Wisconsin Department of Natural Resources
Wastewater Operator Certification

# Advanced Wastewater Study Guide

February 2016


Madison MSD - Nine Springs


New Water - Green Bay

Wisconsin Department of Natural Resources
Operator Certification Program
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## Preface

The Advanced Wastewater Study Guide is an important resource for preparing for the certification exam and is arranged by chapters and sections. Each section consists of key knowledges with important informational concepts you need to know for the certification exam. This study guide also serves as a wastewater treatment plant operations primer that can be used as a reference. Any diagrams, pictures, or references included in this study guide are included for informational/educational purposes and do not constitute endorsement of any sources by the Wisconsin Department of Natural Resources.

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

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

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

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

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

## Acknowledgements

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

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# Part 1 - A1: Biological Treatment - Suspended Growth Processes

## Chapter 1 - Theory and Principles

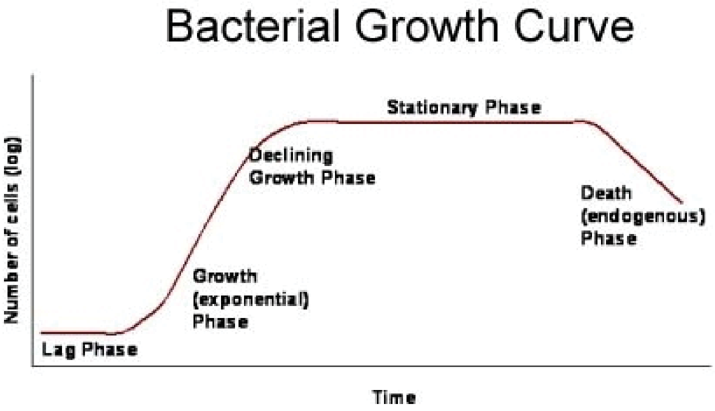
### Section 1.1 - Microbiological Principles

1.1.1 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 to use 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 (mixed liquor suspended solids or 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 1.1.1.1**

Source: Auralene Glymph, Microbiologist



1.1.2 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 MLSS builds and sludge age increases, flagellates and free swimmers will be seen. When the MLSS 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.

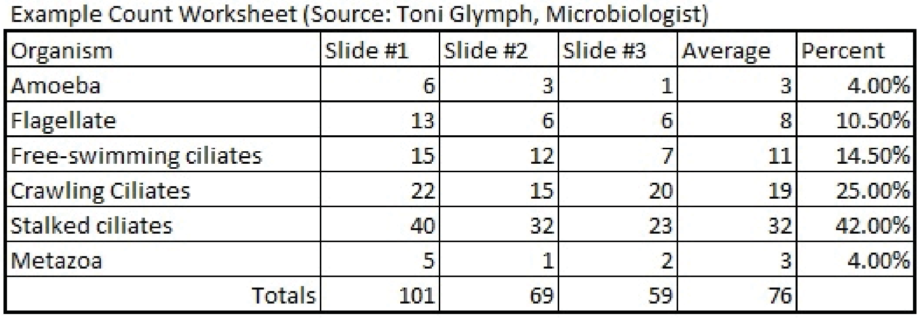
By observing the relative abundance of these indicator organisms the operator will be able to quickly tell the age and health of his activated sludge. The protozoan species that are most dominant indicate the environmental conditions occuring in the process, especially the relative age of the sludge. 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, nematodes, water bear, etc.)

The operator is referred to the references for protozoan count procedures.

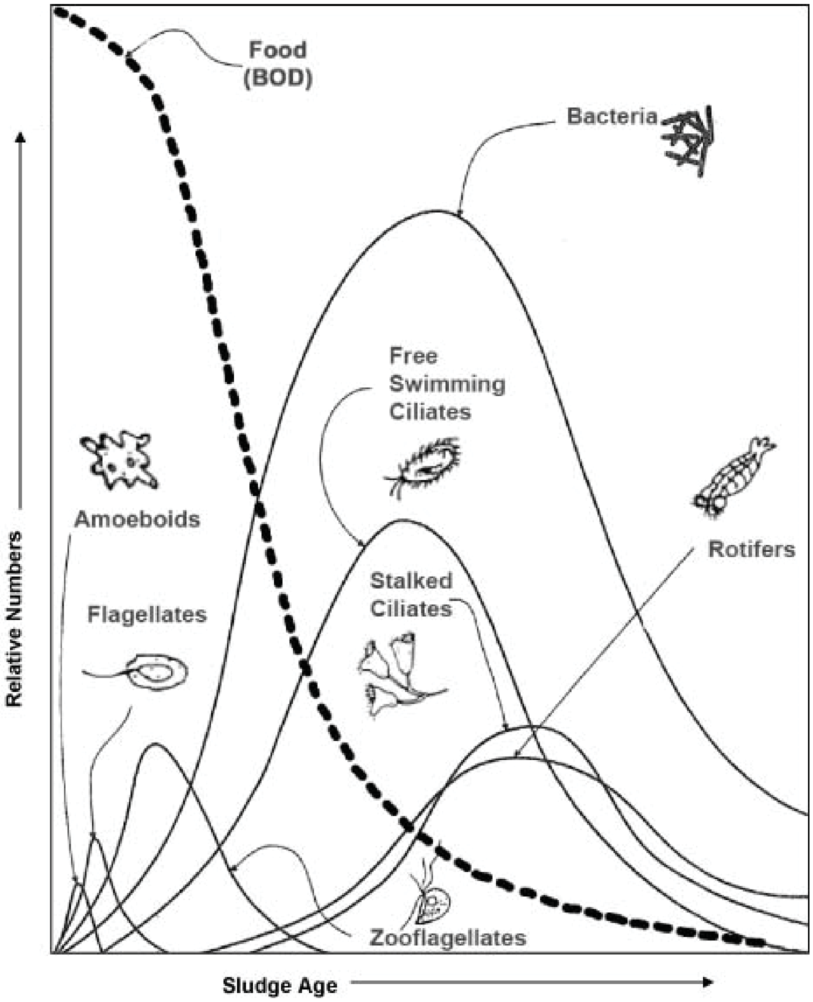
**Figure 1.1.2.1**



Example Count Worksheet (Source: Toni Glymph, Microbiologist)

| Organism | Slide #1 | Slide #2 | Slide #3 | Average | Percent |
|---|---|---|---|---|---|
| Amoeba | 6 | 3 | 1 | 3 | 4.00% |
| Flagellate | 13 | 6 | 6 | 8 | 10.50% |
| Free-swimming ciliates | 15 | 12 | 7 | 11 | 14.50% |
| Crawling Ciliates | 22 | 15 | 20 | 19 | 25.00% |
| Stalked ciliates | 40 | 32 | 23 | 32 | 42.00% |
| Metazoa | 5 | 1 | 2 | 3 | 4.00% |
| Totals | 101 | 69 | 59 | 76 | |

**Figure 1.1.2.2**



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

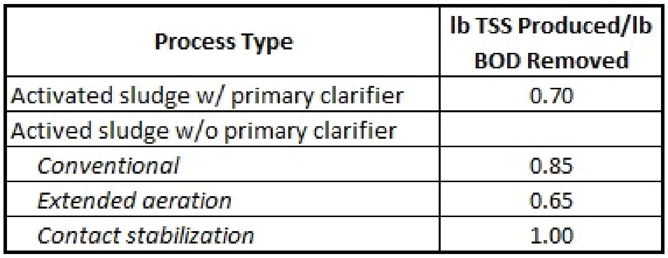
(Source: Amy Garbe (WDNR) and Operation of Municipal Wastewater Treatment Plants, Water Environmnent Federation (WEF) (Vol. II 6th ed.)

1.1.3 State the sludge production (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 (TSS) 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 1 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 the figure below.

**Figure 1.1.3.1**



| Process Type | lb TSS Produced/lb BOD Removed |
|---|---|
| Activated sludge w/ primary clarifier | 0.70 |
| Actived sludge w/o primary clarifier | |
| *Conventional* | 0.85 |
| *Extended aeration* | 0.65 |
| *Contact stabilization* | 1.00 |

## Chapter 2 - Operation and Maintenance

### Section 2.1 - Definitions

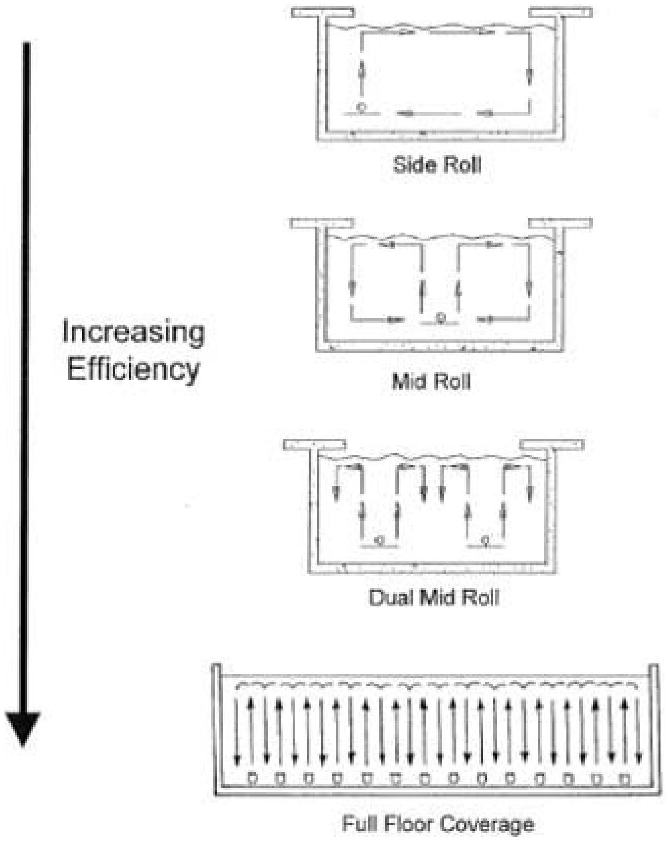
2.1.1 Define oxygen transfer efficiency (OTE).

OTE 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.

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

**Figure 2.1.2.1**

Aeration Layout Efficiency Diagram



Source: Jim Shaw, Shaw Water Treatment and Sanitaire

**Figure 2.1.2.2**

## Section 2.2 - Equipment

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

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 to 18 ft. Using 15 ft, 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 ft of submergence (i.e. 2%/ft × 15 ft = 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% to 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% to 15% from the rules mentioned earlier.

# 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 a 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.

## Section 3.2 - Sampling and 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 nitrogen compounds found in wastewater and their conversion in the activated sludge treatment process.

A. Total Kjeldahl nitrogen (TKN) (Standard Method 4500)
A TKN 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.

TKN = total organic nitrogen + ammonia nitrogen

Levels of TKN in raw domestic wastewater range from 20 to 85 mg/L.

B. Total organic nitrogen
A total organic nitrogen 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 organisms in a stream with elevated levels. Ammonia concentrations in domestic wastewater range from 12 to 50 mg/L.

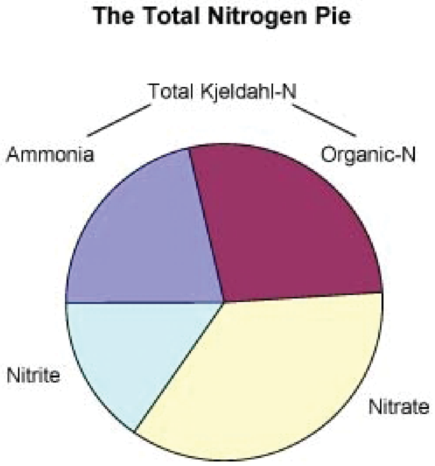
D. Nitrate nitrogen
The formula for nitrate is NO3-. It is found in small quantities in fresh domestic wastewater. However, effluent samples, particularly at plants which provide ammonia removal, will show higher levels of nitrate, because ammonia is converted to nitrite and nitrate under aerobic conditions.

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 nitrite nitrogen is $NO_2^-$. 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 3.2.2.1**



3.2.3 Discuss chemical oxygen demand (COD) tests as a substitute for the biochemical oxygen demand 5-day (BOD5) test.

The 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 5 days at 20ºC. The 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 BOD5. A COD/BOD5 correlation curve should be determined if COD tests are to be used as a substitute for the BOD5 tests for process control.

3.2.4 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 OUR 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 RR 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. OUR is higher where influent first enters an aeration basin.

OUR (O2 mg/L/hr) = [(DO conc. at 0 mins (mg/L) - DO conc. at X mins (mg/L)) ÷ X mins] × 60 min/hr

DO = dissolved oxygen
X = usually 10 mins

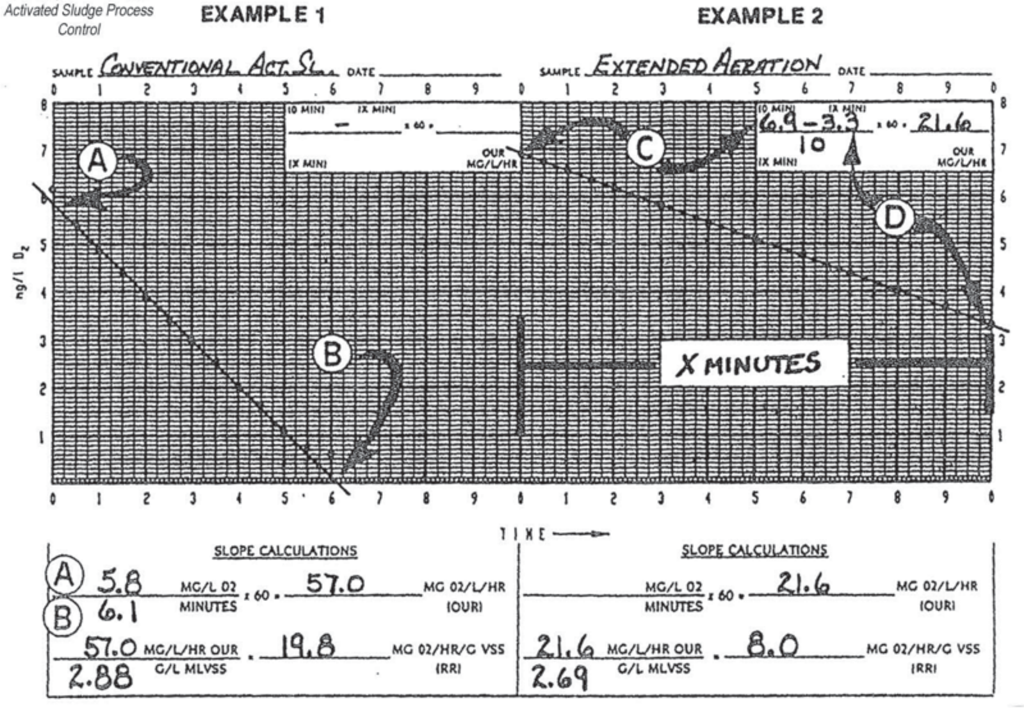
RR (O2 mg/gram/hr VSS) = OUR (O2 mg/L/hr) ÷ MLVSS (g/L)

VSS = volatile suspended solids
MLVSS = mixed liquor volatile suspended solids

The OUR can 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.

**Figure 3.2.4.1**

Courtesy of WEF, *Basic Activated Sludge Process Control*



(0 MIN) 6.9 − (X MIN) 3.3 / (X MIN) 10 × 60 = 21.6 OUR MG/L/HR

SLOPE CALCULATIONS

(A) 5.8 / (B) 6.1 MG/L O2 / MINUTES × 60 = 57.0 MG O2/L/HR (OUR)

57.0 MG/L/HR OUR / 2.88 G/L MLVSS = 19.8 MG O2/HR/G VSS (RR)

SLOPE CALCULATIONS

MG/L O2 / MINUTES × 60 = 21.6 MG O2/L/HR (OUR)

21.6 MG/L/HR OUR / 2.69 G/L MLVSS = 8.0 MG O2/HR/G VSS (RR)

3.2.5 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 results will usually be high (greater than 800 mL/L). To differentiate 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 result 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 and Interpretation

3.3.1 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 have 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 biochemical oxygen demand 5-day test (BOD5) of the effluent by giving a false high reading. The BOD5 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 BOD5 samples to correct for this, and the resultant determination is known as carbonaceous BOD5 (cBOD5). A cBOD5 test can only be reported if allowed as part of the Wisconsin Pollution Discharge Elimination System (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.

## Section 3.4 - Performance Limiting Factors

3.4.1 Discuss the effect fat, oil, and grease (FOG) has on activated sludge microorganisms.

Not only can 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 FOG before it 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 FOG in warmer temperatures, Microthrix has the ability to break down FOG in colder temperatures, and type 1863 has the ability to break down FOG when there is a decline in the aeration basin pH.

Keeping FOG 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 treatment process control.

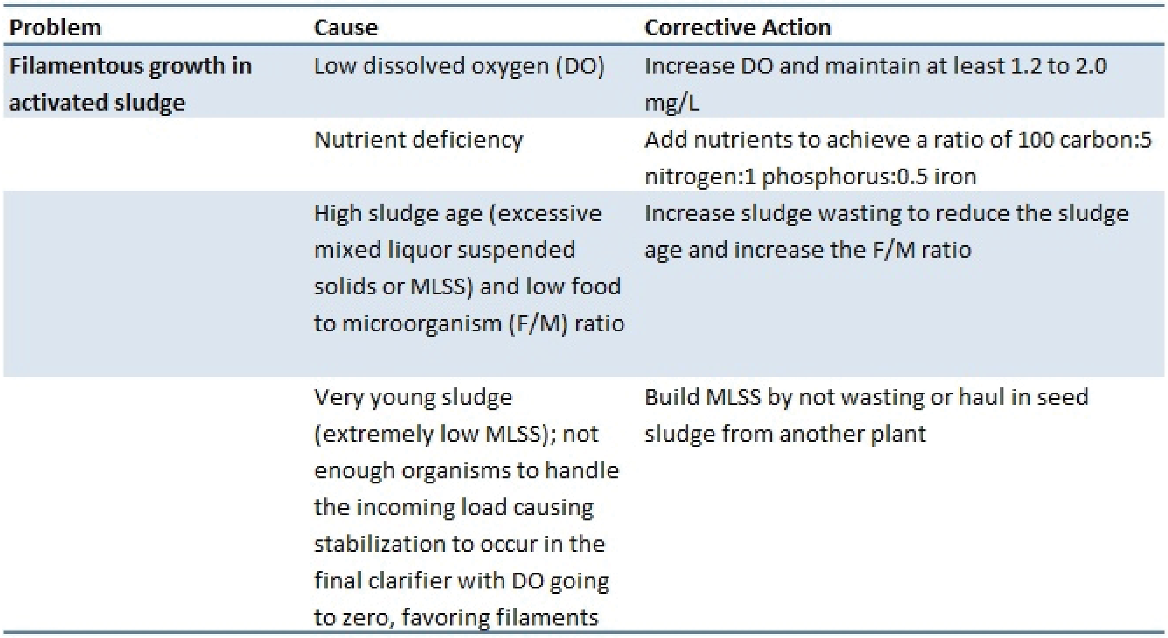
3.4.2 State some environmental conditions that favor the growth of filamentous organisms in activated sludge.

Filamentous organisms will grow in conditions where they have a competitive advantage because of their large surface area, such as low dissolved oxygen (DO), nutrient deficiency, very low food to microorganism (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.

### Section 3.5 - Corrective Actions

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

**Figure 3.5.1.1**



| Problem | Cause | Corrective Action |
|---|---|---|
| **Filamentous growth in activated sludge** | Low dissolved oxygen (DO) | Increase DO and maintain at least 1.2 to 2.0 mg/L |
| | Nutrient deficiency | Add nutrients to achieve a ratio of 100 carbon:5 nitrogen:1 phosphorus:0.5 iron |
| | High sludge age (excessive mixed liquor suspended solids or MLSS) and low food to microorganism (F/M) ratio | Increase sludge wasting to reduce the sludge age and increase the F/M ratio |
| | Very young sludge (extremely low MLSS); not enough organisms to handle the incoming load causing stabilization to occur in the final clarifier with DO going to zero, favoring filaments | Build MLSS by not wasting or haul in seed sludge from another plant |

## Chapter 4 - Safety and Regulations

### Section 4.1 - Regulations

4.1.1 The Wisconsin NR 101 Wastewater Fee Program assesses an annual fee for the amount (lbs) 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:
[MGD = million gallons per day]

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 AND SOLUTION:

BOD discharged (lbs/day) = flow (MGD) × average BOD (mg/L) × 8.34

= 1.75 MGD × 10 mg/L × 8.34
= 145.95 lbs
= 146 lbs

Annual NR 101 cost = avg. BOD discharged (lbs/day) × 365 days/yr × cost ($/lb) × adj. factor
= 146 lbs × 365 days × (1 ÷ 30 mg/L) × 2.451
= 146 lbs × 365 days × 0.033 × 2.451
= $4,310.26

## Chapter 5 - Calculations

### Section 5.1 - Wasting Rates

5.1.1 Given data, calculate how much sludge (gals) to waste to achieve a desired sludge age (days).

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

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

FORMULAS AND SOLUTION:
[MG = million gallons]
[gpd = gallons per day]

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

Sludge age (days) = MLSS under aeration (lbs) ÷ sludge wasted (lbs/day)

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

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

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

GIVEN:

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

FORMULAS AND SOLUTION:

Current MLSS (lbs) = basin vol. (MG) × MLSS (mg/L) × 8.34
= 0.250 MG × 2,200 mg/L × 8.34
=4,587 lbs

Desired MLSS (lbs) = basin vol. (MG) × MLSS (mg/L) × 8.34
= 0.250 MG × 2,000 mg/L × 8.34
= 4,170 lbs

Sludge to waste (lbs) = current MLSS (lbs) - desired MLSS (lbs)
= 4,587 lbs - 4,170 lbs
= 417 lbs

Sludge to waste (gals) = [sludge to waste (lbs) ÷ (WAS conc. (mg/L) × 8.34)] × 1,000,000
= [417 lbs ÷ (4,000 mg/L × 8.34)] × 1,000,000
= 12,500 gals

# Part 2 - A2: Biological Treatment - Attached-Growth Processes

## Chapter 6 - Theory and Principles

### Section 6.1 - Microbiological Principles

6.1.1 Describe the attached growth processes.

Attached-growth processes (also known as fixed-film processes) are biological wastewater treatment processes with the biomass attached to some type of media. The media normally found at wastewater treatment plants are rock, ceramic, plastic materials, and slag. The growth formed on the media is a mixture of mainly aerobic microorganisms. These organisms are similar to those found in other secondary biological treatment processes. The microorganisms include free-swimming and stalked ciliates, rotifers, nematodes, and many others. As the biomass thickens, it loses its ability to adhere to the media and is sloughed. Attached-growth processes are easy to operate and resilient to shock loads, however they are less flexible for process control than activated-sludge process.

6.1.2 Describe the role microorganisms have in the attached-growth process.

The principle role microorganisms have in the attached-growth process is to convert dissolved and particulate organic matter, measured as biochemical oxygen demand (BOD), into cell mass. In a conventional attached-growth process, microorganisms use oxygen to break down organic matter (food) for their growth and survival. Over time and as wastewater moves across the media, food (BOD) decreases with a resultant increase in cell mass.

6.1.3 Describe the environmental factors that influence the health and growth of the attached-growth microorganisms.

The attached-growth process must operate under proper environmental conditions to support a healthy, growing population of microorganisms. The operator must monitor the process to ensure the right environmental conditions are being provided for efficient attached-growth performance.

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

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

C. Oxygen
The attached-growth process is aerobic. The microorganisms need free oxygen 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 for the microorganisms. In trickling filters and biotowers the oxygen is supplied through the voids in the media after the distributor arms have passed by. The microorganisms in a rotating biological contactor (RBC) receive oxygen when they rotate out of the wastewater on the media discs.

D. Temperature
All biological and chemical reactions are affected by temperature. Microorganisms' growth and reaction rates are slow in cold temperatures and much faster at warmer temperatures. Most microorganisms do best under moderate temperatures (10°C to 25°C).

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

F. Nutrients
Microorganisms need nutrients such as nitrogen and phosphorus for their metabolism. Most incoming wastewater to a treatment plant, especially domestic sewage, contains an abundance of these nutrients. The ratio of BOD to nitrogen to phosphorus should be at least 100:5:1. Primary clarifier effluent can be tested to determine this nutrient ratio.

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

6.1.4 Describe the appearance and types of microorganism growth on the various stages of a rotating biological contactor (RBC) unit.

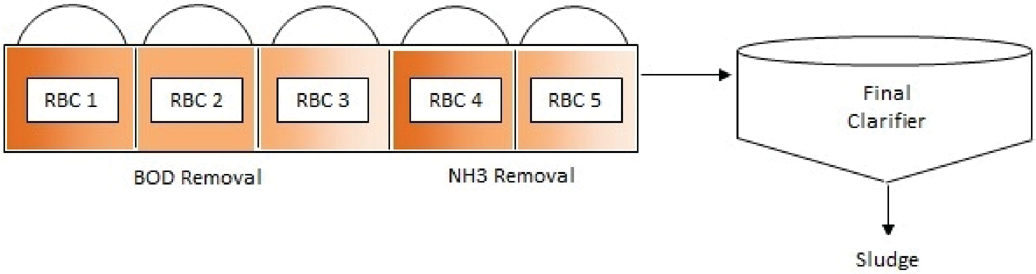
RBC units are designed to work in stages. Each stage receives effluent wastewater from the previous stage. Food (BOD) is less and less as the wastewater passes through the RBC treatment train. The population of microorganisms growing on the RBC media reflects the decreasing level of food available. This is observed by visual appearance of the disk media as well as by microscopic examination. Many of the same organisms observed under a microscope in an activated sludge treatment plant can also be observed in a RBC plant.

On the first few stages, normal healthy growth is rather dense and covers most of the media due to higher growth rates from the higher available food (BOD). The biomass growing on the media is usually tan-brown to light gray (varying with individual plants). Under the microscope, an operator will likely see a lot of motion which is characteristic of free-swimming and crawling ciliates with some stalked ciliates.

On the later stages, where food is lower, there will be less growth on the media. If food becomes very limiting, the attached-floc particle stripping can occur. Still tan-brown to light gray, growth may be splotchy. Microscopic examination will reveal less motion and larger numbers of stalked ciliates, rotifers, and nematodes.

Some RBC plants are designed to provide nitrification to remove ammonia in the later stages of a RBC treatment train. These stages are typically high-density media. When nitrification is occurring, media growth is very different from earlier stages by being thin, very granular (sandpaper texture), and dark brown.

**Figure 6.1.4.1**



## Section 6.2 - Process Variation

6.2.1 Describe hybrid (combined) attached-growth processes.

A. Moving bed bio-reactors (MBBR)
The MBBR processes consist of loose media in an activated-sludge suspended-growth basin. The media remains in the individual basins as the activated sludge travels through the stages. A diffuser on the bottom provides oxygen into the system, mixes the media, and causes excess biomass to be sloughed off the media. This allows for more treatment within a smaller volume. Unlike typical suspended-growth processes, there is no recycle side flow.

B. Integrated fixed-film activated-sludge (IFAS) process
The IFAS process consists of both loose or fixed media (like a MBBR system) and typical activated-sludge solids recycling. This variance allows for more nitrification in the same tank volume.

C. Aerated submerged bio-film (ASBF) reactors
Nitrification (ammonia removal) is very difficult to achieve within pond and lagoon systems in Wisconsin because of extremely cold wastewater temperatures (6°C or less) which inhibit nitrifying bacteria from growing. ASBF reactors may be used to enhance nitrification in municipal wastewater treatment ponds and lagoons by encouraging the growth of a nitrifying bacterial biomass on a submerged-media surface. Supplying air directly to the submerged biofilms enhances the oxygen transfer to the bacteria in the bio-film, encouraging better nitrification.

6.2.2 Describe the solids contact process and how it can improve rotating biological contactor (RBC) performance.

RBC performance can be significantly improved by recirculating final clarifier settled solids back through the RBC unit with supplemental aeration. Such an operational mode creates a hybrid suspended-growth system within an attached-growth system resulting in a mixed liquor suspended solids (MLSS) in the RBC basins. Supplemental aeration maintains desired dissolved oxygen (DO) levels while also providing necessary mixing of the returned solids.

MLSS levels of 1,000 to 3,000 mg/L in the RBC basins have been shown to improve biochemical oxygen demand (BOD), total suspended solids (TSS), and ammonia removal in RBC plants in Wisconsin modified for this operational mode. Improved settleability also results due to a mixed attached-suspended growth floc.

## Chapter 7 - Operation and Maintenance

### Section 7.1 - Definitions

7.1.1 Define recirculation.

Recirculation is the portion of the attached-growth effluent returned back to the influent of the process.

7.1.2 Define recirculation ratios.

Recirculation ratios are expressed as the volume of return recirculation flows to the volume of the attached-growth process influent. Typical recirculation ratios are 1:1 to 4:1.

### Section 7.2 - Equipment

7.2.1 Describe the components and equipment of a rotating biological contactor (RBC).

A. Air- and/or mechanical-drive system
Air-driven units consist of air cups, air diffusers, and air headers. Mechanical-driven units use motor, belts, chain, sprockets, and speed reducers. In figure 2.2.1.1, all of these components are inside the drive casing.

B. Media
The media is a series of large rotating discs constructed of either high- or low-density plastic-polyethylene, in which the biomass adheres. The rotating discs should never be submerged more than 40% of their diameter and never rotated at a speed greater than 1.5 rpms.

C. Baffles
The baffles may be concrete or wood planking and separate one shaft from another. Some baffles contain weirs to control the flow from one stage to the next.

D. Enclosure
Outdoor RBCs normally have covers or enclosures over the entire unit to protect the microorganisms from the weather, for odor control, and for security. An enclosure also includes the building the RBCs are housed. An enclosure is pictured on the front cover of this guide.

E. Bearings
The bearings support the shaft and allow the unit to rotate smoothly without friction.

F. Air cups
The air cups are attached across the outer surface of the media. They are angled to capture air as it rises, rotating the media discs.

G. Shafts
The shaft runs through the center of the media discs and is supported by the bearings.

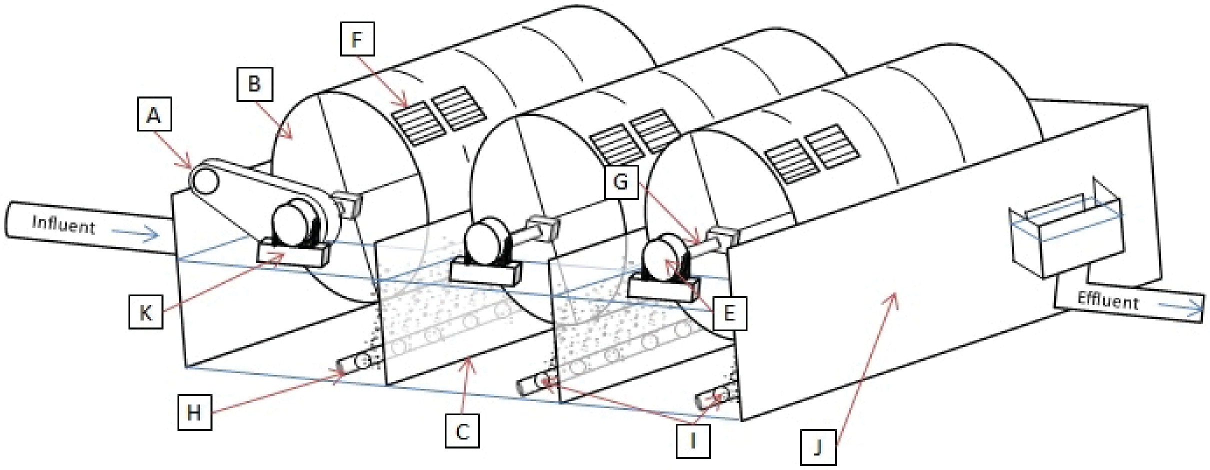
H. Air header
Light-weight air headers carry the air through the system and run the length of the media assembly. The headers are easily removable for cleaning.

I. Air diffusers
Coarse-bubble air diffusers distribute air from the header into the air cups.

J. RBC basin
The RBC basin holds the wastewater being treated and allows the wastewater to come in contact with the organisms on the discs.

K. Load cells
Load cells measure the biomass weight on the discs.

**Figure 7.2.1.1**



Source: Danielle Luke, Wisconsin Department of Natural Resources

7.2.2 Describe the components and equipment of a trickling filter process.

A. Filter media
Attached-growth filter media has a high surface area, high durability, and does not easily clog. Typical media consists of rocks or high-density plastic media over which the wastewater flows and causes a layer of microbial slime growth, covering the media.

B. Containment structure
The containment structure provides housing for the media, typically extending 4 to 5 ft above the media to prevent wind from effecting the rotation of the distributor arms.

C. Distributor arms

The main component of the distribution system, distributor arms convey the wastewater to various holes along the arm, then distributes the wastewater evenly over the filter media. Splash plates under the holes further evenly distribute the wastewater as the thrust of the wastewater spray rotates the distributor arm.

D. Speed-retarder orifices
Located on the back side of the distributor arm, these holes help to regulate the rotation speed, maintaining even wastewater distribution.

E. Distributor end gates
Located on the ends of the distributor arm, the end gates are opened to flush out accumulated debris within the distributor arm.

F. Turnbuckles and stay rods (guy wires)
Turnbuckles and stay rods allow height adjustment of the distributor arms.

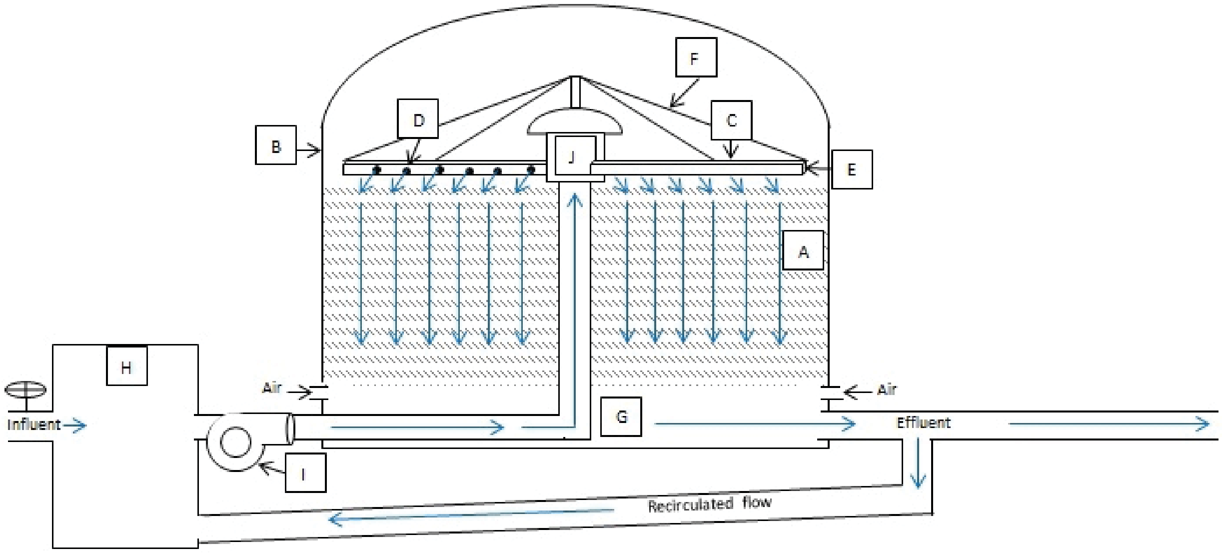
G. Underdrain system
Located underneath the filter media, this system supports the filter media, allows air into the media, and collects the filter effluent then directs it to the outlet box.

H. Wet well
The wet well is the collection point for the primary clarifier effluent and the recirculated filter or biotower effluent.

I. Pumps
Pumps are used to bring wastewater to the top of the trickling filter or biotower allowing wastewater to flow past the media.

J. Motorized drives
Drives are sometimes installed to mechanically rotate distributor arms and control wastewater flow distribution.

**Figure 7.2.2.1**



Source: Danielle Luke from the Wisconsin Department of Natural Resources

## Section 7.3 - Methods

7.3.1 List and explain the purposes for recirculation in trickling filters and biotowers.

Recirculation is the primary process control method for these attached-growth processes by which filter effluent is returned to and reapplied onto the filter. Recycling of the effluent increases the contact time of the wastewater with the microorganisms, increasing and optimizing treatment efficiency. Recirculation can be continuous or intermittent. Return pumping rates can be constant or variable. Recirculation rates range from 2:1 to 4:1.

Recirculation can serve other purposes as follows:

A. Reduce the strength of the wastewater being applied
B. Increase hydraulic detention time
C. Maintain distributor arm rotation during periods of low flow
D. Produce hydraulic shear to increase solid sloughing to prevent ponding
E. Prevent filters from drying out
F. Provide uniform flow distribution
G. Maintain the optimum biomass thickness and growth by more continuous and uniform sloughing rate
H. Prevent freezing during cold winter weather

7.3.2 Explain the importance of even-flow distribution across the media of a trickling filter or biotower.

As distributor arms turn and apply wastewater across the surface of the media, it is extremely important that constant and uniform hydraulic and organic loading rate pass by the attached biomass. The distributor arm ports should be kept unplugged, open, and flowing, and the distributor arms rotating at a constant, uniform rate. Uneven flow distribution means the media volume is not being fully utilized and reduces treatment efficiency.

## Chapter 8 - Monitoring, Process Control, and Troubleshooting

### Section 8.1 - Data Understanding and Interpretation

8.1.1 Discuss the effects of partial nitrification in attached-growth wastewater treatment plants.

Partial nitrification occurs when not all of the ammonia has been converted to nitrate. Higher levels of ammonia can affect the overall quality of the wastewater effluent. Biochemical oxygen demand 5-day (BOD5) test results will read higher than normal because nitrification occurs during the incubation process. In this case, a carbonaceous (cBOD5) test may be used and reported with DNR approval because the result removes the contribution from the nitrification process. Higher levels of ammonia are also more toxic to fish and aquatic life and require more chlorine for disinfection.

### Section 8.2 - Performance Limiting Factors

8.2.1 Explain the purpose of media ventilation in the operation of attached-growth processes.

A. Trickling filters and biotowers
Ventilation to the media in a trickling filter and biotower is important as air provides oxygen necessary for microorganism growth. If inadequate ventilation is occurring, there is the possibility that the aerobic organisms could become anaerobic resulting in odor problems. If it is suspected that ventilation is inadequate, perform a smoke test. If natural ventilation is inadequate, forced air pumped through the underdrain system can be used to enhance oxygen requirements.

B. Rotating biological contactors (RBC)
RBCs rely on passive ventilation. The air spaces on the rotating media provide opportunity for air, food, and microorganisms to come together and provide a space for sloughed biomass to leave the media.

## Chapter 9 - Calculations

### Section 9.1 - Surface Area

9.1.1 Given data, calculate the total surface area (ft²) of a rotating biological contactor (RBC) unit(s).

GIVEN:

Number of RBC trains = 2
RBC shafts per train = 4
Surface area of shafts 1, 2, and 3 = 100,000 ft²
Surface area of shaft 4 = 150,000 ft²

FORMULAS AND SOLUTION:

Total surface area per train (ft²) = shaft 1 (ft²) + shaft 2 (ft²) + shaft 3 (ft²) + shaft 4 (ft²)

= 100,000 ft² + 100,000 ft² + 100,000 ft² + 150,000 ft²
= 450,000 ft²/train

Total surface area (ft²) = (total surface area per train (ft²)) × (# of trains)
= 450,000 ft²/train × 2 trains
= 900,000 ft²

## Section 9.2 - Flows and Loadings

9.2.1 Given data, calculate the influent loading of biochemical oxygen demand (BOD) (lbs/day/1,000 ft² of media) to a trickling filter.

GIVEN:
[MGD = million gallons per day]

Primary effluent BOD = 180 mg/L
Flow to filter = 1.8 MGD
Surface area of filter = 8,790 ft²

FORMULAS AND SOLUTION:

BOD (lbs/day) = flow (MGD) × BOD conc. (mg/L) × 8.34
= 1.8 MGD × 180 mg/L × 8.34
= 2,702.16 lbs of BOD/day

BOD (lbs/day/1,000 ft²) = BOD (lbs/day) ÷ [surface area (ft²) ÷ 1,000 ft²]
= 2,702.16 lbs/day ÷ 8.79 ft²
= 307.41 lbs of BOD/day/1,000 ft²

9.2.2 Given data, calculate the hydraulic loading rate (HLR) (gallons per day (gpd) per square foot) to a trickling filter.

GIVEN:

Filter diameter = 80 ft
Flowrate = 1,000,000 gpd

FORMULAS AND SOLUTION:
[NOTE: This rate can be expressed in gpd/ft² or gpd/acre.]

Area of the filter (ft²) = 3.14 × [radius (ft)]²
= 3.14 × (40 ft)²
= 5,024 ft²

HLR (gpd/ft²) = flow (gpd) ÷ area (ft²)
= 1,000,000 gpd ÷ 5,024 ft²
= 199 gpd/ft²

9.2.3 Given data of the Incoming BOD to a rotating biological contactor (RBC) wastewater treatment plant; media density and surface area, calculate the organic loading.

GIVEN:

Primary clarifier effluent soluble BOD (sBOD) = 200 mg/L
Primary clarifier flow = 0.250 MGD
RBC media surface area of first stage = 200,000 ft²
Recommended loading rate = 2.5 lbs of sBOD/day/1,000ft²

FORMULAS AND SOLUTION:

Organic loading (lbs/day) = influent flow (MGD) × incoming sBOD (mg/L) × 8.34
= 0.250 MGD × 200 mg/L × 8.34
= 417 lbs of sBOD/day

Organic loading (lbs/day/1,000 ft²) = [organic load (lbs/day) ÷ media surface area (ft²)] × 1,000
= [417 lbs of sBOD/day ÷ 200,000 ft²] × 1,000
= 2.1 lbs of sBOD/day/1,000 ft²

## Section 9.3 - Feed Rates

9.3.1 Given data, calculate the feed rate of chlorine for a rotating biological contactor (RBC) (lbs/day).

The amount of chlorine required (lbs/day) to totally strip growth from RBC shafts is dependent on the total biomass to be removed and the chlorine demand of the primary effluent. For this objective, a chlorine dosage is suggested to reduce growth on the shafts.

GIVEN:
[MGD = million gallons per day]

Average daily flow = 0.40 MGD
Desired dosage of chlorine = 15 mg/L

FORMULA AND SOLUTION:

Chlorine (lbs) = flow (MGD) × chlorine conc. (mg/L) × 8.34
= 0.40 MGD × 15 mg/L × 8.34
= 50 lbs of chlorine/day

## Section 9.4 - Recirculation Ratio

9.4.1 Given data, calculate the recirculation ratio.

GIVEN:
[gpm = gallons per minute]

[MGD = million gallons per day]

Recirculation flowrate = 270 gpm
Average influent flowrate = 0.26 MGD
1 day = 1,440 minutes

FORMULAS AND SOLUTION:

Recirculation flowrate (MGD) = [flowrate (gpm) × 1,440 mins/day] ÷ 1,000,000
= [270 gpm × 1,440 min/day] ÷ 1,000,000
= 0.389 MGD

Recirculation ratio = recirculation flowrate (MGD) ÷ influent flowrate (MGD)
= 0.389 MGD ÷ 0.26 MGD
= 1.5 or 1.5:1

# Part 3 - A3: Recirculating Media Filters

## Chapter 10 - Theory and Principles

### Section 10.1 - Principles of Recirculating Media Filters

10.1.1 Discuss the applicability of using recirculating media filters for wastewater treatment.

Recirculating media filters shoud be used for only residential strength waste and most applicable to small rural communities. High-strength wastes from commercial or industrial users may cause organic overloading causing fouling of the filter media leading to ponding and clogging of the distribution piping. High-strength waste may also cause the loss of treatment within the system.

Recirculating media filters may be a good option for small communities that need to provide a higher degree of treatment than ponds or lagoons can provide but simpler and less costly to operate than mechanical activated sludge treatment systems.

10.1.2 Discuss the recirculating media filter treatment process.

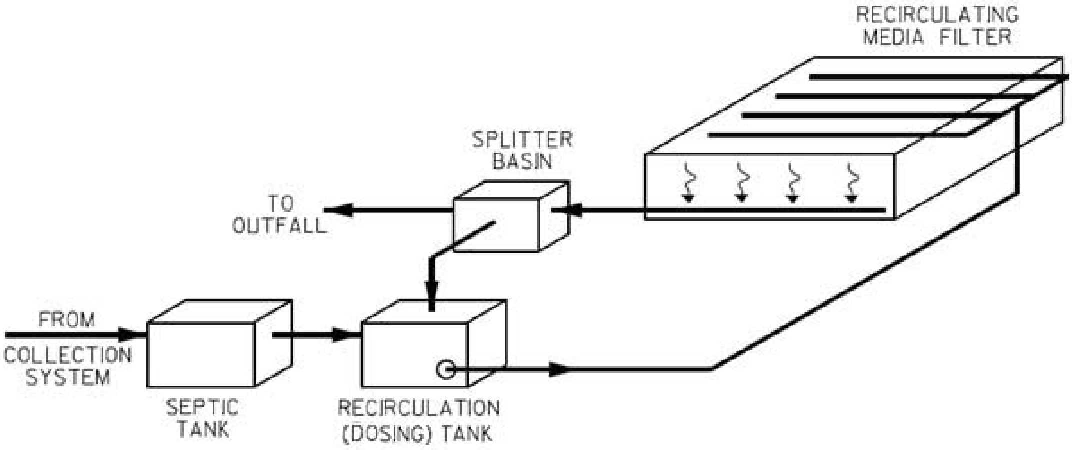
Recirculating media filters are an aerobic, attached-growth secondary treatment unit following primary treatment. The treatment process utilizes aerobic microorganisms that grow on the filter media. The typical depth of the filter media is 24 to 36 inches, with most biological treatment occurring in the upper 12 inches of the filter media. Under the aerobic conditions of the recirculating media filter, the microorganisms oxidize organic matter present in the wastewater. The treatment process is a combination of biological decomposition, biochemical conversions, and filtration.

### Section 10.2 - Process Description

10.2.1 List and show the stages of a recirculating media filter system.

A. Primary treatment (commonly septic tanks)
B. Recirculation tank (also referred to as a dosing chamber or tank)
C. Media filter
D. Splitter basin

**Figure 10.2.1.1**



Courtesy of Iowa Department of Natural Resources
and MSA Professional Services

10.2.2 Describe the role of primary treatment preceding recirculating media filters.

Primary treatment is required and its main purpose is to remove settleable solids prior to secondary treatment. Without proper removal, excessive solids can accumulate and clog the media filter, causing organic overloading, anaerobic conditions, ponding, and fouling. Primary treatment also serves to reduce organic loading and remove grease, which can hinder biological growth on the filter media.

## Chapter 11 - Operation and Maintenance

### Section 11.1 - Methods

11.1.1 Describe the importance of recirculation ratio for operating recirculating media filters.

An operator can control the level of treatment through the number of times wastewater passes through the filter. By increasing the recirculation ratio, a higher portion of water is recirculated back to the filter. Each additional pass through the recirculating media filter results in heightened treatment.

Recirculation ratios typically range between 1:1 and 5:1, and are higher in winter than summer. An operator must find a balance that is right for their system, factoring in energy efficiency, treatment limits, the season, and other considerations.

11.1.2 Describe the importance of filter bed rotation in a recirculating media filter process.

Rotations help to control ponding and weeds by allowing the beds to dry and re-aerate. Weeds can be removed and the media raked/tilled if needed. Maintenence and repairs can be made at this time if needed to exposed distribution piping and headers. A recommendation is to rotate beds every 3 to 6 months, especially in the spring and fall. An operator should determine the best bed rotation schedule for their particular system (see figure 10.2.1.1).

11.1.3 Discuss the significance of hydraulic loading rate (HLR) in a recirculating media filter process.

The HLR is the volume of wastwater applied to a filter bed in a day. It is controlled by pump dosing cycles and recirculation rates. During wet weather, collection system infiltration and inflow (I/I) and the rain falling on the bed itself will increase the HLR. A typical HLR of presettled wastewater is 3 to 5 gallons per day per square foot of filter media (gpd/ft$^2$) for coarse sand and gravel media. The HLR will also effect the organic loading rate (OLR) based on the biochemical oxygen demand (BOD) of the wastewater being applied. An operator can control the OLR by regulating the HLR.

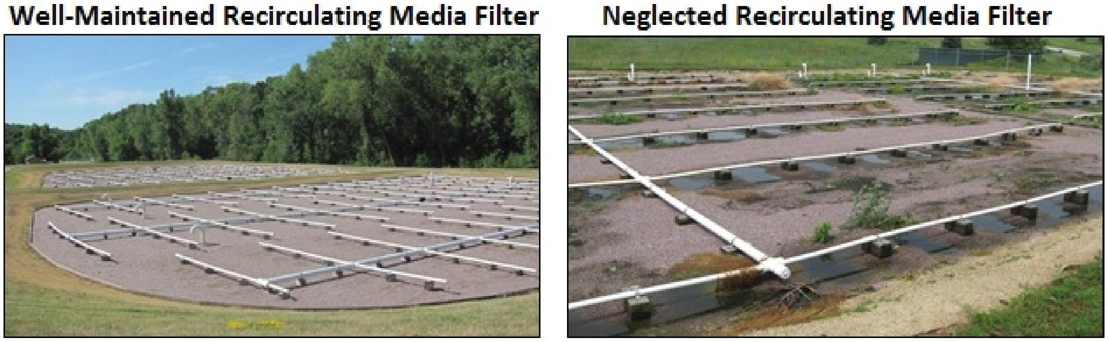
## Chapter 12 - Monitoring, Process Control, and Troubleshooting

### Section 12.1 - Data Understanding and Interpretation

12.1.1 Discuss why a recirculating media filter bed should not become overgrown with vegetation.

Media filters should be kept weed-free. While vegetation and weeds growing in filter media will uptake water and nutrients, once they die and decay the growing and accumulating vegetation can lead to matting of the media surface and plugging within the media. This can then result in media ponding. Rototilling heavy weed growth into the media can result in ponding as well. Manually removing weeds and vegetation, roots and all, is the best preventative maintenance practice for keeping beds free of decaying vegetative matter on and in the media.

**Figure 12.1.1.1**



**Well-Maintained Recirculating Media Filter**

**Neglected Recirculating Media Filter**

# Part 4 - A4: Ponds, Lagoons, and Natural Systems

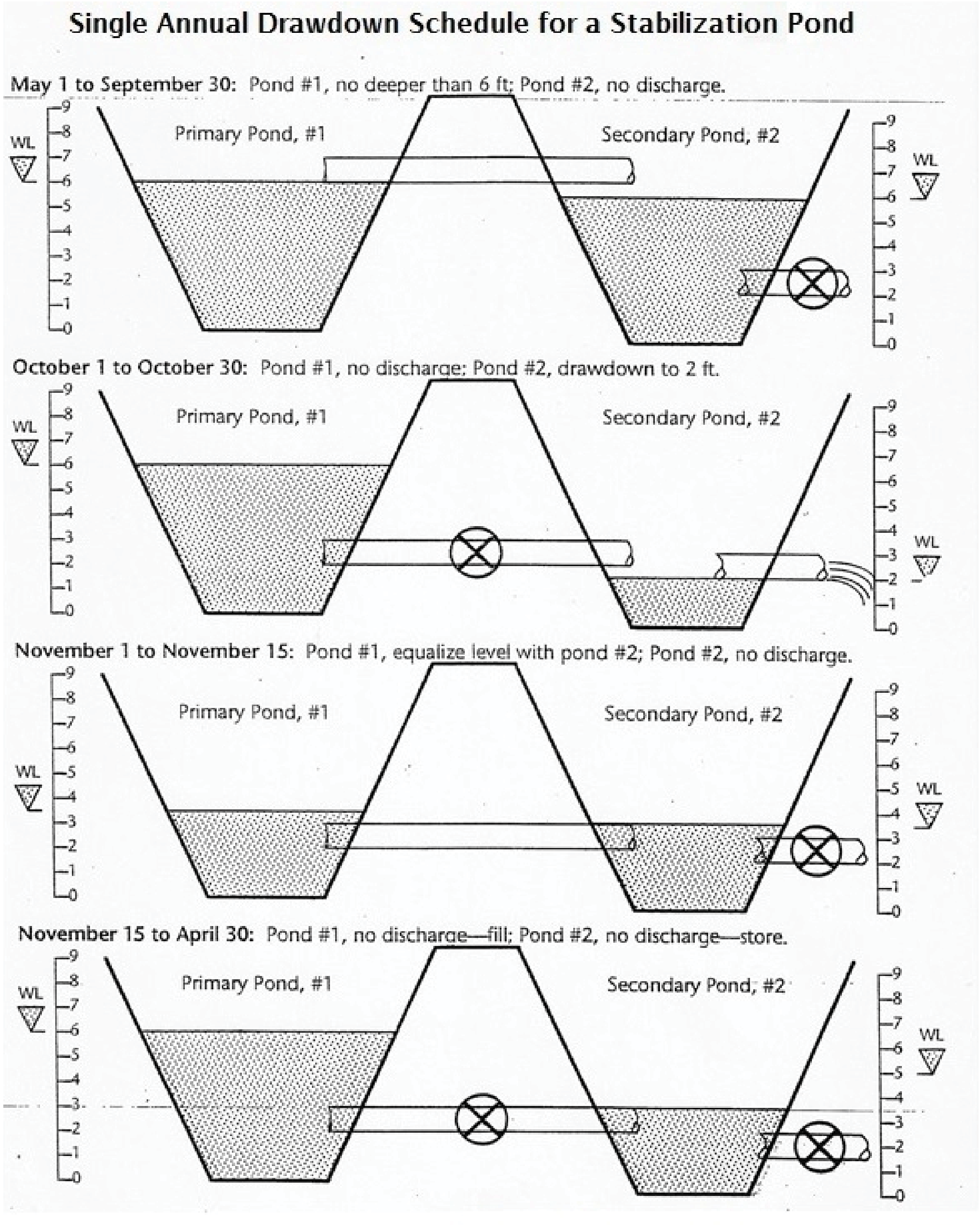
## Chapter 13 - Operation and Maintenance

### Section 13.1 - Methods

13.1.1 Discuss and show a single annual drawdown schedule for a stabilization pond.

To drawdown a pond, isolate the pond, if possible, one month before the discharge period. Begin testing to monitor pond contents effluent limited parameters. Send results to the Department of Natural Resources and notify them of the intent to discharge. Calculate what volume will be needed for storage and discharge at least that amount. Determine from the discharge permit the daily discharge volume and calculate total days required for discharge. Always leave at least 1 to 2 ft of treated wastewater in a pond so the wastewater will have an active bacterial concentration. This greatly aids in maintaining oxygen and prevents odors or organic upsets.

**Figure 13.1.1.1**



Source: WDNR

13.1.2 Describe the effects of seasonal changes on pond treatment efficiency.

A. Winter

Treatment efficiency decreases in the winter with colder temperatures. Shorter periods of sunlight and ice/snow cover limit the amount of photosynthesis. This may reduce dissolved oxygen (DO) in the pond. The cold water also slows down bacterial action, reducing treatment efficiency. If sufficient ice/snow cover is present, the pond may go anaerobic and emergent weeds and duckweed will die off. During this period, fill and draw ponds are operated by storing wastewater for a spring discharge.

B. Spring

After ice-out, odors may occur for several days until DO is restored. As temperatures increase, biological activity increases for both bacteria and algae. Treatment efficiency begins to improve with increasing biological activity. After the pond has stabilized, a spring discharge for fill and draw type systems is usually done prior to active algae growth.

C. Summer

The long sunny days provide maximum oxygen levels from algae photosynthesis. Warm water temperatures increase bacteria action to provide the best environment for efficient treatment. Operational problems include: controlling rooted emergent weeds, removing duckweed, and controlling algae blooms. During this period, fill and draw pond systems are operated by storing wastewater for a fall discharge.

D. Fall

Fall is a transitional time, but in reverse of spring. Water temperatures begin dropping, reducing bacterial activity and photosynthesis as the days get shorter. Treatment efficiencies begin to drop as winter approaches. When the algae levels drop and the biochemical oxygen demand (BOD) stabilizes, fill and draw type systems normally discharge.

13.1.3 Describe factors that affect the amount of metal salt needed to remove phosphorus in a pond system.

The initial estimate of the metal salt dose needed to remove phosphorus in a pond system can be calculated in the same manner as an activated sludge system. As with activated sludge, competing reactions will require more metal salt than the theoretical dose. Total phosphorus in a pond includes soluble and particulate phosphorus and phosphorus contained in algal cells. While the metal salt will react with orthophosphate to create an insoluble precipitate, algae and particulates will also settle with precipitate.

13.1.4 Discuss the ways in which phosphorus removal chemicals can be added at a pond or lagoon system.

For continuous dosing, metal salts to remove phosphorus are usually added to the last pond or lagoon where the precipitation reaction and settling can occur. The chemical should be added where good mixing of the chemical with the wastewater can be achieved, such as the upstream manhole prior to the last pond or just before an aerator. For batch dosing of aluminum sulfate (alum) in fill and draw systems, some operators use a small motorboat to apply the alum where the propeller can provide the mixing. Another alternative is to spay alum directly to the surface.

## Section 13.2 - Equipment

13.2.1 Describe how pond depth and bubble size affect aeration efficiency.

The deeper the pond, the longer the contact time before the bubbles reach the surface. The smaller the bubbles are the more contact surface between the air and water, which increases the transfer rate.

### Section 13.3 - Preventative Maintenance

13.3.1 Discuss the solids buildup in stabilization ponds.

Over time, sewage solids settle and can start to build up on the pond bottoms, especially in the first stabilization pond. Measuring solids deposition should start at about 10 years of operation or the last sludge removal. Solids in a pond or lagoon can be measured using a sludge depth finder such as a Sludge Judge® from a row boat or through holes drilled into the ice. Using a surface grid, sludge depth measurements should be taken every so many feet, perhaps every 50 ft, starting near the influent pipe and recorded on a grid.

Many ponds eventually need to have solids mechanically removed, typically after 15 to 20 years. Accumulated solids reduce the detention time of the pond, which can reduce treatment. For example, every foot of a 3 acre, 5-foot deep pond contains about 1 million gallons (MG) or 50 days of detention time. Every foot of sludge thus reduces the detention time by 50 days (20%); 2 ft by 100 days (40%). Treatment will ultimately be effected. If sludge starts to accumulate to 1 ½ to 2 ft in much of the pond, removal should start to be considered and budgeted. Most solids will deposit within a certain radius of the influent pipe, causing a volcano type buildup effect. Sometimes solids may only need to be removed in the near vicinity of the influent pipe to ensure solids do not affect the influent flowrate.

Sludge removal, when necessary, should be planned and done through a consultant and contractor. It is extremely important that the equipment and methods used do not damage the pond liner and diking. The sludge removal plan must be sent to and approved by the Department of Natural Resources. The disposal of pond or lagoon sludge must meet all sludge sampling, reporting, and land application requirements of the Wisconsin Pollution Discharge Elimination System (WPDES) permit and the Wisconsin Administrative code requirements.

## Chapter 14 - Monitoring, Process Control, and Troubleshooting

### Section 14.1 - Sampling and Testing

14.1.1 Discuss purging a monitoring well so that a representative groundwater sample can be collected.

The goal of sampling a monitoring well is to collect unaltered samples that represent the physical and chemical composition of groundwater. Monitoring wells must be purged of four (4) well volumes before a sample can be collected. The goal of purging is to remove the stagnant water that has been sitting in the well casing. Purging brings fresh groundwater through the well screen and into the well casing for a representative groundwater sample. Stagnant water does not represent groundwater. Purge and sample wells in order from least to most contaminated unless the sampler uses dedicated or disposable equipment.

The volume to be purged from a well can be determined from the following equation:

$V = 3.14 \times [\text{radius (ft)}]^2 \times H \times 7.48 \text{ gals/ft}^3 \times 4$

V = total purge volume, four well volumes (gals)
D = inside diameter of well casing (ft), radius is half the diameter width
H = water in well (ft) = depth from towel bottom (ft) - depth to water (ft)

### Section 14.2 - Data Understanding and Interpretation

14.2.1 Explain why dissolved oxygen (DO) concentrations vary with pond depth.

DO levels vary within pond depth for a number of reasons. The main reason is the relationship of the organisms within the pond; different bacteria survive under different conditions. Other reasons the physical actions within the pond and the loading to the pond. For example:

A. The algae are the main source of oxygen in a pond system. Algae growth is greatest near the surface where light penetration and photosynthesis is the greatest.

B. Oxygen levels decrease with depth, due to less light penetration needed for photosynthesis. The algae use carbon dioxide in the process of photosynthesis and produce oxygen. The bacteria stabilize organic matter using the oxygen and produce carbon dioxide.

C. The diffusion of oxygen occurs at the surface of ponds and is mixed in the upper layers by wind action. The amount of mixing is limited, so the oxygen levels decrease with depth.

D. Organic loading to the pond system can significantly affect oxygen levels. If organic loadings are small, the oxygen levels will be maintained at greater depths. If organic overloading occurs, the whole pond could go anaerobic.

## Chapter 15 - Calculations

### Section 15.1 - Discharge

15.1.1 Given data, determine the fall drawdown volume (gals) and depth (ft).

The daily average influent flow into a fill and draw pond system is 30,000 gallons per day (gpd). An operator needs to drawdown the pond in November to allow for enough storage during the 121 days of winter (December through March). The pond is at 5 ft. Allowing for some extra flow during spring thaw for inflow and infiltration (I/I), the operator determines he wants 150 days of storage. Using the graph provided, to what depth (ft) must the operator lower the pond?

GIVEN:

Daily influent flow = 30,000 gpd
Pond storage volume needed = 150 days
See figure 15.1.1.1 for graph

FORMULAS AND SOLUTION:

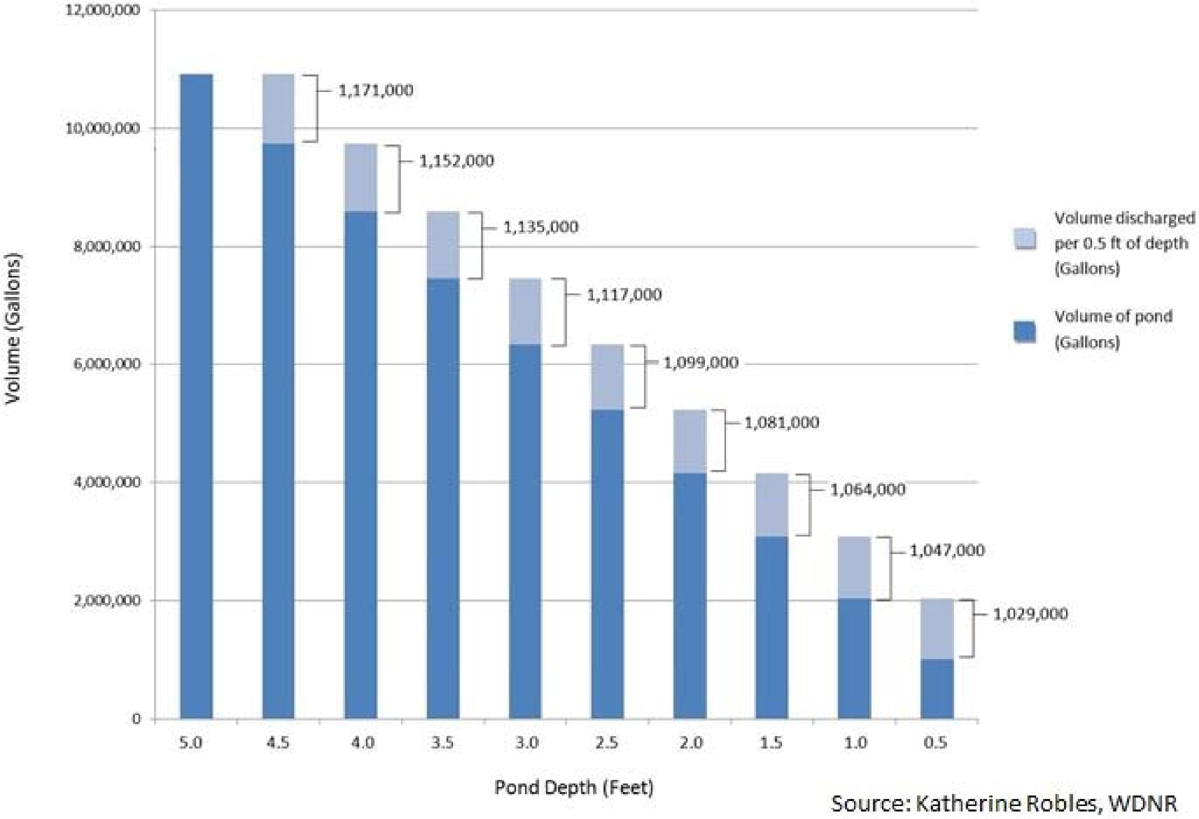
Total drawdown vol. (gals) = influent flow (gpd) × storage needed (days)
= 30,000 gpd × 150 days
= 4,500,000 gals

Reading the graph, the following volumes per half foot of depth is shown:
5.0 to 4.5 feet = 1,171,000 gals
4.5 to 4.0 feet = 1,152,000 gals
4.0 to 3.5 feet = 1,135,000 gals
3.5 to 3.0 feet = 1,117,000 gals

Cumulative vol. per ½ ft of drawdown = 1,171,000 gals + 1,152,000 gals + 1,135,000 gals + 1,117,000 gals
= 4,575,000 gals

The operator must discharge enough wastewater in November to lower the pond from 5 to 3 ft.

**Figure 15.1.1.1**



Source: Katherine Robles, WDNR

## Section 15.2 - Leakage

15.2.1 Given data, estimate the leakage (gals/acre/day or gpad) from a wastewater stabilization pond.

GIVEN:
[MG = million gallons]

[gpd = gallons per day]

Total annual influent = 9.125 MG/yr
Total annual effluent = 7.850 MG/yr
Pond surface area = 2.5 acres
1 year/MG = 0.000365 days/gal

FORMULA AND SOLUTION:

Leakage rate (gpad) = [total influent vol. (MG/yr) - total effluent vol. (MG/yr) ÷ 0.000365 (MG day/gals yr)] ÷ surface area (acres)
= [9.125 MG/yr – 7.850 MG/yr) ÷ 0.000365 MG day/gals yr] ÷ 2.5 acres
= 3,493 gal/day ÷ 2.5 acres
= 1,397 gpad

# Part 5 - B: Solids Seperation

## Chapter 16 - Theory and Principles

### Section 16.1 - Definitions

16.1.1 Define coning in relation to pumping sludge.

Coning would occur when sludge is pumped too fast from the sludge hopper, causing a cone to form in the hopper.

16.1.2 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.

16.1.3 Define solid separation.

Solid separation is any process or combination of processes whose primary purpose is to reduce the concentration of suspended solids in a liquid.

### Section 16.2 - Principles of Solid Separation

16.2.1 Discuss the application and importance of solids separation in wastewater treatment.

A. Primary treatment
The purpose of primary treatment is to settle wastewater solids and capture floatable substances (such as fat, oil, and grease or FOG). Primary treatment commonly consists of circular or rectangular clarifiers or sometimes dissolved air flotation (DAF).

B. Intermediate and final treatment
The purpose of intermediate or final clarification is to settle secondary biological treatment solids and, for final treatment, discharge clear effluent. Final treatment consists of circular or rectangular clarifiers.

C. Tertiary treatment
The purpose of tertiary treatment is to provide advanced wastewater treatment beyond secondary biological treatment. Tertiary treatment commonly consists of sand or mixed media filters, cloth discs, membranes, or other treatment units.

## Chapter 17 - Operation and Maintenance

### Section 17.1 - Definitions

17.1.1 Define solids loading rate (SLR).

SLR is the relationship between the solids entering the clarifier and the surface area of the clarifier. SLR is calculated by taking the suspended solids entering the clarifier (pounds) divided by the surface area of a clarifier ($ft^2$) and is expressed in pounds per square feet ($lbs/ft^2$).

17.1.2 Define surface overflow rate (SOR).

SOR is the relationship of the flow into a clarifier to the surface area of the clarifier. SOR is calculated by taking the daily flow (gallons per day or gpd) divided by the surface area of a clarifier (ft²) and is expressed in gallons per day per square foot (gpd/ft²).

17.1.3 Define weir overflow rate (WOR).

WOR is the flow in relation to weir length. WOR is calculated by taking the flow (gpd) divided by the weir length (ft) and is expressed in gallons per day per foot (gpd/ft).

## Section 17.2 - Clarifier Methods, Equipment, and Maintenance

17.2.1 Discuss the process of primary, intermediate, and final clarifiers.

A. Primary clarifier
The purpose of a primary clarifier is to remove settable solids and fat, oil, and grease (FOG) from the influent and any returned flows. Some biochemical oxygen demand (BOD) is removed in this process. The solids that settle in primary clarifiers and FOG skimmed off the surface are directly removed from the liquid treatment process. Primary clarification should remove 40% to 60% of overall suspended solids.

B. Intermediate clarifier
The purpose of an intermediate clarifier is to settle biological solids and is found between a primary and final clarifier. The intermediate clarifier usually follows an attached-growth process.

C. Final clarifier
The purpose of a final clarifier is to settle secondary biological treatment solids and discharge clear effluent. The settled solids can be returned to the aeration tank or wasted for biosolids and sludge processing. The final clarifier is the last clarifier after the secondary treatment process.

17.2.2 Discuss the importance of even-flow splitting to several clarifiers.

Even-flow splitting to multiple clarifiers is important from both the hydraulic and organic standpoint. Unequal flows will cause changes in detention times, weir overflow rates (WOR), sludge collection volumes, and the primary effluent quality.

17.2.3 Discuss the maintenance needs for rectangular clarifiers.

A. Chains
Chains can stretch and loosen and can become worn. Check for chain wear and flip or replace if needed. Stretched or loose chains can be adjusted with chain adjusters or by removing links.

B. Flights and shoes
Clarifier flights or shoes will wear over time and need to be replaced to avoid alignment issues.

C. Sprockets
A sprocket needs to be replaced if missing any teeth or excessively worn.

17.2.4 List the normal types of pumps used to pump and recirculate sludge.

A. Pump sludge
  1.Centrifugal
  2. Progressive cavity
  3. Diaphragm
  4. Rotary lobe

B. Recirculate sludge
  1. Centrifugal (most common)
  2. Progressive cavity
  3. Rotary lobe

Check with the manufacturer's O&M manual for operational procedures.

For further information about these types of pumps refer to the Wisconsin DNR General Wastewater Study Guide.

17.2.5 Describe the components of a rectangular clarifier.

A. Influent pipe
Conveys the wastewater into the clarifier

B. Target baffle
Distributes the influent evenly across the width of the clarifier

C. Drive unit
Moves the flight and chain system

D. Flight and chain
Flights are moved by the chain along the bottom of the clarifier pushing settled solids and across the top to collect floating solids

E. Wear shoe
Prevents wear on the flights (not shown in the diagram)

F. Sludge sump
Collects the sludge moved by the flight

G. Sludge cross collector
Drags sludge to the deep end of the sump for removal by the sludge pump

H. Scum trough
Collects scum removed by the flight

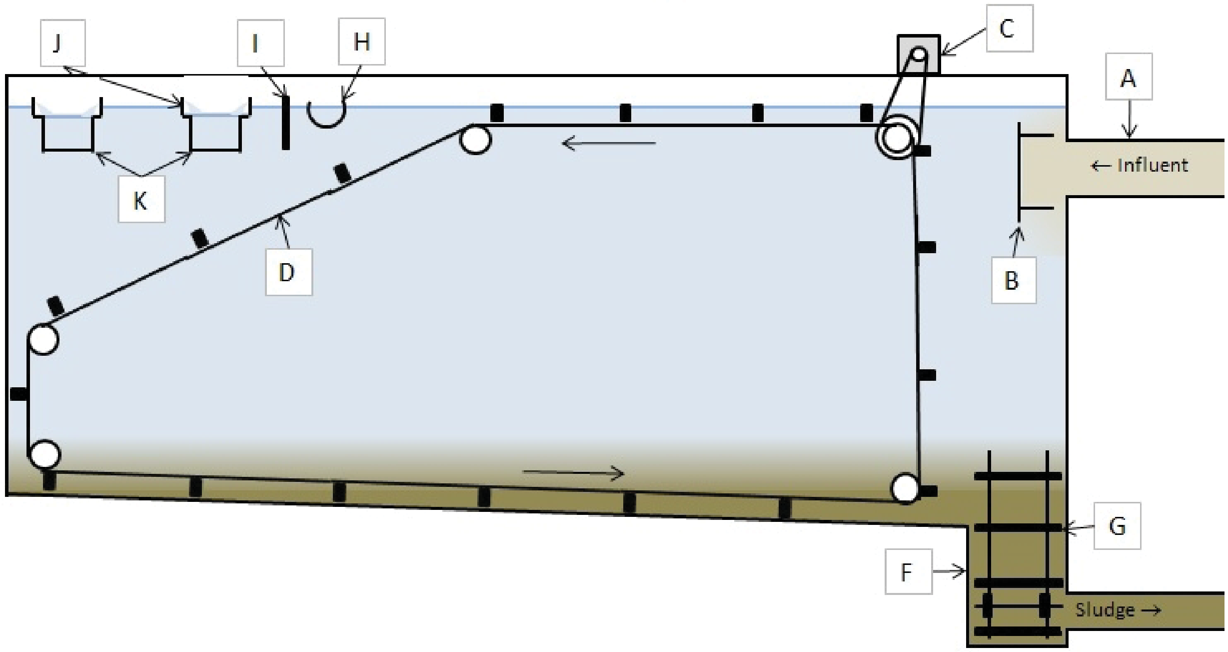
I. Scum baffle
Prevents floating solids and grease from flowing over the weirs

J. Effluent weirs
Provides uniform flow over the surface of the clarifier

K. Effluent trough
Collects and conveys the effluent from the clarifier

**Figure 2.2.7.1**

Cross Section of a Rectangular Clarifier



Courtesy of Danielle Luke, Wisconsin Department of Natural Resources

17.2.6 List the items to check when inspecting primary weirs and baffles for proper function.

A. Level weirs
B. Algae or scum buildup
C. Corrosion
D. Warped or broken baffles
E. Surface currents

17.2.7 Discuss the significance of denitrification occuring in a 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. The free nitrogen gas attaches to the sludge making it buoyant.

17.2.8 Discuss the operational significance of weir overflow rates (WOR), solids loading rate (SLR), and surface overflow rate (SOR) in a clarifier.

A. Weir overflow rate (WOR)
WOR is the amount of water flowing over the weir per linear foot of weir length (gallons per

day (gpd)/ft). Flow over the weirs should be even. If part of the weir is clogged and restricts flow, the flow over other sections of the weir will be faster. This may draw solids up and over the weir.

B. Solids loading rate (SLR)
SLR is the amount of solids per day that can be removed per square foot of surface area by a clarifier (lbs/day/ft²). If the SLR increases above the design limits of the clarifier, there will be an increase in effluent solids.

C. Surface overflow rate (SOR)
SOR is the gallons per day per square foot (gpd/ft²) of clarifier surface area. A SOR that is too high will cause solids to be discharged with the effluent. A SOR that is too low may cause a long detention time and septicity.

## Section 17.3 - Effluent Filtration Methods, Equipment, and Maintenance

17.3.1 Describe the process of granular filtration.

The purpose of granular filtration is to provide advanced wastewater treatment beyond secondary biological treatment by removing fine particles from the effluent through adsorbtion and is most commonly used in treatment plants with more stringent effluent limits. There are two notable types of granular filtration, shallow-bed filters and deep-bed filters.

Shallow-bed filters consist of fine sand media (less than 18 inches deep). Particles are collected on or near the media surface as the effluent moves through the filter. The majority of the solids particles are collected in the upper part of the filter media.

Deep-bed filters have layered media (ranging from 30 to 48 inches) that may consist of anthracite, coarse sand, fine sand, or garnet. These layers may be one media type throughout or a different media type for each layer. The effluent flows through the deep-bed filter from the top, smaller layer of media to the bottom, coarser layer of media.

The overall efficiency in removing pollutants by filtration could exceed 95% removal of suspended solids and phosphorus. An alternative to granular filtration is disc filtration or other patented physical or chemical processes.

17.3.2 Show and discuss the components of granular filtration.

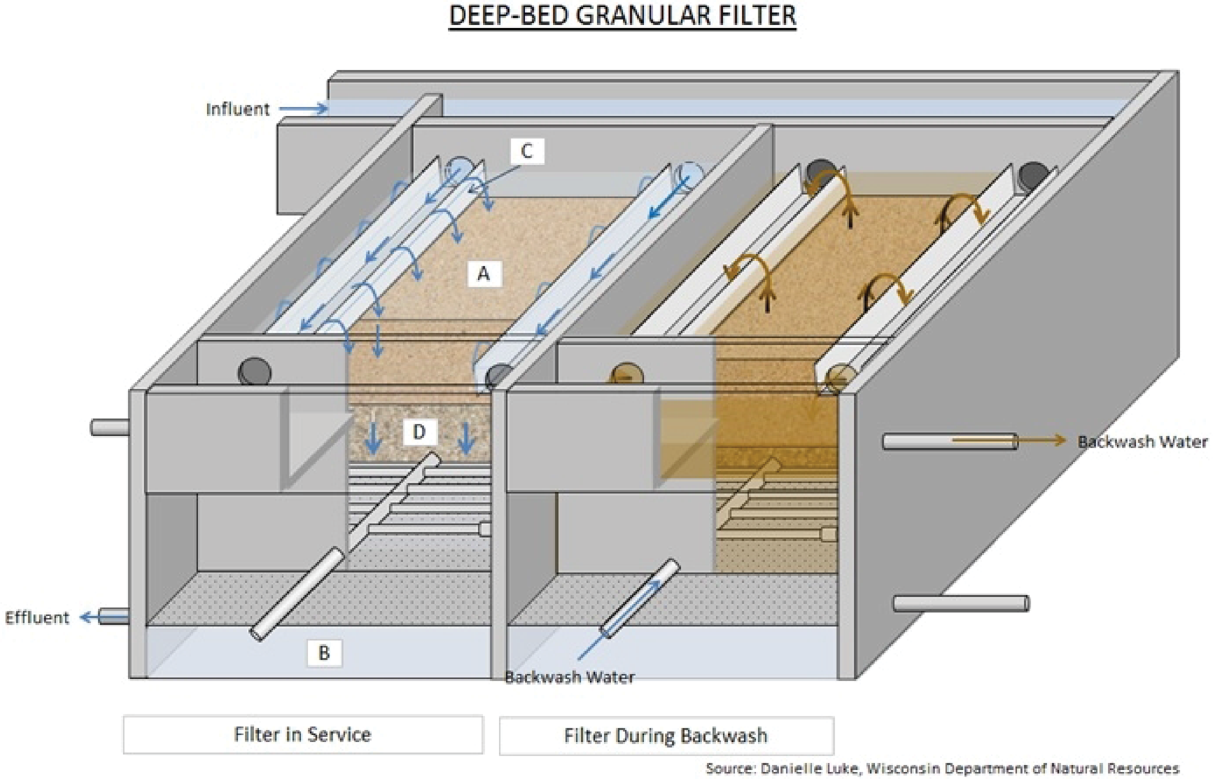
A. Media
The media provides filtering to remove suspended solids

B. Underdrain
The underdrain collects the filtered water and conveys the water away from the filter

C. Wash water trough
The wash water troughs convey the backwash water from the filter when in backwash. When in service, the troughs feed the influent to the media

D. Media support
The media support prevents the media from entering the underdrain system. Depending on the type of filter, the support can include gravel bed, media retaining strainers, or, in the case of shallow-bed filters, various forms of porous plates.

**Figure 17.3.2.1**



Source: Danielle Luke, Wisconsin Department of Natural Resources

17.3.3 List the design and operational factors that affect the filtration rate of an granular filter.

A. Design factors affecting filtration rates
  1. Hydraulic head available over the media
  2. Type of filter (deep bed multi-media versus shallow bed)
  3. Type of media used
  4. Media effective size
  5. Media uniformity coefficient
  6. Filter size compared to hydraulic loading

B. Operational factors affecting filtration rates
  1. Excessive solids buildup in the media
  2. Poor backwashing practices (surface clogging)
  3. Excessive chemical additions
  4. Poor operations of upstream treatment units
  5. Channeling (short-circuiting)

17.3.4 Discuss the recommended schedule for backwashing shallow- and deep-bed filters.

A backwash would be scheduled based on headloss, time in service, or total flow through the filter. Typically, a deep-bed filter can operate longer before needing to be backwashed.

17.3.5 Describe the operating principles of disc filters.

A. Fully submerged disc filters

Fully submerged disc filters are a popular alternate to conventional granular media filtration technology for secondary granular filtration because they typically have 75% less of a footprint. Disc filters use cloth material to filter out fine solids remaining in effluent. The cloth medium is made out of nylon fibers or woven polyester and has a typical pore size of 10 µm. Cloth material creates the faces of the discs. A submerged disc filter will have 1 to 12 vertically mounted discs with a diameter of 1 to 3 ft.

Fully submerged disc filters operate on an outside to inside flow method. During filtration, wastewater flows through the cloth membrane by gravity and enters the filter discs from both sides while solids are retained on the outside of the disc. Once inside the discs, the water flows to a common hollow tube in the center of the disc which conveys filtered effluent out of the filter system. The filters are at rest during the cycle which allows larger solids to also settle to the bottom of the tank. Settled solids are occasionally pumped to the head works or solids processing.

During the backwash cycle, solids are removed from the cloth material by liquid suction. A vacuum apparatus is located on both sides of the disc to apply liquid suction. Typically 1 or 2 discs are backwashed at a time allowing for filtration through the remaining discs. This allows for continuous operation of the system.

B. Partially submerged disc filters

Partially submerged disc filters are similar in operation to fully submerged disc filters except the direction of the flow and depth of submergence. During normal operation, discs are only 60% to 65% submerged. Partially submerged filters operate on inside to outside flow method. Wastewater flows into the filter disc from the center drum by gravity. Clean water exits the disc by passing through the cloth media and entering the collection tank. Solids are retained within the disc.

The backwash cycle initiates when water in the center drum reaches to a specific depth because of solids buildup on the media surface. As the disc rotates, nozzles spray clean effluent on to the disc, washing solids into a collection trough. Solids are then sent to the head works or solids processing.

To view an online video of a disc filter visit:
https://youtu.be/tyW_ZudaCTY

17.3.6 Describe the components of a disc filter.

The main components of a disc filter include:

A. Influent pipe and weir

The influent pipe moves the wastewater over the weir where it is then distributed evenly into the filter tank.

B. Filter tank

The filter tank holds the influent until it is pushed through the cloth media at the same time allowing some solids to settle.

C. Discs
The discs hold the cloth media used for removing the suspended solids.

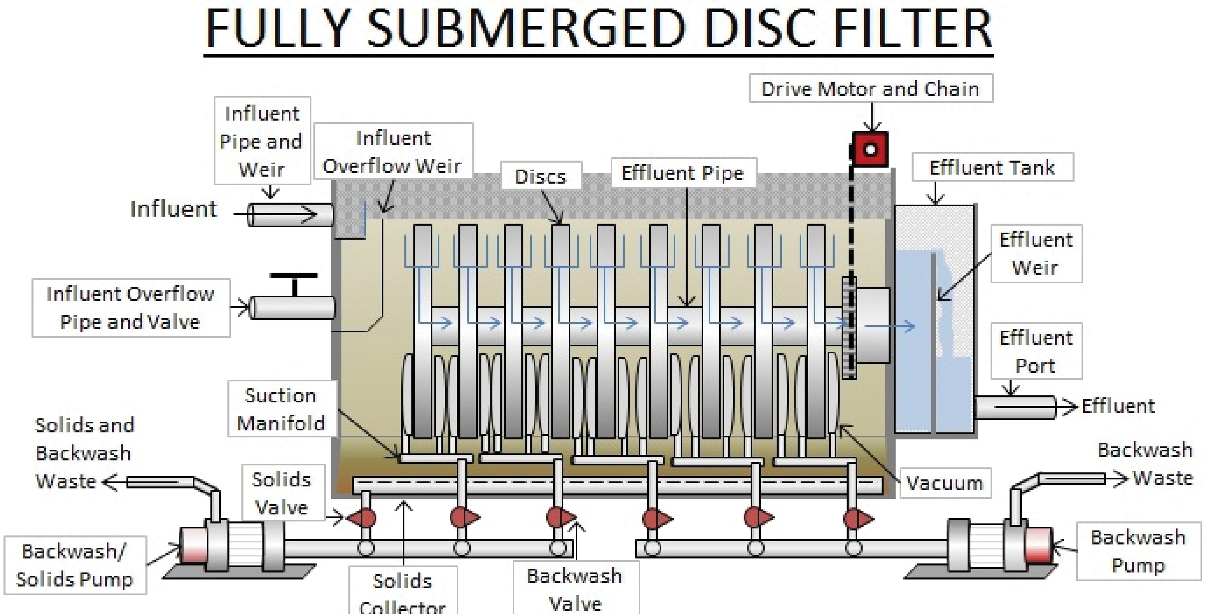
D. Effluent pipe
Once filtered, the wastewater moves through the disc and into the effluent pipe.

E. Effluent tank
The effluent tank receives the wastewater from the effluent pipe where it flows over a weir and away from the filter.

F. Backwash system
The two backwash pumps pull the solids off of the rotating cloth media discs and through the suction manifolds.  Some systems continuously backwash while the filter is online.

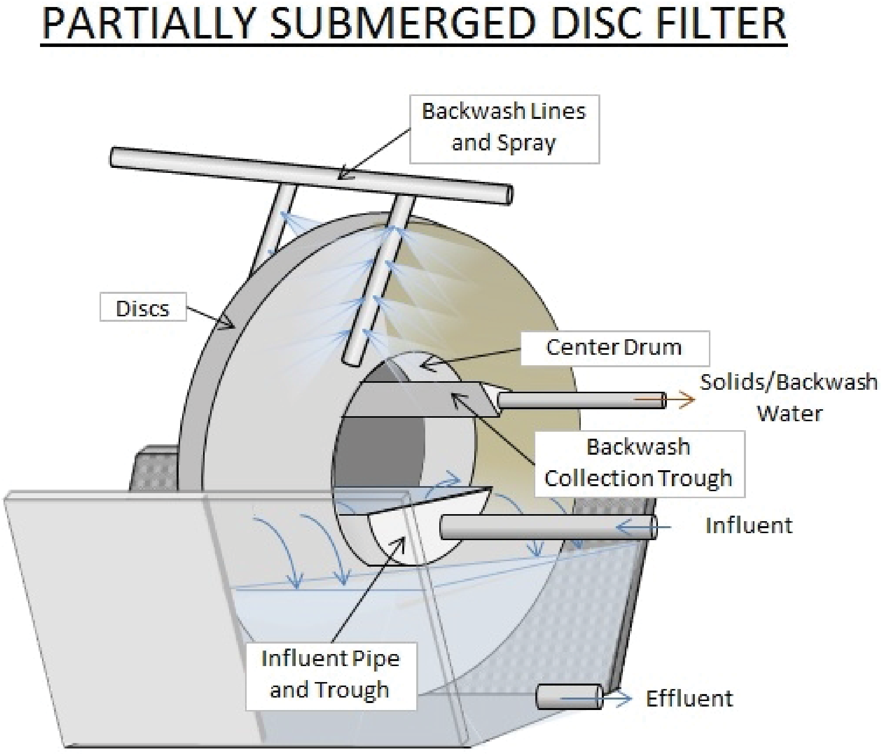
G. Solids collection system
The settled solids are collected off the bottom of the tank using one of the same pumps used for backwashing.

**Figure 17.3.6.1**



Source: Danielle Luke, Wisconsin Department of Natural Resources

**Figure 17.3.6.2**



Source: Danielle Luke, Wisconsin Department of Natural Resources

## Section 17.4 - Dissolved Air Flotation Methods, Equipment, and Maintenance

17.4.1 Discuss the process of dissolved air flotation (DAF).

The purpose of DAF in the liquid treatment train is to help clarify or remove suspended solids from wastewater, and can be rectangular or circular. Removal is achieved by dissolving air in wastewater (under pressure at the bottom of the tank). The air released forms tiny bubbles that adhere to the suspended matter and float to the surface/top of the tank where it is removed by a skimmer. Ferric chloride and aluminum sulfide are sometimes used to enhance the solids capture. Bottom sludge collectors are used to remove any settled sludge or grit.

# Chapter 18 - Monitoring, Process Control, and Troubleshooting

## Section 18.1 - Definitions

18.1.1 Define breakthrough.

Breakthrough is when solids push through the granular filter media and out through the effluent, uncaptured. This occurs when a filter is run too long with insufficient backwashing, becomes overly adsorbed with solids, and headloss increases.

18.1.2 Define filter channeling.

Filter channeling occurs when portions of the filter plug and the wastewater flows in channels, reducing treatment efficiency.

18.1.3 Define washout.

Washout is the loss of solids from any treatment process due to high flows.

## Section 18.2 - Sampling and Testing

18.2.1 List methods used to evaluate the performance of clarifiers.

A. In field
  1. Solids profiling
  2. Dye testing
  3. Drogues (submerged, flow-field indicators)

B. Performance calculations
  1. Surface overflow rates
  2. Weir overflow rates
  3. Solids loading rates

18.2.2 Discuss how to determine if backwashing of a granular filter is effective.

A. Visually check and sample the total suspended solids (TSS) of the backwash water at the beginning and end of the backwash cycles.
B. Measure headloss before and after a backwash.
C. If having chronic backwash inefficiencies, take a core or shovel sample to examine the media.

## Section 18.3 - Data Understanding and Interpretation

18.3.1 Discuss hindered settling in a final clarifier and how to determine if this may be occuring.

When there are too many mixed liquor suspended solids (MLSS) 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 (greater than 800 mL/L). To differentiate 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 that 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.

18.3.2 Describe the effect of high-strength waste (high biochemical oxygen demand or BOD) has on solid separation.

High-strength wastes come from industrial operations such as dairies, breweries, and food processors. Effluent from these industries contains significantly higher biochemical oxygen demand (BOD) as compared to domestic waste. High-strength waste can organically overload a primary clarifier by depleting the dissolved oxygen (DO) in the water. The resulting anaerobic conditions will cause odors and floating sludge. Further in the treatment process, high-strength organic waste will cause additional solids production during the activated sludge process. The additional solids can cause poor supernatant return flow and increases waste sludge hauling. When a municipality has high-strength organic waste contributors, they often require pretreatment.

## Section 18.4 - Sidestreams

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

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

Keys to optimum solids separation are:

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) through (2) operating the treatment plant with regular and consistent process control.

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 RAS flowrate. 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 I/I of clear water entering into the sewer system. An ongoing collection system Capacity, Management, Operation and Maintenance (CMOM) Program should be developed and implemented.

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

## Chapter 19 - Safety and Regulations

### Section 19.1 - Safety

19.1.1 Discuss the negative consequences of leaving sludge sit in a pipe between two closed valves.

If sludge is trapped in a pipe between two closed valves, bacteria in the sludge could generate gas. If the bacteria generate enough gas, the pressure inside the pipe could buildup and rupture the pipe. Not only a safety concern, there is a possibility of clogging the piping system if sludge is left in the pipe over a period of time.

19.1.2 Discuss draining a clarifier and the function of the relief valves.

A. Draining a clarifier
1. Leave as little a solids blanket as possible before draining
2. Close the clarifier influent gate and tag/lock it out. If there is any other piping with valves that are connected to the clarifier being drained, make sure they are closed and lock-out/tag-out, too.
3. Open the drain valve for the clarifier. The sludge withdrawal valve may have to be opened, also. It is possible there is no drain valve and a pump may have to be used.
4. Leave the drive on for a while to scrape as much solids out as possible. The skimmer may have to be pulled up. Tag/lock out the drive after it is turned off.
5. While the clarifier is draining, make sure the pressure relief valves are operable by confirming they open.
6. If the clarifier will not drain completely, set up a portable pump to finish. The pump can also be used while hosing out the clarifier. Once the clarifier is cleaned, enter it for inspection and maintenance.

B. Entering a drained clarifier
1. Follow all confined space procedures!
2. Make sure the clarifier is cleaned out, the drive is locked-out/tagged-out and all gates or valves leading to the clarifier are also locked-out/tagged-out.
3. Before entering, wear the proper PPE (gloves, safety glasses, boots, etc.). A gas detector is also needed for confined space entry. Fill out any paperwork necessary for the job and have at least two people present.
4. A long extension ladder will probably be needed for entry. Be sure to secure it to the clarifier before entering.

## Chapter 20 - Calculations

### Section 20.1 - Clarifier

20.1.1 Given the following data, calculate the weir overflow rate (OLR) and solids loading rate (SLR) of the clarifier.

GIVEN:

[MGD = million gallons per day]

Mixed liquor suspended solids (MLSS) = 3,600 mg/L
Influent flow = 1.03 MGD
Clarifier diameter = 76 ft

FORMULAS AND SOLUTIONS:
[gpd = gallons per day]

Weir length = 2 × 3.14 × clarifier radius (ft)
= 2 × 3.14 × 38 ft
= 238.64 ft

WOR = flow (gpd/ft) ÷ weir length (ft)
= 1,030,000 gpd ÷ 238.64 ft
= 4,316 gpd/ft

Clarifier surface area = 3.14 × [radius (ft)]$^2$
= 3.14 × (38 ft) $^2$
= 4,534 ft$^2$

SLR = solids applied to clarifier (lbs/day/ft$^2$) ÷ clarifier surface area (ft$^2$)
= (1.03 MGD × 3,600 mg/L × 8.34) ÷ (4,534 ft$^2$)
= 6.82 lbs/day/ft$^2$

20.1.2 Given data related to primary clarifier loading, calculate the amount of sludge (gals) that need to be pumped daily.

GIVEN:
[NOTE: every 1% solids is the equivalent of 10,000 mg/L]

Flow = 2 MGD
Influent suspended solids (ISS) = 200 mg/L
Effluent suspended solids (ESS) = 100 mg/L
Sludge solids concentration = 5% (50,000 mg/L)

FORMULAS AND SOLUTION:

Settled solids (lbs) = flow (MGD) × [ISS (mg/L) - ESS (mg/L)] × 8.34
= 2 MGD × (200 mg/L - 100 mg/L) × 8.34
= 1,668 lbs of settled solids

Settled solids (lbs) = sludge to be pumped (MGD) × solids conc. (mg/L) × 8.34
[NOTE: Formula needs to be rearranged to find the amount of sludge to pump]

Sludge to be pumped [MGD] = settled solids (lbs) ÷ [solids conc. (mg/L) × 8.34]
= 1,668 lbs ÷ [50,000 mg/L × 8.34]

= 0.004 MGD or 4,000 gpd of sludge

20.1.3 Given data, calculate the amount of sludge pumped (gals) from the bottom of 2 primary clarifiers using a diaphragm pump.

GIVEN:

Pump runtime = 20 mins/hr
Pump capacity = 4.5 gals/stroke
Pump strokes 4 times per minute
2 clarifiers

FORMULAS AND SOLUTION:

Strokes (#/day) = [pump run time (mins/hr) × 24 hrs/day] × strokes/min
= [20 mins/hr × 24 hrs/day] × 4 strokes/min
= 480 mins/day × 4 strokes/min
= 1,920 strokes/day

Sludge pumped (gals) = [strokes (#/day) × sludge (gals/stroke)] × 2 clarifiers
= [1,920 strokes/day × 4.5 gals/stroke] × 2 clarifiers
= 8,640 gpd × 2 clarifiers
= 17,280 gpd

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

GIVEN:

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

FORMULA AND SOLUTION:

SVI = [settled volume (mL/L) ÷ MLSS (mg/L)] × 1,000
= [800 mL/L ÷ 4,000 mg/L] × 1,000
= 0.2 × 1,000
= 200

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

# Part 6 - C: Biological Solids/Sludge - Handling, Processing, and Reuse

## Chapter 21 - Theory and Principles

### Section 21.1 - Definitions

21.1.1 Define polymers.

Polymers are long chains made of carbon and hydrogen used to aid sludge thickening and dewatering by clumping small sludge particles into larger particles (flocculation). Polymers are available as cationic and anionic, cationic being the most commonly used. The normal floc particle charge is negative. For a polymer to be effective it must have the opposite charge of the floc particle. The operator should work with the facilities polymer vendor to determine the most effective polymer to use, proper dilution, and mixing procedures.

21.1.2 Describe what is meant by a sour anaerobic digester.

A sour anaerobic digester is a digester that is not performing well. It is characterized by low gas production, high volatile acids to alkalinity (VA/ALK) ratio, and often a low pH. It's often caused by excessive organic loading, but can be affected by low temperatures and toxicity.

### Section 21.2 - Biological Principles

21.2.1 Describe how anaerobic digesters work.

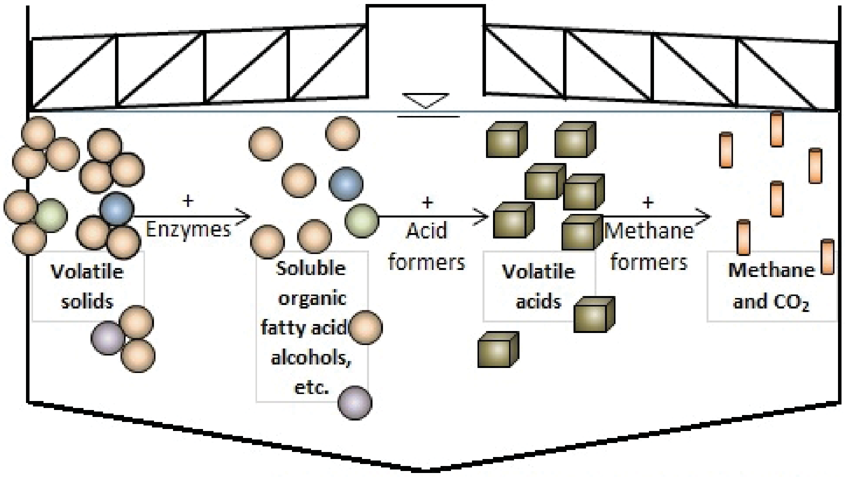
Anaerobic digesters utilize microorganisms without oxygen to digest the remaining organic material in wasted sludge from the liquid primary and secondary treatment processes. The process generates methane gas that can be recovered and used as an energy source in the treatment facility. Most medium to large facilities include both primary and secondary digesters. Primary digesters are mixed, heated and typically provide most of the stabilization, methane gas production and pathogen reduction. Secondary digesters often serve as a component of storage for digested sludge, a standby primary tank, and source of seed sludge and also may be used as a quiescent basin for supernatant withdrawal.

21.2.2 Explain the process where waste entering an anaerobic digester is converted to methane, sludge, and water.

The volatile (organic) solids in the feed sludge are used as food by the bacteria in the digester. Bacteria release extracellular enzymes (enzymes located outside of the bacteria cell) to break down solid complex compounds, cellulose, proteins, etc. into soluble organic fatty acids, alcohols, carbon dioxide, and ammonia.

Acid-forming bacteria convert the products of the first stage into acetic acid, propionic acid, hydrogen, carbon dioxide, and other compounds. Methane-forming bacteria convert the acetate and other volatile acids into methane and carbon dioxide.

**Figure 21.2.2.1**



Source: Danielle Luke, Wisconsin Department of Natural Resources

21.2.3 Contrast the environmental sensitivity of acid-forming bacteria to that of methane-forming bacteria.

The acid-forming bacteria are not as sensitive as the methane-forming bacteria. The methane-forming bacteria are affected by slight changes in organic loading, pH, and temperature (a temperature change greater than 1°F per day will affect the methane formers). The methane formers are strictly anaerobic bacteria and are also extremely sensitive to oxygen. Good digester operations require ensuring the conditions are kept favorable for the methane formers. If the acid former population grows too rapidly (excess volatile acids), a digester upset will occur.

## Chapter 22 - Operation and Maintenance

### Section 22.1 - Thickening Methods, Equipiment, and Maintenance

22.1.1 Explain the importance of the proper start-up of a positive displacement pump.

Positive displacement pump systems can be damaged if flow through the system is prevented by a closed line valve or lack of liquid in the system. Positive displacement pumps can be damaged if run without liquid or against closed valves. Pipe damage can occur with a closed discharge valve if discharge pressure exceeds pipe rated pressure.

### Section 22.2 - Anaerobic Treatment Methods, Equipment, and Maintenance

22.2.1 List some of the key factors related to optimal operation of an anaerobic digester.

A. Organic loading rate (OLR)
B. Volatile acid/alkalinity ratio (VA/ALK)
C. Temperature
D. Mixing or recirculation
E. Solids retention time (SRT)
F. pH
G. Grit and scum blanket
H. Toxicity

22.2.2 List the start-up procedures of an anaerobic digester.

A. To reduce start-up time, add a well-buffered seed sludge from another digester, if available

B. Fill the digester to the minimum operating level with raw sludge, recycled activated sludge (RAS), and preliminary treated raw sewage

C. Start mixing

D. Heat digester to operating temperature

E. Start adding daily feed sludge; begin monitoring and controlling temperature, pH, volatile acids/alkalinity, and organic loading rate

22.2.3 List the common biosolids/sludge treatment processes.

The purpose of sludge treatment is to reduce organic content and pathogenic organisms, allowing for beneficial reuse while protecting public health and the environment. Treated, or stable, sludge has less odor (reducing vector attraction), good dewatering properties, and is more publicly acceptable.

A. Most common treatment processes
  1. Aerobic digestion
  2. Anaerobic digestion

B. Other treatment processes
  1. Composting
  2. Lime stabilization
  3. Pasteurization
  4. Heat drying

22.2.4 Discuss the hydraulic retention time (HRT) needed in an anaerobic digester to achieve adequate sludge treatment.

The HRT, or detention time, is defined as the time that a sludge particle remains within the anaerobic digester. Volatile solids percent reduction is directly related to the HRT. As the HRT increases, so does the volatile solids percent reduction. For an anaerobic digester operating at 95°F to 100°F (35°C to 38°C), the design HRT is 15 days. A short HRT (less than 15 days) may result in low volatile solids reduction (less than 38%) and high fecal coliform values (greater than 2,000,000 colony forming units (cfu)/gram), preventing the digested sludge from being classified as a Class B biosolids.

22.2.5 Describe the temperature-phased anaerobic digestion (TPAD) process.

TPAD is a treatment process that involves multiple stages of treatment including at least one thermophilic (55°C to 60°C or 131°F to 140°F) and one mesophilic (32°C to 38°C or 95°F to 100°F). The thermophilic stage effectively reduces pathogens and volatile solids and is then followed by a mesophilic polishing stage, which helps eliminate the odor and dewatering issues associated with thermophilic digestion.

22.2.6 State the approximate time intervals that anaerobic digesters should be drained, cleaned, inspected, and repaired.

Complete digester cleaning is dependent on the type of waste treated, efficiency of grit removal, efficiency of mixing, tank structure and age, and condition of internal equipment. Cleaning should be done at about a 5 to 10 year interval.

### Section 22.3 - Aerobic Treatment Methods, Equipment, and Maintenance

22.3.1 Describe the reasons to consider aerobic-anoxic operation of anaerobic digester.

A. Energy savings
Turning off aeration equipment reduces the cost of aeration. The savings are increased if the equipment is turned off during peak power periods associated with the electric company billing.

B. Nitrogen removal
The aerobic process promotes nitrifying ammonia to nitrate, while the anoxic zone promotes denitrification of nitrate and the release of nitrogen gas.

C. pH control
Nitrification reduces alkalinity, while denitrification returns alkalinity to the process. The result is less issues associated with pH control.

D. Phosphorus luxury uptake
The cycling from anoxic to aerobic operations helps to promote biological phosphorus uptake. Phosphorus release occurs under anoxic conditions during decanting, primarily after organic matter is added (digester is fed). Up aeration, the phosphorus is absorbed by the microorganisms.

22.3.2 Describe the auto-thermal thermophilic aerobic digestion (ATAD) process.

ATAD is specialized aerobic process that subjects sludge to temperatures greater than 55°C (131°F) without external heat with a short retention time of 6 to 9 days. The reactors are insulated to conserve the heat produced from the biological degradation of organic solids by thermophilic bacteria. This process is capable of producing a Class A biosolids.

### Section 22.4 - Dewatering Methods, Equipment, and Maintenance

22.4.1 Define bound and unbound water as related to sludge dewatering.

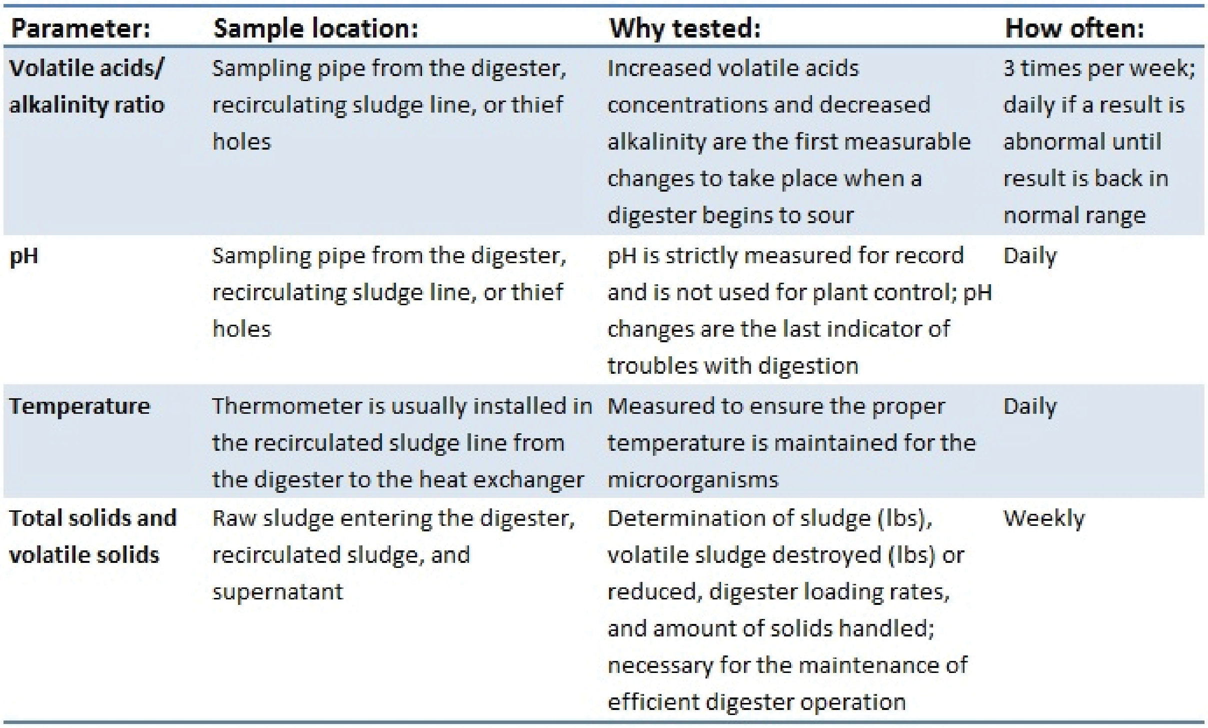
The majority of bound water is inside the cells, unbound water is outside the cells. Most sludge dewatering techniques do not release the bound water. It is difficult to get the biosolids above 25% solid unless the cells are ruptured.

## Chapter 23 - Monitoring, Process Control, and Troubleshooting

### Section 23.1 - Sampling and Testing

23.1.1 Describe tests used to monitor anaerobic digester performance.

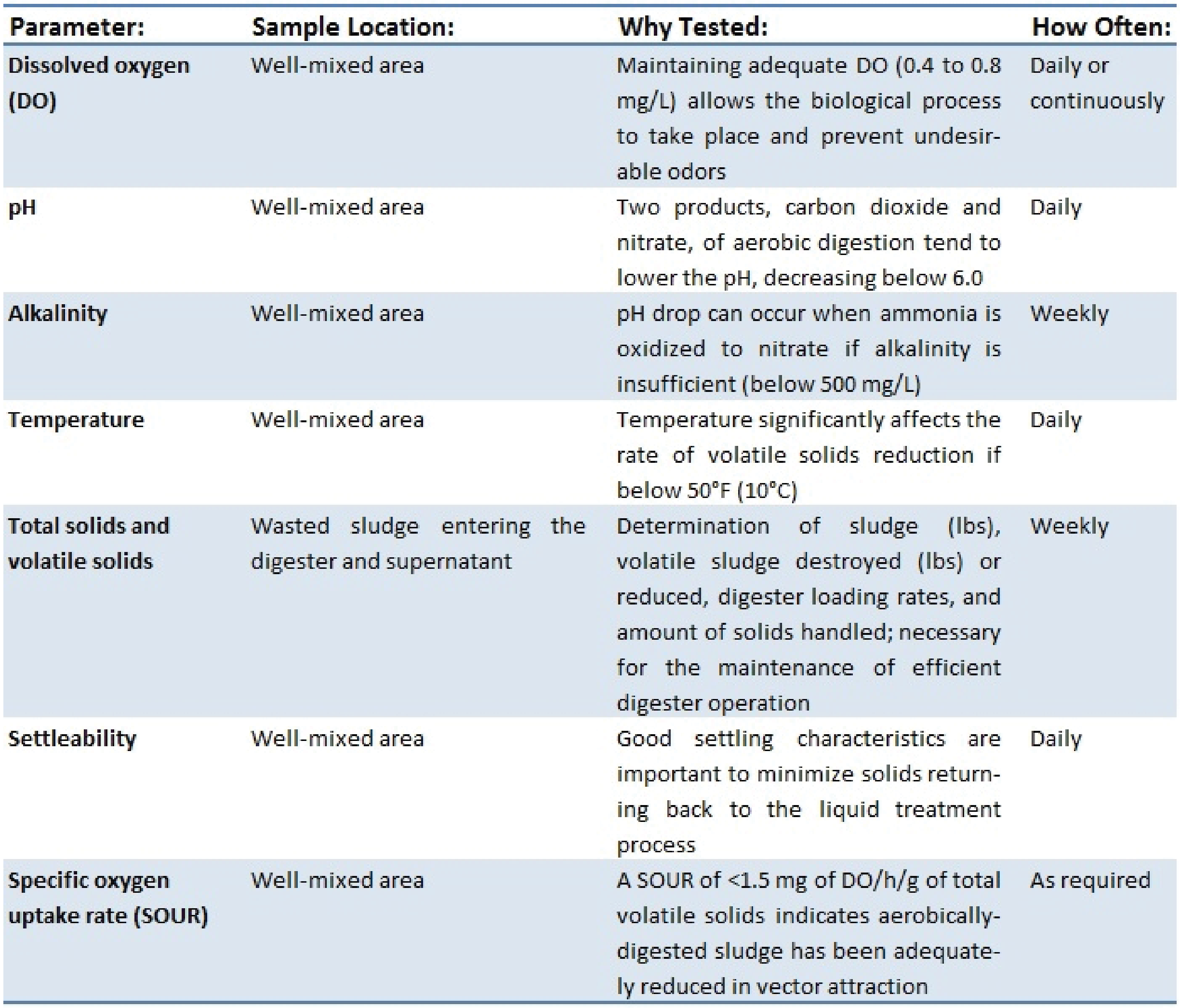
**Figure 23.1.1.1**



| Parameter: | Sample location: | Why tested: | How often: |
|---|---|---|---|
| **Volatile acids/ alkalinity ratio** | Sampling pipe from the digester, recirculating sludge line, or thief holes | Increased volatile acids concentrations and decreased alkalinity are the first measurable changes to take place when a digester begins to sour | 3 times per week; daily if a result is abnormal until result is back in normal range |
| **pH** | Sampling pipe from the digester, recirculating sludge line, or thief holes | pH is strictly measured for record and is not used for plant control; pH changes are the last indicator of troubles with digestion | Daily |
| **Temperature** | Thermometer is usually installed in the recirculated sludge line from the digester to the heat exchanger | Measured to ensure the proper temperature is maintained for the microorganisms | Daily |
| **Total solids and volatile solids** | Raw sludge entering the digester, recirculated sludge, and supernatant | Determination of sludge (lbs), volatile sludge destroyed (lbs) or reduced, digester loading rates, and amount of solids handled; necessary for the maintenance of efficient digester operation | Weekly |

23.1.2 Describe tests used to monitor aerobic digester performance.

**Figure 23.1.2.1**



| Parameter: | Sample Location: | Why Tested: | How Often: |
|---|---|---|---|
| **Dissolved oxygen (DO)** | Well-mixed area | Maintaining adequate DO (0.4 to 0.8 mg/L) allows the biological process to take place and prevent undesirable odors | Daily or continuously |
| **pH** | Well-mixed area | Two products, carbon dioxide and nitrate, of aerobic digestion tend to lower the pH, decreasing below 6.0 | Daily |
| **Alkalinity** | Well-mixed area | pH drop can occur when ammonia is oxidized to nitrate if alkalinity is insufficient (below 500 mg/L) | Weekly |
| **Temperature** | Well-mixed area | Temperature significantly affects the rate of volatile solids reduction if below 50°F (10°C) | Daily |
| **Total solids and volatile solids** | Wasted sludge entering the digester and supernatant | Determination of sludge (lbs), volatile sludge destroyed (lbs) or reduced, digester loading rates, and amount of solids handled; necessary for the maintenance of efficient digester operation | Weekly |
| **Settleability** | Well-mixed area | Good settling characteristics are important to minimize solids returning back to the liquid treatment process | Daily |
| **Specific oxygen uptake rate (SOUR)** | Well-mixed area | A SOUR of <1.5 mg of DO/h/g of total volatile solids indicates aerobically-digested sludge has been adequately reduced in vector attraction | As required |

23.1.3 Explain the purpose of a bench test.

A bench test is an attempt to simulate on a small scale what may be expected under full-scale operation. It is helpful in determining chemical addition doses, process control changes, detention times, and other operational factors. For example, one type of bench test is a jar test wherein a number of jars are set up using different chemicals at different concentrations to determine the best settling characteristics. When the best chemical dosage is determined it can be applied full scale to the sludge-handling process.

23.1.4 Explain why a good bench test might not translate into successful operation.

Bench testing is only an approximation of actual full-scale operations. Bench test results do not always translate to full-scale operation because the actual operating condition cannot be absolutely duplicated. Many factors may affect full-scale operations, such as: temperature, mixing, hydraulic and mechanical loading, and the actual equipment being used. To fully verify operational factors it would be necessary to pilot or test the equipment after the bench testing.

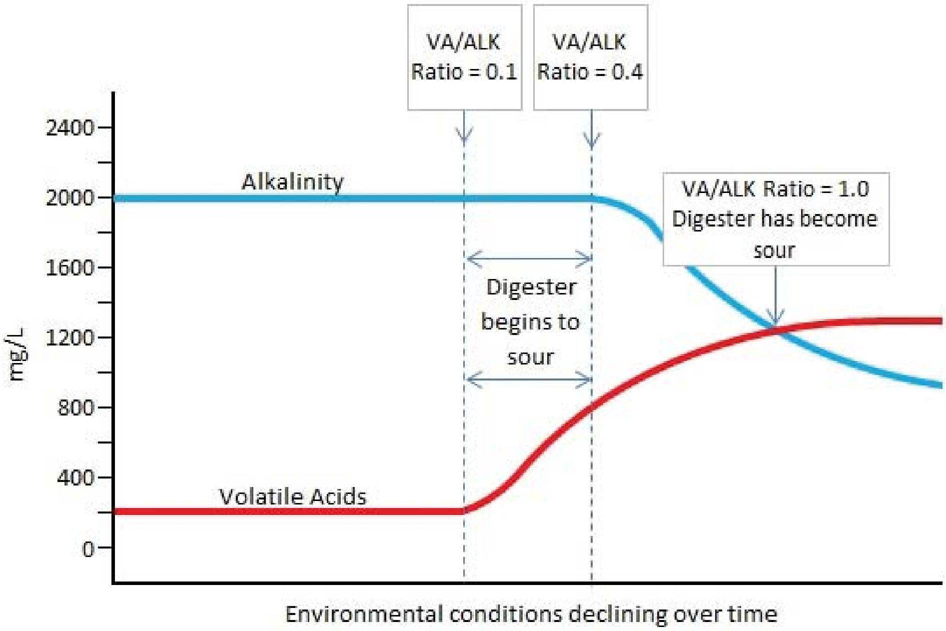
## Section 23.2 - Data Understanding and Interpretation

23.2.1 Discuss the volatile acid/alkalinity (VA/ALK) ratio.

In a stable digester, the volatile acids are used at about the same rate they are produced. If excess volatile solids are fed into a digester, the acid-forming bacteria population will grow creating an overabundance of acids. The methane-forming bacteria reproduce much slower than the acid-forming bacteria and cannot handle the increase in acids, ultimately causing a digester upset.

A good VA/ALK ratio for most digesters is generally less than 0.2. This ratio is the key to proficient operations. VA/ALK should be monitored consistently because it will be the first warning of problems occurring and action taken immediately once it begins to rise.

**Figure 23.2.1.1**



## Section 23.3 - Sidestreams and Recycle Flows

23.3.1 List the alternatives that can be implemented to lessen sidestream impact on treatment plant processes.

A. Delay sidestream introduction to plant (feed at low-loading times)
B. Install a flow equalization system
C. Pretreat the sidestream, especially for phosphorus
D. Dilute or mix with other flows
E. Optimize solids capture
F. Optimize chemical conditioning

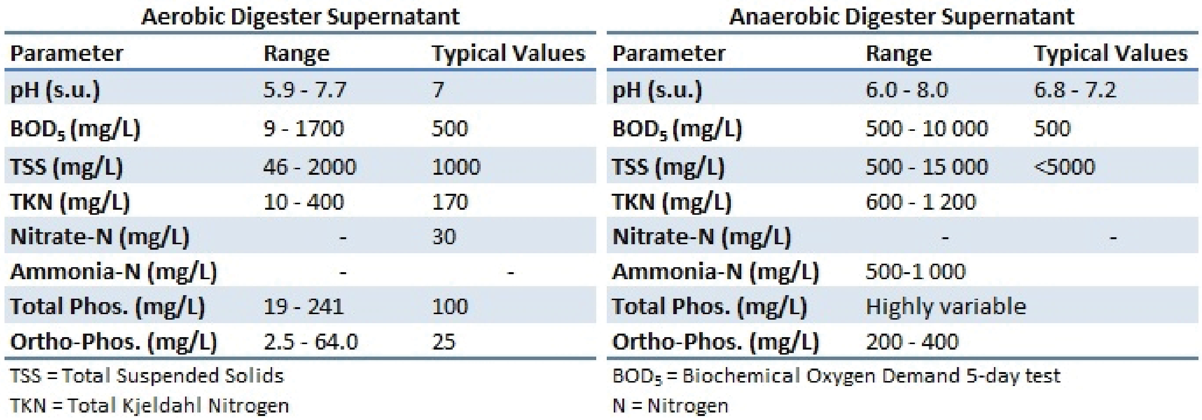
23.3.2 Discuss the possible impact of sidestreams or recycle flows back to the activated sludge process.

Sidestreams or recycle flows usually come from biosolids and sludges dewatering and treatment, such as decanting digesters or sludge storage tanks. Sidestreams may be high in biochemical oxygen demand (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.

23.3.3 Discuss digester decanting.

Digester decanting can increase the performance of the digesters and produce higher total solids in the digester, thereby reducing the volume to haul. The removal of liquid can increase solids retention time, volatile solids destruction, accelerate digestion, and pathogen destruction. An operator needs to be aware supernatant return can cause significant additional BOD, solids, and nutrient loadings to the plant.

**Figure 23.3.3.1**



**Aerobic Digester Supernatant**

| Parameter | Range | Typical Values |
|---|---|---|
| pH (s.u.) | 5.9 - 7.7 | 7 |
| $BOD_5$ (mg/L) | 9 - 1700 | 500 |
| TSS (mg/L) | 46 - 2000 | 1000 |
| TKN (mg/L) | 10 - 400 | 170 |
| Nitrate-N (mg/L) | - | 30 |
| Ammonia-N (mg/L) | - | - |
| Total Phos. (mg/L) | 19 - 241 | 100 |
| Ortho-Phos. (mg/L) | 2.5 - 64.0 | 25 |

TSS = Total Suspended Solids

TKN = Total Kjeldahl Nitrogen

**Anaerobic Digester Supernatant**

| Parameter | Range | Typical Values |
|---|---|---|
| pH (s.u.) | 6.0 - 8.0 | 6.8 - 7.2 |
| $BOD_5$ (mg/L) | 500 - 10 000 | 500 |
| TSS (mg/L) | 500 - 15 000 | <5000 |
| TKN (mg/L) | 600 - 1 200 | |
| Nitrate-N (mg/L) | - | - |
| Ammonia-N (mg/L) | 500-1 000 | |
| Total Phos. (mg/L) | Highly variable | |
| Ortho-Phos. (mg/L) | 200 - 400 | |

$BOD_5$ = Biochemical Oxygen Demand 5-day test

N = Nitrogen

## Section 23.4 - Performance Limiting Factors

23.4.1 Explain why it works better to feed small amounts of thick sludge more often than to feed large amounts of thin sludge less often into an anaerobic digester.

A feed schedule that feeds thick sludge at frequent intervals is the best for anaerobic digester operations. The reasons for this are:

A. Reduces heating costs
B. Reduces supernatant volume
C. Prevents upsets
D. Increases treatment (increases detention time)
E. Stabilizes gas production

23.4.2 Explain how siloxanes affect gas-handling equipment.

Though a portion of siloxanes decompose in the activated sludge process, some end up in sludges. When sludge is treated in the anaerobic digestion process, siloxanes volatize and become part of the biogas. If the gas is combusted, the siloxanes are converted into a glass-like compound called silicon dioxide ($SiO2$). In engines, it is deposited as an abrasive material that causes damage to internal moving parts and deposited on exhaust components. In boilers, its deposited as a white powder that insulates boiler tubes decreasing heating efficiency and may cause high exhaust stack temperatures. Special filters can be used to remove siloxanes from the biogas.

23.4.3 Discuss operational problems caused by the formation of struvite.

Struvite deposits can clog pipes and valves, interfere with instrumentation, and reduce the operating life of equipment such as belt filter presses. Struvite commonly forms in anaerobic digesters where ammonia, magnesium, and phosphate are present and pH increases. Enhanced biological phosphorus removal (EBPR) plants with anaerobic digesters have a higher potential for struvite formation than conventional activated sludge plants. Therefore, struvite formation is common at pipe elbows, mixer blades, valves, pump impellers, and dewatering equipment. Iron salts added to the digester may help balance nutrients and may reduce struvite formation.

23.4.4 Discuss air permits in regards to anaerobic digester emissions.

Governmental air quality requirements may affect wastewater treatment facilities and in some cases require the facility to apply and obtain an air permit. Facilities should inventory their respective air emission sources to determine whether they may need such air permit or determine whether the facility is eligible for a permit exemption. Air emission sources at a wastewater facility may include boilers which burn biogas, engines, turbines, flares, or any other combustion unit. Once air emission sources are inventoried, an operator may want to contact their environmental consultant, use online resources, and/or DNR staff to determine what requirements may apply to the facility. While specific air regulations and requirements are beyond the scope of this study guide, it is a key role of the facility owner to evaluate, obtain, and comply with all appropriate permit requirements.

## Section 23.5 - Corrective Actions

23.5.1 Discuss the important items to consider when an anaerobic digester is taken out of service.

Plant operations that could be affected while the digester is out of service include how to handle waste sludges, heating alternatives if the digester gas is not available, and possible changes to the digester sidestreams that may negatively affect other treatment process.

A possible odor problem can occur if the digester gas system had to be vented to the atmosphere to make the repair. Neighboring residences and other buildings in close proximity to the plant would be affected.

23.5.2 Discuss the toxicity concerns of heavy metals and sulfides in an anaerobic digester.

A. Heavy metals
Heavy metals in solution can act as biocides (killing the bacteria in the digester). Heavy metal sources are often from industries, especially metal-finishing and metal-plating operations. Common toxic heavy metals would include: copper, chromium, mercury, arsenic, nickel, zinc, cadmium, selenium, molybdenum, and lead.

B. Sulfides

Sulfides can come from septage, holding tanks, and industrial sources as sulfate salts that are reduced to sulfides in the digester. The bacteria can tolerate between 50 and 100 mg/L of soluble sulfide but concentrations above 200 mg/L are toxic and would require treatment with iron salts to precipitate the sulfides. The sources of this waste stream should be reduced or eliminated.

23.5.3 Discuss the problems associated with hydrogen sulfide gas.

Hydrogen sulfide in the presence of moisture forms weak sulfuric acid which is highly corrosive to a wide variety of materials (most metals, electrical equipment, and concrete). The gas in low concentrations produces a very noticeable odor. The characteristic odor is often described as smelling similar to rotten eggs. At relatively low concentrations, the gas is very toxic and causes a special problem in confined spaces.

23.5.4 Explain how the generation of hydrogen sulfide gas can be controlled.

Hydrogen sulfide gas is typically associated with low-oxygen conditions and can be controlled by the addition of oxidizing agents such as potassium permanganate and hydrogen peroxide. Other control measures would include aerating the sludge or processing the sludge before septic conditions can occur. Hydrogen sulfide can be removed from digester gas with an absorbing agent such as an iron sponge.

## Chapter 24 - Residuals Management

### Section 24.1 - Sludge Quality

24.1.1 List the three sludge quality criteria which must be satisfied before the sludge may be land applied.

A. Metal concentrations
B. Pathogen control and treatment processes
C. Vector attraction reduction

24.1.2 Discuss biosolids or sludge treatment processes to meet the pathogen control criteria for Class B sludges.

Class B sludges are sludges that can be applied to agricultural lands. Adequate pathogen control for a Class B sludge is less than 2,000,000 colony forming unites per gram (cfu/g) or most probable number (mpn) fecal coliforms or by one of the following methods below. Certain sludge treatment processes are able to significantly reduce fecal coliform bacteria and meet these criteria in Wisconsin.

A. Anaerobically-digested sludge is treated in the absence of oxygen for a certain amount of time at a specific temperature. The time and temperature shall be between 15 days at 35°C to 55°C and 60 days at 20°C.

B. Air-dried sludge is dried on sand beds or on paved or unpaved basins for a minimum of 3 months. During 2 of the 3 months, the average daily temperature has to be above 0°C.

C. Composted sludge is composted using either a within-vessel, static-aerated pile, or windrow composting method and the temperature of the sludge is raised to 40°C or higher for 5 days. For 4 hours during the 5 days, the temperature in the compost pile has to exceed 55°C.

D. Alkaline stabilization lime is added to sludge to raise the pH to 12 for 2 hours of contact. By elevating the pH of sludge to 12, organisms and pathogens are significantly reduced.

E. Another process (usually patented) to equivalently reduce pathogens, as approved by the Department of Natural Resources.

## Section 24.2 - Management Options

24.2.1 List the common methods of sludge reuse or disposal.

Federal and state regulations establish two levels of quality for municipal biosolids for final use or disposal. Class A biosolids receive a very high degree of treatment and can be used by the public in parks, gardens, and golf courses. Some biosolids are used in composting programs. Class B biosolids do not meet all the criteria of a Class A sludge and are land applied on agricultural lands or disposed of in a landfill. Land application is the most common method of sludge reuse in Wisconsin.

24.2.2 Describe the factors that improve the public acceptance of sludge land application.

The most important factor in the acceptance of sludge land application is to have a good education program explaining the benefits of sludge in terms of nutrient value (fertilizer), the soil conditioning it provides, and the regulatory standards the sludge has met. All spreading equipment should be clean and well maintained to provide a good overall appearance.

A strong public relations program is essential. Some aspects of a good program could include:

A. Direct contact with neighbors
B. Use of flyers, news releases, and brochures
C. Provide a point of contact for any questions or concerns
D. Avoid blocking traffic
E. Clean any debris left on the roadways
F. Limit dust during application

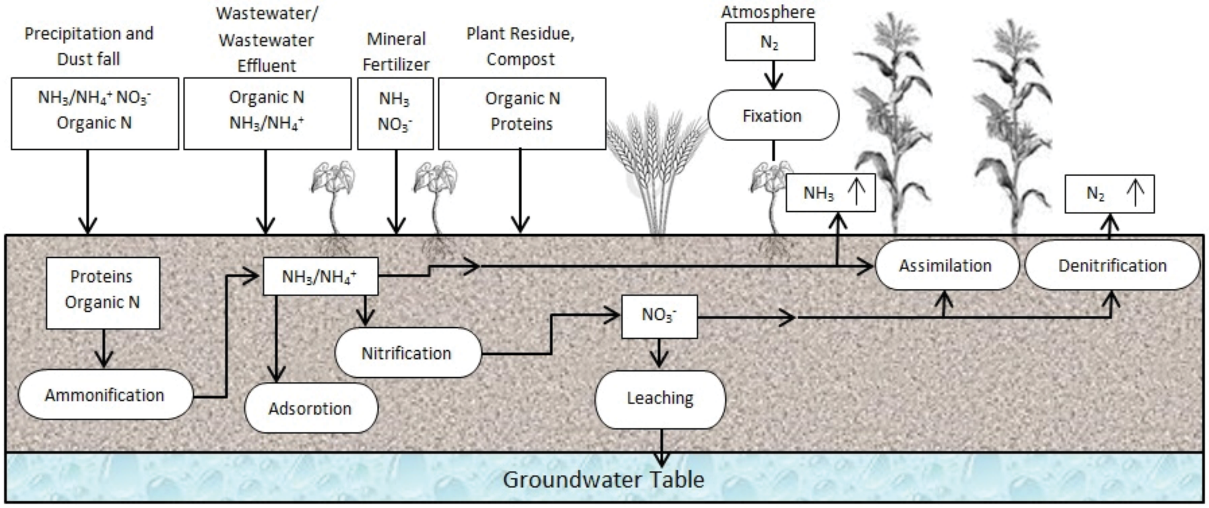
24.2.3 Discuss municipal sludge storage requirements in Wisconsin.

All municipal treatment plants that land apply shall have the ability to store sludge for 180 days. No land spreading is applicable during winter or on frozen ground. Having adequate sludge storage allows the operator the ability to waste the proper amount of sludge at all times during the year.

## Section 24.3 - Land Application

24.3.1 Show the nitrogen cycle in soil and groundwater.

**Figure 24.3.1.1**



Courtesy of Danielle Luke, Wisconsin Department of Natural Resources

### 24.3.2 Discuss nutrient management plans.

Nutrient management plans address the application and budgeting of nutrients for plant production. Nutrient sources such as soil reserves, fertilizers, manure, and crop residue are accounted for in the plan. Nutrient management documentation and planning are required for operators who will be land-applying sludge, for the prevention of over-applying fertilizers to cropland, and assisting with meeting water quality standards. Planning reduces nutrient entry into surface water, groundwater, and atmospheric resources while maintaining and improving the soil condition.

Biosolids managers need to communicate with farmers and land owners when providing biosolids for nutrient reuse. Communication is essential for farmers and land owners to account for the additional nutrients from biosolids as farmers and landowners may be required to complete more extensive nutrient management plans often referred to as 590 plans pursuant to Natural Resource Conservation Service (NRCS) 590 standards required for specific farmers and producers. Communication is also necessary to communicate pathogen control crop harvesting limitations and collect planting and harvesting details such as dates of planting and harvesting, yields, and any changes from proposed crop rotations.

### 24.3.3 Discuss the value of the land application of biosolids.

Biosolids primarily provide nitrogen and phosphorus. Biosolids also provide potassium, calcium, magnesium, sulfur, and micronutrients for plant growth. Applying biosolids to soil has shown to increase water holding capacity, lessen wind and water erosion, and improve aeration due to the addition of organic matter.

### 24.3.4 Discuss crop recommendations.

Using crop recommendations helps minimize excessive nitrogen and phosphorus applications. Wisconsin's nitrogen guidelines are based on crop yield, quality, and economic return. The phosphorous or potassium guidelines are based on the crop in the planned rotation with the highest demand level. Application rate guidelines vary according to the crop grown, soil characteristics and yield potential, and soil organic matter content. The amount of available nitrogen from sludge and other nitrogen sources applied per growing season may not exceed the nitrogen requirement of the crop as determined by the recommendations based on the University of Wisconsin Extension Bulletin A-2809.

A soil test report determines the fertility of a soil. Reports include soil pH, percent organic matter, and phosphorus and potassium analyzed. Nitrogen is not analyzed, but inferred based on the soil type, yield potential, and organic matter. The results support appropriate decision making on the quantity of nutrients that should be added. Soil tests are required every four years on active land spreading sites. Following nutrient application guidelines prevents over application of nutrients, which in turn, also enhances profitability and reduces the potential for runoff and groundwater contamination.

24.3.5 Discuss the potential environmental impacts of excessive nutrients applied from biosolids and sludge.

A. Nitrogen
Nitrogen in surface waters can stimulate aquatic plant growth, be toxic to aquatic life in high concentrations, and can deplete dissolved oxygen (DO). Nitrate nitrogen is very soluble in water and can leach into groundwater where it can contaminate drinking water.

B. Phosphorus
Phosphorus can stimulate aquatic plant growth where it can lead to toxic blue-green algae blooms and deplete DO causing aquatic organism fatalities.

C. Potassium
Potassium, while necessary for plant growth, is not an element limiting algal growth in surface water. It would be rare that biosolids would contain enough potassium to be the limiting crop nutrient, however industrial wastes could be high in potassium.

24.3.6 Compare the performance and costs of dewatering versus liquid hauling, listing advantages and disadvantages of each.

A. Mechanical dewatering
1. Advantages
    a. Less volume to haul, less storage required for sludge
    b. Dry sludge can be hauled with mechanical equipment rather than pumping liquid
1. Disadvantages
    a. Higher capital costs
    b. Higher operating costs
    c. Difficult to apply
    d. Return sidestreams
    e. Cost of chemicals for conditioning
    f. Increased equipment maintenance and replacement

B. Liquid hauling
1. Advantages

   a. Cost effective (with short-haul distances)
   b. Reduced capital and operating costs (no dewatering equipment required)
   c. Easy to apply
   d. No return sidestreams
1. Disadvantages
   a. Large volumes must be hauled
   b. Larger sludge storage required
   c. Increased vehicle costs
   d. Land availability problems
   e. Seasonal spreading limitations

## Chapter 25 - Safety and Regulations

### Section 25.1 - Personal Safety

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

Wisconsin Department of Safety and Professional Services - SPS 332- Public Employee Safety and Health must be followed. Important safety requirements include: confined space, excavation, hearing conservation, bloodborne pathogens, CPR/First Aid, Safety Data Sheet (SDS), electrical, fall protection, hazardous materials, as well as others. Non-public entities follow Occupational Safety and Health Administration (OSHA) CFR 29 part 1910.

25.1.2 Describe how hazards associated with operating sludge handling equipment can be reduced.

A. Education and training of operator personnel in the understanding of the possible equipment hazards

B. Good housekeeping to prevent problems with slips and falls; keep floors and equipment clean and use non-slip surfaces where possible

C. Proper maintenance of equipment including lubrication, all equipment guards, servicing tag, and lock-out equipment; ensuring that ventilation equipment is operating properly

D. Personal protective equipment (PPE) necessary for the type of work being done (eye protection, hearing protection, and appropriate clothing)

E. Develop a positive accident prevention program making sure that all personnel are involved with its implementation

### Section 25.2 - Chemicals and Gasses

25.2.1 Discuss the chemicals used to adjust anaerobic digester pH and the safety considerations.

Chemicals may be used to raise the pH of a sour digester. Two common chemicals used are lime and sodium bicarbonate. The total amount of chemical needed is calculated and then added in small increments, checking pH after each addition. Specific procedures and addition should be checked in the O&M manual or with a consultant.

The use of calcium oxide (quicklime) or calcium hydroxide (slaked or hydrated lime) can be dangerous when these chemicals are mixed with water. Lime must always be added to water and not water added to lime. When water is added to lime, a violent reaction and splashing can occur, splattering this strong caustic. Strong caustic chemicals can burn the skin or eyes (similar to an acid burn).

25.2.2 Discuss the chemicals used for sludge thickening and dewatering and their safety considerations.

When handling polymers, it is important to use the correct personal protective equipment (PPE) and to be aware of the extremely slippery properties. Caution should be used when walking in areas where polymers are used. The addition of rock salt or bleach may be used in clean up. Consult with the Safety Data Sheets (SDS) for additional ways to clean polymer spills.

Oxidizing agents, such as chlorine, are added to elutriate (rinse fine solids out of) the sludge as a way to control biological activity and septicity. Oxidizing agents can be very harmful when exposed to unprotected skin, using the proper PPE is vital. Use equipment that is dedicated solely for the use with these chemicals to avoid cross contamination and possible explosive reactions.

25.2.3 List three purposes for ventilation regarding safety, odor control, and corrosion prevention.

A. Safety
Ventilation removes toxic gases and particulates from work areas.

B. Odor control
Ventilation pulls outside air into work areas and reduces odor.

C. Corrosion prevention
Ventilation keeps the humidity and hydrogen sulfide down which reduces corrosion.

## Chapter 26 - Calculations

### Section 26.1 - Treatment

26.1.1 Given sludge pumped (gals), sludge concentration (%), and volatile solids (VS) in and out of the digester, estimate digester gas production ($ft^3$/day).

GIVEN:
[gpd = gallons per day]

Raw sludge pumped = 12,000 gpd
Raw sludge concentration = 5%
Raw sludge VS = 70%
Digested sludge VS = 45%
Gas production rate per pound of VS destroyed = 9 $ft^3$/day

FORMULAS AND SOLUTION:

[NOTE: Percent expressed as a decimal]
[NOTE: Fixed solids remain constant in the sludge]

Raw fixed matter (%) = 100% - raw sludge VS (%)
= 100% - 70%
= 30% raw fixed matter

Raw fixed solids (lbs/day) = sludge (gpd) × raw sludge conc. (%) × 8.34 × raw fixed matter (%)
= 12,000 gpd × 0.05 × 8.34 × 0.30
= 1,501 lbs/day

Digested fixed matter = 100% - digested sludge VS (%)
= 100% - 45%
= 55% digested fixed matter

Digested sludge VS (lbs) = fixed raw solids (lbs/day) × (digested sludge VS (%) ÷ digested fixed matter (%))
= 1,501 lbs/day × (0.45 ÷ 0.55)
= 1,228 lbs

Raw VS (lbs/day) = sludge (gpd) × raw sludge conc. (%) × 8.34 × raw sludge VS (%)
= 12,000 gpd × 0.05 × 8.34 × 0.70
= 3,503 lbs/day

VS destroyed (lbs/day) = raw VS (lbs/day) - digested sludge VS (lbs)
= 3,503 lbs/day - 1,228 lbs
= 2,275 lbs/day

Gas production ($ft^3$/day) = VS destroyed (lbs/day) × estimated gas production
= 2,275 lbs/day × 9 $ft^3$
= 20,475 $ft^3$/day of gas production

26.1.2 Given data, calculate the amount of sludge (gals) that had been pumped into an anaerobic digester based on the change in height (ft) of the floating cover.

GIVEN:

Diameter = 40 ft
Initial cover height = 20.5 ft
After pumping height = 21.0 ft
1 $ft^3$ = 7.5 gals

FORMULAS AND SOLUTION:

Volume ($ft^3$) = area ($ft^2$) × height (ft)
Change in height (ft) = height at pump stop (ft) - height at pump start (ft)

= 21.0 ft - 20.5 ft
= 0.5 ft

Volume of sludge pumped ($ft^3$) = 3.14 × (radius (ft))$^2$ × change in height (ft)
= 3.14 × (20 ft)$^2$ × 0.05 ft
= 3.14 × 400 ft$^2$ × 0.50 ft
= 628 ft$^3$

Volume of sludge pumped (gals) = volume of sludge ($ft^3$) × 7.48 gals/ft$^3$
= 628 ft$^3$ × 7.48 gals/ft$^3$
= 4,697 gals

26.1.3 Given data, calculate the hydraulic retention time (HRT) (days) in an anaerobic digester.

GIVEN:

Anaerobic digester diameter = 60 ft
Anaerobic digester height = 20 ft
Sludge pumped to anaerobic digester = 20,185 gpd
1 ft$^3$ = 7.48 gals/ft$^3$

FORMULAS AND SOLUTION:

Digester volume ($ft^3$) = 3.14 × [radius (ft)]$^2$ × height (ft)
= 3.14 × (30 ft)$^2$ × 20 ft
= 56,520 ft$^3$

Digester volume (gals) = volume ($ft^3$) × 7.48 gals/ft$^3$
= 56,520 ft$^3$ × 7.48 gals/ft$^3$
= 423,900 gals

HRT (days) = digester volume (gals) ÷ sludge pumped (gpd)
= 423,900 gals ÷ 20,185 gpd
= 21 days

26.1.4 Given data, calculate the volatile acids/alkalinity (VA/ALK) ratio.

GIVEN:

Volatile acids = 300 mg/L
Alkalinity = 2,000 mg/L

FORMULA AND SOLUTION:

VA/ALK ratio = volatile acids (mg/L) ÷ alkalinity (mg/L)
= 300 mg/L ÷ 2,000 mg/L
= 0.15

26.1.5 Given volumes of feed sludge, sludge concentrations, volatile solids (VS), and volume of a digester, calculate the organic loading rate (OLR).

GIVEN:

Digester volume = 40,000 ft$^3$
Raw sludge volume = 5,000 gpd
Sludge concentration = 5%
VS = 80%

FORMULAS AND SOLUTION:
[NOTE: Percent expressed as decimal]

VS (lbs/day) = raw sludge vol. (gpd) × sludge conc. (%) × 8.34 × VS (%)
= 5,000 gpd × 0.05 × 8.34 × 0.8
= 1,668 VS lbs/day

VS lbs/day/ft$^3$ = VS (lbs/day) ÷ digester volume (ft$^3$)
= 1,668 VS lbs/day/ft$^3$ ÷ 40,000 ft$^3$
= 0.042 VS lbs/day/ft$^3$

## Section 26.2 - Dewatering

26.2.1 Given data, calculate the increased loading (%) of suspended solids (SS) (or biochemical oxygen demand (BOD)) to a treatment plant due to the return of sidestreams from dewatering equipment.

GIVEN:
[MGD = million gallons per day]
[gpd = gallons per day]

Plant loading SS = 150 mg/L
Daily plant flow = 10 MGD
Sidestream SS = 1,000 mg/L
Sidestream flow = 200,000 gpd

FORMULAS AND SOLUTION:

Influent SS (lbs/day) = plant flow (MGD) × influent SS conc. (mg/L) × 8.34
= 10 MGD × 150 mg/L × 8.34
= 12,510 lbs/day

Sidestream SS (lbs/day) = sidestream flow (MGD) × sidestream SS conc. (mg/L) × 8.34
= 0.2 MGD × 1,000 mg/L × 8.34
= 1,668 lbs/day

Increase in SS (%) = [sidestream SS (lbs/day) ÷ influent SS (lbs/day)] × 100
= [1,668 lbs/day ÷ 12,510 lbs/day] × 100

= 13.3% increase

26.2.2 Given data, calculate the proper setting for a chemical feed pump (gallons per minute or gpm).

GIVEN:

Undiluted polymer used = 10 gpd
Polymer feed concentration = 1%

FORMULAS AND SOLUTION:
[NOTE: percent is expressed as a decimal]

Polymer flow (gpd) = undiluted polymer (gpd) ÷ polymer conc. (%)
= 10 gpd ÷ .01
= 1,000 gpd of diluted polymer

Polymer flow (gpm) = polymer flow (gpd) ÷ 1,440 mins/day
= 1,000 gpd ÷ 1,440 mins/day
= 0.7 gpm

### Section 26.3 - Land Application

26.3.1 Given data, calculate the cost comparison of hauling sludge at different concentrations.

GIVEN:

Volume A = 72,000 gals
Concentration A = 2%
Concentration B = 8%
Volume per load = 6,000 gallons
Cost per load = $100.00

FORMULAS AND SOLUTION:

C1V1 = C2V2
Volume B = volume A (gals) × [conc. A (%) ÷ conc. B (%)]
= 72,000 gals × [2% ÷ 8%]
= 18,000 gals

Loads of volume A = volume A (gals) ÷ volume of load (gals/load)
= 72,000 gals ÷ 6,000 gals/load
= 12 loads

Cost to haul volume A = loads of volume A × cost per load
= 12 loads × $100/load
= $1,200 total hauling cost for volume A

Loads of volume B = volume B (gals) ÷ volume of load (gals/load)

= 18,000 gals ÷ 6,000 gals/load
= 3 loads

Cost to haul volume B = loads of volume B × cost per load
= 3 loads × $100/load
= $300 total hauling cost for volume B

The cost of hauling sludge at 2% solids is $1,200 whereas the cost of hauling sludge at 8% would only be $300. Dewatering sludge to 8% solids would result in saving the plant a total of $900 in hauling fees.

# Part 7 - P: Nutrient Removal - Total Phosphorus

## Chapter 27 - Theory and Principles - Biological Removal

### Section 27.1 - Definitions

27.1.1 Define glycogen.

Glycogen is a polysaccharide of glucose which is energy storage inside a cell. It is present in all cells, but microorganisms which accumulate glycogen in cells during the anaerobic stage of an enhanced biological phosphorus removal (EBPR) process are not able to perform biological phosphorus removal.

27.1.2 Define polyhydroxyalkanoates (PHA).

PHAs are energy-rich carbon polymers inside a bacterial cell, which are converted from readily available organic molecules such as volatile fatty acids (VFA) in the wastewater. PHAs are the intracellular energy storage of the phosphorus-accumulating organisms (PAO). The PAOs utilize PHA as an energy source to uptake phosphorus from the wastewater in the aerobic zone of the EBPR process.

### Section 27.2 - Performance Limiting Factors

27.2.1 Discuss supplemental food (carbon source) that can be purchased for enhanced biological phosphorus removal (EBPR) when volatile fatty acids (VFA) are limiting.

A readily biodegradable food source such as VFAs is needed for successful EBPR. If the level of soluble biochemical oxygen demand (BOD) in an anaerobic selector is too low, there may not be enough VFAs available to promote the growth of phosphorus-accumulating organisms (PAO). Supplemental chemical sources of highly soluble food can be commercially purchased, such as methanol, acetic acid, sugar solutions, and glycerol. Other supplemental sources can be used as well. Because acetic acid is the most easily used VFA by PAOs, it is the VFA of choice to add as a supplemental food (carbon source) for anaerobic and anoxic selectors.

## Chapter 28 - Operation and Maintenance - Biological Removal

### Section 28.1 - Reactors

28.1.1 Discuss the use of a fermenter for enhanced biological phosphorus removal (EBPR).

When influent volatile fatty acids (VFA) are insufficient, sludge fermentation, usually primary sludge, can be a way for large plants to augment the supply of VFAs (especially acetic and propionic acids) needed for EBPR. Onsite fermenters can be designed and incorporated into the biological phosphorus removal system if needed. The reader is referred to MOP-29, Chapter 9 for sludge fermentation information.

### Section 28.2 - Biosolids Issues

28.2.1 Discuss operational problems caused by the formation of struvite.

Struvite deposits can clog pipes and valves, interfere with instrumentation, and reduce the operating life of equipment such as belt filter presses. Struvite commonly forms in anaerobic digesters where ammonia, magnesium, and phosphate are present and where pH increases. Enhanced biological phosphorus removal (EBPR) plants with anaerobic digesters have a higher potential for struvite formation than conventional activated sludge plants. phosphorus-accumulating organisms (PAO) will uptake positively charged magnesium ions to balance the negative charge associated with phosphate accumulation. This results in a higher magnesium loading to the digesters.

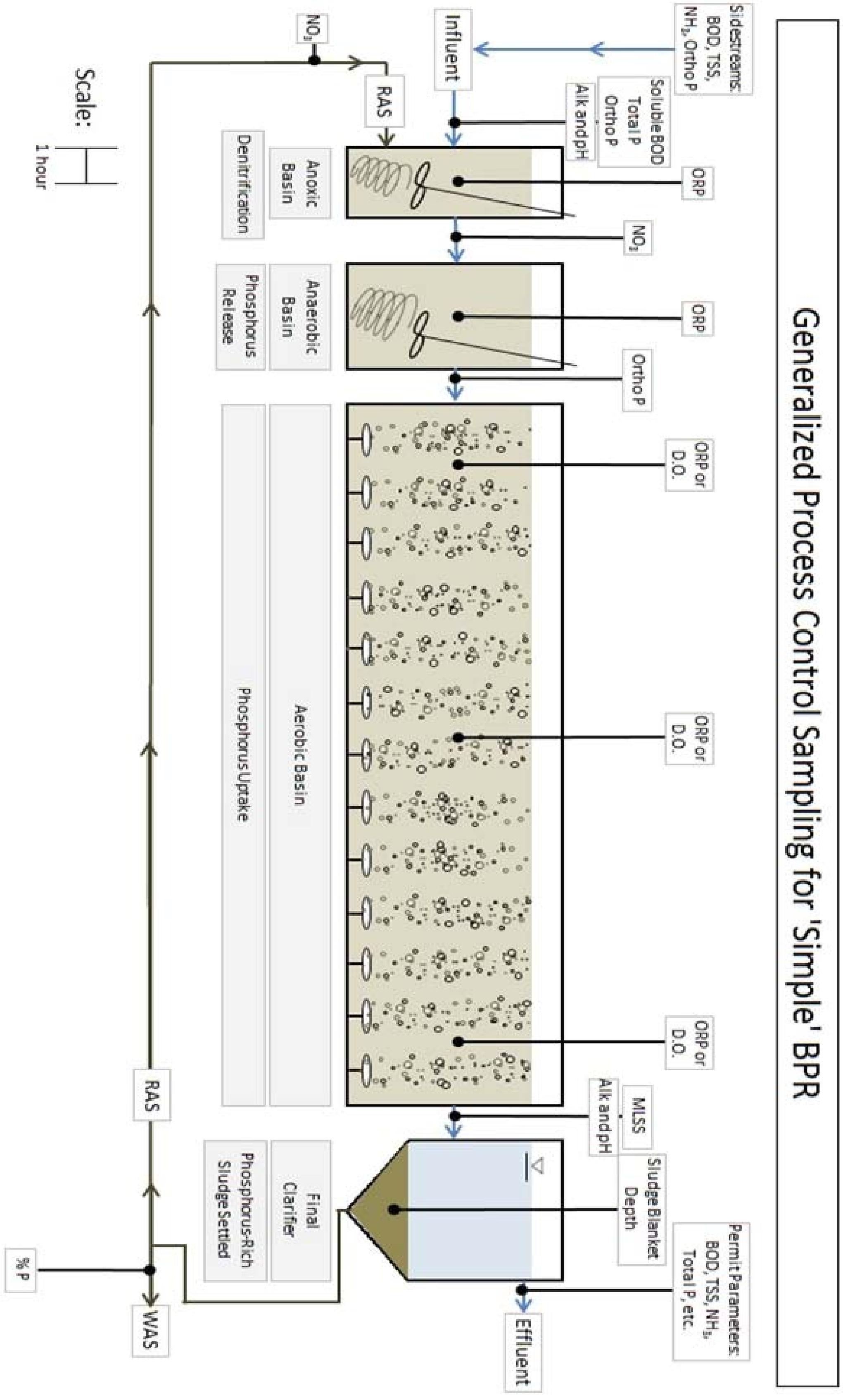
Struvite formation is very sensitive to pH. Digested sludge in an anaerobic digester is near neutral and supersaturated with carbon dioxide. When the sludge is removed from the digester, carbon dioxide escaping from the sludge will increase the pH. Carbon dioxide loss is likely wherever turbulence occurs. Therefore struvite formation is common at pipe elbows, mixer blades, valves, pump impellers, and dewatering equipment.

## Chapter 29 - Monitoring, Process Control, and Troubleshooting - Biological Removal

### Section 29.1 - Sampling and Testing

29.1.1 Show a generalized process control sampling for a simple biological phosphorus removal (BPR) plant.

**Figure 29.1.1.1**



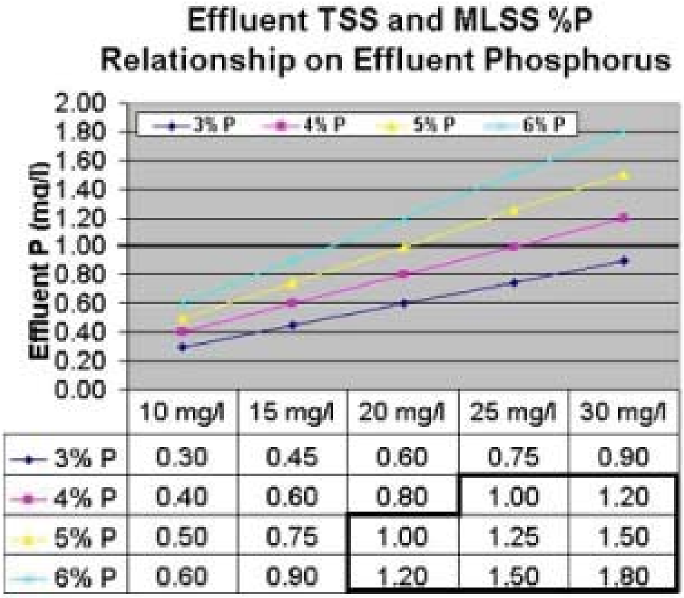
Source: Danielle Luke and Jack Saltes, Wisconsin Department of Natural Resources
08/11/2015

## Section 29.2 - Data Understanding and Interpretation

29.2.1 Describe the significance of phosphorus content in the sludge as related to biological phosphorus efficiency and effluent phosphorus.

Sludge phosphorus content is defined as the percentage of phosphorus in cell mass and is expressed as phosphorus/volatile suspended solids % (P/VSS%). In a conventional activated sludge treatment process, the sludge phosphorus content is approximately 1.5% to 2.5%. In an enhanced biological phosphorus removal (EBPR) system, the sludge phosphorus content is 3.0% to 6.0% or higher. The more efficient the EBPR system is, the higher the sludge phosphorus content will be. Phosphorus is removed from the treatment system by wasting sludge. Because the activated sludge phosphorus content is high in an EBPR plant, effluent total suspended solids (TSS) should be kept low. A small amount of TSS with high phosphorus content could contribute to a high total phosphorus (TP) concentration in the effluent.

**Figure 29.2.1.1**



| | 10 mg/l | 15 mg/l | 20 mg/l | 25 mg/l | 30 mg/l |
|---|---|---|---|---|---|
| 3% P | 0.30 | 0.45 | 0.60 | 0.75 | 0.90 |
| 4% P | 0.40 | 0.60 | 0.80 | 1.00 | 1.20 |
| 5% P | 0.50 | 0.75 | 1.00 | 1.25 | 1.50 |
| 6% P | 0.60 | 0.90 | 1.20 | 1.50 | 1.80 |

29.2.2 Discuss how much phosphorus is released in the anaerobic selector of an optimized municipal EBPR plant.

The amount of phosphorus released in the anaerobic selector varies from plant to plant. Generally, phosphorus released is 4 times the total phosphorus in the influent. EBPR plants have been successful at a release of 2.5 times the influent concentration (Bernard, J.L and M.T Steichen, WEF, 2007). Monitoring the influent phosphorus and the phosphorus level in the effluent of the anaerobic selector is a good process control practice for assessing the phosphorus release in this reactor.

## Section 29.3 - Sidestreams

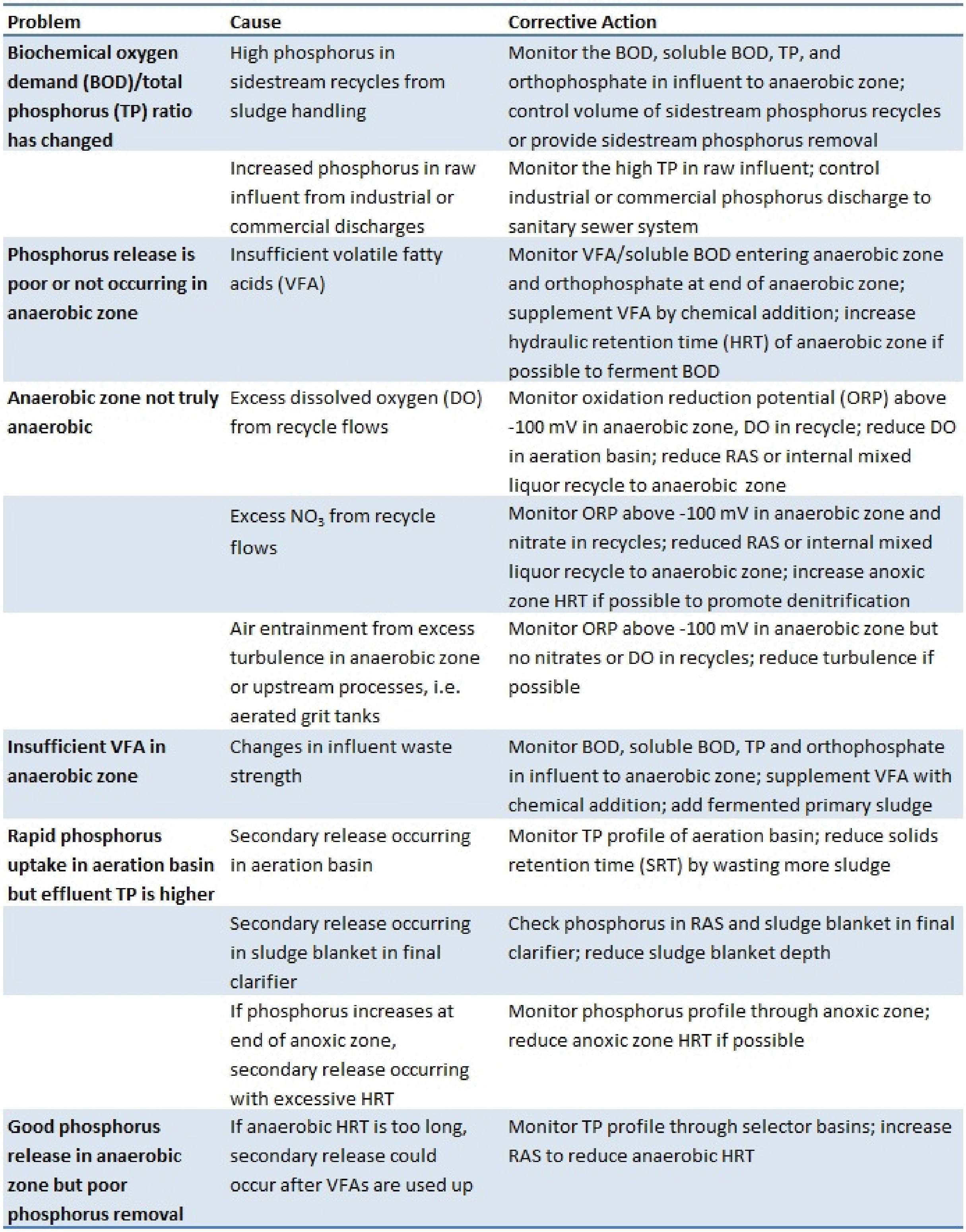
29.3.1 Discuss sidestream treatment of phosphorus when using enhanced biological phosphorus removal (EBPR).

The idea of EBPR is to create conditions in secondary treatment that result in the microorganisms absorbing excess phosphorus. This phosphorus is removed from the flow when the activated sludge is wasted. If a sidestream is high in phosphorus, the sidestream can be treated. Metal salts can be added to these sidestreams to precipitate the phosphorus to avoid overloading the plant. If only the sidestream is treated chemically, biological phosphorus effluent limits still apply.

## Section 29.4 - Corrective Actions

29.4.1 Discuss corrective actions that can be taken when problems removing phosphorus biologically occur.

**Figure 29.4.1.1**



| Problem | Cause | Corrective Action |
|---|---|---|
| **Biochemical oxygen demand (BOD)/total phosphorus (TP) ratio has changed** | High phosphorus in sidestream recycles from sludge handling | Monitor the BOD, soluble BOD, TP, and orthophosphate in influent to anaerobic zone; control volume of sidestream phosphorus recycles or provide sidestream phosphorus removal |
| | Increased phosphorus in raw influent from industrial or commercial discharges | Monitor the high TP in raw influent; control industrial or commercial phosphorus discharge to sanitary sewer system |
| **Phosphorus release is poor or not occurring in anaerobic zone** | Insufficient volatile fatty acids (VFA) | Monitor VFA/soluble BOD entering anaerobic zone and orthophosphate at end of anaerobic zone; supplement VFA by chemical addition; increase hydraulic retention time (HRT) of anaerobic zone if possible to ferment BOD |
| **Anaerobic zone not truly anaerobic** | Excess dissolved oxygen (DO) from recycle flows | Monitor oxidation reduction potential (ORP) above -100 mV in anaerobic zone, DO in recycle; reduce DO in aeration basin; reduce RAS or internal mixed liquor recycle to anaerobic zone |
| | Excess $NO_3$ from recycle flows | Monitor ORP above -100 mV in anaerobic zone and nitrate in recycles; reduced RAS or internal mixed liquor recycle to anaerobic zone; increase anoxic zone HRT if possible to promote denitrification |
| | Air entrainment from excess turbulence in anaerobic zone or upstream processes, i.e. aerated grit tanks | Monitor ORP above -100 mV in anaerobic zone but no nitrates or DO in recycles; reduce turbulence if possible |
| **Insufficient VFA in anaerobic zone** | Changes in influent waste strength | Monitor BOD, soluble BOD, TP and orthophosphate in influent to anaerobic zone; supplement VFA with chemical addition; add fermented primary sludge |
| **Rapid phosphorus uptake in aeration basin but effluent TP is higher** | Secondary release occurring in aeration basin | Monitor TP profile of aeration basin; reduce solids retention time (SRT) by wasting more sludge |
| | Secondary release occurring in sludge blanket in final clarifier | Check phosphorus in RAS and sludge blanket in final clarifier; reduce sludge blanket depth |
| | If phosphorus increases at end of anoxic zone, secondary release occurring with excessive HRT | Monitor phosphorus profile through anoxic zone; reduce anoxic zone HRT if possible |
| **Good phosphorus release in anaerobic zone but poor phosphorus removal** | If anaerobic HRT is too long, secondary release could occur after VFAs are used up | Monitor TP profile through selector basins; increase RAS to reduce anaerobic HRT |

# Chapter 30 - Calculations - Biological Removal

## Section 30.1 - Calculations

30.1.1 Given data, determine the hydraulic retention time (HRT) (hrs) in an anaerobic selector.

GIVEN:
[MGD = million gallons per day]
[RAS = recycled activated sludge]

Influent flow = 1.15 MGD
RAS flow = 0.600 MGD
Selector volume = 150,000 gals

FORMULA AND SOLUTION:

HRT (hrs) = (tank vol. (MG) ÷ [influent flow (MGD) + RAS flow (MGD)]) × 24 hrs/day
= (0.150 MG ÷ [1.15 MGD + 0.600 MGD]) × 24 hrs/day
= 2.1 hrs

30.1.2 Given data, determine the sludge age (days) in an enhanced biological phosphorus removal (EBPR) plant.

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

Anaerobic selector volume = 45,000 gals
Anoxic selector volume = 55,000 gals
Aeration basins volume = 500,000 gals
MLSS = 3,400 mg/L
Wasting rate = 20,000 gpd
WAS concentration = 5,000 mg/L

FORMULAS AND SOLUTION:

Biological reactor solids (lbs) = tank vol.s (MG) × MLSS (mg/L) × 8.34
= (0.045 MG + 0.055 MG + 0.500 MG) × 3,400 mg/L × 8.34
= 17,014 lbs

Solids removed (lbs/day) = WAS rate (MGD) × WAS conc. (mg/L) × 8.34
= 0.020 MGD × 5,000 mg/L × 8.34
= 834 lbs

Sludge age (days) = biological reactors solids (lbs) ÷ solids removed (lbs/day)
= 17,014 lbs ÷ 834 lbs/day
= 20 days

30.1.3 What is the concentration of total phosphorus (TP) (mg/L) in plant effluent if the soluble phosphorus is 0.2 mg/L and effluent total suspended solids (TSS) is 30 mg/L. The phosphorus content of the mixed liquor is 5%.

GIVEN:

Effluent soluble phosphorus = 0.2 mg/L
Effluent TSS = 30 mg/L
MLSS phosphorus = 5%

FORMULA AND SOLUTION:
[NOTE: percent is expressed as a decimal]

TP (mg/L) = soluble phos. (mg/L) + particulate phos. (mg/L)
= soluble phos. (mg/L) + [effluent TSS (mg/L) × phos. (%)]
= 0.2 mg/L + (30 mg/L × 0.05)
= 0.2 mg/L + 1.5 mg/L
= 1.7 mg/L

30.1.4 Given data, determine the total phosphorus (TP) loading (lbs/day) into a treatment plant.

GIVEN:

Influent flow = 0.240 MGD
Influent TP = 6 mg/L
Sludge storage tank decant flow = 10,000 gpd
Sludge storage tank decant TP = 48 mg/L
Belt press filtrate flow = 12,000 gpd
Belt press filtrate TP = 20 mg/L

FORMULAS AND SOLUTION:

Decant TP (lbs/day) = decant flow (MGD) × decant TP conc. (mg/L) × 8.34
= 0.010 MGD × 48 mg/L × 8.34
= 4.0 lbs of TP/day

Filtrate TP (lbs/day) = filtrate flow (MGD) × filtrate TP conc. (mg/L) × 8.34
= 0.012 MGD × 20 mg/L × 8.34
= 2.0 lbs of TP/day

TP from sidestreams (lbs/day) = decant TP (lbs/day) + filtrate TP (lbs/day)
= 4.0 lbs/day + 2.0 lbs/day
= 6.0 lbs/day

Influent TP (lbs/day) = influent flow (MGD) × influent TP conc. (mg/L) × 8.34
= 0.240 MGD × 6 mg/L × 8.34
= 12.0 lbs/day

TP loading (lbs/day) = influent TP (lbs/day) + TP from sidestreams (lbs/day)
= 12 lbs/day + 6 lbs/day
= 18 lbs of TP/day

## Chapter 31 - Theory and Principles - Chemical Removal

### Section 31.1 - Chemicals and Chemical Reactions

31.1.1 Describe the chemical reaction of metal salts with phosphorus (on a mole basis).

A positively charged iron ion (+3) combines with a negatively charged phosphate ion (-3) to form the precipitate, iron phosphate.

$Fe^{+3} + PO4^{-3} <\!\!-\!\!-\!\!> FePO4$ (solid precipitate)

This equation shows that 1 mole of iron (Fe) will react with one mole of phosphorus (P). The mole ratio is therefore 1:1. Mole ratios sound intimidating, but what they are really about is the ratio of the metal atom (either Fe or aluminum (Al)) to the influent P atom. The mole ratio describes how many atoms of Fe or Al are needed to treat 1 atom of influent P.

For a ferric iron (+3), on an atom-to-atom basis, (mole can be thought of as short for molecular weight), 1 mole of Fe will react with 1 mole of P so the mole ratio is 1:1. The weight of one mole of iron is 56 grams and the weight of one mole of phosphorus is 31 grams (see figure 31.1.1.1). The weight ratio of Fe+3 to P therefore is 56 ÷ 31 = 1.8:1.

For ferrous, iron (+2), the mole ratio of Fe to P is 3:2 (see figure 31.1.1.2), assuming iron stays in the +2 form, 3 moles of iron (168 grams) are needed to remove 2 moles (62 grams) of phosphorus. The weight ratio is thus 2.7:1.

For aluminum, the mole ratio of Al+3 to P is 1:1 (see figure 31.1.1.3). One mole of aluminum (26.98 grams) is needed to remove one gram of phosphorus (30.97 grams). The weight ratio is thus 0.87:1.

**Figure 31.1.1.1**

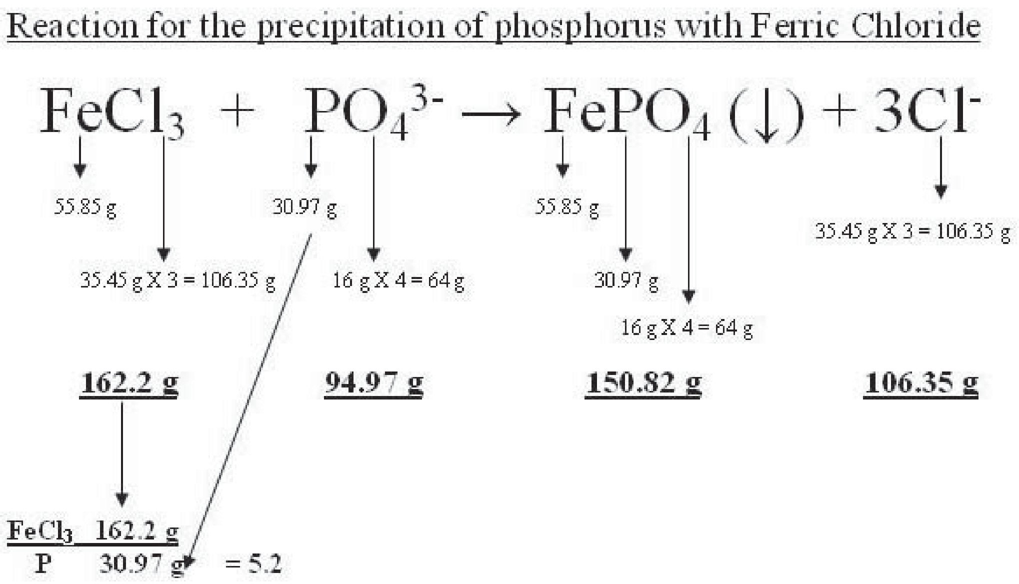


**Figure 31.1.1.2**

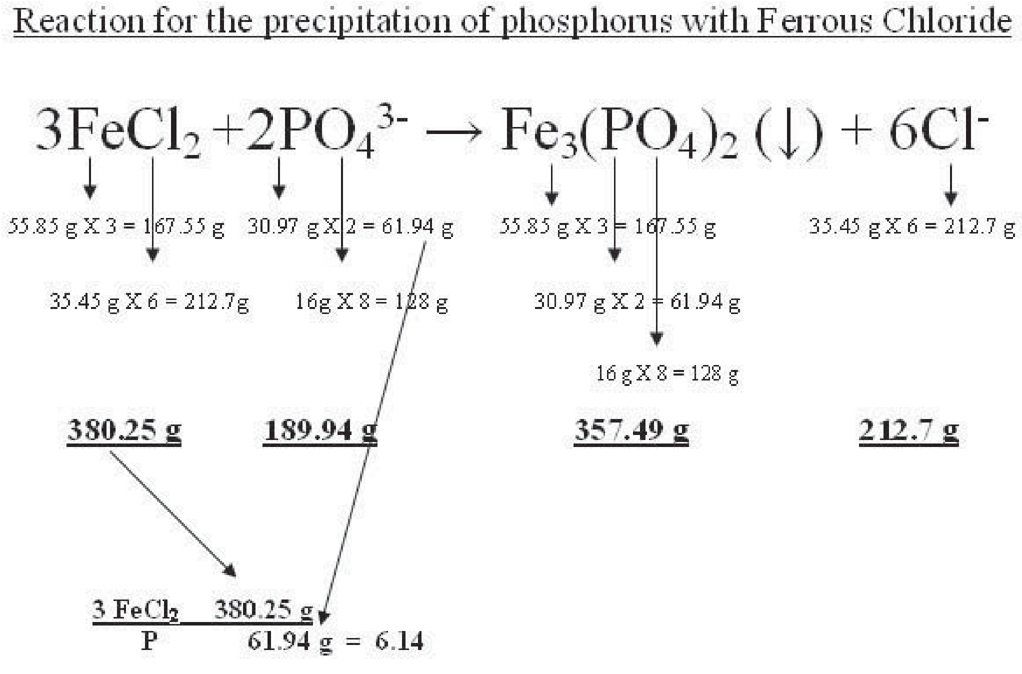
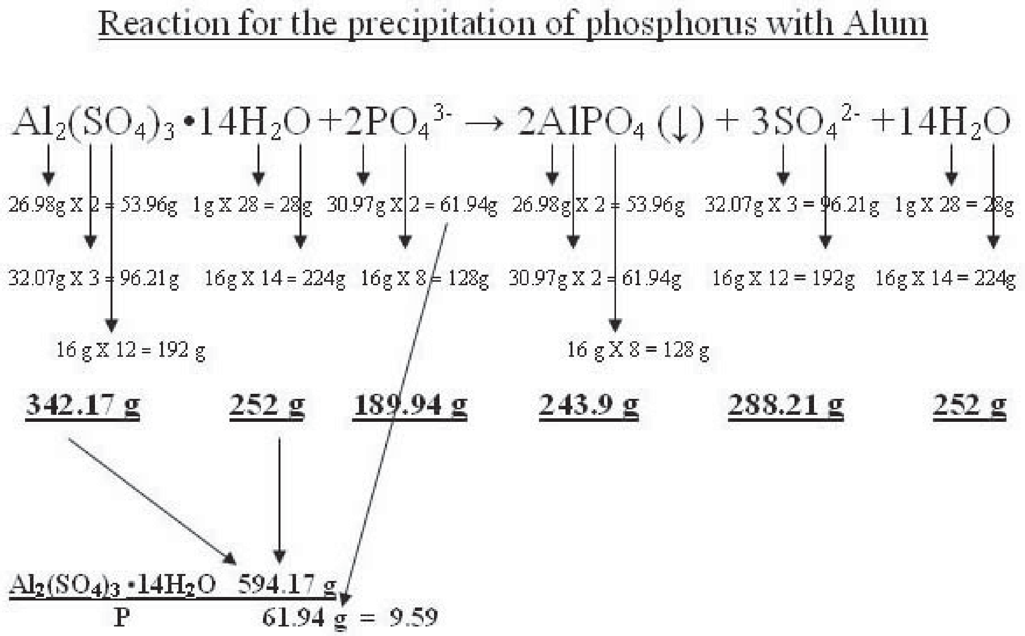


**Figure 31.1.1.3**



31.1.2 Discuss the effect of wastewater pH on phosphorus removal chemical feed requirements.

Each phosphorus removal chemical (metal salt) has an optimum pH range for precipitating out the phosphorus as a metal phosphate. Iron phosphate [FePO4] and aluminum phosphate [AlPO4] are least soluble at a pH of 6.8 to 7.0, thus precipitate out best at this pH range. Wastewater pH levels outside of this optimum range will require more chemical to achieve the same removal efficiency. While not all wastewaters are at a pH of 6.8 to 7.0, metal phosphates still precipitate out well in the pH range of most wastewaters of 6.0 to 8.5.

31.1.3 Discuss the effects of influent wastewater with high sulfides on phosphorus removal using iron salts.

Sulfide will react with iron forming a black precipitate. High sulfide wastewater will require higher dosages of iron salts.

Sources of sulfides include hauled and certain industrial wastes and collection systems with long detention times.

31.1.4 Describe how the metal salt dose changes to meet very low effluent phosphorus limits.

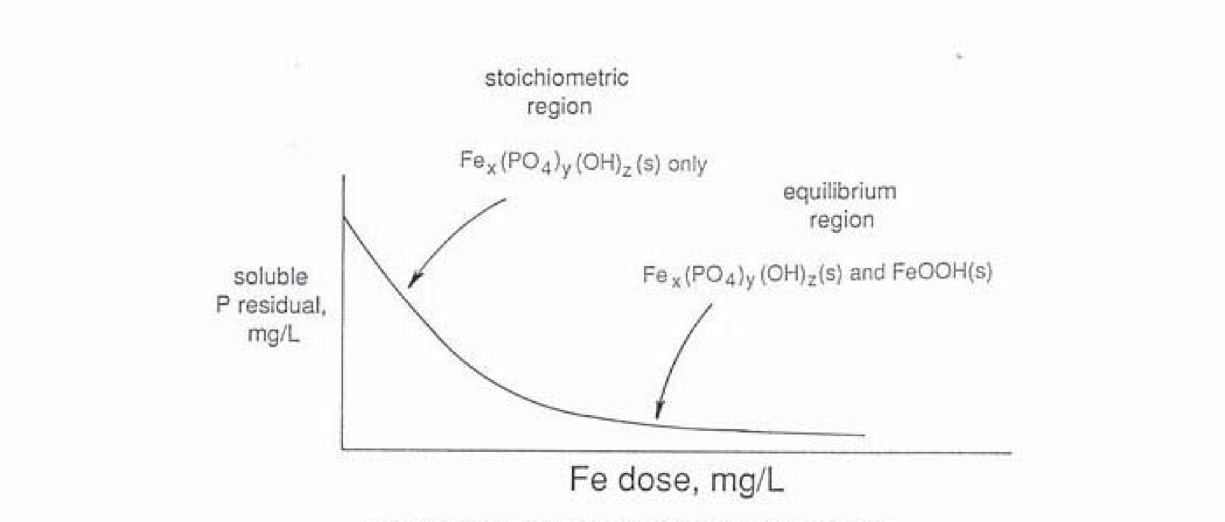
Reaching very low effluent phosphorus concentrations requires increasing amounts of metal salt because of the competition between phosphate and hydroxide precipitation.

Using either aluminum or iron salts, a graph of metal dose versus residual dissolved phosphorus can be drawn that illustrates this relationship (see figure 31.1.4.1).

At a given pH and alkalinity, the dissolved orthophosphate concentration in the wastewater will determine whether metal phosphates or metal hydroxides are formed. As the dissolved phosphorus concentration (effluent phosphorus) decreases, more metal hydroxides will be formed.

To achieve low effluent phosphorus limits, increasingly larger doses of metal salts are required to remove additional phosphorus. Eventually, chemical equilibrium will be reached with no further reduction in phosphorus.

**Figure 31.1.4.1**



**Typical Fe dose versus soluble P residual curve.**

## Chapter 32 - Operation and Maintenance - Chemical Removal

### Section 32.1 - Definitions

32.1.1 Define vivianite.

Vivianite, a hydrated iron phosphate (Fe3(PO4)2•8(H$^2$0)), is a hard crystal that can form in a wastewater treatment plant's piping and valving when iron salts are added in excess for chemical phosphorus removal. Vivianite is associated with anaerobic conditions. Vivianite is the desired product when iron is added to control struvite. When added upstream from head exchanges, it can accumulate causing plugging and interfering with heat transfer.

## Chapter 33 - Monitoring, Process Control, and Troubleshooting - Chemical Removal

### Section 33.1 - Sidestreams

33.1.1 Discuss the possible impact of a sidestream high in suspended solids.

Sidestreams or recycle streams usually come from solids handling, treatment, or dewatering processes, such as decanting digesters or sludge storage tanks. These sidestreams could be problematic if the decant or filtrate is high in suspended solids. The suspended solids could contain large amounts of phosphorus, reintroducing both the solids and phosphorus back into the treatment process. The amount of phosphorus being recycled back through the treatment processes via high suspended solids could be significant. Old sludge solids may also be harder to settle, thus, if carried out in the effluent, could result in elevated suspended solids, biochemical oxygen demand (BOD), and phosphorus. Solids processing should be operated to minimize the amount of suspended solids in the sidestreams.

33.1.2 List common sidestreams or recycle streams within a treatment plant.

The most common sidestreams are from:

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

B. Stabilization and storage
  1. Aerobic digester decant
  2. Anaerobic digestion supernatant
  3. Biosolids storage decant
  4. Effluent sand filter backwash

## Chapter 34 - Calculations - Chemical Removal

### Section 34.1 - Calculations

34.1.1 Using metal salt chemical data, theoretically calculate the amount of chemical salt solution to add (gallons per day or gpd) to remove phosphorus.

GIVEN:
[TP = total phosphorus]
[MGD = million gallons per day]

Influent flow = 2.0 MGD
Influent TP = 8.0 mg/L

Metal salt solution
  Specific gravity = 1.40
  Percent metal in solution = 12.5%
  Metal to phosphorus removal ratio (weight basis) = 1.8:1.0

FORMULAS AND SOLUTION:

A. Determine the amount of influent phosphorus to remove
  TP to remove (lbs) = influent flow (MGD) × TP conc. (mg/L) × 8.34
    = 2.0 MGD × 8.0 mg/L × 8.34
    = 133 lbs of phosphorus

B. Determine the metal salt in a solution (lbs/gal) knowing the specific gravity

Metal salt (lbs/gal) = specific gravity × 8.34
= 1.40 × 8.34
= 11.68 lbs of metal salt/gal

C. Determine the actual metal in a metal salt solution (lbs/gal) with a certain percent metal content

Metal in solution (lbs/gal) = metal salt (lbs/gal) × % metal
= 11.68 lbs × 0.125
= 1.5 lbs of metal/gal

D. Look up removal ratio for the metal salt being used

E. Determine the metal needed (lbs) to remove the incoming phosphorus (lbs)

Metal (lbs/day) to add to remove TP (lbs) = removal ratio × influent TP (lbs)
= 1.8 × 133 lbs TP
= 239 lbs/day of metal to add

F. Determine the metal salt solution to add (gpd) with a certain percent metal content to add.

Metal salt solution to add (gals) = metal to add (lbs) ÷ metal (lbs/gal)
= 239 lbs ÷ 1.5 lbs/gal
= 159 gpd of metal salt solution

34.1.2 Given the costs associated with chemical phosphorus removal, calculate the cost per pound of phosphorus removed.

GIVEN:

Average influent TP = 12 mg/L
Average influent flow = 0.650 MGD
Chemical cost per year = $4,400
Chemical feed O&M cost per year = $600
Sludge handling cost per year = $975

FORMULA AND SOLUTION:

TP removed ($/lb) = (chem. cost + O&M cost + sludge handling cost) ÷ TP removed (lbs/yr)
= ($4,400 + $600 + $975) ÷ (0.650 MGD × 12 mg/L × 8.34 × 365 days/yr)
= $5,975 ÷ 23,744 lbs of TP
= $0.25/lb of TP removed

34.1.3 Given the specific gravity of a metal salt solution and actual % metal content, determine the pounds of actual metal in a gallon of metal salt solution.

GIVEN:

Ferric chloride solution with a specific gravity of 1.40 and 12.5% iron content

FORMULAS AND SOLUTION:

Metal salt/gal. solution (lbs) = specific gravity × 8.34
= 1.40 × 8.34
= 11.7 lbs/gal

lbs metal/gallon metal salt solution = metal salt (lbs/gal) × % metal
= 11.7 lbs/gal × 0.125
= 1.46 lbs/gal

# Part 8 - D: Disinfection

## Chapter 35 - Theory and Principles - Chlorination

### Section 35.1 - Chlorination and Dechlorination Chemistry

35.1.1 Discuss the reactions of gaseous chlorine and hypochlorites when mixed with water.

A. Gaseous chlorine ($Cl2$)
Gaseous chlorine mixed with water forms hypochlorous ($HOCl$) and hypochloric ($HCl$) acids.

They are expressed as:
1. Hypochlorous acid
   $Cl2 + H2O \dashrightarrow HOCl + HCl$
2. Hypochloric acid
   $Cl2 + H2O \dashrightarrow HOCl + H + Cl$

The hypochlorous acid ionizes (depending on pH) to form hydrogen ions ($H+$) and hypochlorite ions ($OCl-$), and would be expressed as:
$HOCl \dashrightarrow H+ + OCl-$

Hypochlorous acid is a weak acid and is not dissociated (ionized) when the pH is less than 6. This is important, as hypochlorous acid ($HOCl$) has 40 to 80 times greater disinfection ability than the hypochlorite ion ($OCl-$). In wastewater with a pH of 7.3 (depending on temperature), about 50% of the chlorine will be in the form of $HOCl$ and 50% in the form of $OCl-$. The higher the pH level the greater the percent of $OCl$ and the more chlorine required to achieve disinfection.

B. Hypochlorites ($OCl-$)
Usually, sodium hypochlorite ($NaOCl$) is used, rather than calcium hypochlorite [$Ca (OCl) 2$], because calcium hypochlorite is more costly, causes calcium sludge, and is more dangerous to handle.

The sodium hypochlorite reaction with water is similar to gaseous chlorine, forming sodium hydroxide ($NaOH$), hypochlorous acid ($HOCl$), hypochlorite ion ($OCl-$), and hydrogen ion ($H+$). This is usually expressed as:
$2NaOCl + 2H2O \dashrightarrow 2NaOH + HOCl + OCl- + H+$

The hydrochloric acid ionizes the same as gaseous chlorine, and is pH dependent.
$HOCl \dashrightarrow H+ + OCl-$

The main difference between chlorine gas and hypochlorite compounds is that gas tends to decrease pH, which favors hypochlorous acid formation. Hypochlorite compounds tend to increase pH with the occurrence of sodium hydroxide which favors hypochlorite ion formation.

### Section 35.2 - Process Understanding and Performance Limiting Factors

35.2.1 Discuss the effect of the following on chlorination.

A. Mixing

Good mixing at the point of application optimizes disinfection.

B. Contact time
The longer the contact time, the better the disinfection will be. The minimum contact times under average and peak flows are 60 minutes and 30 minutes, respectively.

C. Temperature
With higher temperatures of the wastewater, the rate of disinfection will occur more rapidly.

D. pH
The lower the pH of the wastewater, the more effective the disinfection will be. This is because more hypochlorous acid will be present and less of the hypochlorite ion. The hypochlorous acid is a much better disinfectant than the hypochlorite ion.

E. Suspended solids
High suspended solids from poor upstream treatment will reduce the effectiveness of disinfection. Suspended solids will contain higher concentrations of microorganisms and will tend to shield microorganisms from contact with the chlorine in solution. This will cause an increased chlorine demand to achieve disinfection.

F. Organic and inorganic materials
Since chlorine is such a strong oxidizing agent, it will react with various organic and inorganic materials using up chlorine and reducing the effectiveness of disinfection. If these materials are present, they will increase the chlorine demand and require larger amounts of chlorine to achieve the desired disinfection.

## Chapter 36 - Operation and Maintenance - Chlorination

### Section 36.1 - Handling and Storage

36.1.1 Describe the materials used in handling chlorine gas and liquid.

A. Permanent piping
  1. Chlorine gas permanent piping under pressure
    a. Permanent piping for dry pressurized chlorine gas should be constructed from seamless carbon steel, schedule 80; a 1-inch diameter is adequate for most applications.
    b. Pipe with a 3/4-inch diameter can be used for 150-pound cylinders or 1-ton tanks, but smaller sizes are not recommended.
    c. Permanent piping joints should be welded.
    d. All piping needs to be cleaned before being placed in service. Use an approved solvent to remove all grease and oil and a dry air or inert gas purge to remove all residual solvent.
  2. Chlorine gas permanent piping under vacuum
    a. Permanent piping for a dry vacuum chlorine gas should be constructed from PVC (polyvinyl chloride) 80 piping.
    b. Permanent PVC 80 pipe joints should be solvent welded.
    c. All the piping should be cleaned and burrs removed as it is installed. A dry air or

inert gas purge of the process piping should be done before placing the system in service.

  - d. Flexible polyethylene tubing can be used for vacuum transfer of chlorine gas for short distances (less than 50 feet).
- 3. Permanent piping for chlorine solution (chlorine gas and water)
  - a. Permanent piping for chlorine solution should be constructed from PVC 80 or flexible polyethylene tubing.
  - b. Rubber lined steel piping can also be used to transfer chlorine solution, but has limited application as it cannot be easily altered by field application.
  - c. Permanent piping can be solvent welded or be threaded.

B. Temporary connections

- 1. Pressurized chlorine
  - a. Stainless steel and titanium tubing and fittings can be used for temporary connections on a pressurized gas chlorine system.
- 2. Chlorine gas under vacuum
  - a. Polyethylene tubing and fittings can be used for a temporary connection on vacuum systems.

C. Gaskets

- 1. Recommended gasket materials for pressurized and vacuum gas chlorine systems
  - a. Teflon
  - b. Lead
  - c. Compressed asbestos
  - d. Ordinary rubber or plastic should never be used. A new gasket must be used anytime a new connection is made or a connection is changed.

D. Valves

- 1. Valves for pressurized chlorine
  - a. Forged carbon steel with monel seats and stems can be used.
    All materials for valves should be as approved by the Chlorine Institute and will be tagged by the manufacturer for the specific use. All valves should be carefully inspected for proper preparation, especially that they are free of all grease or oil. If in question, new valves should be degreased with an approved solvent and thoroughly dried to remove all solvent by purging with dry air or inert gas.
- 2. Valves for chlorine gas under vacuum
  - a. Valves constructed from PVC 80 with Teflon seats can be used. Without Teflon, the valve will become hard to open or close.
  - b. Forged carbon steel with monel seats, Hastalloy C, or 316 stainless steel ball valves can also be used.

36.1.2 List the maximum withdrawal rates, under vacuum, from 150-pound cylinders and 1-ton tanks for chlorine and sulfur dioxide gas at room temperature (70°F), and what alternatives can be used if higher rates are required.

A. 150-pound cylinder

- 1. Chlorine: 4.0 lbs/hr

    2. Sulfur dioxide:  3.0 lbs/hr

B. 1-ton tank
1. Chlorine:  20.8 lbs/hr
2. Sulfur dioxide:  15.0 lbs/hr

## Chapter 37 - Monitoring, Process Control, and Troubleshooting - Chlorination

### Section 37.1 - Data Understanding and Interpretation

37.1.1 List the materials that can cause an increase in chlorine demand.

A. Inorganic materials
Chlorine reacts with many materials that will cause an increased chlorine demand.  Some of the inorganic materials would be hydrogen sulfide, ammonia, ferrous iron, manganese, and nitrites.

B. Organic materials
Chlorine will also react with any organic materials forming chlororganic compounds.  When a treatment plant partially nitrifies, the chlorine demand exerted by nitrites can consume significant quantities of chlorine.

## Chapter 38 - Safety - Chlorination

### Section 38.1 - Chemical Considerations

38.1.1 State the reasons why sodium bisulfite or sodium metabisulfite might be used instead of sulfur dioxide for dechlorination.

One reason to use sulfites for dechlorination would be a safety consideration, as they do not pose the toxic concerns of sulfur dioxide gas.  Another reason would be sulfite systems are relatively easy to operate, involving only a solution tank and metering pumps.  At small plants, it would be a low cost system with limited operation and maintenance concerns.

38.1.2 Discuss why soapy water is not used for leak detection for chlorine gas or sulfur dioxide gas.

The use of soapy water or any form of water with a gas leak will form an acid (hydrochloric for chlorine and sulfuric for sulfur dioxide) which is very corrosive and will only make the leak worse.  Use only an ammonia swab to provide an ammonia vapor in the vicinity of the suspected leak.   The ammonia vapor with chlorine will form a white smoke.

## Chapter 39 - Calculations - Chlorination

### Section 39.1 - Feed Rates

39.1.1 Given data, calculate the detention time (mins) in a chlorine contact tank.

GIVEN:
[gpd = gallons per day]

Average daily flow = 2.0 MGD

Chlorine contact tank baffled to provide 4 passes
Chlorine contact tank length = 40 ft
Chlorine contact tank width = 40 ft
Chlorine contact tank depth = 8 ft

FORMULAS AND SOLUTION:
[NOTE: Neglecting the thickness of baffle walls, find the detention time (mins) at average daily flow]

Tank vol. ($ft^3$) = length (ft) × width (ft) × depth (ft)
= 40 ft × 40 ft × 8 ft
= 12,800 $ft^3$

Tank vol. (gals) = tank vol. ($ft^3$) × 7.48 gals/$ft^3$
= 12,800 $ft^3$ × 7.48 gals/$ft^3$
= 95,744 gals

Detention time (days) = tank vol. (gal) ÷ flowrate (gpd)
= 95,744 gals ÷ 2,000,000 gpd
= 0.048 days

Detention time (mins) = detention time (days) × 1,440 mins/day
= 0.048 days × 1,440 mins/day
= 69 mins

39.1.2 Given data, calculate the discharge of chlorine into a receiving water and resultant annual environmental fee.

GIVEN:

Plant flow = 0.150 MGD
Average chlorine residual = 0.02 mg/L
Cost of chlorine ($/lb) = 1 ÷ limit (mg/L)
Adjustment factor = 2.451
Limit = 0.038 mg/L

FORMULAS AND SOLUTION:

Chlorine discharged (lb/day) = flow (MGD) × residual chlorine conc. (mg/L) × 8.34
= 0.150 MGD × 0.02 mg/L × 8.34
= 0.025 lbs/day

Annual NR101 cost = chlorine discharged (avg. lbs/day) × 365 days/yr × cost ($/lb) × adj. factor
= 0.025 lbs/day × 365 days/yr × (1 ÷ 0.038) × 2.451
= 0.025 lbs/day × 365 days/yr × $26.32/lb × 2.451
= $588.65

ALTERNATE FORMULA:

Annual NR 101 cost = chlorine (lbs/day) × 365 days/yr × cost ($/lb) × adj. factor
= 0.025 lbs × 365 days/yr × $26.32/lb × 2.451
= $588.65

## Chapter 40 - Theory and Principles - Ultraviolet

### Section 40.1 - Definitions

40.1.1 Define photoreactivation.

Photoreactivation is the ability of microorganisms to repair cellular damage caused by ultraviolet (UV) radiation. When injured microorganisms are exposed to light energy at wavelengths between 310 and 500 nanometers (nm), cell function can be restored. These repair mechanisms allow UV inactivated microorganisms to regain viability following the disinfection process.

### Section 40.2 - Pathogen Knowledge

40.2.1 Discuss the operational effectiveness of ultraviolet (UV) disinfection.

When properly designed and operated, UV disinfection is very effective for inactivation of bacteria and viruses. Effectiveness increases with less complex organisms and with decreasing cell wall thickness. Some viruses are sensitive to UV radiation, much more than chlorine. Higher organisms are less sensitive and cysts are only affected to a limited extent.

40.2.2 Describe the photochemical change that takes place in microorganisms due to UV radiation.

Proteins and nucleic acids are strong absorbers of UV radiation at 254 nm, and thus impair the ability of the microorganisms to reproduce.

### Section 40.3 - Process Understanding and Performance Limiting Factors

40.3.1 State the primary wavelength at which photochemical change occurs.

254 nm is the primary wavelength for photochemical change. Ultraviolet (UV) radiation is generated using mercury vapor lamps emitting about 85% to 90% of their light at 254 nm in low-pressure lamps.

## Chapter 41 - Operation and Maintenance - Ultraviolet

### Section 41.1 - Equipment

41.1.1 Discuss the effect of effluent temperature on lamp output.

Liquid temperatures between 15°C and 25°C will typically result in lamp temperature conditions that are near optimum for low-pressure lamps (85% of maximum output). At temperatures above or below this range, outputs fall significantly. Medium-pressure lamps operate in much wider temperature range and effluent temperature is not a factor.

## Chapter 42 - Monitoring, Process Control, and Troubleshooting - Ultraviolet

### Section 42.1 - Data Understanding and Interpretation

42.1.1 Describe the affect on the quality of ultraviolet (UV) disinfection of the following situations.

A. Suspended solids in the effluent
UV systems provide the best disinfection when suspended solids in the treated wastewater are low (less than 15 mg/L). Higher suspended solids tend to shield the microorganisms from the UV radiation, reducing the effectiveness of the disinfection. If suspended solids are consistently greater than 25 mg/L, they may prevent the UV system from meeting the fecal coliform limits. It is very important that the upstream treatment units be well operated to minimize the amount of suspended solids that reach the UV disinfection system. An effluent filtration system prior to UV radiation will increase the effectiveness of the disinfection.

B. Certain soluble organic and inorganic chemicals
Certain soluble organic and inorganic chemicals can impair the transmission of UV radiation at 254 nm. This is known as UV absorbance and can be determined using a spectrophotometric measurement. All of the exact chemicals causing UV absorbance are not known, but organic and ammonia-nitrogen are two that do reduce UV transmission. A well-nitrified effluent, ammonia and organic nitrogen of less than 2 mg/L, will produce better disinfection using UV radiation.

C. High iron or color in the effluent
The use of iron salts for phosphorus removal can leave some ferric iron in the final effluent and can cause absorption of the radiation in the UV range. An effluent that has a discernible color can also interfere with the transmission of UV radiation.

D. Visible light on UV treated effluent (photoreactivation)
The damage caused to microorganisms by the UV radiation can, to a limited extent, be repaired by exposure to sunlight in the visible range of 310 nm to 490 nm. This photoreactivation occurs within minutes after exposure to the reactivating light. Generally, viruses do not have repair ability, but many higher organisms do photorepair. This occurrence can cause an increase in fecal coliform concentrations.

## Chapter 43 - Safety - Ultraviolet

### Section 43.1 - Equipment

43.1.1 Discuss the risk of exposure to ultraviolet (UV) radiation if the water level in the UV channel gets too low.

UV quartz sleeves and lamps must remain submerged and below the water surface at all times when in use. Should the water level drop below the UV sleeves and lamps, the direct exposure to UV radiation significantly increases and can result in burns and eyesight damage.

# Part 9 - L: Laboratory

## Chapter 44 - Sampling, Preservation, and Sample Handling

### Section 44.1 - General Information

44.1.1 Discuss sample handling concerns and how they can affect laboratory results.

A. Samples not maintained at proper temperature
Sample temperature preservation requirements are to maintain samples below 6°C but not frozen prior to analysis. Cold temperature reduces microbial activity. If samples are not maintained below 6°C prior to analysis, biological activity may change the properties of the sample.

It is important to reduce microbial degradation of the sample in order to obtain a true measure of the sample's biochemical oxygen demand (BOD). If samples are not kept cold, microbial activity result in oxygen depletion and reduction (low bias) of sample BOD. Similarly, if nitrifying organisms are present and a sample contains ammonia, conversion to nitrate will occur if samples are not kept below 6°C. This will also result in low bias for ammonia results.

B. Improper or lack of chemical preservation
If proper chemical preservation is not added, biological or chemical activity may change the characteristics of the sample. Without acid preservation for phosphorus, microorganisms will continue to grow and assimilate phosphorus from the water sample. In addition, acid preservative is critical to prevent phosphorus from adsorbing onto the walls of the sampling container.

C. Composite sampler settings
In order to collect the most representative sample, the sampler should be set to reduce sample volume per sample increment and increase the frequency at which subsamples of the waste stream are collected. Consider two samplers set for time-proportional compositing. Sampler "A" is set to collect a 2,400 mL samples every 12 hours. This gets us 4.8 L of sample, but "misses" the concentration of pollutants during 22 of the 24-hour collection period. Sampler "B" is set to collect 50 mL of sample every 15 minutes. That would result in collection of 200 mL every hour, for a total volume collected of 4.8 L. Obviously, sampler "B" would provide a much more representative sample.

Similarly, a sampler incorrectly set for time-proportional compositing versus flow-proportional compositing can miss critical changes in the waste stream during periods of high flow. Time-proportional sampling does not consider variations in flow unless the sampler is set to minimize the time between samples.

## Chapter 45 - Lab Equipment and Instrumentation

### Section 45.1 - General Information

45.1.1 Describe the instrumentation used for general wastewater chemistry parameters.

A. Colorimeter
In chemistry, the colorimeter is an apparatus that allows the absorbance of a solution at a

single fixed wavelength (color) of visual light to be determined. This is usually done by preparing a sample according to directions and comparing its color against a reference, or series of references. These comparisons are done visually in some cases and instrumentally at a fixed wavelength of light in other instances.

Because measurements are made at a fixed wavelength, three separate colorimeters would be required to measure ammonia, phosphorous, and residual chlorine.

B. Spectrophotometer

A spectrophotometer is simply an advanced colorimeter that can provide measurements at every wavelength in the visible spectrum (usually 320 to 760 nanometers or nm). Each analyte has a characteristic wavelength that must be used as required by the method employed. Spectrophotometers are typically used for determination of phosphorus (total and ortho-phosphate), ammonia, and residual chlorine.

In short, a colorimeter provides an overall measure of the light absorbed at a SINGLE wavelength, while a spectrophotometer measures the light absorbed at varying wavelengths. A single spectrophotometer could be used for all standard wastewater parameters by colorimetry.

Larger laboratories may use an automated-flow injection or segmented-flow system to automatically mix sample and reagents in much smaller quantities, but ultimately the detector is still small scale spectrophotometer.

C. Dissolved oxygen (DO) meter

DO meters are used to determine DO, biochemical oxygen demand (BOD) and carbonaceous BOD (cBOD). DO meters use a probe. Older probes are either galvanic or polarographic. The difference between the two is that galvanic probes use lead-based anodes within the electrode that provide current (much like a battery) due to the potential difference that exists between the lead anode and the cathode. Polarographic probes typically use silver anodes and gold cathodes. The potential difference between the two metals is insufficient so an external current must be applied to charge the sensor before operation. Galvanic probes offer better accuracy at very low oxygen levels.

Current technology probes are electro-optically based (often called luminescent). DO is dependent on temperature and pressure, so the meter must be calibrated properly before each use.

D. pH meter

A pH meter is an ion meter that measures pH or the concentration of hydrogen ions in a solution. It does NOT measure the acidity or alkalinity of a solution. A specific electrode (or probe) is used that is used to covert hydrogen ions to current which is then measured by the meter and displayed as pH value. A pH meter and probe are dedicated for the measurement of pH.

E. Multiple ion meter

Modern ion meters are largely enhanced pH meters that provide connectivity for a pH electrode and multiple ion selective electrodes.

## Chapter 46 - General Lab Practices

### Section 46.1 - Reagent Water

46.1.1 Discuss some of the techniques for evaluating and troubleshooting laboratory reagent water quality.

Conductivity, the ability of a solution to conduct an electrical current, provides a measure of water quality. Pure water is actually a poor conductor. If water has even a tiny amount of ionic impurities, then it can conduct electricity much better, because ions such as salts separate (“ionize”) into free ions in aqueous solution by which an electric current can flow. Therefore, measurable conductivity means ions are present and the presence of ions clearly means that the water is not “pure”. Conductivity is useful as an indication that ion exchange resin is overloaded, that a reverse osmosis membrane has been breached, or simply that the reagent water may not be of sufficient quality for use in testing.

In theory, lab reagent water should be “pure” and thus contain no dissolved solids or ions. Therefore, one would expect the conductivity of lab reagent water to be zero. The American Society of Testing and Materials (ASTM) has defined Type I reagent water as water having a maximum conductivity of 0.056 µS/cm at 25°C. ASTM Type II water has a maximum conductivity of 1.0 µS/cm at 25°C.

The drawbacks to using conductivity alone as a means of verifying water quality are:
A. Conductivity ONLY measures substances that ionize (i.e. form ions). You can dissolve 1,000 parts per billion (ppb) or more of sugar in pure water and still not exceed ASTM Type I water criteria for conductivity.

B. It is virtually impossible to measure conductivity accurately to Type I or Type II levels without a closed system and VERY sensitive conductivity equipment. The nominal levels of carbon dioxide (CO2) in the atmosphere will cause gaseous CO2 to enter pure water causing a chemical ionization reaction which increases conductivity well above even Type II water standards.

Some of the most critical sources of contamination that affect reagent water and the analytical tests which are performed using reagent water are as follows:

A. High conductivity
Elevated conductivity is an indication of an increase in dissolved ions in the water. Some of these can be interfering substances, such as, copper, chromium, or ammonia. The more substances which are dissolved in the theoretically "pure" lab reagent water, the more likely it will be to have interferences in the tests. Elevated levels of trace metals could affect biochemical oxygen demand (BOD) results, while elevated ammonia levels will impact ammonia test results. Some municipal water systems add phosphate to the water source to remove iron and manganese. Without proper treatment (distillation or deionization) phosphate can interfere with total phosphorus determinations, leading to high bias.

B. Heavy metals
Copper and chromium are quite toxic to organisms. High levels of either could significantly affect any biological tests (BOD, fecal coliform) by inhibiting biological growth.

C. Dissolved organics
Many systems employ a carbon filtration step to remove dissolved organics. In the absence of such a system, or if the carbon filter is not functioning, contamination from compounds such as volatile organic compounds (VOC, a product of industrial pollution and runoff) can occur. Additionally trihalomethanes (THMs) may be present in municipal systems that rely on chlorination for disinfection.

While disinfection kills or inactivates most bacteria and many viruses, microbial byproducts and cell fragmentation can release compounds such as endotoxins to the water system. Many of these contaminants can serve as toxins and interfere with BOD test.

## Section 46.2 - Calibration

46.2.1 Discuss instrument calibration requirements.

Though much attention is given to the generation and evaluation of quality control standards in ensuring analytical accuracy, perhaps the most overlooked aspect is calibration. Analysts are provided with a wide array of options, including instrument pre-programmed calibrations, hand-drawn calibration curves, the use of sophisticated scientific calculators, and even computer software. Unfortunately, the advantages and disadvantages of these various techniques are rarely discussed.

The calibration process is designed to generate an algorithm which can be used to determine analyte concentration based on instrument response. Concentration is always plotted along the X-axis (horizontal) and response is plotted on the Y-axis (vertical). The following “rules” should be applied to this process to ensure the generation of accurate data.

A. Use an appropriate number of calibration standards.
Calibrations must be constructed using a minimum of 3 standards and a blank (except for pH).

B. Keep it simple. Use linear fits.
Most instruments used in the laboratory relate response to concentration linearly or transform the primary signal to produce a linear output. Although deviations from linearity are encountered in the analytical range, they are more common at the extremes where detector saturation or insensitivity cause curvature. For example, phosphorus is generally linear only up to about 1 part per million (ppm). The simplest means to generate a calibration curve is linear regression with concentration as the X-axis and response the Y-axis.

C. Know when to include a zero point in the calibration.
A good rule of thumb to follow is: if you can adjust your instrument to read zero in the presence of a blank, then include a zero point in your calibration curve. Including a zero is

generally appropriate for colorimetric procedures which use a spectrophotometer to measure response.

D. Do not force calibrations through zero (the origin).
Doing this manipulates the data mathematically to obtain a Y-intercept equal to zero. As a result, we lose information about the lower limits of the analytical signal. Even when it is justified to include a zero point in the calibration curve, forcing the intercept to read zero is not appropriate. Note, however, that the Standard Methods procedures for phosphorus DO instruct the user to “Plot absorbance versus phosphate concentration to give a straight line passing through the origin”. Consequently, while this practice should be discouraged, it remains an allowable option for phosphorus calibrations.

E. Define the calibration range properly
You would not use a telescope to examine a cell or a microscope to observe lunar craters. Similarly, the calibration range should be appropriate for the samples being analyzed (i.e. don't calibrate from 1 to 5 mg/L when all the samples fall between 0.05 and 0.5 mg/L). For low level work, it is best to choose points at or very near the limit of quality (LOQ). For high level work, defining the upper limit of the calibration range is more important. The most accurate results are obtained when the response of unknowns (i.e., samples) are close to those found in the knowns used to establish the calibration curve.

All curves should be accompanied by the equations or coefficients (slope, Y-intercept, correlation coefficient) that define them and should be generated using, as much as possible, evenly distributed points, the more (at least three), the better. Always use the full calibration curve to quantitate samples. Never use a daily calibration verification standard to quantitate samples.

46.2.2 Discuss the use of pre-programmed calibrations.

A laboratory MUST generate its own standard curve. A manufacturer's claim that its method is approved or acceptable does not mean that the approval extends to pre-programmed calibrations. The Environmental Protection Agency (EPA) only considers the chemistry of the method when granting equivalencies.

A number of commercially available instruments offer ‘pre-programmed’ calibration curves for many of the routine wastewater tests, including chlorine residual and phosphorus. Note that these types of calibrations are never provided for higher order instruments such as those used to perform metals or organics testing. The use of pre-programmed calibrations is unacceptable for compliance testing.

Pre-programmed calibrations establish a fixed relationship between concentration and instrument response. The relationship is formed using new instruments under very controlled conditions by a single analyst. Such an approach does not take into account variables such as instrument maintenance, the lifespan and variability with an aging spectrophotometer bulb, quality and accuracy of reagents and standards, or analyst technique. We all recognize that these variables DO affect the analysis. Therefore, a calibration must be performed using the laboratory’s instrument, reagents, and personnel under the conditions of that laboratory.

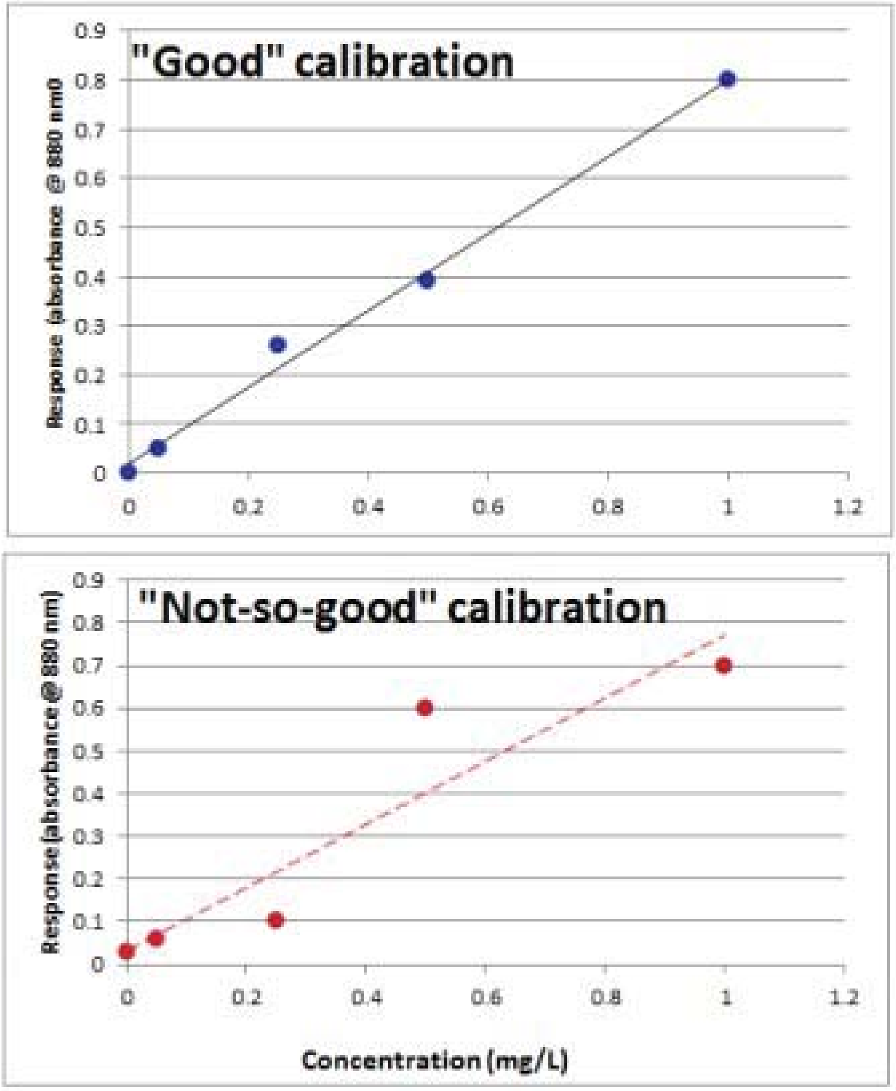
46.2.3 Discuss the method of evaluating calibrations.

Consider the calibration graphs shown in figure 46.2.3.1. Most people would agree that the graph on the right is not a very good calibration. Unfortunately, little advice beyond ‘plot concentration versus response’ is offered by most analytical methods. Consequently, these types of curves are occasionally encountered. Take note that a line ‘of best fit’ drawn through a set of calibration points is just that. Without a means of evaluating the resultant line, data quality can suffer.

One measure of a particular curve’s validity is the correlation coefficient. A correlation coefficient of at least 0.995 generally indicates acceptable characterization of the curve. If this degree of correlation is not obtained, the reason for the lack of linearity should be investigated, any necessary corrective action taken, and a new calibration curve must be constructed. Many inexpensive scientific calculators provide the correlation coefficient of a set of data with a single keystroke.

Another way of evaluating a calibration curve is to utilize the calibration equation (e.g., slope and intercept) to convert the response obtained for the calibration standards into concentration. This ‘predicted’ concentration should agree reasonably well with the known or ‘true’ concentration of the standards. Opinions differ as to what constitutes ‘reasonable’ agreement, however, if the predicted concentration is generally within 5% to 10% of the ‘true’ concentration, the calibration is acceptable.

**Figure 46.2.3.1**



## Chapter 47 - Lab Analyses

### Section 47.1 - Biochemical Oxygen Demand

47.1.1 Discuss the impact of supersaturation in the biochemical oxygen demand (BOD) determination.

Supersaturation means the water contains more dissolved oxygen (DO) than it SHOULD contain according to physics. According to tables, the saturation point of oxygen in water at 20°C and 760 mm Hg pressure, standard temperature and pressure at sea level, is 9.06 mg/L. So, yes, at sea level and 20°C, anything over 9.06 mg/L represents supersaturation.

In Wisconsin, altitudes typically are about 1,000 ft above sea level and standard pressure drops to about 734 mm Hg (pressure drops about 26 mm of Hg for every 1,000 ft of altitude). Therefore, at 20°C and 734 mm Hg pressure, DO saturation falls to 8.76 mg/L. Under these conditions, DO values greater than 8.76 mg/L represent supersaturation. If a lab is warmer than 20°C, the altitude is higher than 1,000 ft above sea level, and there is a low pressure system in effect, saturations can be much lower.

The bottom line is that the method infers that supersaturation is anything above 9.0 mg/L. However, in reality saturation will vary with temperature and pressure. Always determine temperature and barometric pressure and consult a DO saturation table.

The oxygen saturation concentration varies as much as ± 0.3 mg/L with normal fluctuations in barometric pressure. In the BOD5 test, you calibrate the DO meter initially (Day 0) and then again at the conclusion of the test (Day 5). If sample incubation begins under a high pressure system and then come out under a low pressure system, the apparent oxygen depletion of blanks can exceed method requirements (less than 0.2 mg/L).

How? We know that water can hold more oxygen as pressure increases. As an example, on Day 0 when you calibrate your meter, it's a sunny, but bitter cold day under a very high pressure system. The barometric pressure in your lab is 29.53 inches (750 mm Hg) and the lab temperature is a steady 20°C. Water at this temperature and pressure can hold (is saturated at) 8.94 mg/L oxygen. Five days later, when you take samples out of the incubator, a winter blizzard is underway outside and the barometric pressure has dropped to 28.35 inches (720 mm Hg). The pressure has dropped 30 mm Hg over the 5 days. Under the conditions when the test is concluded, the oxygen saturation point of water is 8.58 mg/L.

Assume for a moment that your dilution water is contamination free and thus no change in the DO from the initial reading is expected. Unfortunately, the blanks were saturated initially with 8.94 mg/L DO and now these samples are supersaturated. What happens to the 0.36 mg/L of oxygen by which the blanks are oversaturated? Oxygen does not like to be supersaturated and it doesn't take much for any excess to dissipate from the system. Occasionally you will see that bubbles have formed in the BOD bottle; remove the cap and the oxygen quickly dissipates before the DO in the blank is measured. This can result in a perceived DO depletion of 0.36 mg/L, more than enough to "fail" the method specified criteria for blanks.

47.1.2 Discuss the process to determine the proper sample dilution volumes for the BOD5 (5-day) test.

There are tables and charts that have been developed to assist analysts in making the best dilutions for any given sample. See figure 47.1.2.1 for a chart developed by chemists at the State Laboratory of Hygiene, to help analyst choose proper volumes for BOD analysis. To use these charts, however, the analyst needs to have some idea of the sample BOD. All of these tables work off of a simple concept:

A. Under typical conditions, at saturation in Wisconsin, initial DO should be about 8.5 mg/L.
B. The final DO cannot be less than 1.0 mg/L.
C. Therefore, the working range of DOs for any dilution is about 7.5 mg/L.

To determine optimal dilution, divide the expected BOD of the sample by 7.5. For example, if you have a very clean effluent and BOD is typically 5 to 10 mg/L, then 5 ÷ 7.5 = 0.7 and 10 ÷ 7.5 = 1.3. Therefore, your optimal dilution factor is between 0.7 and 1.3.

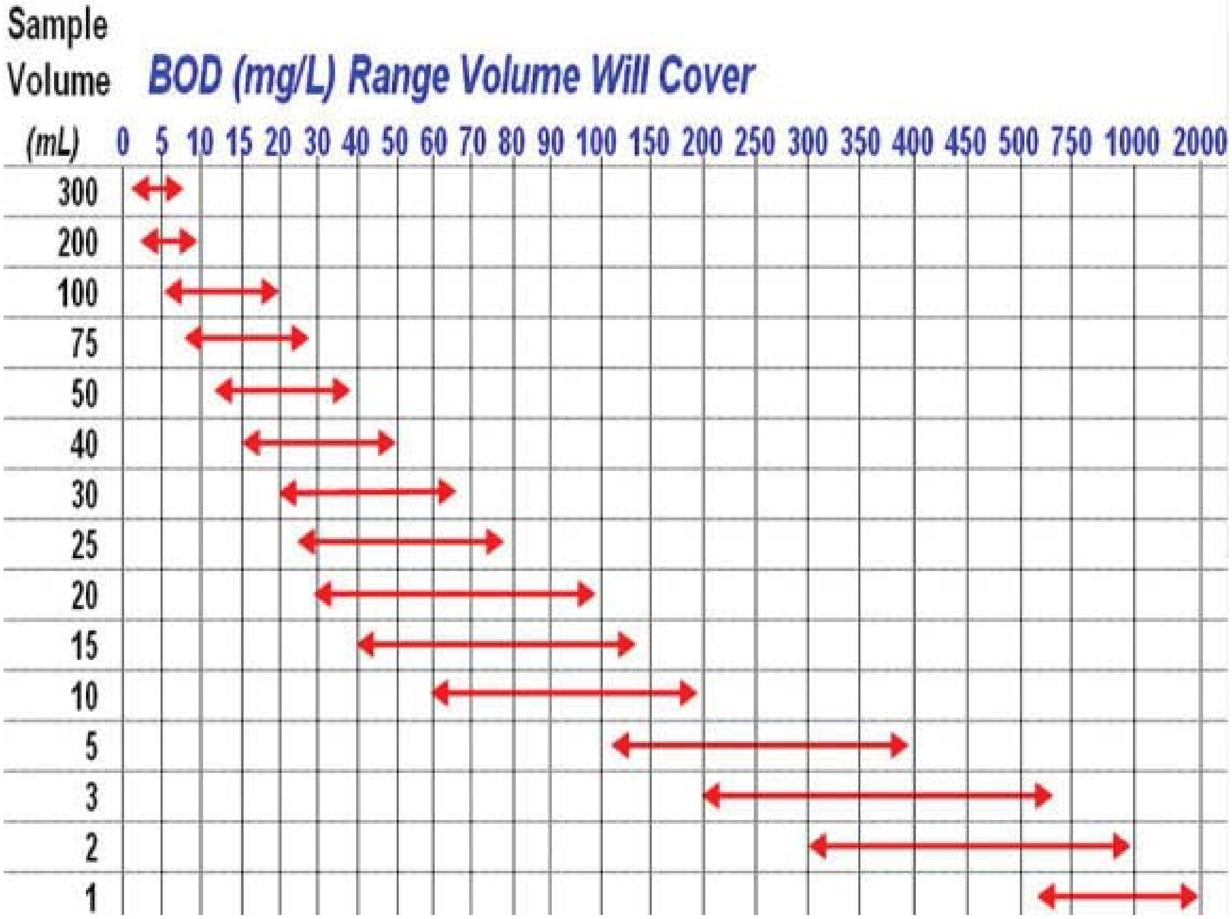
The middle of this range is a dilution factor of 1.0. Now, divide the maximum volume of sample in a BOD bottle (300 mL) by that dilution factor 300 mL ÷ 1.0 = 300 mL. Therefore, the BEST dilution for a sample with an expected BOD of 5 to 10 mg/L is 300 mL.

Typically you would then generate one dilution using slightly more volume and one dilution of slightly less volume to bracket the expected BOD range. Since this sample requires a full bottle, you can't use MORE sample volume. Therefore, a second dilution of about 250 mL is appropriate. Note that 300 ÷ 250 represents a dilution factor of 1.2.

Now consider an influent wastewater sample which typically ranges between 150 and 250 mg/L for BOD. 150 ÷ 7.5 = 20 and 250 ÷ 7.5 = 33 (round it to 30). The best dilutions for this sample would be using dilution factors of 20 to 30. A dilution factor of 20 means a sample volume of 15 mL and a dilution factor of 30 means a sample volume of 10 mL. Therefore, use sample volumes between 10 and 15 mL.

In the absence of prior knowledge, use the following guidelines for dilutions:
A. Strong industrial wastes: less than 3 mL of sample (less than 1% dilution)
B. Raw and settled wastewater: 3 to 15 mL of sample (1% to 5% dilution)
C. Biologically treated effluent: 15 to 75 mL of sample (5% to 25% dilution)
D. Polluted river waters: 75 to 300 mL of sample (25% to 100% dilution)

**Figure 47.1.2.1**



47.1.3 Describe the process of troubleshooting glucose and glutamic acid (GGA) results in the BOD5 test.

The main cause of low GGAs is either not enough seed material (“bugs”) or a very weak seed material. There are several different types/vendors that offer synthetic seeds. On occasion, there have been reports of poor quality lots. Best results have been obtained using mixed liquor, primary wastewater, or raw influent as a seed source.

High bias in GGA typically occurs as a result of contamination, although nitrification and using GGA standard while it is still cold can also cause high bias.

NOTE: Contamination from either “bugs” or BOD material alone will cause high bias in GGA but is not likely to cause an exceedance in blanks. There must be contamination from BOTH “bugs” AND waste material for contamination to result in blank exceedances. This explains a common statement from lab analysts that “my GGA is failing high, but my blanks are fine”.

**Figure 47.1.3.1**

| Problem | Cause | Corrective Action |
|---|---|---|
| **Low bias in GGA** | Not enough seed | Adjust the amount used until you consistently achieve GGA results in the acceptable range |
| | Seed materials too weak or variable | Same as above, a very weak seed will require larger volumes of seed added to samples |
| | Old or contaminated GGA | If GGA is too old, or has been broken down by contamination, low results will be observed. Discard expired or contaminated solutions or try another vender. |

**Figure 47.1.3.2**

| Problem | Cause | Corrective Action |
|---|---|---|
| **High bias in GGA** | Nitrification | Seed source selection is critical; if the plant process includes co-settling (wasted sludge from the final clarifier is pumped back into the primary clarifiers) you could be adding nitrifying organisms to the seed (if you use primary effluent as seed material). To determine if nitrification is occurring, try adding a nitrification inhibitor. Compare GGAs seeded with domestic wastewater versus commercial (Polyseed, BOD seed). If nitrification is occurring, select another source (that does not receive final wastewater) or use a commercially obtained synthetic seed. |
| | Contamination from organic matter | The contamination is likely “dirty glassware”, providing a food source. Your blanks may even meet depletion criteria because -despite availability of a food source (the “crud”) - there is no source of bugs and therefore no oxygen can be used. GGAs will typically fail high due to the extra oxygen consumed by the bugs as they attack both the GGA and the “crud”. Contamination can also result from insufficient rinsing of the DO probe after measuring highly concentrated samples. |
| | Contamination from microorganisms ("bugs") | The contamination source may be from “bugs” in the lab reagent water, possibly from a bad filter in a deionization (DI) system. As long as your glassware is clean, blanks will meet depletion criteria. If there is no “food source” (e.g., "crud" on the glassware) to keep bugs going and expending oxygen, GGAs will generally fail high due to the extra oxygen consumed by the bugs as they attack the GGA. Contamination, when it occurs, tends to be a LARGE effect (i.e. DO depletions of > 0.5 |
| | Cold GGA solution | If you don’t warm the GGA to room temperature (20 ± 3°C) before use, results will be consistently high |

## Section 47.2 - Total Suspended Solids

47.2.1 Explain the importance of total suspended solids (TSS) in wastewater analyses.

TSS are those which are visible and in suspension in the water. They are the solids which can be removed from wastewater by physical or mechanical means such as sedimentation, flocculation, or filtration. TSS will include the larger floating particles and consist of silt, grit, clay, fecal solids, paper, fibers, particles of food, garbage, and similar materials. Suspended solids are approximately 70% organic and 30% inorganic. TSS determinations may be used to assess wastewater strength, process efficiency, and loadings.

High levels of TSS pose an additional demand on chlorine as well as potentially reducing the effectiveness of ultraviolet (UV) disinfection. By reducing the TSS in your effluent discharge, you are going to get better disinfection, which will in turn reduce your fecal coliform and/or E. coli counts, allowing you to maintain compliance.

High TSS can block light from reaching aquatic vegetation. Photosynthesis is inhibited as the amount of light passing through the water is cut down. Without photosynthesis, aquatic plants produce less oxygen, which is a significant source of dissolved oxygen (DO). If light is completely blocked from bottom dwelling plants, the plants will stop producing oxygen and will die. As the plants are decomposed, bacteria will consume what oxygen (DO) is present in the water. Low DO is a major contributor to fish kills.

High concentrations of TSS can also result in an increase in surface water temperature, because the suspended particles absorb heat from sunlight. Higher temperatures consequently result in a reduced ability of the water to hold DO.

In summary:

A. High TSS interferes with disinfection efficiency

B. High TSS raises surface water temp. (particles absorb sunlight)…which also lowers DO

C. High TSS reduces light for aquatic plants
  1. Without light, plants die
  2. Plants provide oxygen, so less plants = less DO
  3. Dying and decomposing plants pose an additional demand on available DO
  4. Low oxygen results in fish kills

## Section 47.3 - Ammonia

47.3.1 Describe factors affecting ammonia toxicity.

Ammonia-nitrogen is a major end product of fish metabolism, it is toxic to aquatic life and toxicity is affected by system pH. Ammonia-nitrogen (NH3-N) has a more toxic form at high pH [un-ionized ammonia or NH3] and a less toxic form at low pH [ionized ammonia or NH4+]. In addition, ammonia toxicity increases as temperature rises. The un-ionized form is considered more toxic since, as a gas, it can diffuse passively across the gill membrane.

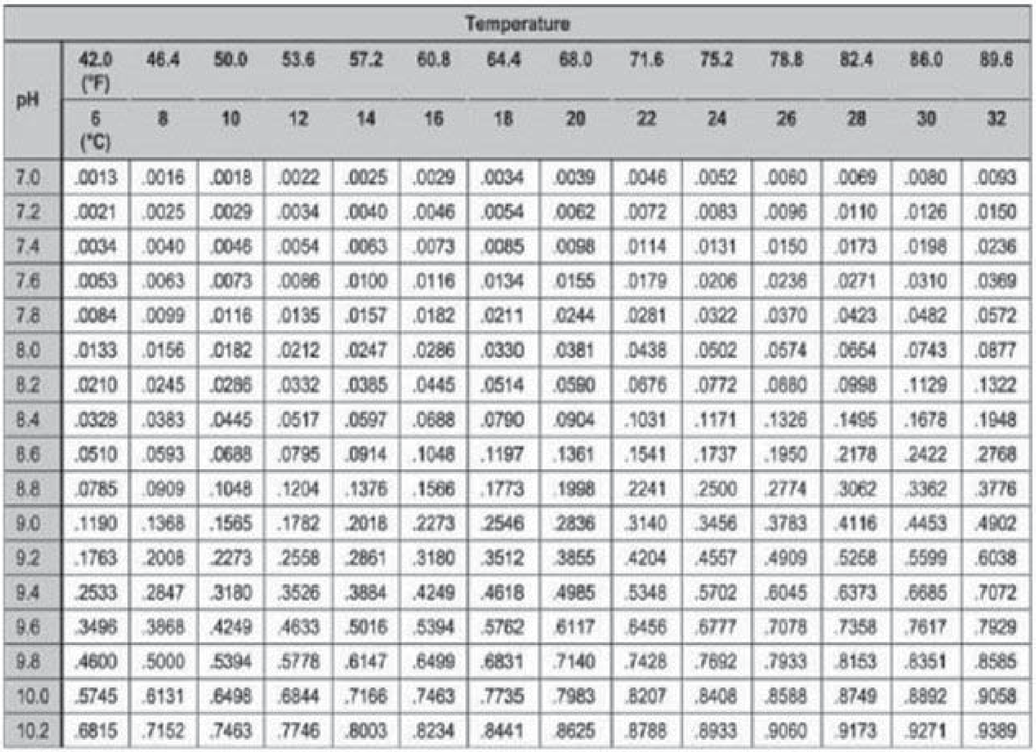
At or below a pH of 8.5, less than 20% of ammonia exists in the highly toxic un-ionized (gaseous) form. Above a pH of 8.5, the percentage of ammonia that exists in the un-ionized form increases rapidly.

The effect of increased temperature is far less significant than increases of pH. Consider a lagoon or pond system containing 10 mg/L ammonia (NH3-N). As can be seen from the table in figure 47.3.1.1, the temperature change during the day from 20°C to 30°C accounts for less than 20% of the increase in toxicity as compared to a rise in pH from 7.0 to 8.0.

Essentially, the higher the pH and temperature, the greater the proportion of total ammonia in the system will be in the form of the highly toxic un-ionized ammonia (NH3). A useful rule of thumb is that at a pH of 8 ammonia is 10 times more toxic than at a pH of 7, and at 20°C it is two (2) times more toxic than at 10°C.

To calculate the amount of un-ionized ammonia present, the total ammonia nitrogen (TAN) must be multiplied by the appropriate factor selected from the table in figure 47.3.1.1 using the pH and temperature from your water sample.

**Figure 47.3.1.1**



| pH | Temperature | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 42.0 (°F) | 46.4 | 50.0 | 53.6 | 57.2 | 60.8 | 64.4 | 68.0 | 71.6 | 75.2 | 78.8 | 82.4 | 86.0 | 89.6 |
| | 6 (°C) | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 |
| 7.0 | .0013 | .0016 | .0018 | .0022 | .0025 | .0029 | .0034 | .0039 | .0046 | .0052 | .0060 | .0069 | .0080 | .0093 |
| 7.2 | .0021 | .0025 | .0029 | .0034 | .0040 | .0046 | .0054 | .0062 | .0072 | .0083 | .0096 | .0110 | .0126 | .0150 |
| 7.4 | .0034 | .0040 | .0046 | .0054 | .0063 | .0073 | .0085 | .0098 | .0114 | .0131 | .0150 | .0173 | .0198 | .0236 |
| 7.6 | .0053 | .0063 | .0073 | .0086 | .0100 | .0116 | .0134 | .0155 | .0179 | .0206 | .0236 | .0271 | .0310 | .0369 |
| 7.8 | .0084 | .0099 | .0116 | .0135 | .0157 | .0182 | .0211 | .0244 | .0281 | .0322 | .0370 | .0423 | .0482 | .0572 |
| 8.0 | .0133 | .0156 | .0182 | .0212 | .0247 | .0286 | .0330 | .0381 | .0438 | .0502 | .0574 | .0654 | .0743 | .0877 |
| 8.2 | .0210 | .0245 | .0286 | .0332 | .0385 | .0445 | .0514 | .0590 | .0676 | .0772 | .0680 | .0998 | .1129 | .1322 |
| 8.4 | .0328 | .0383 | .0445 | .0517 | .0597 | .0688 | .0790 | .0904 | .1031 | .1171 | .1326 | .1495 | .1678 | .1948 |
| 8.6 | .0510 | .0593 | .0688 | .0795 | .0914 | .1048 | .1197 | .1361 | .1541 | .1737 | .1950 | .2178 | .2422 | .2768 |
| 8.8 | .0785 | .0909 | .1048 | .1204 | .1376 | .1566 | .1773 | .1998 | .2241 | .2500 | .2774 | .3062 | .3362 | .3776 |
| 9.0 | .1190 | .1368 | .1565 | .1782 | .2018 | .2273 | .2546 | .2836 | .3140 | .3456 | .3783 | .4116 | .4453 | .4902 |
| 9.2 | .1763 | .2008 | .2273 | .2558 | .2861 | .3180 | .3512 | .3855 | .4204 | .4557 | .4909 | .5258 | .5599 | .6038 |
| 9.4 | .2533 | .2847 | .3180 | .3526 | .3884 | .4249 | .4618 | .4985 | .5348 | .5702 | .6045 | .6373 | .6685 | .7072 |
| 9.6 | .3496 | .3868 | .4249 | .4633 | .5016 | .5394 | .5762 | .6117 | .6456 | .6777 | .7078 | .7358 | .7617 | .7929 |
| 9.8 | .4600 | .5000 | .5394 | .5778 | .6147 | .6499 | .6831 | .7140 | .7428 | .7692 | .7933 | .8153 | .8351 | .8585 |
| 10.0 | .5745 | .6131 | .6498 | .6844 | .7166 | .7463 | .7735 | .7983 | .8207 | .8408 | .8588 | .8749 | .8892 | .9058 |
| 10.2 | .6815 | .7152 | .7463 | .7746 | .8003 | .8234 | .8441 | .8625 | .8788 | .8933 | .9060 | .9173 | .9271 | .9389 |

## Section 47.4 - Process Control

47.4.1 Describe the nitrification process and its impact on wastewater testing.

This process of the breakdown of ammonia nitrogen (NH3-N) and conversion to nitrite (NO2-N) and then further to nitrate (NO3-N) is called nitrification. In the first stage, the bacteria Nitrosomonas sp. converts the ammonia to nitrite. In the second phase, the bacteria Nitrobacter converts the nitrite to nitrate. During wastewater treatment, the breakdown of organic nitrogen to ammonia only adds to the supply of ammonia for the nitrification process.

A. Nitrification presents an oxygen demand leading to high bias for biochemical oxygen demand (BOD)
Unfortunately, nitrification requires oxygen to fuel the process and this creates an oxygen demand that is measured during the BOD test. The demand is known as nitrogenous oxygen demand (NOD). If a wastewater contains ammonia (and some do, particularly lagoons) AND nitrifying bacteria are present, then oxygen will be used during the conversion of ammonia in to nitrate and nitrite. This oxygen used up is measured as BOD, leading to BOD results biased high.

B. For nitrification, every 1 mg/L of ammonia uses up 4.57 mg/L oxygen
Theoretically, 1 mg/L of $NH_3$-N requires 4.57 mg/L $O_2$ to oxidize $NH_3$-N to $NO_3$--N. Why is this important? We have to remember that our dilution water contains ammonia!!! That means that even if the SAMPLE contains no ammonia, but nitrifying organisms ARE present, we can have nitrogenous demand adding to the BOD. $NH_3$-N in dilution water can contribute up to 1.9 mg NOD [× any dilution factor] to a BOD sample. Thus a 200 mL sample dilution yields 1.9 mg/L × (300 ÷ 200) or 2.85 mg/L BOD.

If your facility experiences NOD you should consider analyzing carbonaceous (cBOD) rather than BOD. This decision must be made in consultation with your DNR Basin Engineer. In the absence of nitrogenous demand and nitrifying organisms, BOD and cBOD values should be equivalent. The only difference between samples analyzed for BOD and those analyzed for cBOD is NOT the letter “c”; rather, it is the addition of a chemical inhibitor to all samples for which cBOD is determined.

C. cBOD differs from BOD by the addition of an inhibitor for cBOD
The inhibitor theoretically suppresses only Nitrosomonas sp., the primary microorganism responsible for nitrification. In a sample in which no nitrification is expected to occur, adding the inhibiting agent should not change the results, thus explaining why, in these cases, BOD and cBOD would be expected to be equivalent. In practice, however, a low bias has been reported for cBOD results relative to BOD results, when nitrification would not be expected. This may be due to a toxic affect that the inhibitor agent has on microbial species other than Nitrosomonas.

D. Nitrification causes reduction in alkalinity and possibly pH
As ammonia is converted to nitrite and nitrate, alkalinity decreases and pH of the wastewater may drop. For every 1 lb of ammonia nitrogen oxidized, 7 lbs of alkalinity are used up. During nitrification, the oxygen molecule is stripped from the alkalinity in the wastewater (as calcium carbonate, or $CaCO_3$). As the $CaCO_3$ is destroyed, the buffering action that it provides is also decreased, lowering the pH.

## Chapter 48 - Quality Systems

### Section 48.1 - General Information

48.1.1 Describe quality control (QC) and quality assurance (QA).

Although often used interchangeably, QC and QA are two different, but related, ideas. In today's technical world, QC can be likened to a smart phone, while QA is like a 10" tablet PC. You can do a lot with a smartphone, but the detail is often lacking (you could, but who would want to, watch a movie on a smartphone). On the other hand, a tablet PC (i.e., QA gives us a better perspective on things and has many powerful tools (software "apps") to help us.

QC is bench level, small picture activity. It is analytical work at the bench level. You analyze samples and QC samples and determine whether or not everything meets criteria and if not, how to qualify the data. QC is the practice of establishing standards to be met, for example the frequency and acceptance criteria for blanks, calibration checks, and laboratory control samples (LCS).

QA is a higher level review function. It's the 30,000-foot view of all the analytical work. QA looks at the data for trends and where problems are identified, attempts to determine the root cause for the exceedances and adjust the test accordingly. QA verifies, and adjusts as needed, QC protocols to ensure that they will be adequate for the lab to generate data of a quality required.

A. QC activity examples
   1. Analyzing LCS samples at a specific frequency against control limits.
   2. Filling out a corrective action form for a QC exceedance.
   3. Revising standard operating procedures (SOP) in response to an audit.
   4. Performing an initial demonstration of capability (IDC).

B. QA activity examples
   1. Reviewing QC sample frequency and control limits to ensure they are appropriate for data quality standards.
   2. Ensuring that the root cause analysis is performed in response to corrective actions associated with chronic problems.
   3. Looks into why SOPs do not reflect current practice. Is training required? Supervisor follow-up?
   4. Reviews and adjust IDC protocols to ensure that they reflect the analyst's ability.

In the context of laboratory certification, QC is a variety of techniques that the sampler and analyst perform to verify that the sampling and analytical protocols meet the desired goals for data quality. QC functions help to ensure data validity and traceability. QA is the system for checking and ensuring that QC criteria are met and what actions are taken in the event they are exceeded.

Using a specific example, a QC process is the requirement to establish QC limits for the evaluation of QC samples including lab control standards (LCS). Let's assume Acme Laboratory has established QC limits for phosphorus LCS, and those limits are (-21%) to +300% recovery. Therefore, Acme Laboratory has certainly fulfilled its QC requirement. All they have to do with each batch of samples is analyze an LCS within these criteria. Right?

Wrong…and that's where QA comes in. Most operators would agree that 21% to 300% is not a very good set of QC limits. QA would agree. The role of QA in the laboratory is to ensure that the QC program will guide the laboratory towards generating data which meets its goals for accuracy and precision. In the case of Acme Laboratory, this lab could actually forget to add standard to the LCS, obtain a recovery of 0%, and pass! The role of the QA program then, is to continually review all aspects of the QC program and make adjustments, or initiate corrective action, as needed to achieve the laboratory's data quality goals.

48.1.2 Discuss proper corrective action protocols.

Corrective action is anything done in response to an out-of-control situation. Corrective action must, however, be designed to identify the reason for the failure and then correct it. There also must be a plan to quickly verify that the action taken has the desired effect. What is meant by "out-of-control"? Anything unexpected that could impact data.
Examples include:

1. Failure to meet QC limits for QC sample or proficiency test (PT) sample
2. Calibration standard responses significantly different than typically observed
3. Instruments or equipment such as balances or mechanical pipettes that are not operating within specifications
4. A refrigerator or oven that is not holding its proper temperature

A. Chronic versus acute issues
Is this a sporadic (acute) problem, or has it been going on (without addressing it) for some time now (chronic)? Too often labs simply say "BOD blank failed" without trying to diagnose why it failed. So they do nothing which is not satisfactory. Doing nothing is not corrective action and an auditor will likely cite the lab for "failure to take corrective action to address a chronic QC failure".

B. Determining the root cause
While it may be difficult to assign a root cause for an acute issue that just as suddenly disappears, repetitive out of control situations absolutely require follow-up to ensure that the corrective action taken is appropriate. Only if the appropriate corrective action is taken will the situation be resolved. Get in the habit of being a detective and answering the following questions:

1. What was the problem (or what failed)?
2. What was done to try and fix the problem?
3. Did the fix work?
4. How do you know the fix worked?

Of the detective work, the most critical is to determine whether or not the corrective action solved the problem. If you experience biochemical oxygen demand (BOD) blank failures even after cleaning and replacing all tubing and carboys, it's time to consider what else might be causing the exceedances. If your dissolved oxygen (DO) meter calibration procedure is not correct you could experience frequent but intermittent blank failures. The bottom line is that if your corrective action doesn't solve the problem, some other corrective action must be taken.

C. Corrective action must be documented
Documentation of corrective action is required of all accredited labs. Labs should consider documenting corrective action by analyte. For example they should have separate corrective action logs for BOD, total suspended solids (TSS), total phosphorus (TP), and ammonia-nitrogen (NH3-N) and another log for instruments and support equipment.

If a lab documents corrective action, in one place they can often use the log to look for trends or to determine what corrective was successful in the past. For example, if they have problems with the DO probe membrane failing they may be able to look at the log and see it typically fails every 4 weeks. The corrective action would then be to perform preventative maintenance by replacing the membrane every 3 weeks. If they see their continuing calibration verification (CCV) standard for total phosphorus fails every time they change lot numbers of TNT vials then the corrective action would be to buy a larger quantity of TNT vials with the same lot numbers or simply generate a new calibration curve every time the change lots.

D. Does your data require qualification?
If the root cause behind an exceedance affects data quality, then analytical results must be qualified on the monthly Discharge Monitoring Report (DMR). In some cases, it may not be clear whether analytical results have been affected. When in doubt it is wisest to opt for qualifying the data. Qualified data is not “bad” data; it is merely data that requires some additional explanation. Let the ultimate data user decide what to do with the results.

# Part 10 - Management of Wastewater Treatment Plants

## Chapter 49 - Rules and Regulations

### Section 49.1 - Rules and Regulations

49.1.1 List the wastewater 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 the plant (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 treatment plant
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 (DO) control system?
K. What is the post aeration DO 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 treatment plant?
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 onsite?

# References and Resources

1. **UW WATER LIBRARY**

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

   www.aqua.wisc.edu/waterlibrary

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

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

   www.wef.org

3. **OPERATION OF WASTEWATER TREATMENT PLANTS**

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

   www.owp.csus.edu

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

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

   www.awwa.org

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

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

   www.wwoa.org

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

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

   www.wef.org

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

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

   www.wef.org

### 8. PRINCIPLES OF DESIGN AND OPERATIONS OF WASTEWATER TREATMENT POND SYSTEMS FOR PLANT OPERATORS, ENGINEERS, AND MANAGERS

Office of Research and Development. (2011). Principles of Design and Operations of Wastewater Treatment Pond Systems for Plant Operators, Engineers, and Managers. Cincinnati, OH: Land Remediation and Pollution Control Division, National Management Research Laboratory.

nepis.epa.gov

### 9. STABILIZATION POND OPERATION AND MAINTENANCE MANUAL

Erickson, G., Curtin, K., & Duerre, S. (2013). Stabilization Pond Operation and Maintenance Manual (2013 ed.). St. Paul, MN: Minnesota Pollution Control Agency.

www.pca.state.mn.us

### 10. INTRODUCTION TO LAGOONS

The Lagoon Task Force. (2003). Introduction to Lagoons. Retrieved from Lagoon Systems in Maine: www.lagoonsonline.com

www.lagoonsonline.com

### 11. PREFILL AND WATER BALANCE CRITERIA

Ballavance, P.E., B., Erickson, G., Groh, N., Meyer, P.E., P., Sahli, P.E., D., Sathyaseelan, V., et al. (2010, December). Division of Water Quality Municipal Wastewater Treatment. Retrieved from Minnesota Pollution Control Agency: www.pca.state.mn.us

www.pca.state.mn.us

### 12. GROUNDWATER SAMPLING PROCEDURES

Karklins, S. (1996). Groundwater Sampling Field Manual. (J. Lenon, Ed.) Madison, WI: Wisconsin Department of Administration.

dnr.wi.gov

### 13. NR 140 GROUNDWATER QUALITY

Wisconsin Administrative Code NR 140 Groundwater Quality (2015)

docs.legis.wisconsin.gov

### 14. RECIRCULATING MEDIA FILTER TECHNOLOGY ASSESSMENT AND DESIGN GUIDANCE

Iowa Department of Natural Resources. (2007). Recirculating Media Filter Technology Assessment and Design Guidance. (T. Dr. Loudon, Ed.) Pleasant Hill, IA: MSA Professional Services.

15. **NUTRIENT APPLICATION GUIDELINES FOR FIELD, VEGATABLE, AND FRUIT CROPS IN WISCONSIN (A2809)**

    Laboski, C. A., & Peters, J. B. (2012). Nutrient Application Guidelines for Field, Vegetable, and Fruit Crops in Wisconsin (A2809). Madison, WI: Cooperative Extension Publishing.

    www.soils.wisc.edu

16. **WISCONSIN ADMINISTRATIVE CODE CHAPTER NR 204: DOMESTIC SEWAGE SLUDGE MANAGEMENT**

    Wisconsin Administrative Code Chapter NR 204: Domestic Sewage Sludge Management. (2011).

    docs.legis.wisconsin.gov

17. **WISCONSIN ADMINISTRATIVE CODE CHAPTER NR 214: LAND TREATMENT OF INDUSTRIAL LIQUID WASTE, BY-PRODUCT SOLIDS AND SLUDGES**

    Wisconsin Administrative Code Chapter NR 214: Land Treatment of Industrial Liquid Wastes, By-Product Solids and Sludges. (2015).

    docs.legis.wisconsin.gov

18. **STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER**

    United States Environmental Protection Agency (USEPA). (2012). Standard Methods for the Examination of Water and Wastewater (22nd ed.). Washington, DC: American Water Works Association.

    www.standardmethods.org

19. **WASTEWATER DISINFECTION: MANUAL OF PRACTICE FD-10**

    Water Environment Federation. (1996). Wastewater Disinfection: Manual of Practice Fd-10. Alexandria, VA: Water Environment Federation.

    www.wef.org

20. **WISCONSIN ADMINISTRATIVE CODE CHAPTER NR 110: SEWERAGE SYSTEMS**

    Wisconsin Administrative Code Chapter 110: Sewerage Systems. (2014).

    docs.legis.wisconsin.gov

21. **BIOLOGICAL NUTRIENT REMOVAL (BNR) OPERATION IN WASTEWATER TREATMENT PLANTS**

    Water Environment Federation (WEF). (2005). Biological Nutrient Removal (BNR) Operation in Wastewater Treatment Plants (Vol. Manual of Practice No. 29). New York, NY: McGraw-Hill.

    www.wef.org

**22. PHOSPHORUS AND NITROGEN REMOVAL FROM MUNICIPAL WASTEWATER PRINCIPLES AND PRACTICES**

Sedlak, R. I. (2002). Phosphorus and Nitrogen Removal From Municipal Wastewater Principles and Practices (2nd ed.). Florence, KY: Taylor & Frances Group.

**23. PHOSPHORUS REMOVAL DESIGN MANUAL**

US Environmental Protection Agency (EPA) Technology Transfer. (1987). Phosphorus Removal Design Manual. Cincinnati, OH: Center for Environmental Research Information.

nepis.epa.gov

**24. OPTIMIZING BPR PLANT OPERATIONS FOR ACHIEVING SUSTAINABLE LOW EFFLUENT PHOSPHORUS**

Barnard, J. L., & Steichen, M. T. (2007). Optimizing BPR Plant Operations for Achieving Sustainable Low Effluent Phosphorus. New York, NY: McGraw-Hill.

www.wef.org

**25. PHOSPHORUS REMOVAL IN LAGOON TREATMENT SYSTEMS**

USEPA Special Evaluation Project Report. (1992). Phosphorus Removal in Lagoon Treatment Systems. Chicago: Water Compliance Branch-Technical Support Section.

nepis.epa.gov

**26. NR 217 EFFLUENT STANDARDS AND LIMITATIONS FOR PHOSPHORUS**

Wisconsin Administrative Code NR 217 Effluent Standards and Limitations for Phosphorus (2011)

docs.legis.wisconsin.gov

**27. NR 101 REPORTS AND FEES FOR WASTEWATER DISCHARGES**

Wisconsin Administrative Code NR 101 Reports and Fees for Wastewater Discharges (2011)

docs.legis.wisconsin.gov

**28. SPS 332 PUBLIC EMPLOYEE SAFETY AND HEALTH**

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

http://docs.legis.wisconsin.gov

**29. OSHA CFR 29 PART 1910**

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

www.osha.gov