Wisconsin Department of Natural Resources
Wastewater Operator Certification

Advanced 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/org/es/science/opcert/

Printed on 02/13/12

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 DNR Operator Certification home page http://dnr.wi.gov/org/es/science/opcert/. 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:

Chris Marx, Chilton WWTP
Matt Schmidt, Green Bay Metro
Joe Flanagan, Blanchardville WWTP
Gary Hanson, AECom
Doug Nelson, Ruekert & Mielke
Jim Shaw, ITT Sanitaire
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Chapter 1 - Theory and Principles

Section 1.1 - Definitions

1.1.1 Define Hydraulic Retention Time (HRT)

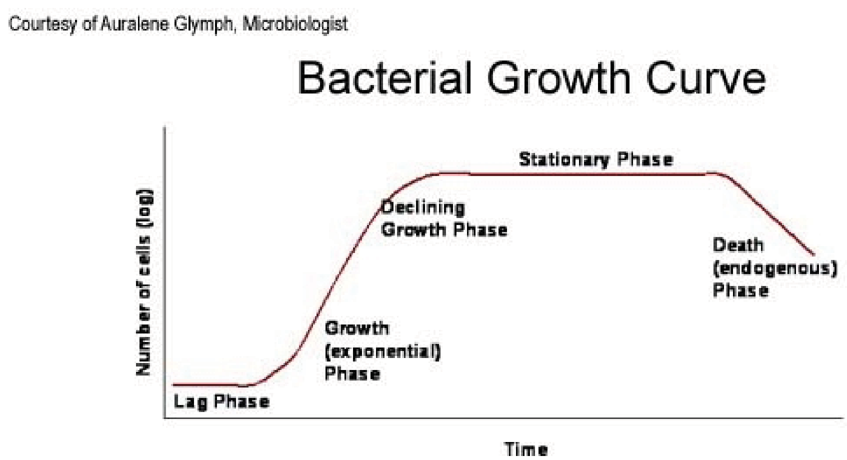
The period of time that wastewater remains in a tank. This is important because treatment processes require sufficient time for the wastewater to be treated.

Section 1.2 - Microbiological Principles

1.2.1 Describe the growth curve 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 waste so it can be used as food for their growth and survival. Over time and as wastewater moves through the aeration basin, food (BOD) decreases as microorganisms utilize it in the presence of oxygen for growth and reproduction with a resultant increase in cell mass (MLSS concentration). This is known as the Growth Phase, where excess food (BOD) is available allowing for optimal bacterial cell growth with the uptake of oxygen. As food (BOD) is used and decreases, growth declines (Declining Growth Phase) and bacteria eventually reach a level production. This is known as the Stationary Phase. As the food (BOD) is used up and decreases over time to very low levels, microorganisms will then use stored food in their cells and slowly begin to die. Cell mass (MLSS) will decrease. This is known as the Endogenous Phase.

Figure 1.2.1.1



1.2.2 Discuss the relative abundance of activated sludge indicator organisms (protozoa and rotifers) relative to sludge age an operator can expect to see under the microscope.

When an activated sludge system is first started up, the activated sludge is very young and thin, the organisms an operator would see under the microscope are ameoba and some flagellates. During the Growth Phase, as the mixed liquor suspended solids (MLSS) builds and sludge age increases, flagellates and free swimmers will be seen. When the mixed liquor suspended solids and sludge age reach an optimum level for treatment, flagellates decline, and free swimming ciliates and stalked ciliates will be seen in more abundance. As activated sludge gets older, more stalked ciliates and rotifers will be commonly seen. If the sludge gets too old, rotifers and nematodes will dominate.

By observing the relative abundance of these indicator organisms the operator will be able to quickly tell the age and health of his activated sludge. The protozoan species that are most dominant indicate the environmental conditions occuring in the process, especially the relative age of the sludge. Sludge age is controlled by wasting, the operator can adjust the wasting rate to influence the microbiological population and health of the activated sludge system and resultant effluent quality.

A protozoan count procedure is used to determine the relative numbers of protozoa in the activated sludge treatment process. The protozoan species that dominate are very helpful in assessing the conditions of the activated sludge process. The count examines protozoa in the following categories:

A. Amoeba
B. Flagellates
C. Free-swimming ciliates
D. Crawling ciliates
E. Stalked ciliates
F. Metazoa (rotifers, neamatodes, water bear, etc.)

See figure 1.2.2.1 for an example count worksheet. The operator is referred to the references for Protozoan Count procedures.

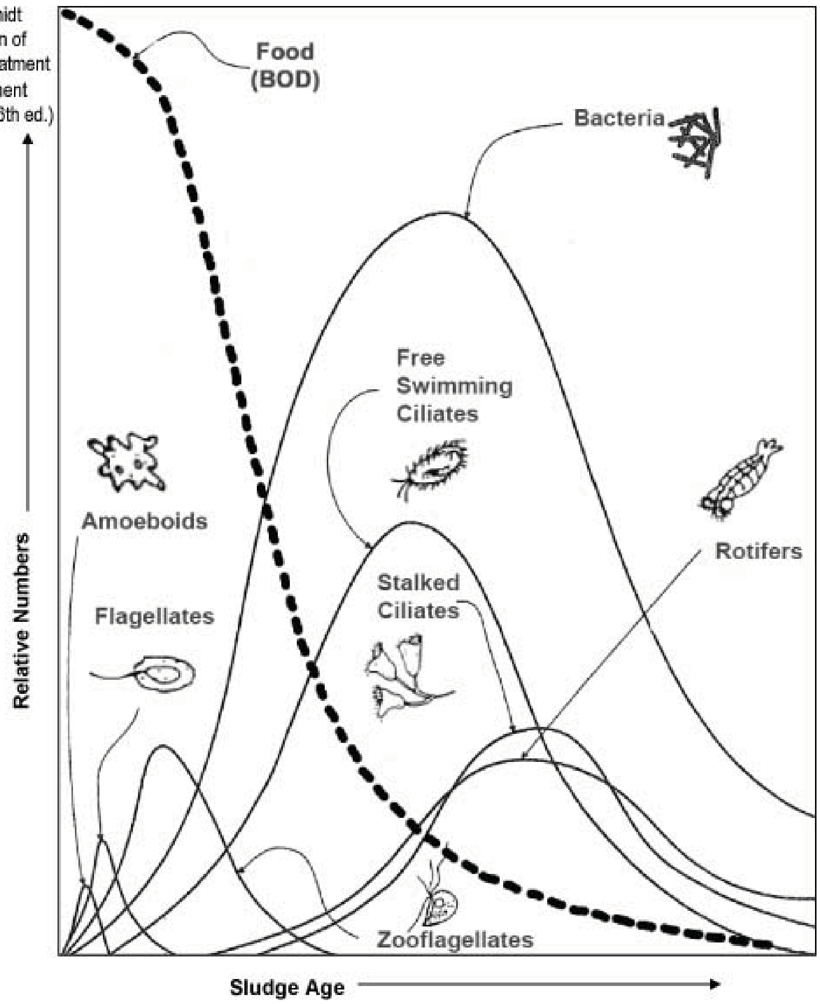
Figure 1.2.2.1

Example Count Worksheet (Courtesy of Toni Glymph, Microbiologist)

Organism	Slide #1	Slide #2	Slide #3	Average	Percent
Amoeba	6	3	1	3	4%
Flagellate	13	6	6	8	10.50%
Free-swimming ciliates	15	12	7	11	14.50%
Crawling ciliates	22	15	20	19	25%
Stalked ciliates	40	32	23	32	42%
Metazoa	5	1	2	3	4%
Totals	101	69	59	76	

Figure 1.2.2.2

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



The growth of microorganisms over time (sludge age) due to the presence of food (BOD) in the aeration basin.

1.2.3 State the sludge production (in pounds of volatile matter per pound of BOD removed) in the activated sludge process.

The total pounds of sludge produced per pound of BOD removed can vary considerably depending on plant specific conditions. The amount of inert total suspended solids must be handled as well as the sludge volatile (biological) matter produced in the process. Total sludge production can reach 1 pound of total sludge per pound of BOD removed, especially, in facilities without primary clarification or poor preliminary treatment. Sludge handling facilities must be sized to handle the total sludge production.

Typical unit sludge production values for various processes are shown in figure 1.2.3.1.

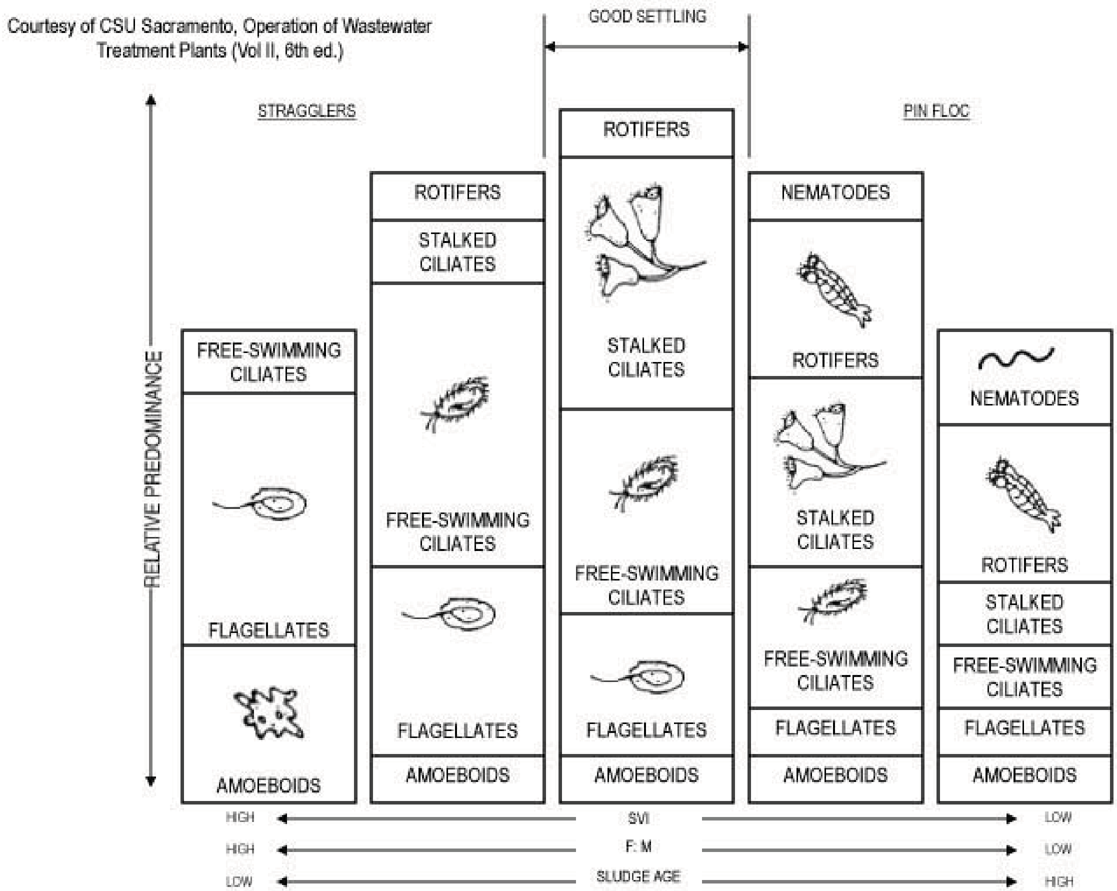
Figure 1.2.3.1

Process Type	lb TSS Produced/ lb BOD Removed
Activated Sludge w/ Primary Clarifier	0.7
Activated Sludge w/o Primary Clarifier	
Conventional	0.85
Extended Aeration	0.65
Contact Stablization	1

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 amoeba, 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

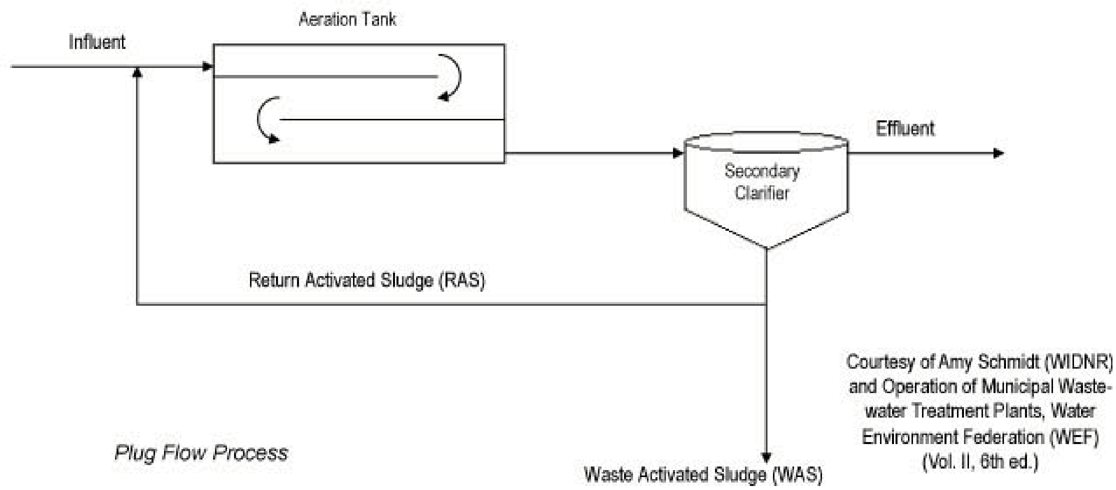


Section 1.3 - Process Variations

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.

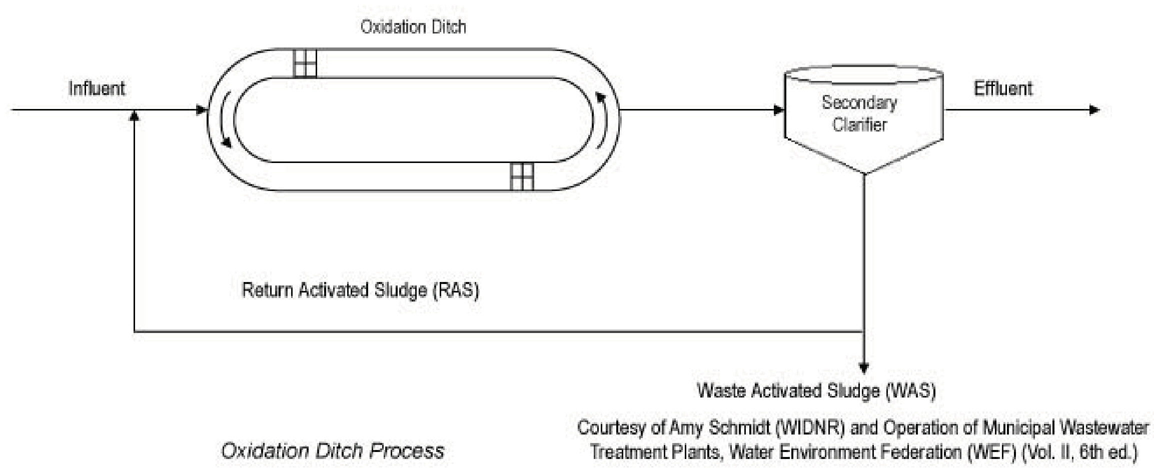
Figure 1.3.1.1



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



Chapter 2 - Operation and Maintenance

Section 2.1 - Definitions

2.1.1 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.

2.1.2 Define oxygen transfer efficiency (OTE).

Oxygen transfer efficiency is measured by the exchange of oxygen between the gas that is absorbed in a liquid compared to the amount of gas fed into the liquid. This is normally expressed as a percentage.

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

Figure 2.1.3.1

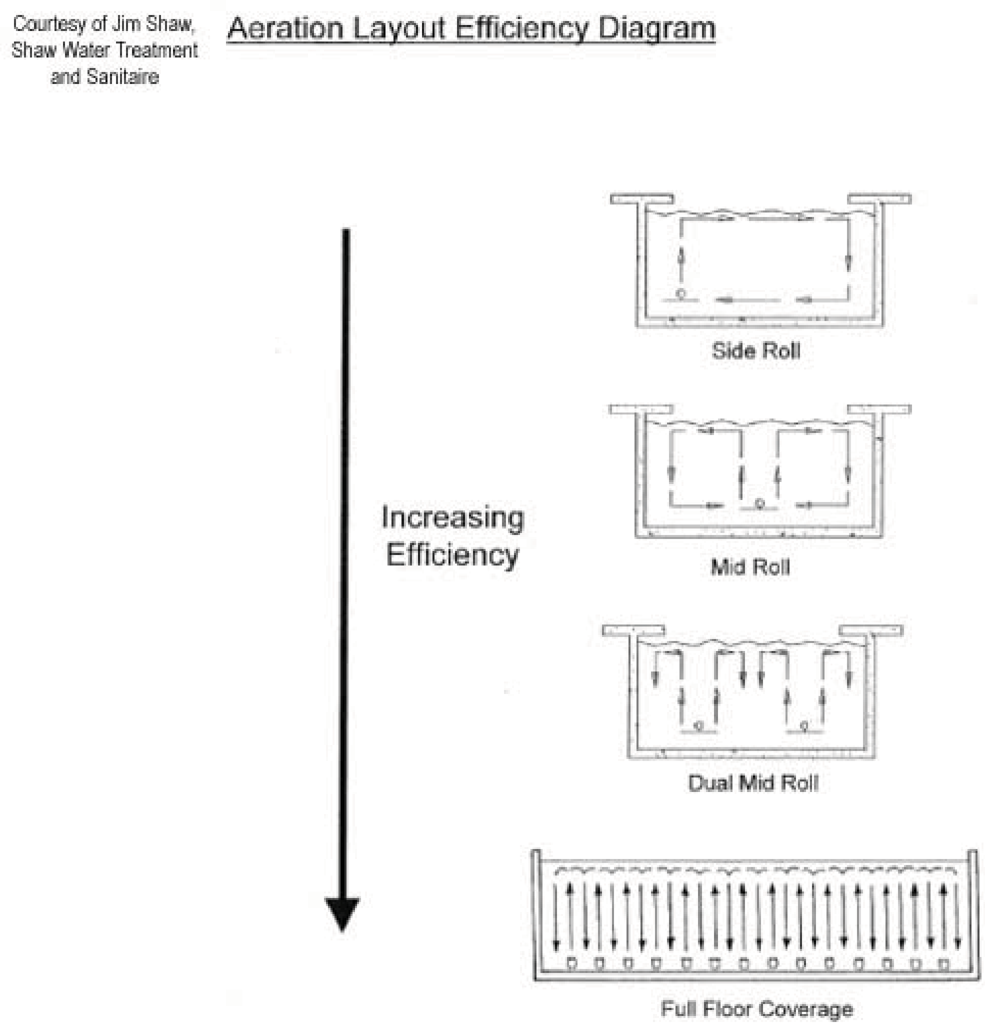

Courtesy of Jim Shaw,
Shaw Water Treatment
and Sanitaire
Aeration Layout Efficiency Diagram
Increasing
Efficiency
Side Roll
Mid Roll
Dual Mid Roll
Full Floor Coverage

Figure 2.1.3.2

Section 2.2 - Methods

2.2.1 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.

Equipment:
A. Type of aeration system diffusers (ultra fine bubble, fine bubble, coarse bubble)
B. Diffuser placement on the tank floor (full floor coverage, side placement or center placement)
C. System operating pressure
D. Oxygen transfer efficiency (following ASCE standard test)

Operations:
A. Diffuser maintenance
B. Mixed liquor suspended solids
C. Excess process dissolved oxygen

The most efficient aeration system is a combination of fine bubble and high oxygen transfer efficiency with the diffusers placed in full floor coverage with a mid-range system pressure

(6-8 psi) and annual cleaning. A coarse bubble diffuser system placed in full floor coverage has low maintenance requirements but a much lower oxygen transfer efficiency (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.

2.2.2 Outline the start-up 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 clarifiers at least 2 complete rotations checking for proper operation
H. Check RAS/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/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

2.2.3 List the steps that might be taken to speed-up the formation of sufficient mixed liquor suspended solids when starting or restarting an activated sludge plant.

A. Obtain "seed" activated or return sludge without filamentous organisms from a near-by plant
B. Return 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

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

A. Weekly
If loadings can be anticipated, adjust mixed liquor suspended solids 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 mixed liquor suspended solids or add/remove tankages from service.

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

A. Increase the mixed liquor suspended solids concentration
B. Winterize equipment and tankage to prevent freezing problems

2.2.6 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.

Section 2.3 - Equipment

2.3.1 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 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.

2.3.2 Discuss the factors that effect oxygen transfer efficiency (OTE).

Oxygen transfer efficiency (OTE) depends on several factors which include water depth, layout, and diffuser air rate. For this discussion we will forget about the diffuser air rate component and focus on water depth and layout.

Most plants in Wisconsin have a water depth of 15-18 feet. Using 15 feet, a rule of thumb for a fine bubble grid (full floor coverage) aeration system OTE in clean water is about 2% per foot up to about 25 feet of submergence i.e. 2%/ft × 15 feet = 30% OTE. That is a very efficient OTE for an aeration system. A mechanical aeration system or coarse bubble system is typically about 0.75% OTE per foot of submergence or roughly half of a fine bubble (full floor coverage) aeration system. Fine bubble diffusers NOT configured in full floor coverage (side roll or cross roll) will have an OTE of 1% - 1.25%. This is typical of fine bubble tube diffuser layouts.

These are rough estimates of OTE that can be used to check a diffuser manufacturer's OTE claim. Actual OTE can range about 10% - 15% from the rules of thumb above.

2.3.3 List the treatment plant information and questions that would be part of an energy audit of an activated sludge plant.

A. 12 months of energy bills (electric and natural gas)
B. 12 months of average monthly loadings to WWTF (influent flows and wastewater strength)
C. Information on:

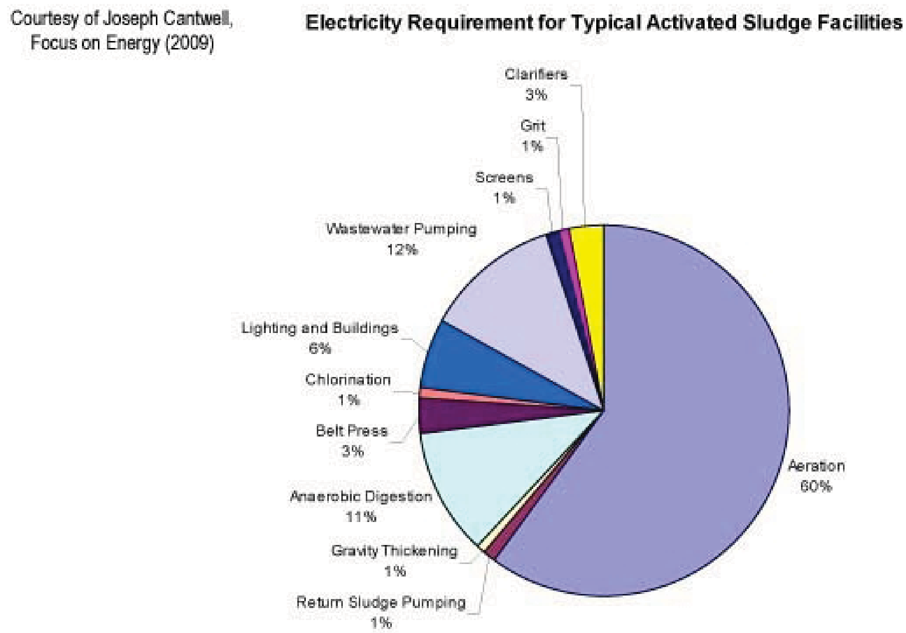
1. On-peak electric schedule
2. Off-peak electric schedule
3. On-peak electric rates
4. Off-peak electric rates
5. On-peak demand periods

D. Discharge permit limits
E. Unit processes at the WWTF
F. Aeration tank dimensions
G. Type of aeration diffusers
H. Type and size of aeration blowers
I. Type and size of pumps and motors
J. Is there dissolved oxygen control system?
K. What is the post aeration dissolved oxygen concentration requirement?
L. What type of heating system do you have?
M. What areas of the plant, if any, have unit heaters?
N. What areas have hot water heating system?
O. What is your interior lighting?
P. What is your exterior lighting system?
Q. What is the size of each building within the WWTF?
R. What is the type of construction for each building?
S. What type of windows is in each building?
T. What is the type and thickness of insulation for each building?
U. Do you have watt or amp readings on each piece of major equipment?
W. What temperature are the buildings set at?
X. What type of ventilation system does your facility have, upon entrance or continuous?
Y. What are the highest maintenance items on-site?

2.3.4 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 2.3.4.1



2.3.5 Discuss 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 1-4sec)
G. Motor protection in controller
H. Phase converter
I. Installation easy and fast

Chapter 3 - Monitoring, Process Control, and Troubleshooting

Section 3.1 - Definitions

3.1.1 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.

3.1.2 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 60-80%.

Section 3.2 - Sampling & Testing

3.2.1 Explain bench scale testing and how it is used at a treatment plant.

Bench scale testing is operating a process under a controlled continuous basis to determine its effectiveness. This could include evaluation of aeration equipment, trying a different treatment mode, alternative treatment devices, polymer effectiveness, treatability studies, etc.

3.2.2 Discuss the following tests in monitoring activated sludge operations:

A. Soluble Biochemical Oxygen Demand (BOD)
B. Carbonaceous Biochemical Oxygen Demand (CBOD)
C. Chemical Oxygen Demand (COD)

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 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).

3.2.3 Discuss the nitrogen compounds found in wastewater and their conversion in the activated sludge treatment process.

A. Total Kjeldahl Nitrogen (Standard Method 4500)
Total Kjeldahl Nitrogen test measures both the organic-nitrogen and ammonia-nitrogen in the wastewater. If only two of these results are given on a lab report, the other portion can be found by adding or subtracting as appropriate.

Total Kjeldahl Nitrogen = Total Organic Nitrogen + Ammonia Nitrogen

Levels of Total Kjeldahl Nitrogen in raw domestic wastewater range from 20 to 85 mg/L.

B. Total Organic Nitrogen
This test measures organic nitrogen compounds such as proteins, peptides, amino acids, and urea. Levels of these compounds found in raw domestic wastewater range from 8 to 35 mg/L.

C. Ammonia-Nitrogen

Lab results labeled as ammonia-nitrogen (NH3-N) reflect the level of both ammonia (NH3) and ammonium ion (NH4+). Treatment plants that discharge to small streams often have to meet discharge limits for ammonia-nitrogen, as ammonia can be toxic to stream organisms in elevated levels. Ammonia concentrations in domestic wastewater range from 12 to 50 mg/L.

D. Nitrate-Nitrogen

The formula for nitrate is NO3-. It is found in small quantities in fresh domestic wastewater. However, effluent samples, particularly at plants which provide ammonia removal, will show higher levels of nitrate, because ammonia is converted to nitrite and nitrate under aerobic conditions.

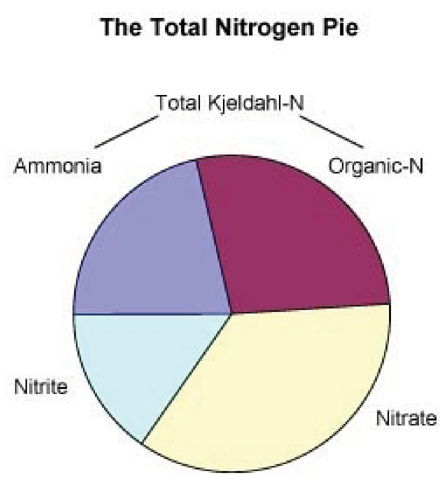
Nitrate levels are of particular concern in drinking water, as excessive amounts can cause a disorder in infants called "infant methemoglobinemia". This condition causes improper oxygen utilization in the infant's blood.

E. Nitrite-Nitrogen

The chemical formula for this compound is NO2-. It is formed in an intermediate step when ammonia is oxidized to nitrates.

All of these types of nitrogen can be converted from one form to another. Fresh, cold influent is usually high in organic nitrogen, lower in ammonia, with only traces of nitrates and nitrites. Stale, warm influent will have high concentrations of ammonia and low concentrations of organic nitrogen. As mentioned above, ammonia present in the influent can be converted to nitrite and nitrate-nitrogen in the treatment process through nitrification.

Figure 3.2.3.1



3.2.4 Discuss Chemical Oxygen Demand (COD) tests as a substitute for the BOD test.

The biochemical oxygen demand (BOD5) is a standard wastewater test for assessing wastewater strength. The BOD5 test measures the biological uptake of oxygen in the oxidation of organic matter in five days at 20ºC. The chemical oxygen demand test (COD) is a wastewater test that measures the chemical oxidation of organic material in wastewater, including those organic materials that are not easily used by bacteria. Sample results are thus higher for COD than BOD. A COD/BOD correlation curve should be determined if COD tests are to be used as a subsitute for the BOD tests for process control.

3.2.5 Discuss Oxygen Uptake Rate (OUR) and Respiration Rate (RR) and what these tests mean in the activated sludge process.

These tests measure the health and activity of the microorganisms through the amount of oxygen they consume. The Oxygen Uptake Rate test is a measure of the oxygen consumed in a sample of activated sludge and is expressed as mg/L of oxygen per hour. The Respiration Rate relates the OUR test results to the concentration of organisms in the activated sludge sample. OUR results are used to calculate the RR. OUR results are usually graphed and the linear part of the graph used for determining the oxygen consumption in that time interval. OURs are higher where influent first enters an aeration basin.

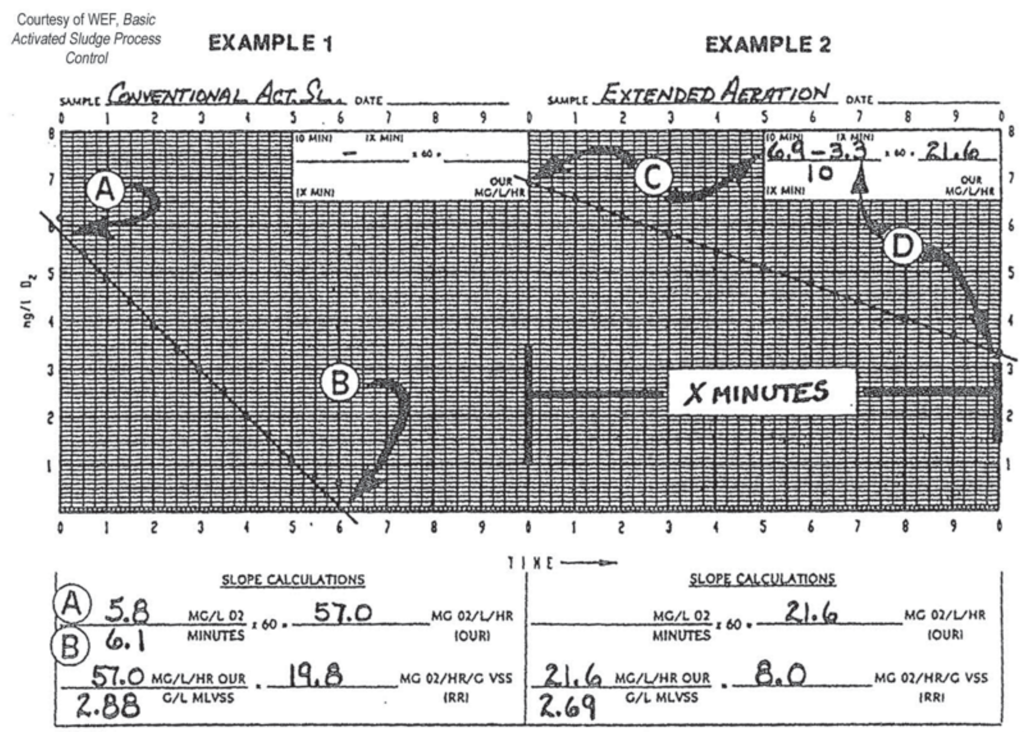
OUR (O2mg/L*hr) = [(D.O. concentration at 0 minutes (mg/L)- D.O. concentration at x minutes (mg/L)) ÷ x minutes] × 60 min/hr
x is usually ten minutes

RR (O2mg/gram*hr VSS) = OUR (O2mg/L/hr) ÷ MLVSS (grams)

The OUR can be be affected by the microorganism population and viability, temperature, alkalinity/pH, BOD loading and toxicity. OUR results are often shown on a line graph, showing higher results at the head of a treatment basin and lower results at the end.

The operator is referred to the Basic Activated Sludge Process Control Manual (WEF 1994) given at the end of the study guide for more detailed information and procedures for these tests.

Figure 3.2.5.1



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

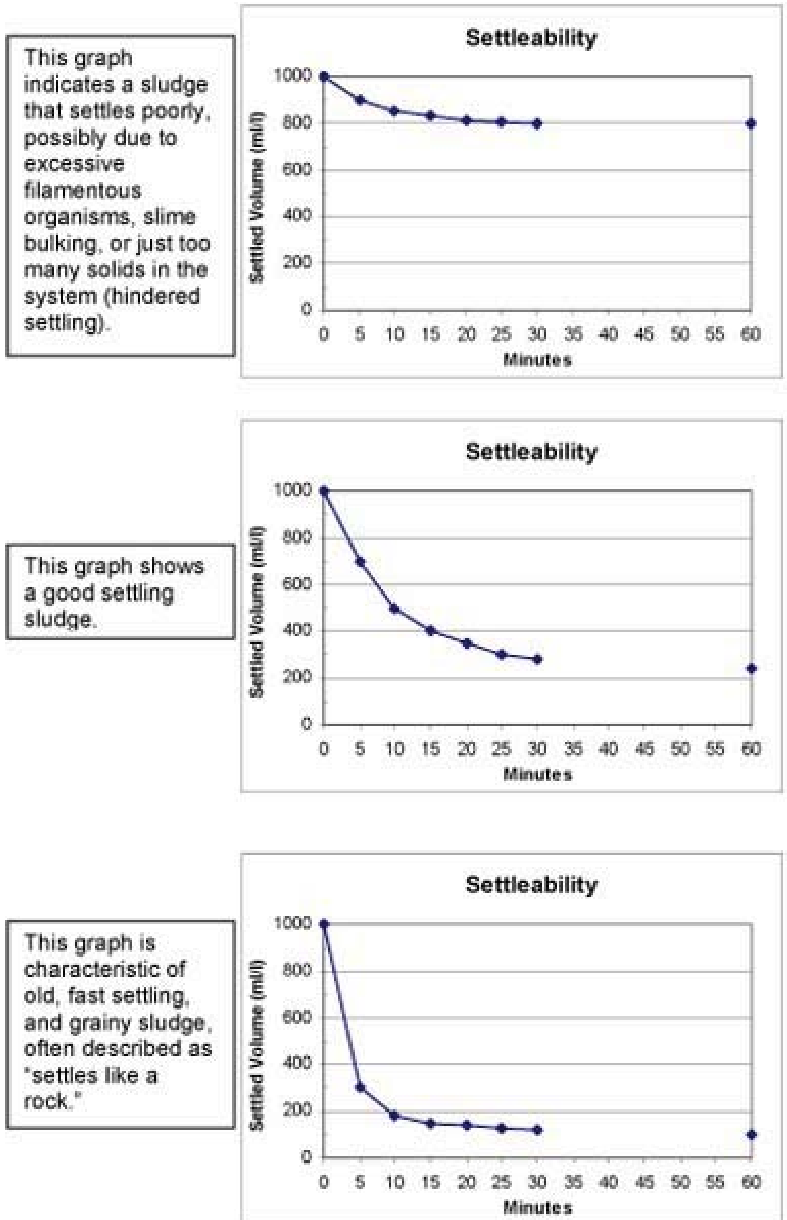
Real time in-line monitoring allows for better process control and energy efficiency of the activated sludge process. Instrumentation and monitoring equipment are installed directly in the tankages for automatic and continuous readings. Process adjustments and timely operational changes can then be made,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

Sampling and in-line testing of various pollutants of interest (such pH, ammonia, ortho-phosphorus, 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 dissolved oxygen 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 consistant 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.

3.2.7 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 3.2.7.1



3.2.8 Discuss hindered settling and how to determine if this may be occuring.

When there are too many solids in the system, the solids settling in the final clarifier may "hinder" the settling of solids above them. There are just too many solids in the water column to settle well. This can be observed in 30 minute settling tests and the tests will usually be high (>800 mL/L). To differeniate a settling problem caused by hindered settling versus excessive filaments, an operator can do a diluted settleability test by diluting the mixed liquor sample in half (50%) with clear final effluent. If the 30 minute settleability test and settling curve improves, this indicates with less solids, settling is better. Additional wasting would be warranted. If settling does not improve after diluting the sample, filaments may be present and the operator should use their microscope for filamentous organism identification.

Section 3.3 - Data Understanding & Interpretation

3.3.1 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.

3.3.2 List three factors that affect dissolved oxygen in aeration basins, and explain how they affect plant operation.

A. BOD Loading
An increase in influent BOD will increase dissolved oxygen demand and more aeration (oxygen) 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 dissolved oxygen because dead bacteria will be unable to consume the oxygen supplied. The source of the toxicity should be identified/eliminated and the mixed liquor may need to be wasted from the plant to remove the dead bacteria. Reseeding may be necessary.

3.3.3 Discuss problems that may occur as a result of partial nitrification.

Partial nitrification occurs when only a part of the ammonia is converted to nitrates. Partial nitrification can occur in treatment plants that were not designed for nitrification (no ammonia limits), or at a sludge age that is too short to allow complete nitrification. The effluent will then contain some ammonia, nitrites and nitrates. This can cause a problem with the BOD determination of the effluent by giving a false high reading. The BOD determination will show oxygen depletion for carbon based pollutants as well as the nitrogen based compounds, which will cause the measured reading to be high. A nitrification inhibitor can be added to the BOD samples to correct for this, and the resultant determination is known as Carbonaceous BOD (CBOD). A CBOD test can only be reported if allowed as part of the WPDES permit effluent limits. The operator can adjust the sludge age of the treatment process to correct for partial nitrification.

Chlorine disinfection is also affected by partial nitrification, as nitrites will be present in the effluent. Nitrites react with chlorine, and the presence of them in the effluent will require a higher chlorine dosage to meet disinfection requirements.

3.3.4 Compare activated sludge solids results expressed as milligrams per liter (mg/L) and % solids.

In activated sludge aeration basins, mixed liquor suspended solids is expressed in milligrams per liter (mg/L) . As solids are thickened and the concentration gets to 10,000 mg/L or above, the solids are then often expressed as a percent. Every 10,000 mg/L is 1% and can be expressed as follows:

10,000 mg/L = 1.0 % solids
15,000 mg/L = 1.5 % solids
20,000 mg/L = 2.0 % solids
25,000 mg/L = 2.5 % solids
30,000 mg/L = 3.0 % solids

Section 3.4 - Side Streams/Recycle Flows

3.4.1 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 strong in BOD, TSS, ammonia, phosphorus and sulfides (see figure 3.4.1.1). They may also be high in organic acids and FOG. Plants that accept these wastes should control the discharge of these wastes 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 (refer to Intro Activated Sludge Study Guide Key Knowledge 1.2.3 for more information). 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 flowrate as to not upset the plant and at a reasonable cost of treatment. Hauled-in wastes should also be regularly sampled and monitored.

Figure 3.4.1.1

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 operational problems related to hydraulic overloads from inflow and infiltration, 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
B. Clarifier operating performance
C. Clarifier solids loadings.

A. Mixed Liquor Settleability:
The key to optimizing settleability is (1) maintaining the proper environmental conditions that favor the growth and health of good large floc-forming bacteria that settle well (not filamentous organisms) (see Intro Activated Sludge Study Guide Key Knowledge 1.2.3 for more information) through (2) operating the treatment plant with regular and consistent process control (see Intro Activated Sludge Study Guide Key Knowledge 2.2.2 for more information).

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
The clarifier solids loading rate (SLR) is affected by the incoming flow and return activated sludge flow rate. Some ways to reduce the solids loading to the final clarifier(s) is to (1) bring any extra, unused tankages on-line if they are available, such as another clarifier or aeration basin; (2) take some aeration basin(s) off-line and storing 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, and (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 inflow/infiltration 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 The Clarifier (2005-2006). For complete details on ways to maximize secondary treatment wet weather capacity, the reader is referred to these six articles.

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 WIDNR 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 (1) have a high BOD or COD, (2) have a low or high pH, (3) are toxic or (4) 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 effect fat, oil, and grease (FOG) has on activated sludge microorganisms.

Although FOG can be very problematic on equipment once it reaches a plant, it is difficult for bacteria to break down. Bacteria are only capable of using soluble organics for food. In order to utilize FOG, the bacteria have to expend extra energy to produce enzymes to solubilize the greases and fats before they can be used for food. On the other hand, foam-causing filamentous bacteria such as Nocardia, Microthrix and type 1863 can utilize FOG very easily and will dominate when there is an excess amount available. Nocardia will favor greases and oils in warmer temperatures, Microthrix has the ability to break down greases and oils in colder temperatures and type 1863 has the ability to break down greases and oils when there is a decline in the aeration basin pH.

Keeping grease out of sewer systems and the treatment plant through a comprehensive Sewer Use Ordinance and Grease Control Program is an imperative element of good collection system O&M and WWTP process control.

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

Hydraulic residence time refers to the wastewater liquid within the treatment plant. Hydraulic residence time 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 20-30 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 hydraulic residence time and sludge age are very important for proper wastewater treatment and the removal of pollutants to occur.

3.5.5 State some environmental conditions that favor the growth of filamentous organisms in activated sludge.

Filamentous organisms will grow in conditions where they have a competitive advantage because of their large surface area, such as low dissolved oxygen, nutrient deficiency, very low F/M ratio (old sludge) and excess organic acids or sulfides. There are many types of filamentous organisms and identifying them can help an operator in troubleshooting the plant. Adding chlorine is not a long-term solution to filamentous settling problems and in some cases can make things worse. The most important thing an operator can do is restore or operate the plant at the environmental conditions that favor good floc-forming bacteria and not filamentous organisms. See Intro Activated Sludge Study Guide key knowledges 1.2.3 and 1.2.5 for more information.

Section 3.6 - Corrective Actions

3.6.1 State the causes and corrective actions for filamentous growth in activated sludge.

A. Cause - low dissolved oxygen
Correction - increase dissolved oxygen and maintain at least 1.5 to 2 mg/L

B. Cause - nutrient deficiency
Correction - add nutrients to achieve a ratio of 100 carbon:5 nitrogen:1 phosphorus:0.5 iron

C. Cause - high sludge age (excessive MLSS) and low F/M ratio
Correction - increase sludge wasting to reduce the sludge age and increase the F/M ratio

D. Cause - very young sludge (extremely low MLSS). Not enough organisms to handle the incoming load. This causes stabilization to occur in the final clarifier with dissolved oxygen going to zero. This will favor filaments.
Correction - build MLSS by not wasting, or haul in "seed" sludge from another plant

Chapter 4 - Safety and Regulations

Section 4.1 - Personal Safety

4.1.1 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.

4.1.2 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.

Section 4.2 - Regulations

4.2.1 The Wisconsin Department of Natural Resources NR 101 Wastewater Fee Program assesses an annual fee for the amount (in pounds) of Biological Oxygen Demand (BOD) discharged each year. Given data, calculate the discharge of BOD into a receiving water and resultant annual environmental fee.

GIVEN:
Average Daily Plant Flow = 1.75 MGD
Average BOD Effluent = 10 mg/L
Cost ($) per lb of BOD = 1 ÷ Limit (mg/L)
Municipal Adjustment Factor = 2.451
Limit = 30 mg/L

FORMULAS & SOLUTIONS:

(1)lbs of BOD discharged per day = Flow (MGD) × Avg. BOD (mg/L) × 8.34 lbs/gal
(2)Annual NR101 cost = Avg. lbs/day of BOD discharged × 365 days/yr × Cost/lb × Adj. Factor

(1)lbs BOD/day = 1.75 MGD × 10 mg/L × 8.34 lbs/gal
= 145.95 lbs
= 146 lbs

(2) Annual NR101 Cost = 146 lbs × 365 × (1÷30 mg/L) × 2.451
= 146 × 365 × 0.033 × 2.451
= $ 4310.2
= $ 4310

Chapter 5 - Calculations

Section 5.1 - Sludge Age Calculations

5.1.1 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 5.2 - Food to Microorganism Ratio Calculations

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

GIVEN:
Influent BOD5 = 40 pounds
Aeration basin MLSS = 4000 pounds

FORMULA & SOLUTION:
F/M Ratio = pounds of incoming BOD5 ÷ pounds of MLSS under aeration
F/M Ratio = 40 lbs BOD5 ÷ 4000 lbs MLSS
F/M Ratio = 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 (BOD5) coming in

Section 5.3 - Sludge Volume Index Calculations

5.3.1 Given treatment plant data, calculate the sludge volume index (SVI) and discuss possible causes.

GIVEN:
30 minute settling test = 800 mL/L
MLSS = 4000 mg/L

FORMULA & SOLUTION:
SVI = [settled volume in 30 minutes (mL/L) ÷ MLSS (mg/L)] × 1000
SVI = [800mL/L÷ 4000mg/L] × 1000
SVI = 200

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

Section 5.4 - Wasting Rates Calculations

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

GIVEN:
Aeration basin volume = 90,000 gallons
MLSS = 1800 mg/L
WAS concentration = 5000 mg/L
Desired sludge age = 9 days

FORMULAS:
(1) lbs MLSS under aeration = (aeration basin volume in MG) × (MLSS in mg/L) × 8.34 lbs/gal
(2) sludge age (days) = lbs MLSS under aeration ÷ lbs of sludge wasted per day
Rearranging this
(2A) lbs of sludge to waste = lbs MLSS under aeration ÷ desired sludge age in days
(3) gallons of sludge to waste = [(lbs of sludge to waste) ÷ (WAS concentration in mg/L × 8.34 lbs/gal)] × 1,000,000

(1) lbs MLSS under aeration = 0.09 MG × 1800 mg/L × 8.34 lbs/gal
= 1351 lbs

(2A) lbs of sludge to waste = 1351 lbs ÷ 9 days
= 150 lbs

(3) gallons of sludge to waste = [150 lbs ÷ (5000 mg/L × 8.34 lbs/gal)] × 1,000,000
= 3600 gallons

5.4.2 Given data, calculate how many gallons of sludge to waste to achieve a desired MLSS level.

GIVEN:
Aeration Basin Volume = 250,000 gallons
Current MLSS = 2200 mg/L
Desired MLSS = 2000 mg/L
WAS concentration = 4000 mg/L

FORMULAS & SOLUTION:

(1) Current MLSS (lbs) = (basin volume in MG) × (MLSS in mg/L) × 8.34 lbs/gal
(2) Desired MLSS (lbs) = (basin volume in MG) × (MLSS in mg/L) × 8.34 lbs/gal
(3) WAS (lbs) to be wasted = Current MLSS (lbs) - Desired MLSS (lbs)
(4) Gallons to be wasted = [WAS (lbs) to waste ÷ (WAS concentration in mg/L × 8.34 lbs/gal)] × 1,000,000

(1) Current MLSS (lbs) = (0.250 MG) × (2200 mg/L) × 8.34 lbs/gal
= 4587 lbs

(2) Desired MLSS (lbs) = (0.250 MG) × (2000 mg/L) × 8.34 lbs/gal
= 4170 lbs

(3) WAS (lbs) to be wasted = 4587 lbs - 4170 lbs
= 417 lbs

(4) Gallons to be wasted = [WAS (lbs) to waste ÷ (WAS concentration in mg/L × 8.34 lbs/gal)] × 1,000,000
= [417 lbs ÷ (4000 mg/L × 8.34 lbs/gal)] × 1,000,000
= 12,500 gallons

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