier and can be used to help diagnose clarifier settling problems.

Section 3.2 - Sampling & Testing

3.2.1 Describe 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 3.2.1.1

Courtesy of Auralene Glymph, Microbiologist

3.2.2 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 alot 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, 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.

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

A. Dissolved Oxygen Meter
Used to monitor aeration basin dissolved oxygen levels. Many plants have in-line dissolved oxygen 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 1000 mL beaker or cylinder

is most commonly used. The mixed liquor suspended solids 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
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
Used to measure pHs and temperatures of wastewater entering the plant and the aeration basins.

F. Flow Meters
Used to measure influent, sidestream, RAS, WAS and effluent flows.

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

A. sight and smell
B. dissolved oxygen/pH/temperature
C. 30 minute settling test and settling curve
D. sludge volume index (SVI)
E. sludge age
F. F:M ratio
H. return activated sludge (RAS) flow and concentration
I. waste activated sludge (WAS) and concentration
J. mixed liquor suspended solids (MLSS of MLVSS)
K.clarifier sludge depths
I. 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.

Section 3.3 - Data Understanding & 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 200-300 mL/L. The SVI would be 80-150. The supernatant would be clear with little or no floc particles. Sludge age for conventional systems would be 3-10 days and 15-30 days for extended aeration systems.

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 F/M. 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
B. Nocardia Filaments Present
C. Return Rates Too Low
D. Return Rates Too High

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 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 return activated sludge.

3.3.4 Discuss the significance of denitrification occuring in a final clarifier.

In the absence of oxygen, a sludge blanket that is too thick and remains in the clarifier too long can denitrify. Nitrates in the sludge will be converted to nitrogen gas. The release of nitrogen gas will cause small gas bubbles that will be observed at the clarifier surface. Clumps of sludge may also rise to the surface.

Section 3.4 - Side Streams/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 BOD, suspended solids, 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 recycle streams are from:

A. Thickening/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/Storage
1. Aerobic digester decant
2. Anaerobic digestion supernatant
3. Biosolids storage decant
4. Tertiary sand filter backwash

Section 3.5 - Performance Limiting Factors

3.5.1 List operational problems caused by hydraulic overloads.

A. Solids washouts
If the flow is too high through the final clarifier, the solids will not have enough time to settle and can wash out over the weirs. This can result in a loss of solids from the system and effluent permit violations.

B. Reduced treatment efficiency
High flows can reduce the detention time in the aeration basins and thus reduce treatment efficiency. If too many solids also flow out of the clarifier, there may not be enough biomass to effectively treat the incoming organic load.

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

Fat, oil and grease have 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 (50-100 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 house-keeping practices and regularly manitained grease traps/interceptors at restaurants and institutions are a must along with ongoing information and education (I&E) mailings to residents and businesses.

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
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, the operator is referred to the references found at the end of this study guide.

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

CAUSE: Dissolved oxygen meter/probes
CORRECTION: Check the calibration of DO monitoring equipment. Clean probes and monitoring equipment regularly to ensure accurate DO measurements

CAUSE: Inadequate air supply
CORRECTION: Increase air supply. See key knowledges 2.2.7 and 2.2.8

CAUSE: Excessive organic loading
CORRECTION: Reduce influent loading through enforcement of the sewer use ordinance; a pretreatment program; equalization basins or bringing additional aeration basins on-line if available.

3.6.3 List and discuss possible causes and corrective actions for clarifier settling problems.

CAUSE: Excessive filamentous organisms
CORRECTION: Adjust the environmental conditions to support a healthier biomass. See key knowledge 1.2.3

CAUSE: Sludge age. Too young or too old a sludge can result in a poor settling sludge.
CORRECTION: Adjust wasting to achieve the proper sludge age. See key knowledge 3.3.2.

CAUSE: Clarifier washouts due to high flows
CORRECTION: Develop and implement a collection system CMOM Program to reduce infiltration/inflow (I/I)

CAUSE: Too many solids in the system
CORRECTION: Waste regularly to maintain proper MLSS, F/M ratio and sludge age for influent organic loads

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

CAUSE: Young sludge (white billowing foam)
CORRECTION: Increase sludge age

CAUSE: Filamentous foaming organisms (Nocardia, Microthrix)
CORRECTION: Adjust environmental conditions. Adjust F/M ratio, sludge age and dissolved oxygen. Reducing incoming grease is one of the most important factors to control surface filamentous forming organisms.

CAUSE: Industrial/chemical discharges (surfactants, phosphates, etc)
CORRECTION: Enforce sewer use ordinance

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

CAUSE: Improper environmental conditions
CORRECTION: Nitrifying bacteria are very sensitive to environmental factors, such as very low dissolved oxygen, 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).

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 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 you 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 them 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 Commerce Adm. Code Chapter Comm 32- Public Employee Safety and Health must be followed. Some of the important safety requirements are confined space; excavation; hearing conservation; bloodborne pathogens; CPR- First Aid; MSDS; electrical; fall protection; hazardous materials; as well as others. Non-public entities follow OSHA CFR 29 part 1910.

Section 4.4 - Chemical

4.4.1 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. Material Safety Data Sheets for them are required to be kept on-site and readily available. In the event of a spill, WIDNR must be contacted.

4.4.2 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 leaks 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 your yard/storm drains to prevent off-site loss of chemical.

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

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

4.4.4 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.

Chapter 5 - Calculations

Section 5.1 - Tank Volume

5.1.1 Given the dimensions of a rectangular clarifier, calculate its volume in gallons.

GIVEN:

Length = 50 feet
Width = 30 feet
Depth = 10 feet
1 cubic foot = 7.48 gallons

FORMULA & SOLUTION:

Tank Volume(gal) = [length(ft) × width(ft) × depth(ft)] × 7.48 gal/cu.ft
= [50 ft × 30 ft × 10 ft] × 7.48 gal/cu.ft
= 15,000 cu.ft × 7.48 gal/cu.ft
= 112,200 gallons

5.1.2 Given the dimensions of a circular clarifier, calculate its volume in gallons.

GIVEN:

Diameter = 30 feet
Depth = 14 feet
1 cubic foot = 7.48 gallons

FORMULA & SOLUTION:

Tank Volume(gal) = [3.14 × (radius squared)] × depth(ft) × 7.48 gal/cu.ft
= [3.14 × (15 ft×15 ft)] × 14 ft × 7.48 gal/cu.ft
= 706.5 sq. ft × 14 ft × 7.48 gal/cu.ft
= 73,985 gallons

Section 5.2 - Flows/Loadings

5.2.1 Given data, calculate the pounds of BOD5 entering the treatment plant each day.

GIVEN:
Influent flow = 0.845 MGD
Influent BOD = 320 mg/L
One gallon of water weighs 8.34 pounds

FORMULA & SOLUTION:

Influent BOD5 (lbs/day) = influent flow in MGD × influent BOD5 in mg/L × 8.34 lbs/gal
= (0.845 MGD) × (320 mg/L) × 8.34 lbs/gal
= 2255 lbs/day

5.2.2 Given data, calculate the pounds of BOD5 being treated and removed.

GIVEN:
Influent flow = 1.2 MGD Influent BOD5 = 240 mg/L
Effluent flow = 1.2 MGD Effluent BOD5 = 10 mg/L

FORMULA & SOLUTION:
BOD5 Removed (lbs) = influent BOD5 (lbs) - effluent BOD5(lbs)
= [(influent flow in MGD) × (influent BOD5 in mg/L) × 8.34 lbs/gal]
minus
[(effluent flow in MGD) × (effluent BOD5 in mg/L) × 8.34 lbs/gal]
= [(1.2 MGD) × (240 mg/L) × 8.34 lbs/gal] - [(1.2 MGD) × (10 mg/L) × 8.34 lbs/gal]
= 2400 - 100
= 2300 lbs BOD5 removed (96% removal)

Section 5.3 - Sludge Age

5.3.1 Given treatment plant data, calculate the sludge age in days.

GIVEN:
Mixed liquor suspended solids (MLSS) = 2400 mg/L
Aeration basin volume = 35,000 gallons = 0.0350 million gallons (MG)
Waste activated sludge (WAS) concentration = 3500 mg/L
Waste activated sludge (WAS) flowrate = 0.001 MGD

FORMULA & SOLUTION:

Sludge Age (days) = [(MLSS in mg/L) × (aeration basin volume in MG) × 8.34 lbs/gal]
divided by
[(WAS concentration in mg/L) × (WAS flowrate in MGD) × 8.34 lbs/gal]

Sludge Age = [(2400 mg/L) × (0.0350 MG) × 8.34 lbs/gal] ÷ [(3500 mg/L) × (0.001 MGD) × 8.34 lbs/gal]

Sludge Age = 700 lbs ÷ 29 lb per day

= 24 days

Section 5.4 - Food to Microorganism Ratio

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

GIVEN:
Influent flow = 0.275 MGD
Influent BOD5 = 230 mg/L
Aeration basin volume = 0.432 MG
Aeration basin MLSS = 1750 mg/L

FORMULA & SOLUTION:
F/M Ratio = pounds of incoming BOD5 ÷ pounds of MLSS under aeration
F/M Ratio = [(influent flow in MGD) × (influent BOD5 in mg/L) × 8.34 lbs/gal]

divided by
[(aeration basin volume in MG) × (MLSS in mg/L) × 8.34 lbs/gal]
F/M Ratio = [(0.275 MGD) × (230 mg/L) × 8.34 lbs/gal] ÷ [(0.432 MG) × (1750 mg/L) × 8.34 lbs/gal]
F/M Ratio = 528 lbs BOD5 ÷ 6305 lbs MLSS
F/M Ratio = 0.08

Section 5.5 - Sludge Volume Index

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

GIVEN:
30 minute settling test = 250 mL/L
MLSS = 2500 mg/L

FORMULA & SOLUTION:
SVI = [settled volume in 30 minutes (mL/L) ÷ MLSS (mg/L)] × 1000
SVI = [250 mL/L ÷ 2500 mg/L] × 1000
SVI = 100

References and Resources

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   www.wef.org

2. **OPERATION OF WASTEWATER TREATMENT PLANTS – A FIELD STUDY TRAINING PROGRAM (2002)**

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   http://www.owp.csus.edu/ or available through inter-library loan at http://aqua.wisc.edu/waterlibrary

3. **BASIC ACTIVATED SLUDGE PROCESS CONTROL (1994)**

   PROBLEMS-RELATED OPERATIONS-BASED EDUCATION (PROBE), WATER ENVIRONMENT FEDERATION, ALEXANDRIA, VA

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4. **Aeration (1996)**

   WPCF Manual of Practice FD-13/ASCE Manuals and Reports on Engineering Practice No. 63.