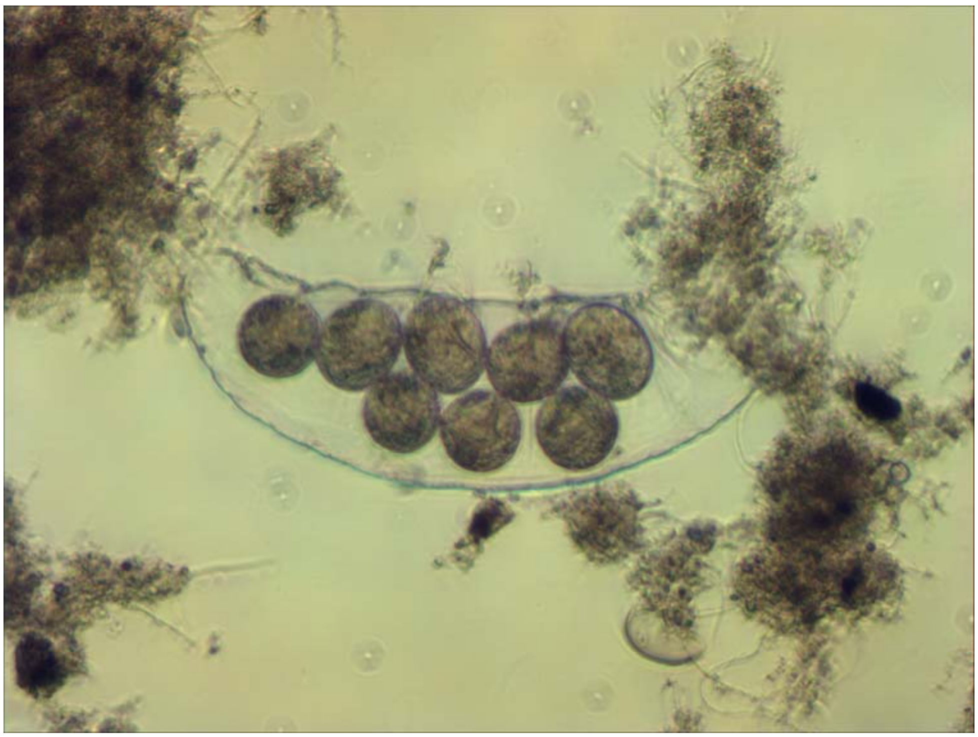
Wastewater Treatment
Grade 1 – 4



TENNESSEE DEPARTMENT OF ENVIRONMENT AND CONSERVATION

Fleming Training Center
February 11 – 15, 2013

http://tn.gov/environment/fleming/

Wastewater Treatment

State of Tennessee

GRADE 1 & 2	GRADE 3 & 4
COURSE #1205	COURSE #2201
FEBRUARY 11 - 15, 2013	FEB 11-15 & FEB 25-MAR 1, 2013

Monday February 11:

8:30	Introduction to Wastewater Treatment	Shannon Pratt
12:00	Lunch	
1:00	Flow Measurement	Shannon
2:30	Preliminary Treatment	Shannon

Tuesday, February 12:

8:30	Basic Math Review (Solving for X ; Area and Volume Calculations and Conversions)	Shannon
10:00	Flow and Velocity Calculations	
12:00	Lunch	
1:00	Sedimentation and Flotation	Shannon

Wednesday, February 13:

8:30	Activated Sludge	Shannon
12:00	Lunch	
1:00	Activated Sludge (cont.)	Shannon

Thursday, February 14:

8:30	Waste Treatment Ponds	Shannon
10:00	Safety	Shannon
12:00	Lunch	
1:00	Wastewater Disinfection	Shannon

Friday, February 15:

8:30	Tour	Shannon
10:00	Review	Shannon
11:00	LUNCH	
12:00	Exam #1	

State of Tennessee

Fleming Training Center
2022 Blanton Dr.
Murfreesboro, TN 37129

Phone: 615-898-6506
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Wastewater Treatment

State of Tennessee

GRADE 3 & 4
COURSE #2201
FEBRUARY 25— MARCH 1, 2013

Monday, February 25:

8:30	Review Exam # 1	Shannon
9:30	Tour	
12:00	LUNCH	
1:00	Maintenance	Shannon
2:30	Cross Connection Control	Dennis Conger

Tuesday, February 26:

8:30	Activated Sludge Math	Shannon
12:00	LUNCH	
1:00	Sampling/Laboratory Analyses	Shannon

Wednesday, February 27:

8:30	Trickling Filters	Shannon
10:45	Rotating Biological Contactors	Shannon
12:00	LUNCH	
1:00	Microscopic Exam	Shannon

Thursday, February 28:

8:30	Sludge Digestion and Solids Handling	Shannon
12:00	LUNCH	
1:00	Effluent Disposal	Shannon

Friday, March 1:

8:30	Math Review	Shannon
11:00	LUNCH	
12:00	Exam # 2 (Comprehensive)	Shannon

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Wastewater Treatment Grade 1-4

Week 1

Suggested Wastewater Treatment Exam References

The following are approved as reference sources for the wastewater treatment examinations. Operators should use the latest edition of these reference sources to prepare for the exam.

Textbooks

California State University, Sacramento (CSUS) Foundation, Office of Water Programs (www.owp.csus.edu)

- Operation of Wastewater Treatment Plants, Volume I and II
- Advanced Waste Treatment
- Manage for Success

National Environmental Training Center for Small Communities (NETCSC)

- Protecting Your Community's Assets: A Guide for Small Wastewater Systems
  A PDF version of this guide is available from: www.nesc.wvu.edu/training.cfm

Water Environment Federation (www.wef.org)

- Operation of Municipal Wastewater Treatment Plants - Manual of Practice No. 11
- Activated Sludge - Manual of Practice OM-9.

Regulations

- National Pollutant Discharge Elimination System (NPDES) Permit, State of Tennessee, Department of Environment and Conservation, Division of Water Pollution Control, Nashville, TN, 1977.

- Design Criteria for Sewage Works, State of Tennessee, Department of Health and Environment, Division of Water Pollution Control, Nashville, 1995.

- Rules Governing Water and Wastewater Operator Certification, State of Tennessee, Department of Environment and Conservation, Board of Certification for Water and Wastewater Operators, Nashville, TN, December 2009, Section 1200-5-3.

- State of Tennessee Water Quality Standards, State of Tennessee, Department of Environment and Conservation, Division of Water Pollution Control, Nashville, TN, December 1991, Section 1200-4-3.

- Protection of Environment, (40 CFR Part 136), U.S. Environmental Protection Agency,

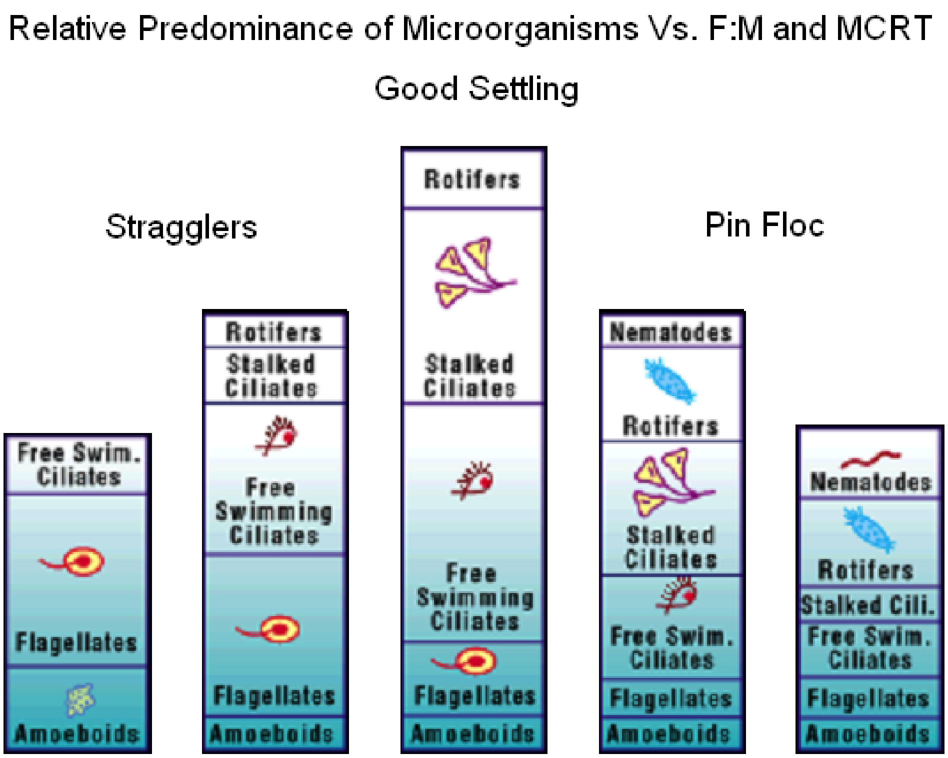
Study Guides

- Applied Math for Wastewater Plant Operators. Price, Joanne. 2000. Boca Raton, FL: CRC Press (www.crcpress.com)

- WEF/ABC Wastewater Operators' Guide to Preparing for the Certification Examination, Water Environment Federation, (www.wef.org)

Section 1

Introduction to Wastewater



Intro to Wastewater Treatment

Why do we treat waste?

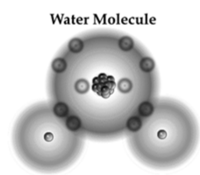
Prevention of Pollution

- Protection of receiving streams is main job
- Today's technology is capable of treating wastewater so that receiving streams are reasonably unaffected

Purpose of Wastewater Treatment

- To protect public health by:
  - Removing solids
  - Stabilizing organic matter
  - Removing pathogenic organisms

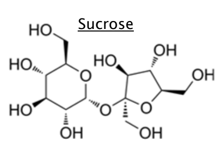
What is Pure Water?



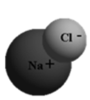
H_2O

- Water is made up of two hydrogen atoms and one oxygen atom
- "Pure" water is manufactured in labs
- Even rain and distilled water contain other substances called impurities

Types of Waste



- Organic waste
  - Contains carbon
- Inorganic waste
  - Salts
  - Metals
  - Gravel
  - Sand



- Both may come from domestic or industrial waste

Organic Waste

- Domestic wastewater contains a large amount of organic waste
- Industries also contribute some amounts of organic wastes
- Some of these organic industrial wastes come from vegetable and fruit packing, dairy processing, meat packing, tanning and processing of poultry, oil, paper and fiber.



Inorganic Waste

- Domestic and industrial wastewater also contain inorganic material.
- Some inorganic wastes that may come to the plant are salts, metals (chromium or copper), gravel, soil, sand and grit
- A strong indicator that a toxic load has entered an activated sludge plant is an increase in oxygen concentration in the aeration basin.
  - You continue to aerate, but the microorganisms have been killed or injured and they do not use the oxygen at the rate before the toxic load.

Sludge and Scum

- If wastewater does not receive adequate treatment, solids may build up in the receiving stream as sludge in the bottom or scum floating to the surface
  - Sludge and scum are unsightly and may contain organic material that consumes oxygen or be an odor problem

Oxygen Depletion

- Most living creatures, including fish, need oxygen to survive
  - Most fish can survive with at least 5 mg/L DO
- When organic wastes are discharged to a receiving stream bacteria begin to feed on it, these bacteria need oxygen for this process
  - As more organic waste is added to the receiving stream, the bacteria reproduce
  - As the bacteria reproduce, they use up more oxygen, faster than it can be replenished by natural diffusion from the atmosphere
  - This can potentially cause a fish kill and odors

Oxygen Depletion

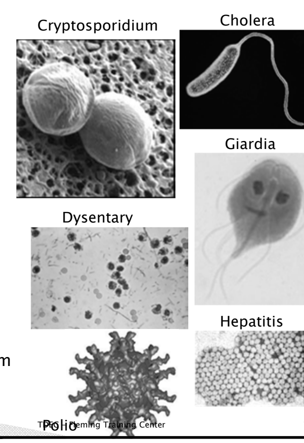
- One of the principal objectives of wastewater treatment is to prevent as much of this "oxygen-demanding" organic material as possible from entering the receiving water.
- The treatment plant actually removes the organic matter the same way a stream would in nature, but it works more efficiently by removing the wastes in secondary treatment
- The treatment plant is designed and operated to use natural organisms such as bacteria to stabilize and remove organic matter

Human Health

- Initial efforts came from preventing disease outbreaks
  - Most bacteria in wastewater are not harmful to humans
  - Humans who have a disease caused by bacteria or viruses can discharge some of these pathogens
  - Many serious outbreaks of communicable diseases have been traced back to contamination of drinking water or food from domestic wastewater
- Good personal hygiene is your best defense against infections and disease

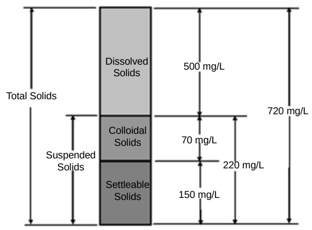
Diseases

- Bacteria
  - Cholera
  - Dysentery
  - Shigella
  - Salmonella
  - Typhoid
- Viruses
  - Polio
  - Hepatitis (Jaundice)
- Protozoa
  - Giardia lamblia
  - Cryptosporidium parvum



Solids

- Total solids
- Dissolved solids
- Suspended solids
  - Settleable
  - Nonsettleable
- Organic and inorganic solids
- Floatable solids



NPDES Permit

- National Pollutant Discharge Elimination System
  - Required by the Federal Water Pollution Act Amendments of 1972 to help keep the nation's water suitable for swimming and for fish and other wildlife
  - Regulates discharges

Water Pollution

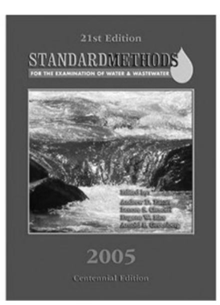
- Any condition caused by human activity that adversely affects the quality of stream, lake, ocean, or groundwater.

Water Pollution Impacts

- Unpolluted water has a wide diversity of aquatic organisms and contains enough dissolved oxygen.
- Polluted water inhibits the growth of aquatic organisms.

Reference Material

- *40 CFR 136*
- *Standard Methods for the Examination of Water and Wastewater.* AWWA, APHA, EPA.



Organic Compounds

- An organic compound is a substance that contains carbon.
  - Cyanide
  - Cyanates
  - Carbon dioxide and its relatives are exceptions to that rule and are considered inorganic
  - Organic waste comes mainly from animal or plant sources
    - They generally can be consumed by bacteria and other small organisms.

Importance of Organic Matter

- Organic material consumes oxygen in water.
  - Bacteria will "feed" on organic matter and most need oxygen to be able to do this.
  - We want these bacteria to "feed" on the organic matter and use it up in the plant and not in our receiving water.
- High concentrations of organic material can cause taste and odor problems in recreational and drinking water.
- Some material may be hazardous.

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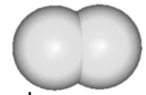
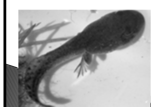
Dissolved Oxygen



- Dissolved oxygen is oxygen that has been incorporated into water.
- Many aquatic animals require it for their survival.



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Dissolved Oxygen

- There are two important factors that can influence the amount of dissolved oxygen present:
  - Water Temperature
  - Organic matter

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Dissolved Oxygen

- Temperature:
  - Greater temperature → Less DO
  - Lower temperature → More DO

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Dissolved Oxygen

- Organic material
  - Organic material requires oxygen to decompose.
  - More organic material requires more DO, and will tend to deplete water of DO.

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Oxygen Demand

- The oxygen demand is the amount of oxygen required to oxidize a material.

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Biochemical Oxygen Demand

- Biochemical oxygen demand, or BOD is the amount of oxygen used during the breakdown of organic material.
- BOD is considered an indirect measure of the organic content of a sample.
- Dissolved oxygen measured by Winkler method (titration) or using a meter and electrode.

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BOD_5

- BOD_5 analysis must be done under these conditions:
  - Must be in the dark at 20°C ± 1°C
  - Initial D.O.<9.0 mg/L (blanks and samples)
  - Min. sample depletion 2 mg/L and final D.O. of 1 mg/L
  - Max depletion of blanks is 0.2 mg/L

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BOD_5 Procedure

- Measure initial D.O.
- Incubate sample for 5 days
- Measure final D.O.
- The BOD_5 is the amount of D.O. used up over the 5-day period.

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BOD

$$BOD_t = \frac{DO_i - DO_f}{\frac{V_s}{V_b}} = \frac{DO_i - DO_f}{P}$$

- BOD_t = BOD at t days ($^{mg}/_{L}$)
- DO_i = Initial DO ($^{mg}/_{L}$)
- DO_f = Final DO ($^{mg}/_{L}$)
- V_s = Volume of sample (mL)
- V_b = Volume of BOD bottle (mL) = 300 mL
- P = Percent sample, decimal

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Ultimate BOD

- The ultimate BOD is the total amount of dissolved oxygen it would take to completely breakdown all the organic material in a sample over an infinite amount of time.
- BOD consumed + BOD remaining = ultimate BOD

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Chemical Oxygen Demand (COD)

- COD is the equivalent amount of oxygen needed to break down organic matter using strong oxidizing agents.
- Sometimes measured to use as quick (2-4 hrs) process control test.
- Usually higher than BOD, but ratio varies.

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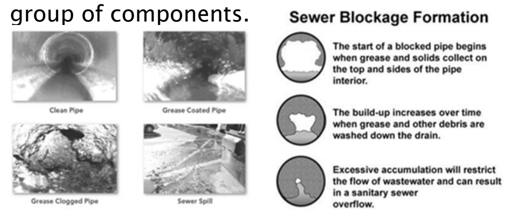
Chemical Oxygen Demand

- Approximation of BOD
- Faster than BOD
- Generally somewhat higher than BOD

Oil and Grease

- Generally listed under one heading called FOG (fats, oils and greases) as it is often not important to know the exact make-up of this group of components.



Solids

- Cause many problems:
  - Fill storage areas, clog ditches and channels.
  - Interfere with mechanical systems.
  - Associated with taste/color/clarity problems in drinking water.

Total Solid (TS)

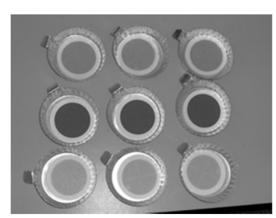
- Total solids of a sample is the matter left behind after drying a sample of water at 103-105°C.

Total Solids

- There are two ways that solid materials may be classified:
  - Suspended solids and dissolved solids
  - Volatile solids and fixed solids

Solids

- Total suspended solids are the part of the sample that may be caught with a 1.5 μm filter.
- Total dissolved solids are the part of the sample that will pass through the filter.



Solids

- Total volatile solids is the portion of the sample lost after the sample has been heated to 550°C. It is an approximation of the organic material present.
- Total fixed solids is the portion that still remains after heating. It is an approximation of the mineral matter present.

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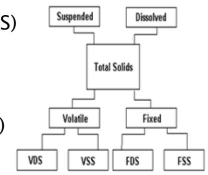
Solids

- These categories may be further groups:
  - Volatile dissolved solids (VDS)
  - Volatile suspended solids (VSS)
  - Fixed dissolved solids (FDS)
  - Fixed suspended solids (FSS)



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Solids

- The mass of solids per known volume of water is:

$$S = \frac{m_t - m_c}{vol}$$

- S = Solids concentration (mg/L)
- Mt = Mass of solids and container (mg)
- Mc = Mass of container (mg)
- Vol = volume of liquid sample (L)

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Nutrients

- Problems associated with excess nutrients:
  - Cause an increase in productivity of aquatic plants, leading to depleted DO levels
  - May cause odor problems
  - Extra vegetation near surface may inhibit light penetration of light into water
- Macronutrients:
  - Nitrogen (many WWTPs test for ammonia)
  - Phosphorus
  - Iron

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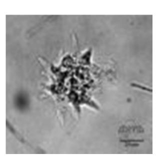
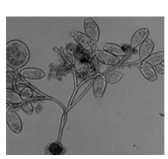
Microbial Organisms

- Serve many important purposes including degrading waste materials
- Some may be dangerous to human health and must be removed from water (pathogens)





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Testing for Microbial Organisms

- Fecal coliforms are used as an indicator organism.
- The sample material is placed in a nutrient bath (mFC broth) and incubated at 44.5±0.2°C for 24 hrs.

Dry air incubator and UV sterilizer for filter funnel.

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Testing for Microbial Organisms

- The number of colonies that form are proportional to how many microbial organisms are present in a sample.
- NPDES permits now require additional testing for *E. coli*.
  - Incubated at 35 ±0.5ºC for 24 hrs

Colilert media® and sample bottle (top) and results after incubation in QuantiTrays® (bottom).

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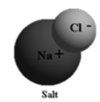
Salts

- Problems associated with excess salt:
  - Salty water not suitable to drink
  - Detrimental to plant growth
  - Can damage crops and the health of livestock.
  - Cation exchange capacity of soil measured in land application systems.



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Metals

- Problems associated with excess metals:
  - Can make water taste and smell bad.
  - Can stain
  - Metals in high enough concentrations are pollutants and can be serious health risks.

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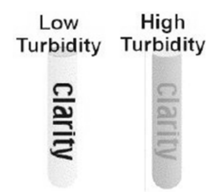
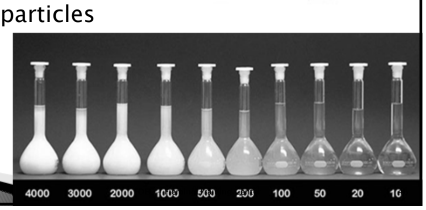
Turbidity

- Turbidity is a measure of the clarity of water or wastewater.
- Turbidity is influenced by the number of insoluble particles present.





pH

- pH is the negative log of the hydrogen ion concentration.
- It can have a major impact on biological and chemical reactions.
- Electrometric method
- Discharge limit 6 to 9.

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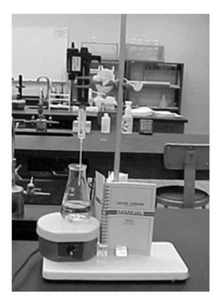
Alkalinity

- Alkalinity is the capacity of water to absorb hydrogen ions without significant pH change.
- Bicarbonates, carbonates, and hydroxides are the three chemical forms that contribute to alkalinity.



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Typical Wastewater Characteristics

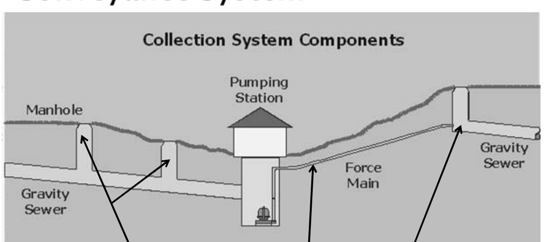
- Fresh wastewater is usually a grey/dishwater color
  - Typically septic wastewater will have a black color
- Fresh domestic wastewater has a musty/earthy odor
  - If the wastewater is allowed to go septic, this will change significantly to a rotten egg odor associated with the production of hydrogen sulfide gas

Typical Influent Concentrations

Parameter	Influent Concentration	Effluent Goal**
BOD_5	200 mg/L	< 30 mg/L
TSS	200 mg/L	< 30 mg/L
TDS	800 mg/L	< 1000 mg/L
Settleable Solids	10 mL/L	< 0.1 ml/L
pH	6 - 9	6 - 9
Fecal Coliform	Too Numerous to Count	< 500 cfu/100 mL
TNK (Ammonia + Organic Nitrogen)	30 mg/L	< 10 mg/L Total Nitrogen
Nitrate-Nitrite	< 1.0 mg/L	
Phosphorous	2.0 mg/L	< 1.0 mg/L
Fats, Oils and Grease	Varies	None visible

** Depends on NPDES permit

Wastewater Collection and Conveyance System



Manholes should be placed every 300-500 feet apart to provide access for inspections and cleaning

Min size is 4"

Constant minimum slope is required to provide a velocity of at least 2 fps to avoid solids depositing

Wastewater Collection and Conveyance System

- Manholes must be installed:
  - At the ends of any line 8" in diameter or larger line
  - Changes in grade, size of pipe or alignment
  - At intersections
  - And not greater than 400 ft. on a 15" diameter and smaller sewers or 500 ft. on 18-30" sewers
- Horizontal Separation – sewers should be laid with at least 10 feet of horizontal clearance from any existing or proposed water line
- Vertical Separation – when sewers must cross a water line, they should be laid 18" below the bottom of the water line

Wastewater Collection and Conveyance System

- Hydrogen sulfide is made in the collection system and can:
  - Make waste more difficult to treat
  - Damage concrete structures
  - Cause odor problems
- Biological activity in long, flat sewer lines will likely cause:
  - Hydrogen sulfide production
  - Oxygen deficiency in sewers, manholes or wetwells
  - Metal and concrete corrosion
- Chlorine can be used in the collection system or at the plant headworks to oxidize hydrogen sulfide

Wastewater Collection Safety

- When excavating sewers 5 feet or more, cave-in protection is required
  - Contouring
  - Drag shields
  - Shoring
  - Sloping

  The most practical and best protection
- If the ditch is 4 feet or deeper, ladders are required every 25 feet in the ditch

Wastewater Collection Safety

- When entering a confined space, such as a manhole, you will need to have and use:
  - An approved man hoist
  - Forced air ventilator
  - Gas detector that checks for
    - Oxygen
    - Hydrogen sulfide
    - Explosive

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Sanitary, Storm and Combined

- Sanitary
  - Waste carried in from homes and commercial businesses in the city plus some industrial waste
- Storm
  - Storm runoff from streets, land and building roofs
  - Normally discharged to a watercourse without treatment
- Combined
  - Combination of sanitary and storm
  - Sanitary portions may become overloaded during storms

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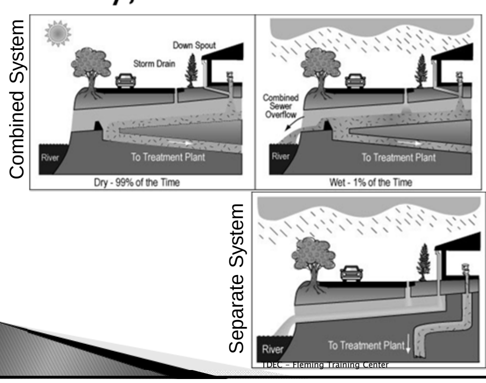
Sanitary, Storm and Combined



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Wastewater Treatment Processes

Preliminary Treatment → **Primary Treatment** → **Secondary Treatment**

- Preliminary Treatment
  - Screening
  - Grit Removal
  - Preaeration
  - Flow Metering and Sampling
- Primary Treatment
  - Sedimentation and Flotation
- Secondary Treatment
  - Biological Treatment
  - Sedimentation

Tertiary Treat. (Advanced) → **Disinfection**; **Solids Treatment**

- Tertiary Treat. (Advanced)
  - Chemical Phosphorous Removal
  - Biological Nutrient Removal
  - Multimedia Filtration
- Disinfection
  - Ultraviolet Irradiation
  - Chlorine Gas
  - Sodium Hypochlorite
  - Calcium Hypochlorite
- Solids Treatment
  - Digestion
  - Dewatering
  - Disposal

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Wastewater Treatment Processes

Preliminary Treatment → **Primary Treatment** → **Secondary Treatment**

- Screening
- Grit Removal
- Preaeration
- Flow Metering and Sampling

Tertiary Treat. (Advanced) → **Disinfection**; **Solids Treatment**

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Aerated grit chamber
- 1 ft/sec flow through grit chamber
- Used to remove grit – heavy, mainly inorganic solids (sand, egg shells, gravel, seeds, etc.)
- Aeration also freshens wastewater and helps remove floatables

Mechanical bar screen with debris
- Failure to keep a bar screen clean can result in a shockload
- Removes roots, rags, cans, etc

Muffin Monster (grinder)

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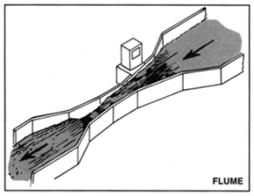
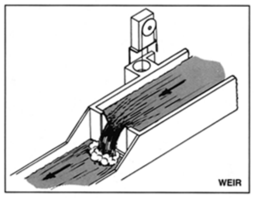
Flow Metering





- According to TN regulations concerning NPDES permits, flow measuring devices must be calibrated and maintained to ensure a ± 10% of true flow
- Flow is determined by the depth of the water

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Wastewater Treatment Processes

Preliminary Treatment → Primary Treatment → Secondary Treatment

- Sedimentation and Flotation

→ Tertiary Treat. (Advanced) → Disinfection

Solids Treatment

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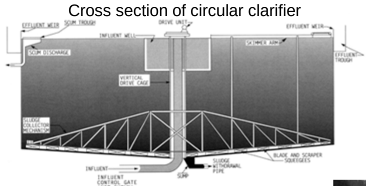
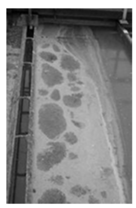
Primary Clarifier

Cross section of circular clarifier



Scum removal



- Velocity drops to < 1 fps
- Separates settleable and floatable solids
- Detention time ~ 1.5-2.0 hrs
- Raw water is gray

Rectangular clarifier

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Wastewater Treatment Processes

Preliminary Treatment → Primary Treatment → Secondary Treatment

- Biological Treatment
- Sedimentation

→ Tertiary Treat. (Advanced) → Disinfection

Solids Treatment

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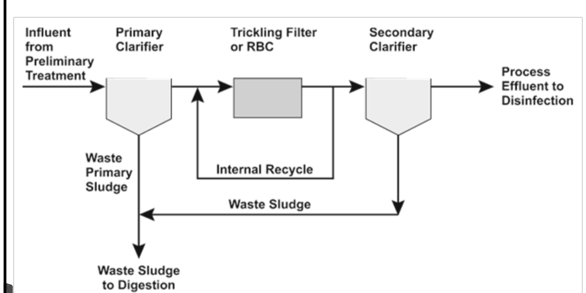
Attached Growth Biological Treatment Processes



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Trickling Filter

Secondary clarifier

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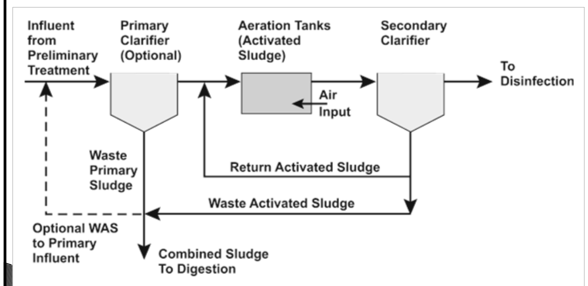
Suspended Growth Process Schematic



Fine Bubble Diffusers

Mechanical Aeration

Oxidation Ditch

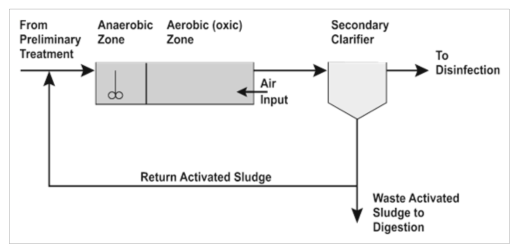
SBR – Sequencing Batch Reactor

Wastewater Treatment Processes

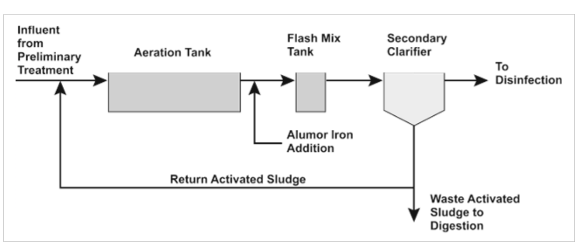
Preliminary Treatment → Primary Treatment → Secondary Treatment → Tertiary Treat. (Advanced) → Disinfection → Solids Treatment

- Chemical Phosphorous Removal
- Biological Nutrient Removal
- Multimedia Filtration

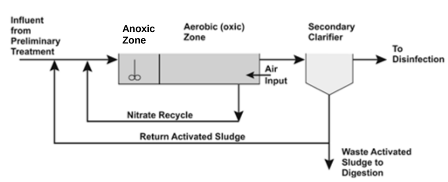
Biological Phosphorus Removal Process Schematic



Chemical Precipitation Process Schematic



Denitrification Process Schematic



Anoxic or anaerobic zone added to aerobic activated sludge to denitrify to achieve low total N.

Sand Filtration

Wastewater Treatment Processes

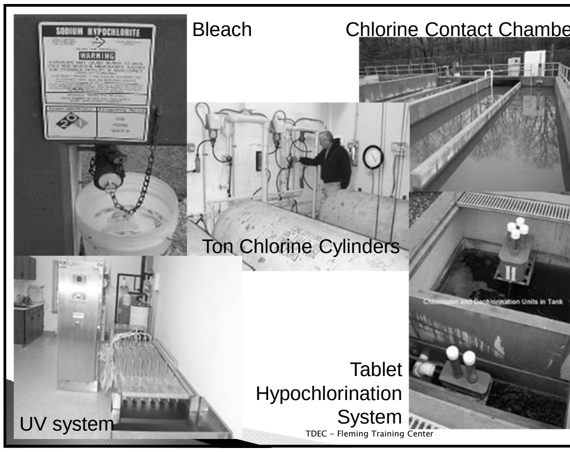
Preliminary Treatment → Primary Treatment → Secondary Treatment → Tertiary Treat. (Advanced) → Disinfection

Disinfection:
- Ultraviolet Irradiation
- Chlorine Gas
- Sodium Hypochlorite
- Calcium Hypochlorite

Solids Treatment

Disinfection

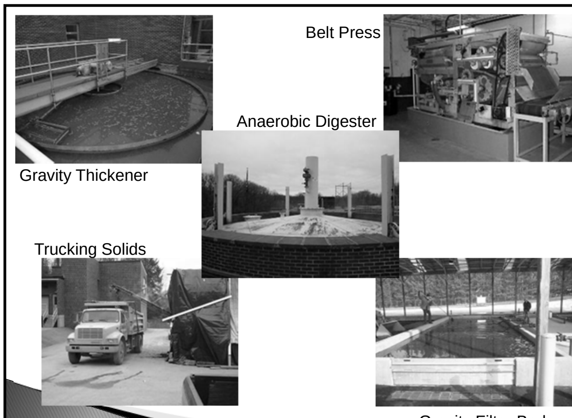
- Purpose is to kill pathogenic organisms still in wastewater.
- Typically wastewater must contain 200 cfu/100mL for Fecal coliforms or 126 cfu/100mL for *E. coli* to be considered "disinfected"



Solids Treatment

Primary Treatment → Solids Treatment ← Secondary Treatment

Solids Treatment
- Digestion
- Dewatering
- Disposal



Effluent Discharge

- Most wastewater is discharged to a receiving stream, river, lake or ocean.
- Some is reclaimed or reused on golf courses, cemeteries, parks, etc.

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Wastewater Treatment Overview Vocabulary

______1. Aerobic Bacteria
______2. Anaerobic Bacteria
______3. Biochemical Oxygen Demand (BOD)
______4. Biochemical Oxygen Demand (BOD) Test
______5. Combined Sewer
______6. Detention Time
______7. Disinfection
______8. Effluent
______9. Grit
______10. Headworks
______11. Infiltration
______12. Inflow
______13. Inorganic Waste
______14. Organic Waste
______15. Pathogenic Organisms
______16. pH
______17. Primary Treatment
______18. Receiving Water
______19. Sanitary Sewer
______20. Secondary Treatment
______21. Septic
______22. Sludge
______23. Stabilize
______24. Storm Sewer
______25. Supernatant
______26. Weir
______27. Wet Well

A. A stream, river, lake, ocean or other surface or groundwaters into which treated or untreated wastewater is discharged.
B. The process designed to kill most microorganisms in wastewater, including essentially all pathogenic (disease-causing) bacteria.
C. The facilities where wastewater enters a wastewater treatment plant. This may consist of bar screen, comminutors, and a wet well and pumps.
D. An expression of the intensity of the basic or acidic condition of a liquid. The range is from 0 to 14 where 0 is most acidic, 14 most basic and 7 neutral. Natural waters usually range between 6.5 and 8.5.
E. To convert to a form that resist change. Bacteria that convert the material to gases and other relatively inert substances stabilize organic material. Stabilized organic material generally will not give off obnoxious odors.
F. The seepage of groundwater into a sewer system, including service connections. Seepage frequently occurs through defective or cracked pipes, pipe joints, connections or manhole walls.
G. Bacteria that will live and reproduce only in an environment containing oxygen that is available for their respiration, namely atmospheric oxygen or oxygen dissolved in water.
H. Water discharged into a sewer system and service connections from sources other than regular connections.
I. A wastewater treatment process used to convert dissolved or suspended materials into a form more readily separated from the water being treated. Usually the process follows primary treatment by sedimentation. The process commonly is a type of biological treatment process followed by secondary clarifiers that allow the solids to settle out from the water being treated.

J. A pipe or conduit (sewer) intended to carry wastewater or waterborne wastes from homes, businesses and industries to the POTW (Publicly Owned Treatment Works).

K. The heavy material present in wastewater, such as sand, coffee grounds, gravel, cinders and eggshells.

L. The rate at which organisms use the oxygen in water or wastewater while stabilizing decomposable organic matter under aerobic conditions. These measurements are used as a measurement of the organic strength of wastes in water.

M. A sewer designed to carry both sanitary wastewaters and storm- or surface-water runoff.

N. The settleable solids separated from liquids during processing.

O. Chemical substances of mineral origin.

P. A separate pipe, conduit or open channel (sewer) that carries runoff from storms, surface drainage and street wash, but does not include domestic and industrial wastes.

Q. Bacteria that live and reproduce in an environment containing no “free” or dissolved oxygen. These bacteria obtain their oxygen supply by breaking down chemical compounds that contain oxygen, such as sulfate (SO_4^{2-}).

R. Liquid removed from settled sludge.

S. Bacteria, viruses or protozoa that can cause disease (typhoid, cholera, dysentery) in a host.

T. (1) A wall or plate placed in an open channel and used to measure the flow. The depth of the flow over the weir can be used to calculate the flow rate, or a chart or conversion table may be used. (2) A wall or obstruction used to control flow (from settling tanks and clarifiers) to assure a uniform flow rate and avoid short-circuiting.

U. A condition produced by anaerobic bacteria. If sever, the wastewater produces hydrogen sulfide, turns black, gives off foul odors, contains little or no dissolved oxygen and creates a high oxygen demand.

V. The time required to fill a tank at a given flow or the theoretical time required for a given flow of wastewater to pass through a tank.

W. Waste material that comes mainly from animal or plant sources. Bacteria and other small organisms generally can consume these.

X. A compartment or tank in which wastewater is collected. The suction pipe of a pump may be connected to the wet well or a submersible pump may be located in the wet well.

Y. A procedure that measures the rate of oxygen use under controlled conditions of time and temperature. Standard test conditions include dark incubation at 20° C for a specified time (usually five days).

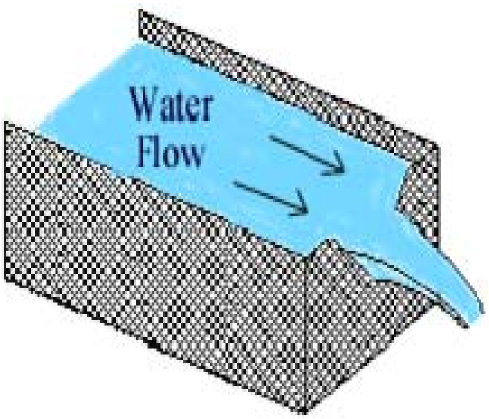
Z. Wastewater or other liquid – raw (untreated), partially or completely treated – flowing from a reservoir, basin, treatment process or treatment plant.

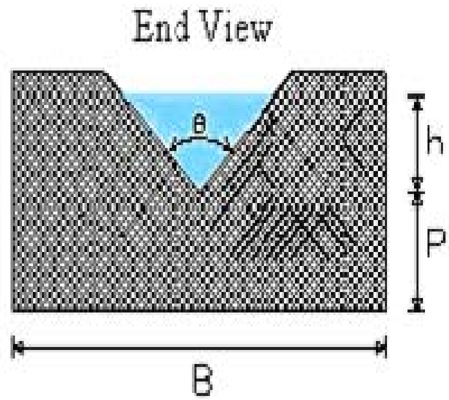
AA. A wastewater treatment process that takes place in a rectangular or circular tank and allows those substances in wastewater that readily settle or float to be separated from the water being treated.

Answers to Vocabulary

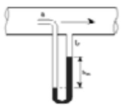
1. G
2. Q
3. L
4. Y
5. M
6. V
7. B
8. Z
9. K
10. C
11. F
12. H
13. O
14. W
15. S
16. D
17. AA
18. A
19. J
20. I
21. U
22. N
23. E
24. P
25. R
26. T
27. X

Section 2
Flow



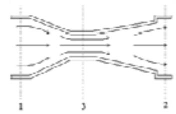


Parshall Flume

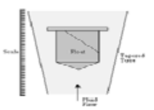


Pitot Tube

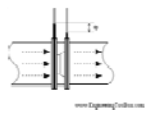
Flow Measurement



Venturi meter



Rotameter



Orifice Plate

Flow Measurement

- Basics of Flow Measurement
- Open Channel Flow Measurement
  - Primary Elements
  - Secondary Elements
- Closed Pipe Flow Measurement
  - Differential Pressure
  - Mechanical Devices
- Flow Equalization

Flow is …

- Amount of water going past a reference point over a certain time
- Units: volume per unit time
  - (ft^3/sec, gal/min, MGD)
- Calculated by the equation: $Q = AV$

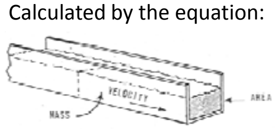


Fig. 15.57 Flow mass

Q = quantity of flow

A = cross-sectional area of flow

V = velocity of flow

Sewer System Evaluations

- Flow monitoring is primary tool for identifying high inflow/infiltration (I/I)
- System problems:
  - Back flooding into private property due to surcharging of sewer mains
  - Bypassing of untreated wastewater to environment
  - Reduced system capacity

Flow Measurement & Wastewater Treatment

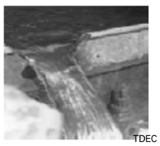
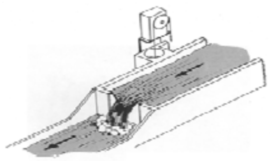
- Unit processes are designed for specific flow levels
- Pumping rates, aeration rates, chemical feed rates, etc. based on current flow
- Accurate flow measurement is key to identify, correct and prevent operational problems
  - All devices of flow measurements will calibrated and maintained to insure that the accuracy of the measurements are ± 10% from the true flow

Open Channel Flow Primary Elements

- Weirs and flumes
- Creates a condition that produces known relationship between flow and depth
- Channel width is known, but velocity is not needed
- Secondary element senses depth at measurement point, converting this to flow

Weir

- Measures liquid flow in partially full channels or basins
- Blocks the flow in the channel
- Depth of water proportional to amount of flow

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Weir

- Used in open channels and is placed across the channel, weirs are made of thin materials and may have either a rectangle or V-notch opening.
- The flow over the weir is determined by the depth of flow going through the opening.
- A disadvantage in using a weir at the influent of the plant is that solids may settle upstream of the weir and cause odors and unsightliness.

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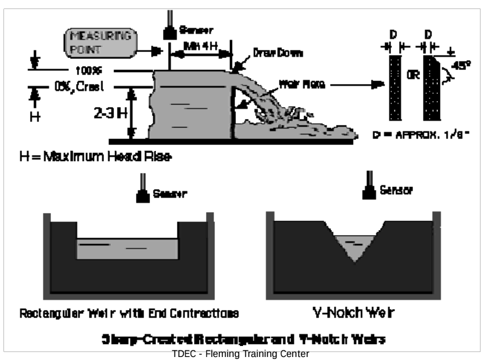
Weir



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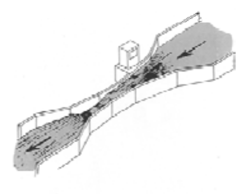
Flume

- Entrance, Throat, Discharge
- Depth is measured behind flume crest
- Best for:
  - Flow with solids or debris
  - Large Flows
  - Variable flows



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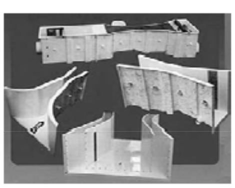
Some Different Flumes…




Influent / Effluent Parshall Flume (9" throat)

Palmer-Bowlus flumes
measure flow in existing sewers

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Parshall Flume

- Parshall flume is one of the most common measuring devices.
- It is a narrow place in a open channel which allows the quantity of wastewater flow to be determined by measuring the depth of flow with ultra sonic device, floats or manually with measuring device.

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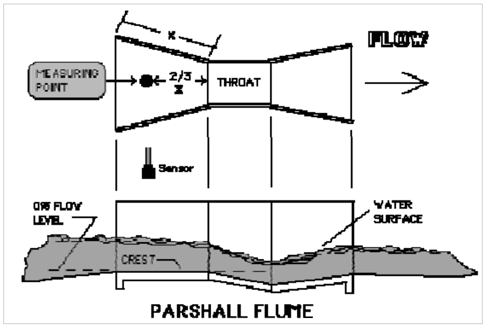
Parshall Flume



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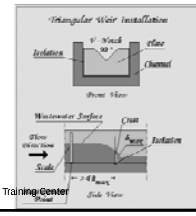
Open Channel Flow Secondary Elements

- Measures or indicates liquid level in primary device
- Used with instruments to convert head to flow
- Selection based on location, type of information required & cost
- Types
  - Staff gauge
  - Floats in stilling well
  - Ultrasonic devices
  - Bubblers



Staff gauge

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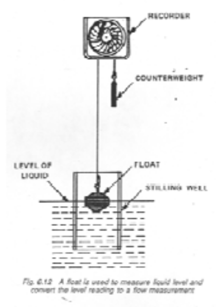
Secondary Elements

- Measure the water level in the Primary Device (weir or flume)
- Example 1 – Float
  - Simple, Inexpensive
  - Grease, solids may interfere



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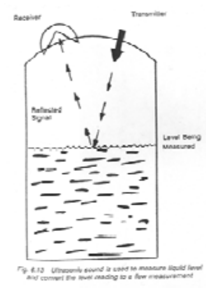
Secondary Elements

- Example 2 – Ultrasonic Meter
  - Sound pulse
  - No direct contact with wastewater
  - Limit – Cannot measure less than 3 inches



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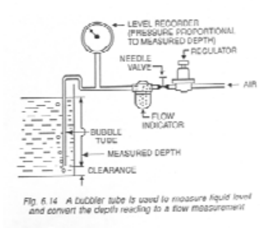
Secondary Elements



- Example 3 – Bubbler Tube
  - Constant flow of air
  - Depth determined by air pressure

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Closed Pipe Flow Measurement

- Differential Producers
  - Venturi meter
  - Orifice plate
- Velocity Meters
  - Propeller-type
  - Pitot tube
  - Magnetic meter
- Constant Differential
  - Rotameter

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Closed Pipe Flow Measurement: Differential Producers

- Venturi system
  - Pipe diameter gradually reduces at the throat and returns to original diameter
  - Low pressure is created in throat
  - Difference in pressure indicates amount of flow
  - Simple and inexpensive
  - Need straight runs of pipe before and after
  - Excellent for gases and liquids (not sludge)

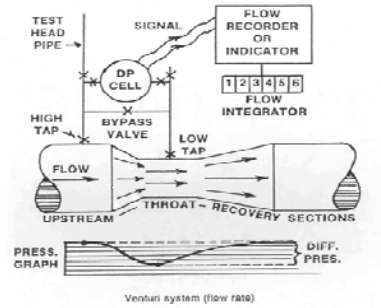
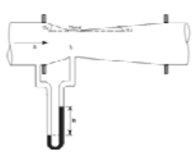
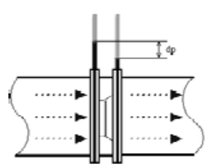


Fig. 6.15 Schematic diagrams of differential pressure flow metering for Venturi systems and orifice plates

Closed Pipe Flow Measurement: Differential Producers



Venturi meter: liquid passes through reduced throat section & velocity increases. Pressure differential then measured using **manometer**.



Orifice plate

www.EngineeringToolBox.com

Closed Pipe Flow Measurement: Velocity Meters

- Magnetic Flowmeter
  - Creates magnetic field in water stream
  - Conductor (water) moving through magnetic field produces electric current
  - Measure of electricity indicates amount of flow
  - Very accurate, Low maintenance
  - Can be expensive (esp. for larger diameters)

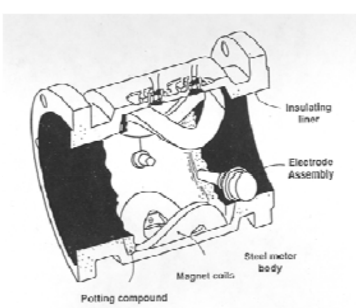
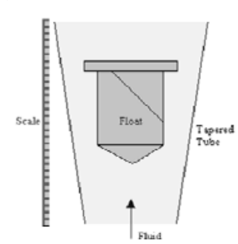


Fig. 6.16 Magnetic flowmeter
(Permission of Fischer and Porter Co.)

Closed Pipe Flow Measurement: Constant Differential

- Example: Chemical Feed Systems
- Rotameter
  - Float or ball in vertical tube
  - Increased flow causes float to ride higher
  - Simple, accurate, easy
  - Must keep tube and float clean



Maintenance of Flow Measuring Devices

- Clean devices regularly
  - Grease build up on floats & magnetic meter coils
  - Weir plate clogged with debris
- Periodically inspect devices for damage & deterioration
  - Pneumatic lines may have air leaks
  - Electrical parts may short out
- Recalibrate secondary devices regularly

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Flow Equalization

- Smoothes out fluctuations in flow volume and pollutant concentrations
- Provides for constant flow with less variations in loading
- Improves performance of downstream processes
- TN Design Criteria says you must maintain a 1.0 mg/L DO throughout the EQ tank

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Flow Equalization

- Types:
  - Surge – prevents flows above max. hydraulic capacity
  - Diurnal – reduces the magnitude of daily flow variations
  - Complete – eliminates flow variations
- Two Schemes
  - In-line equalization
  - Side-line equalization

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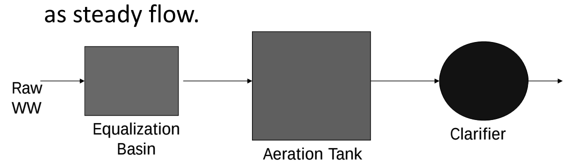
Flow Equalization: In-Line

- All flow enters equalization basin before entering STP.
- Flow is stored as required and later released as steady flow.



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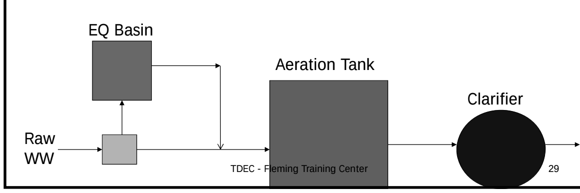
Flow Equalization: Side-Line

- Equalization basin in collection system or at STP.
- Only flow greater than daily average is diverted to basin.
- Can occur after screening and grit removal, eliminating major grit and settleable solids problems.



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Flow Equalization

- Requires mechanical or diffused air mixing, pumps & flow measurement
- Blend entire tank contents
- Benefits:
  - Increased DO
  - Better grease separation
  - Better settling in primary
  - Better settling in final
  - 10% - 20% BOD reduction
  - Improved response to shock loads

Landsdale, PA 2.5 MG equalization basin

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Flow Measurement Vocabulary

______1. Analog
______2. Composite
______3. Conductivity
______4. Density
______5. Digital Readout
______6. Head
______7. Head Loss
______8. Manometer
______9. Orifice
______10. Primary Element
______11. Secondary Element
______12. Sensor
______13. Surcharge
______14. Totalizer
______15. Venturi Meter

A. An opening (hole) in a plate, wall or partition. An orifice flange or plate placed in a pipe consists of a slot or a calibrated circular hole smaller than the pipe diameter. The difference in pressure in the pipe above and at the orifice may be used to determine the flow in the pipe.
B. A measure of the ability of a solution (water) to carry an electric current.
C. The secondary measuring device or Flowmeter used with a primary measuring device (element) to measure the rate of liquid flow. In open channels bubblers and floats are secondary elements. Different pressure measuring devices are the secondary elements in pipes or pressure conduits.
D. The readout of an instrument by a pointer (or other indicating means) against a dial or scale. Also the continuously variable signal type sent to an analog instrument.
E. An indirect measure of loss of energy or pressure. Flowing water will lose some of its energy when it passes through a pipe, bar screen, Comminutor, filter or other obstruction. This is measured as the difference in elevation between the upstream water surface and the downstream water surface and may be expressed in feet or meters. Flow measuring devices like venturi tubes and orifice plates use it.
F. The supply of water to be carried is greater than the capacity of the pipes to carry the flow. The surface of the wastewater in manholes rises above the top of the sewer pipe, and the sewer is under pressure or a head, rather than at atmospheric pressure.
G. The vertical distance (in feet) equal to the pressure (in psi) at a specific point. The pressure head is equal to the pressure in psi times 2.31 ft/psi.
H. A measure of how heavy a substance (solid, liquid or gas) is for its size. It is expressed in terms of weight per unit volume, which is grams per cubic centimeter or pounds per cubic foot. The density of water (at 4° C or 39° F) is 1.0 gram per cubic centimeter or about 62.4 pounds per cubic foot.
I. A device or meter that continuously measures and calculates a process rate variable in cumulative fashion.
J. An instrument for measuring pressure. Usually it is a glass tube filled with a liquid that is used to measure the difference in pressure across a flow-measuring device such as an orifice or a Venturi meter.
K. A collection of individual samples obtained at regular intervals, usually every one or two hours during a 24-hour time span. Each individual sample is combined with the

others in proportion to the rate of flow when the sample was collected. The resulting mixture forms a representative sample and is analyzed to determine the average conditions during the sampling period.

L. A flow-measuring device placed in a pipe. The device consists of a tube whose diameter gradually decreases to a throat and then gradually expands to the diameter of the pipe. The flow is determined on the basis of the difference in pressure (caused by different velocity heads) between the entrance and throat of the device.

M. The use of numbers to indicate the value or measurement of a variable. The readout of an instrument by a direct, numerical reading of the measured value.

N. A device that measures a physical condition or variable of interest. Floats and thermocouples are examples of these.

O. The hydraulic structure used to measure flows. In open channels weirs and flumes are primary elements or devices. Venturi meters and orifice plates are the primary elements in pipes or pressure conduits.

Flow Measurement Questions

1. When do open channel flow conditions occur?

2. What are the commonly used methods of measuring plant flows?

3. Where are flumes used instead of weirs to measure flows?

4. What are the two basic types of flow systems?

5. What are the three different sections of a flume?

6. What are the advantages of an electromagnetic/magnetic flow meter?

7. Why measure flows before and after an equalization basin?

Answers to Vocabulary and Questions

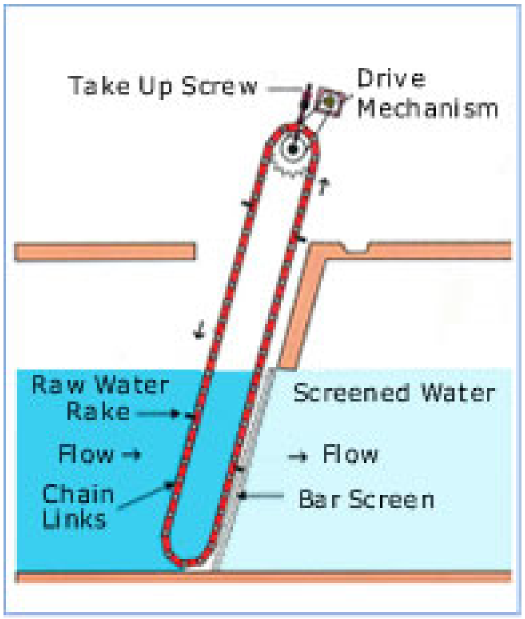
Vocabulary:

1. D	6. G	11. C
2. K	7. E	12. N
3. B	8. J	13. F
4. H	9. A	14. I
5. M	10. O	15. L

Questions:

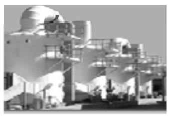
1. When the flow upstream has a free or unconfined surface that is open to the air.
2. Velocity area and use of a hydraulic structure.
3. Where head loss is a concern, larger flows or flows with debris.
4. open channel flow and closed channel (or closed pipe)
5. ① the entrance section (converging section), ② throat section and ③ discharge (diverging) section
6. an obstruction less design, high accuracy and an output signal that is directly proportional to the flow rate
7. in order to control the basin's operation and optimize its effectiveness

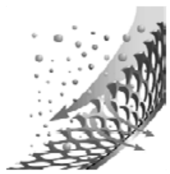
Section 3
Pretreatment



Preliminary Treatment

and
Odor Control





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Purpose

- Removal untreatable solids (rags, rocks, grit, sand, etc.)
- Protect downstream treatment units
  - Metal and rocks plug pipes and may damage pumps or jam sludge collector mechanisms in clarifiers
- Improve performance other treatment units
  - Preaeration enhances sludge settling and removal of floatable materials in a primary clarifier

2
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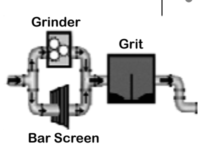
Preliminary Treatment

- At headworks of the facility
- Screens sometimes included in pump stations in collection system
- Some facilities may have screens & comminutors (grinders)
- Reduced treatment efficiency in primary clarifier if trash still in WW
- Potential discharge to receiving stream



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Bar Screen and Racks

- Most screens in treatment plants consist of parallel bars placed at an angle in a channel in such a manner that the wastewater flows through the bars that catch large solids and debris
- Trash is collected on the bars and is periodically raked off by hand or mechanically

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Bar Rack

- Bars that have 3-4 inch spacing.
- Racks are typically found in bypass channels
- Due to their infrequent use, they are manually cleaned

5
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Manually Cleaned Bar Screen

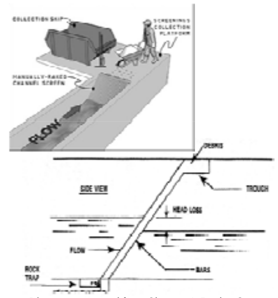

Diagram excerpted from Chapter 4: Racks, Screens, Comminutors and Grit Removal. In *Operators of Wastewater Treatment Plants Volume I.*

- $^{3}/_{8}$ - 2 inch spaces
- Require frequent cleaning with rake by operator
- Head loss as debris collects
- Rush of septic WW is shock load into plant

6
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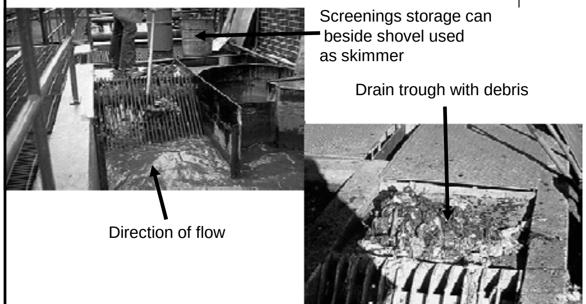
Manually Cleaned Bar Screen



7

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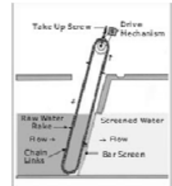
Mechanically Cleaned Bar Screen

- Automatically controls cleaning (3 inch headloss)
- Traveling rakes bring debris up channel & into hopper
- Frequent washdown by operator prevents slime buildup with odors/flies
- Advantages of mechanically cleaned vs manually cleaned: usually don't have a back up of the influent flow



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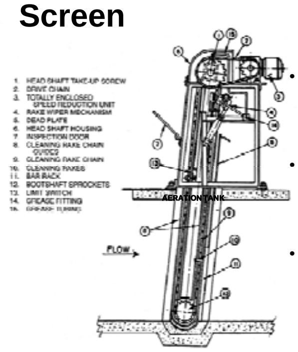
Mechanically Cleaned Bar Screen



- Bent or broken bars can damage rakes & must be replaced
- Limit switch (13) controls travel distance of chain
- Keep rakes well lubricated/greased

9

Diagram excerpted from Chapter 4: Racks, Screens, Comminutors and Grit Removal. In *Operators of Wastewater Treatment Plants Volume I.*

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Screenings Disposal

- Disposed of in landfill or incineration then landfill
- Conventional bar screen capture rate:
  - 6 cu. ft. /MG

10

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Paint Filter Test

- Must pass paint filter test for landfill disposal.
  - Pour in 100 mL of sample
  - Wait five minutes
  - After five minutes if any liquid collects in cylinder see 40 CFR 264.314 and 265-314
- Measures leaching effect of material

11

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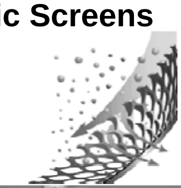
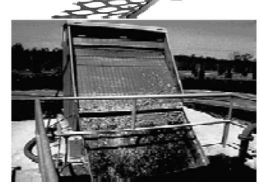
Fine Screens: Static Screens

- Stainless steel screen cabinet
- No moving parts
- Woven wedge wire effectively dewaters solids
- Wedge wire has 0.010 to 0.100 inch opening





12

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Fine Screens: Rotating Drum

- Wastewater fed inside drum
- Screenings captured inside (0.060-0.250 inch openings)
- Water passes through & discharged by gravity
- Internal & external spray systems- automatic wash cycles
- Advantage: don't dam the flow

3

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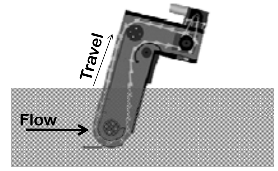
Fine Screens: Continuous Conveyor

- Stainless steel plates with 0.125-0.250 inch openings
- No underwater drive components
- Daily observe operation
- Weekly: inspect & lube bearings
- Monthly: check gear oil & surface for damage



14

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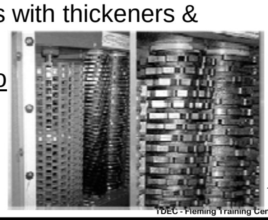
Comminutors

- Screens and shred solids
- Rotating drum with slots & cutting blades
- Solids remain in wastewater
- May cause problems with thickeners & clarifiers in plant
- Muffin Monster video



15

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Comminutor with Bypass Screen

- Wood, rocks, & metal rejected & collect in trap
- Flow bypassed to other channel with rack or screen
- Maintenance: trap cleaned manually as needed; remove ropes of rags; check rubber seal under drum

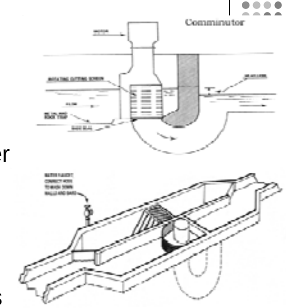

Diagram excerpted from Chapter 4: Racks, Screens, Comminutors and Grit Removal. In *Operators of Wastewater Treatment Plants Volume I.* 16

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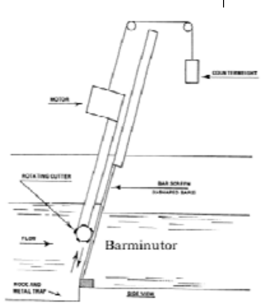
Barminutor

- This unit consists of a bar screen made of U-shaped bars and a rotating drum with teeth and "shear bars."
- The rotating drum travels up and down the bar screen



17

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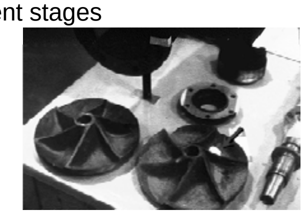
Grit Removal

- Grit refers to heavy inorganic and organic matter that will not decompose in later biological treatment stages
- Mainly inorganic:
  - Sand
  - Gravel
  - Rocks
  - Seeds
  - Egg shells, etc.



18

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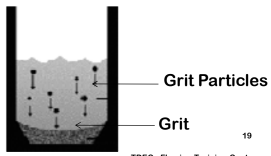
Grit Removal: Gravity

- Water velocity slowed to 0.7-1.4 ft/sec
- Use proportional weirs to slow down WW
- Often covered to control odors & flies
- Maintenance: keep walls clean & inspect periodically for corrosion & cracks

19

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Aerated Grit Chamber

- Diffused air rolls WW at 1 ft/sec
- Particles travel in spiral direction
- Grit removed from hopper by conveyor or is pumped
- Aeration
  - Adds DO
  - Freshens raw WW
  - Improves sludge settleability
  - Removal floatables

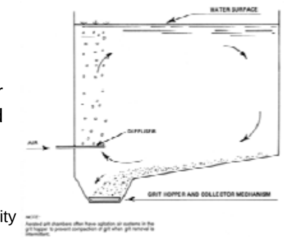

Diagram excerpted from Chapter 4: Racks, Screens, Comminutors and Grit Removal. In *Operators of Wastewater Treatment Plants Volume I.*

20

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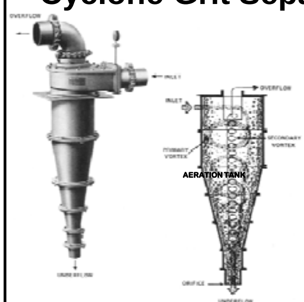
Cyclone Grit Separator



- Flow enters at top
- Effluent exits the center of the top from "eye" of fluid
- Grit settles by gravity
- Detention time: 20-30 sec

Diagram excerpted from Chapter 4: Racks, Screens, Comminutors and Grit Removal. In *Operators of Wastewater Treatment Plants Volume I.*

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Grit Washer

- Removes organic matter from grit
- Inclined screw moves grit up ramp
- Final grit disposal in landfill

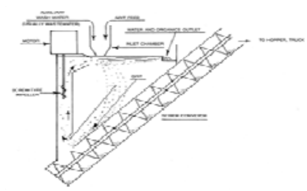

Diagram excerpted from Chapter 4: Racks, Screens, Comminutors and Grit Removal. In *Operators of Wastewater Treatment Plants Volume I.*

22

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Odor Control

- Odor Problem
  - On Site Problem
    - Employee Safety and Health
    - Working Conditions
  - Community Problem
    - Public Relations

23

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Hydrogen Sulfide

- Most common raw WW odor
- Poisonous to respiratory system
- Rotten egg odor
- Produced under anaerobic conditions
- Explosive, flammable, corrosive
- Dulls sense of smell on exposure

Hydrogen Sulfide Toxicity	
Effect	Concentration mg/L
Odor Threshold	0.1
Offensive Odor	3 – 10
Headache / Nausea	10 – 50
Eye Injury	50 – 100
Respiratory Tract Irritation	100 – 300
Pulmonary Edema	300 – 500
Nervous System Problems	500 – 1000
Death	> 1000

24

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Hydrogen Sulfide Control

- Chlorine and chlorine compounds
- Hydrogen peroxide
- Metal salts
  - Iron
  - Zinc
  - Copper
- Ozone
- Strong alkalis
  - Sodium hydroxide
  - Lime
- Nitrates

25

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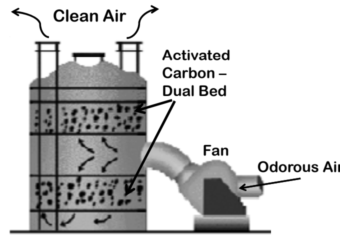
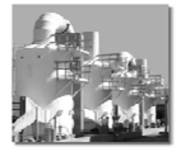
Odor Control

- Activated Carbon Adsorber



- Chemical Scrubbers



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Safety

- Slips and falls- slippery surfaces
- Drowning
- Disease exposure- good hygiene essential
- Run equipment only when guards are in place
- Back injuries and muscle strains
- Hazardous conditions

27

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Safety

- NEVER try to un-jam cutter blades on comminutor without FIRST bypassing the unit.

- Tag operating controls, lock off the power & keep the key when working on mechanical equip.

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CHAPTER 4

Preliminary and Pretreatment Facilities

PRELIMINARY AND PRETREATMENT FACILITIES

4.1 Screening and Grinding

4.1.1 General

Some type of screening and/or grinding device shall be provided at all mechanical wastewater plants. The effective removal of grit, rocks, debris, excessive oil or grease and the screening of solids shall be accomplished prior to any activated sludge process. Any grinding which does not dispose of the shredded material outside of the wastewater stream must be evaluated with regard to the influent characteristics (rags, combined sewers) of the waste prior to any activated sludge process.

4.1.2 Location

4.1.2.1 Indoors

Screening devices installed in a building where other equipment or offices are located shall be accessible only through an outside entrance. Adequate lighting, ventilation and access for maintenance or removal of equipment and screenings shall be provided.

4.1.2.2 Outdoors

The removal point for screenings should be as practical as possible for the plant personnel, preferably at ground level. Ladder access is not acceptable unless hoisting facilities for screenings are provided. Separate hoisting is not required for bar screens in manual bypass channels.

4.1.2.3 Deep Pit Installations

Stairway access, adequate lighting and ventilation with a convenient and adequate means for screenings removal shall be provided.

4.1.3 Bar Screens

4.1.3.1 Manually Cleaned

Clear openings between bars shall be from 1 to 2 inches. Slope of the bars shall be 30 to 60 degrees from the vertical. Bar size shall be from 1/4 to 5/8 inches with 1 to 3 inches of depth, depending on the length and material to maintain integrity. A perforated drain plate shall be installed at the top of the bar screen for temporary storage and drainage.

4.1.3.2 Mechanically Cleaned

Mechanically cleaned bar screens are recommended for all plants greater than 1 MGD. Both front cleaned or back cleaned models may be acceptable. Clear openings no less than 5/8 inch are acceptable. Protection from freezing conditions should be considered.

Other than the rakes, no moving parts shall be below the water line.

4.1.3.3 Velocities

Approach velocities no less than 1.25 fps nor a velocity greater than 3.0 fps through the bar screen is desired.

4.1.4 Fine Screens

4.1.4.1 General

Fine screens shall be preceeded by a trash rack or coarse bar screen. Comminution shall not be used ahead of fine screens. A minimum of two fine screens shall be provided, each capable of independent operation at peak design flow. The design engineer must fully evaluate a proposal where fine screens are to be used in lieu of primary sedimentation. Fine screens shall not be considered equivalent to primary sedimentation or grit removal, but will be reviewed on a case-by-case basis. Oil and grease removal must be considered.

4.1.4.2 Design

The operation should be designed to not splash operating personnel with wastewater or screenings. Fine screens will generally increase the dissolved oxygen content of the influent which may be beneficial in certain circumstances. The screens must be enclosed or otherwise protected from cold weather freezing conditions. Disposal of screenings must be addressed. To be landfilled, screenings must be dried to approximately 20% solids. Odors may be a problem in sensitive locations.

4.1.5 Comminution

4.1.5.1 General

In-line comminution may not be acceptable prior to an activated sludge process for facilities with a history of problems with rags. Out-of-stream comminution or disintegration is acceptable for activated sludge processes; however, screenings should not return to the wastewater stream.

4.1.5.2 Design

A coarse bar screen with an automatic bypass shall precede comminution for all mechanical plants. Gravel traps shall precede comminution which is not preceded by grit removal. Clear openings of 1/4 inch are prefered in the comminution device. An automatic unit bypass or other means of protection shall be provided to protect the comminutor motor from flooding. The design shall incorporate a method for removing the equipment from service and for repairs or sharpening of the teeth.

4.1.6 Operability

All screening devices shall have the capability of isolation from the wastewater stream. Sufficient wash water shall be available for cleanup of the area. All mechanical screening devices shall be provided with a manually cleaned bar screen bypass. Multiple bar screens should be considered for plants with rag problems instead of comminutors.

Adequate space must be provided for access to each screening or comminution device. This is critical in elevated, indoor or deep pit installations.

4.1.7 Disposal

All screenings shall be disposed of in an approved manner. Suitable containers shall be provided for holding the screenings. Run-off control must be provided around the containers, where applicable. If fine screens are proposed, consideration must be given to the wastewater overflow if the screens clog or blind. Overflows must be contained and bypassed around the screens by dikes or other means.

4.2 Grit Removal

4.2.1 General

Grit removal is recommended for all mechanical wastewater plants and is required in duplicate for plants receiving wastewater from combined sewers. Systems with a history of substantial grit accumulations may be required to provide for grit removal. Where a system is designed without grit removal facilities, the design shall allow for future installation by providing adequate head and area. Grit washing may be required.

4.2.2 Location

Wherever circumstances permit, grit removal shall be located prior to pumps and comminution when so equiped. Bar screens shall be prior to grit removal. Adequate lighting, ventilation and access for maintenance and removal of grit shall be provided. Stairway access is required if the chamber is above
or below ground level. Adequate and convenient means of grit removal shall be provided.

4.2.3 Design

4.2.3.1 Channel Type

A controlled velocity of one foot per second is recommended. Control by either sutro or proportional weir should be used. If a Parshall flume is used for control, the grit chamber must be designed to approach a parabolic cross-section. The length of the channel depends on the size of grit to be removed. The design engineer shall provide this information. Inlet and outlet turbulence must be minimized.

4.2.3.2 Square Type

Square-type basins or similar arrangements should be sized for an overflow rate of 46,300 (WPCF) gallons per day per square foot at the peak flow based on 65-mesh grit at a specific gravity of 2.65. Other overflow rates may be used when the design incorporates particle travel distance and detention. Inlet and outlet turbulence must be minimized.

4.2.3.3 Aerated Type

Aerated grit chambers shall be designed on the basis of detention and/or particle travel distance. Detention time of 2-5 minutes at peak flow is acceptable. Control of the air shall be provided for flexibility. Skimming equipment must be provided in the aerated grit chamber if the outlet is below the water surface.

4.2.3.4 Other Types

Cyclone or swirl-type grit removal processes may be acceptable. The design engineer will be expected to provide a complete treatment analysis for approval.

4.2.4 Disposal

Temporary storage containers shall be provided to hold the grit. Run-off control shall be provided. Attention should be given to operations which may splash waste or grit on operating personnel. Grit washing is required before removal to drying beds. If not washed, the grit shall be disposed of in an approved landfill.

4.2.5 Operability

Adjustable control valves shall be included in each diffuser air line to control mixing and particle segregation. Variable speed arrangements should be provided in cyclone or mechanical type systems. Provisions shall be made for isolation and dewatering each unit or units.

4.3 Pre-Aeration

Pre-aeration is desirable in certain instances, such as to reduce septicity. Pre-aeration may be required where pressure or small diameter collection systems are used. Long detention times in pump stations or collection lines should also be considered. Units shall be designed so that removal from service will not interfere with normal plant operations.

4.4 Flow Equalization

4.4.1 General

Equalization may be used to minimize random or cyclic peaking of organic or hydraulic loadings when the total flow is ultimately processed through the plant. Either in-line or side-line equalization is acceptable. Equalization may be required where peak flows are greater than 2 times the average design flow.

4.4.2 Location

Tanks are generally located after screening and grit removal. Care should be taken in design to minimize solids deposition if located upstream of primary clarifiers. Equalization downstream of primary clarifiers should be investigated, as primary clarifier performance is less sensitive to flow peaking when compared to other processes. Other locations will be evaluated on a case-by-case basis.

4.4.3 Design and Operability

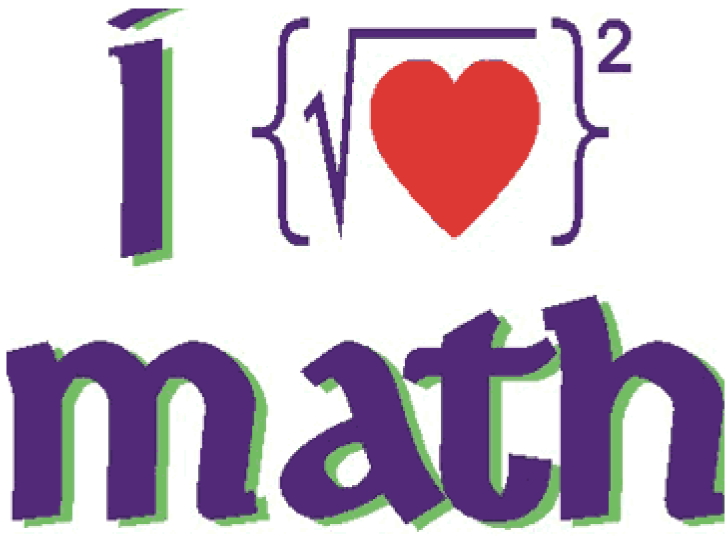
Generally, aeration will be required. Minimum requirements are to maintain 1.0 mg/l of dissolved oxygen. Odor consideration must be addressed when a plant is located in a sensitive area or large equalization basins are used. Large tanks must be divided into compartments to allow for operational flexibility, repair and cleaning. Each compartment shall be capable of dewatering and access. In plant upgrades, existing units which are otherwise to be abandoned may be used for equalization, where possible. Sizing the tankage and compartments will depend on the intended use; i.e., when equalization is for periodic high organic loadings, peak flow events, toxics, etc. A complete analysis shall accompany all engineering report (or plan) submission. The tank must be capable of being drained and isolated. Controlling the flow rate from the equalization tank to the plant is desirable.

4.5 <u>Swirls and Helical Bends</u>

General

These units are not to be used in lieu of primary clarification unless special design considerations are used. They are primarily designed for 'coarse' floating and settleable solids removal and will be considered only on a case-by-case basis for in-plant processes. They will, however, be approved for replacing regulators in combined sewer systems, as an interim measure until separation of the sanitary and storm flows is completed. Treatability studies will be required as part of the design. A separate NPDES permit will be required for each of these units that will discharge to a surface water.

Section 4
Math



Math Problem Strategies

Use these rules of operation to approach math problems (*especially when working with formulas*):

1) Work from left to right.
2) Do all the work inside the parentheses first.
3) Do all the multiplication/division above the line (numerator) and below the line (denominator).
4) Then do all the addition and subtraction above and below the line.
5) Perform the division (divided the numerator by the denominator).

Strategy for solving word problems:

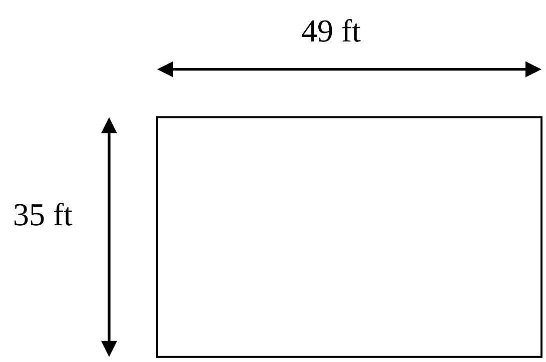
1) Read the problem, disregard the numbers (What type of problem is it? What am I asked to find?)
2) Refer to the diagram, if provided. If there isn't one, draw your own.
3) What information do I need to solve the problem, and how is it given in the statement of the problem?
4) Work it out.
5) Does it make sense?

It might be helpful to write out everything that is known in one column and the unknown (what am I asked to find?) in another column. Identify the correct formula and write it in the middle, plug in the numbers and solve.

Known		**Unknown**
Length = 35 ft Width = 49 ft		Area = ?

$A = (l)(w)$

$A = (35\text{ ft})(49\text{ ft})$
$A = 1715\text{ ft}^2$



*****Remember: make sure measurements agree; if diameter of pipe is in inches then change to feet; if flow is in MGD and you need feet or feet/sec then change to ft^3/sec before you plug values into formula.***

Solving for the Unknown

Basics – finding x

1. $8.1 = (3)(x)(1.5)$

2. $(0.785)(0.33)(0.33)(x) = 0.49$

3. $\frac{233}{x} = 44$

4. $940 = \frac{x}{(0.785)(90)(90)}$

5. $x = \frac{(165)(3)(8.34)}{0.5}$

6. $56.5 = \frac{3800}{(x)(8.34)}$

7. $114 = \frac{(230)(1.15)(8.34)}{(0.785)(70)(70)(x)}$

8. $2 = \frac{x}{180}$

9. $46 = \frac{(105)(x)(8.34)}{(0.785)(100)(100)(4)}$

10. $2.4 = \frac{(0.785)(5)(5)(4)(7.48)}{x}$

11. $19{,}747 = (20)(12)(x)(7.48)$

12. $\dfrac{(15)(12)(1.25)(7.48)}{x} = 337$

13. $\dfrac{x}{(4.5)(8.34)} = 213$

14. $\dfrac{x}{246} = 2.4$

15. $6 = \dfrac{(x)(0.18)(8.34)}{(65)(1.3)(8.34)}$

16. $\dfrac{(3000)(3.6)(8.34)}{(0.785)(x)} = 23.4$

17. $109 = \dfrac{x}{(0.785)(80)(80)}$

18. $(x)(3.7)(8.34) = 3620$

19. $2.5 = \dfrac{1{,}270{,}000}{x}$

20. $0.59 = \dfrac{(170)(2.42)(8.34)}{(1980)(x)(8.34)}$

Finding x^2

21. $(0.785)(D^2) = 5024$

22. $(x^2)(10)(7.48) = 10{,}771.2$

23. $51 = \dfrac{64{,}000}{(0.785)(D^2)}$

24. $(0.785)(D^2) = 0.54$

25. $2.1 = \dfrac{(0.785)(D^2)(15)(7.48)}{(0.785)(80)(80)}$

Percent Practice Problems

Convert the following fractions to decimals:

1. $\frac{3}{4}$

2. $\frac{5}{8}$

3. $\frac{1}{4}$

4. $\frac{1}{2}$

Convert the following percents to decimals:

5. 35%

6. 99%

7. 0.5%

8. 30.6%

Convert the following decimals to percents:

9. 0.65

10. 0.125

11. 1.0

12. 0.05

Calculate the following:

13. 15% of 125

14. 22% of 450

15. 473 is what % of 2365?

16. 1.3 is what % of 6.5?

Answers for Solving for the Unknown

Basics – Finding x

1.	1.8	8.	360	15.	2817
2.	5.7	9.	1649	16.	4903
3.	5.3	10.	244.7	17.	547,616
4.	5,976,990	11.	11	18.	117
5.	8256.6	12.	5	19.	508,000
6.	8.1	13.	7994	20.	0.35
7.	0.005	14.	590.4		

Finding x^2

21.	80	23.	40	25.	10.9
22.	12	24.	0.83		

Percent Practice Problems

1.	0.75	7.	0.005	13.	18.75
2.	0.625	8.	0.306	14.	99
3.	0.25	9.	65%	15.	20%
4.	0.5	10.	12.5%	16.	20%
5.	0.35	11.	100%		
6.	0.99	12.	5%		

Area, Volume and Conversions

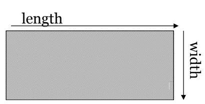
Area

- Surface of an object
- Two dimensional
- Measured in:
  - Square inches
  - Square feet
  - Square meters, etc.

Area Formulas

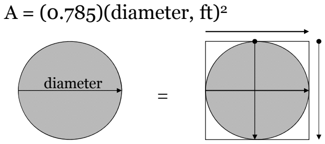
- Rectangle

  A = (length, ft)(width, ft)



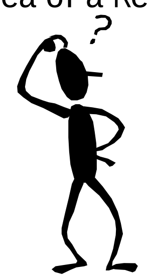
- Circle

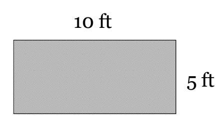
  A = (0.785)(diameter, ft)^2



Diameter is equal to length and width of a square and a circle takes up 78.5% of square

Area of a Rectangle



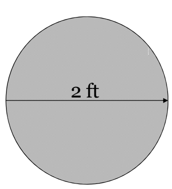


A = (l, ft)(w, ft)

A = (10 ft)(5 ft)

A = 50 ft^2

Area of a Circle



Diameter = 2 ft

A = (0.785)(D, ft)^2

A = (0.785)(2ft)(2ft)

A = 3.14 ft^2

Volume

- The amount of space an object occupies
- Volume = (area)(third dimension) or

  V = (l)(w)(d)

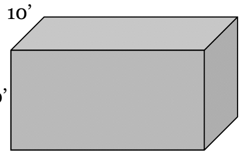
- Measured in:
  - Cubic inches
  - Cubic feet
  - Gallons
  - Acre-feet, etc.

Volume of a Rectangular Tank, ft^3

V = (length, ft)(width, ft)(depth, ft)

V = (12 ft)(10ft)(10ft)

V = 1200 ft^3



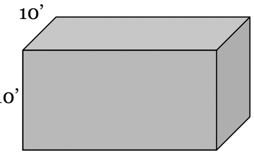
Volume of a Rectangular Tank, gal

V, ft^3 = 1200 ft^3

V, gal = (Volume, ft^3)(7.48 gal/ft^3)

V, gal = (1200 ft^3)(7.48)

V, gal = 8976 gal

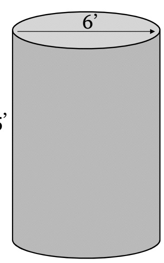


Volume of a Cylinder, ft^3

V = (0.785)(D, ft)^2(height, ft)

V = (0.785)(6 ft)(6 ft)(15 ft)

V = 424 ft^3



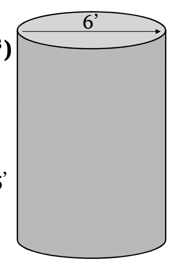
Volume of a Cylinder, gallons

V, ft^3 = 424 ft^3

V, gal = (Volume, ft^3)(7.48 gal/ft^3)

V, gal = (424 ft^3)(7.48)

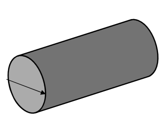
V, gal = 3171.52 gal



Note

- When calculating area and volume, if you are given a pipe diameter in inches, convert it to feet.

$$8\,\cancel{in.} \times \frac{1\text{ ft}}{12\,\cancel{in}} = 0.6667\text{ ft}$$



Diameter = 8 in

Conversions

- Need to know:
- The number that relates the two units
  - Ex: 12 inches in a foot, 454 grams in a pound, 3785 mL in a gallon
- Whether to multiply or divide
  - Ex: smaller to larger or larger to smaller

Conversions

Conversion Factors

1 acre	=	43,560 ft^2
1 foot of head	=	0.433 psi
1 psi	=	2.31 feet of head
1 yd^3	=	27 ft^3
1 gal	=	3.785 Liters
1 gallon of water	=	8.34 lbs
1 cubic foot of water	=	7.48 gallons
1 lb	=	453.6 grams
1 mile	=	5280 feet
1%	=	10,000 mg/L

Multiply

- Just looking at the units, if you are given miles and you need feet, we are going from left to right on the page, therefore multiply

Conversions

- You have just laid ¼ mile of sewer line. How many feet is this?

¼ = 0.25 miles

(0.25 miles)(5280 feet/mile) = 1320 feet

Percent to Decimal

Percent = per one hundred

20%	=	20/100	=	0.20
5%	=	5/100	=	0.05
12.25%	=	12.25/100	=	0.1225
0.5%	=	0.5/100	=	0.005

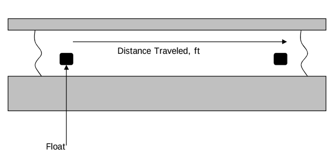
Move decimal 2 places to the left.

Velocity

- Distance per time
- Measured in:
  - Miles per hour
  - Feet per second
  - Feet per minute

Velocity Formulas

- Velocity, ft/sec = $\frac{\text{distance traveled, ft}}{\text{time, sec}}$
- Velocity, ft/min = $\frac{\text{distance traveled, ft}}{\text{time, min}}$



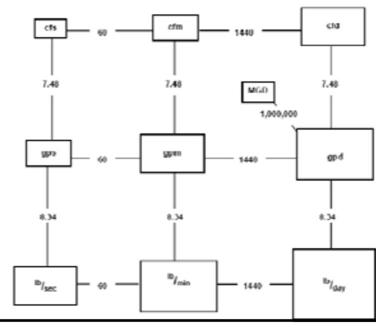
Velocity

- A cork is placed in a channel and travels 400 feet in 2 minutes and 25 seconds. What is the velocity of the wastewater in the channel, ft/min?

- 25 seconds/60 = 0.4167
- Vel = $\frac{400 \text{ ft}}{2.4167 \text{ min}}$ = 165.5 ft/min

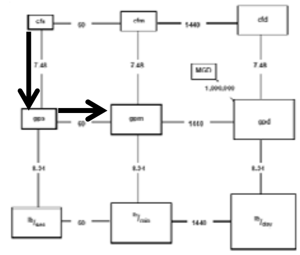
Flow Conversions – Box Method

Small to Big → multiply
Big to Small → divide



Flow Conversions – Box Method

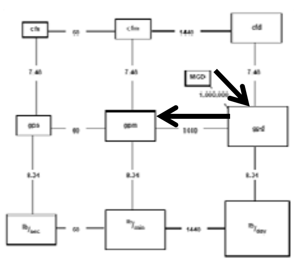
- Convert a flow of 2.7 cfs to gpm.



(2.7)(7.48)(60) = 1211 gpm

Flow Conversions – Box Method

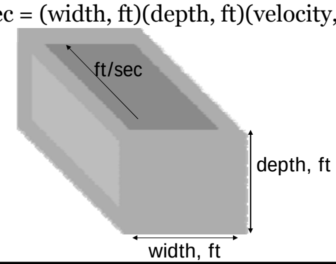
- Convert a flow of 1.0 MGD to gpm.



$\frac{(1.0)(1{,}000{,}000)}{1440}$ = 694 gpm

Flow in a Channel

- Q, ft^3/sec = (Area, ft^2)(Velocity, ft/sec)
- Q, ft^3/sec = (width, ft)(depth, ft)(velocity, ft/sec)



Flow in a Channel

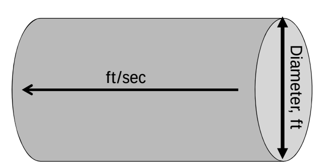
- A channel 36 inches wide has water flowing to a depth of 2 feet. If the velocity of the water is 1.2 ft/sec, what is the flow in the channel in ft^3/sec?

- Q = (3ft)(2 ft)(1.2 ft/sec)

  = 7.2 ft^3/sec

Flow in a Pipe Flowing Full

- Q, ft^3/sec = (Area, ft^2)(Velocity, ft/sec)
- Q, ft^3/sec = (0.785)(Diameter, ft)^2(velocity, ft/sec)



Flow in a Pipe Flowing Full

- The flow through a 10-inch diameter sewer is flowing full at 2.5 ft/sec. What is the flow rate in ft^3/sec and gal/day?
- Q = (0.785)(0.8333)(0.8333)(2.5) = 1.36 ft^3/sec
- (1.36 ft^3/sec)(7.48 gal/ft^3)(60 sec/min)(1440 min/day) = 880,699.5 gal/day

Flow in a Partially Full Pipe

- Q = (factor from d/D table)(Diameter, ft)^2(vel, fps)

depth/Diameter Table

0.01	0.0013	0.26	0.1623	0.51	0.4027	0.76	0.6404
0.02	0.0037	0.27	0.1711	0.52	0.4127	0.77	0.6489
0.03	0.0069	0.28	0.1800	0.53	0.4227	0.78	0.6573
0.04	0.0105	0.29	0.1890	0.54	0.4327	0.79	0.6655
0.05	0.0147	0.30	0.1982	0.55	0.4426	0.80	0.6736
0.06	0.0192	0.31	0.2074	0.56	0.4526	0.81	0.6813
0.07	0.0242	0.32	0.2167	0.57	0.4625	0.82	0.6893
0.08	0.0294	0.33	0.2260	0.58	0.4724	0.83	0.6969
0.09	0.0350	0.34	0.2355	0.59	0.4822	0.84	0.7043
0.10	0.0409	0.35	0.2450	0.60	0.4920	0.85	0.7115
0.11	0.0470	0.36	0.2546	0.61	0.5018	0.86	0.7186
0.12	0.0534	0.37	0.2642	0.62	0.5118	0.87	0.7254
0.13	0.0600	0.38	0.2739	0.63	0.5212	0.88	0.7320
0.14	0.0668	0.39	0.2836	0.64	0.5308	0.89	0.7384
0.15	0.0739	0.40	0.2934	0.65	0.5404	0.90	0.7445
0.16	0.0811	0.41	0.3032	0.66	0.5499	0.91	0.7504
0.17	0.0885	0.42	0.3130	0.67	0.5594	0.92	0.7560
0.18	0.0961	0.43	0.3229	0.68	0.5687	0.93	0.7612
0.19	0.1039	0.44	0.3328	0.69	0.5780	0.94	0.7662
0.20	0.1118	0.45	0.3428	0.70	0.5872	0.95	0.7707
0.21	0.1199	0.46	0.3527	0.71	0.5964	0.96	0.7749
0.22	0.1281	0.47	0.3627	0.72	0.6054	0.97	0.7785
0.23	0.1365	0.48	0.3727	0.73	0.6143	0.98	0.7816
0.24	0.1449	0.49	0.3827	0.74	0.6231	0.99	0.7841
0.25	0.1535	0.50	0.3927	0.75	0.6319	1.00	0.7854

Flow in a Partially Full Pipe

- A 10-inch diameter pipeline has water flowing at a depth of 4 inches. What is the gal/min flow if the velocity of the wastewater is 3.1 fps?
- d/D = 4 inches of water ÷ 10-inch diameter
  = 4/10 = 0.4 $\rightsquigarrow$ 0.2934
- Q = (0.2934)(0.8333)(0.8333)(3.1) = 0.6316 ft^3/sec
- (0.6316 ft^3/sec)(7.48 gal/ft^3)(60 sec/min) = 408,169 gpm

Area, Volume and Conversions

AREA

1. A basin has a length of 45 feet and a width of 12 feet. Calculate the area in ft^2.

2. A tank has a length of 90 feet, a width of 25 feet, and a depth of 10 feet. Calculate the surface area in ft^2.

3. Calculate the cross-sectional area (in ft^2) for a 2 foot main that has just been laid.

4. Calculate the cross-sectional area (in ft^2) for a 24” main that has just been laid.

5. Calculate the cross-sectional area (in ft^2) for a 2 inch line that has just been laid.

VOLUME

6. Calculate the volume (in ft^3) of a tank that measures 10 feet by 10 feet by 10 feet.

7. Calculate the volume (in gallons) of a basin that measures 22 feet by 11 feet by 5 feet deep.

8. Calculate the volume (in gallons) of water in a tank that is 254 feet long, 62 feet wide, and 10 feet deep if the tank only contains 2 feet of water.

9. Calculate the volume of water in a tank (in gallons) that is 12 feet long by 6 feet wide by 5 feet deep and contains 8 inches of water.

10. Calculate the maximum volume of water (in gallons) for a kids' swimming pool that measures 6 feet across and can hold 18 inches of water.

11. How much water (in gallons) can a barrel hold if it measures 3.5 feet in diameter and can hold water to a depth of 4 feet?

12. A water main has just been laid and needs to be disinfected. The main is 30” in diameter and has a length of 0.25 miles. How many gallons of water will it hold?

13. A water main is 10” in diameter and has a length of 5,000 feet. How many million gallons of water will it hold?

14. A 3 million gallon water tank needs to be disinfected. The method you will use requires you to figure 5% of the tank volume. How many gallons will this be?

15. What is 5% of a 1.2 MG tank?

CONVERSIONS

16. How many seconds in 1 minute?

17. How many minutes in 1 hour?

18. How many hours in 1 day?

19. How many minutes in 1 day?

20. The flow through a pipe is 3.6 cfs. What is the flow in gps?

21. The flow through a pipe is 2.4 cfs. What is the flow in gpm?

22. A pump produces 22 gpm. How many cubic feet per hour is that?

23. A treatment plant produces a flow of 6.31 MGD. What is the flow in gpm?

24. A pump produces 700 gpm. How many MGD will the pump flow?

25. A three-eights mile segment of pipeline is to be repaired. How many feet of pipeline is this?

26. If there is a 2,200 gallon tank full of water, how many pounds of water is in the tank?

ANSWERS:

1. 540 ft^2
2. 2,250 ft^2
3. 3.14 ft^2
4. 3.14 ft^2
5. 0.0218 ft^2
6. 1,000 ft^3
7. 9,050.8 gal
8. 235,590 gal
9. 359 gal
10. 317 gal
11. 288 gal
12. 48,442 gal
13. 0.02 MG
14. 150,000 gal
15. 60,000 gal or 0.06 MG
16. 60
17. 60
18. 24
19. 1440
20. 26.9 gps
21. 1,077 gpm
22. 176.5 ft^3/hr
23. 4,382 gpm
24. 1.008 MGD
25. 1,980 ft
26. 18,348 lbs

Basic Math Review for Wastewater Treatment
Flow Conversions
(round to the nearest tenth)

1. Express a flow of 5 cfs in terms of gpm.

2. What is 38 gps expressed as gpd?

3. Convert a flow of 4,270,000 gpd to cfm.

4. What is 5.6 MGD expressed as ft^3/sec?

5. Express 423,690 cfd as gpm.

6. Convert 2730 gpm to gpd.

Answers:

1. 2244 gpm
2. 3,283,200 gpd
3. 396 cfm
4. 8.7 cfs
5. 2201 gpm
6. 3,931,200 gpd

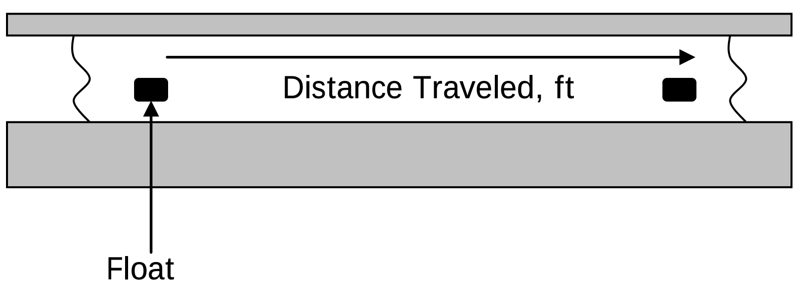
Applied Math for Wastewater
Flow and Velocity

<u>Velocity</u>

1. A cork is placed in a channel and travels 370 feet in 2 minutes. What is the velocity of the wastewater in the channel, ft/min?

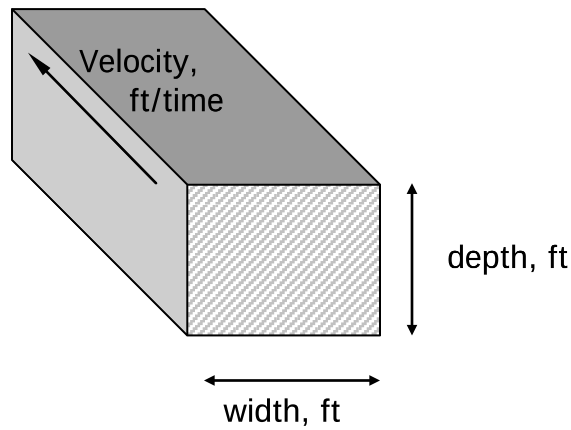
2. A float travels 300 feet in a channel in 2 minutes and 14 seconds. What is the velocity in the channel, ft/sec?

3. The distance between manhole #1 and manhole #2 is 105 feet. A fishing bobber is dropped into manhole #1 and enters manhole #2 in 30 seconds. What is the velocity of the wastewater in the sewer in ft/min?



$$\text{Velocity} = \frac{\text{Distance Traveled, ft}}{\text{Duration of Test, min}}$$

$$= \text{ft/min}$$



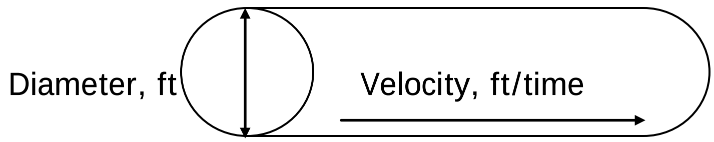
$$\underset{ft^3/time}{Q} = \underset{(ft)(ft)}{(A)} \; \underset{(ft/time)}{(V)}$$

<u>Flow in a channel</u>

4. A channel 48 inches wide has water flowing to a depth of 1.5 feet. If the velocity of the water is 2.8 ft/sec, what is the flow in the channel in cu ft/sec?

5. A channel 3 feet wide has water flowing to a depth of 2.5 feet. If the velocity through the channel is 120 feet/min, what is the flow rate in cu ft/min? in MGD?

6. A channel is 3 feet wide and has water flowing at a velocity of 1.5 ft/sec. If the flow through the channel is 8.1 ft^3/sec, what is the depth of the water in the channel in feet?



$$\underset{ft^3/time}{Q} = \underset{ft^2}{(A)}\ \underset{(ft/time)}{(V)}$$

$$\underset{ft^3/time}{Q} = \underset{(ft)(ft)}{(0.785)\,(D)^2}\ \underset{(ft/time)}{(vel)}$$

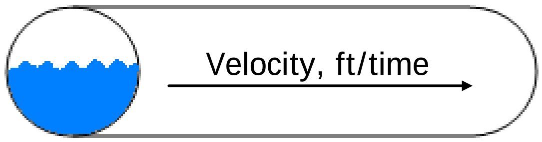
<u>Flow through full pipe</u>

7. The flow through a 2 ft diameter pipeline is moving at a velocity of 3.2 ft/sec. What is the flow rate in cu ft/sec?

8. The flow through a 6 inch diameter pipeline is moving at a velocity of 3 ft/sec. What is the flow rate in ft^3/sec?

9. An 8 inch diameter pipeline has water flowing at a velocity of 3.4 ft/sec. What is the flow rate in gpm?

10. The flow through a pipe is 0.7 ft^3/sec. If the velocity of the flow is 3.6 ft/sec, and the pipe is flowing full, what is the diameter of the pipe in inches?

Diameter, ft 

Q	=	(A)	(V)
ft^3/time		ft^2	(ft/time)

Q	=	(Factor from d/D Table) $(D)^2$	(vel)
ft^3/time		(ft)(ft)	(ft/time)

<u>Flow through pipe flowing less than full</u>

11. A 12-inch diameter pipeline has water flowing at a depth of 6 inches. What is the gpm flow if the velocity of the wastewater is 300 fpm?

12. A 10-inch diameter pipeline has water flowing at a velocity of 3.2 fps. What is the gpd flow rate if the water is at a depth of 5 inches?

13. An 8-inch pipeline has water flowing to a depth of 5 inches. If the flow rate is 415.85 gpm, what is the velocity of the wastewater in fpm?

Answers:

1. 185 ft/min
2. 2.2 ft/sec
3. 210 ft/min
4. 16.8 ft^3/sec
5. 900 ft^3/min and 9.69 MGD
6. 1.8 ft
7. 10 ft^3/sec
8. 0.59 ft^3/sec
9. 532 gpm
10. 6 in
11. 881 gpm
12. 563,980 gpd
13. 240 ft/min

Solving for the Unknown

Basics – finding x

1. $8.1 = (3)(x)(1.5)$

$8.1 = (4.5)(x)$

$\frac{8.1}{4.5} = x$

$\boxed{1.8 = x}$

2. $(0.785)(0.33)(0.33)(x) = 0.49$

$(0.0854865)(x) = 0.49$

$x = \frac{0.49}{0.0854865}$

$\boxed{= 5.7}$

Flip Flop

only when x is on bottom

3. $\frac{233}{x} = \frac{44}{1}$

$\frac{233}{44} = x$

$\boxed{5.3 = x}$

4. $940 = \frac{x}{(0.785)(90)(90)}$

$\frac{940}{1} = \frac{x}{6358.5}$

$(940)(6358.5) = x$

$\boxed{5,976,990 = x}$

5. $x = \frac{(165)(3)(8.34)}{0.5}$

$x = \frac{4128.3}{0.5} = \boxed{8256.6}$

6. $56.5 = \frac{3800}{(x)(8.34)}$

$x = \frac{3800}{(56.5)(8.34)} = \frac{3800}{471.21} = \boxed{8.1}$

7. $114 = \frac{(230)(1.15)(8.34)}{(0.785)(70)(70)(x)}$

$114 = \frac{2205.93}{(3846.5)(x)}$

$x = \frac{2205.93}{(3846.5)(114)} = \frac{2205.93}{438501} = \boxed{0.005}$

8. $\frac{2}{1} = \frac{x}{180}$

$(2)(180) = x$

$\boxed{360 = x}$

9. $46 = \frac{(105)(x)(8.34)}{(0.785)(100)(100)(4)}$

$\frac{46}{1} = \frac{(875.7)(x)}{31400}$

$(46)(31400) = (875.7)(x)$

$\frac{1444400}{875.7} = x = \boxed{1649}$

10. $2.4 = \frac{(0.785)(5)(5)(4)(7.48)}{x}$

$2.4 = \frac{587.18}{x}$

$x = \frac{587.18}{2.4} = \boxed{244.7}$

11. $19{,}747 = (20)(12)(x)(7.48)$

$19{,}747 = (1795.2)(x)$

$\frac{19{,}747}{1795.2} = x$

$\boxed{11 = x}$

12. $\frac{(15)(12)(1.25)(7.48)}{x} = 337$

$\frac{1683}{x} = 337$

$\frac{1683}{337} = x$

$\boxed{5 = x}$

13. $\frac{x}{(4.5)(8.34)} = 213$

$\frac{x}{37.53} = 213$

$x = (213)(37.53)$

$= \boxed{7994}$

14. $\frac{x}{246} = 2.4$

$x = (2.4)(246)$

$\boxed{x = 590.4}$

15. $6 = \frac{(x)(0.18)(8.34)}{(65)(1.3)(8.34)}$

$6 = \frac{(x)(1.5012)}{704.73}$

$(6)(704.73) = (x)(1.5012)$

$\frac{4228.38}{1.5012} = x$

$\boxed{2817 = x}$

16. $\frac{(3000)(3.6)(8.34)}{(0.785)(x)} = 23.4$

$\frac{90072}{(0.785)(x)} = 23.4$

$\frac{90072}{(0.785)(23.4)} = \frac{90072}{18.369} = \boxed{4903}$

17. $109 = \frac{x}{(0.785)(80)(80)}$

$109 = \frac{x}{5024}$

$(109)(5024) = x$

$\boxed{547{,}616 = x}$

18. $(x)(3.7)(8.34) = 3620$

$(x)(30.858) = 3620$

$x = \frac{3620}{30.858}$

$\boxed{x = 117}$

19. $2.5 = \frac{1{,}270{,}000}{x}$

$x = \frac{1{,}270{,}000}{2.5}$

$\boxed{x = 508{,}000}$

20. $0.59 = \frac{(170)(2.42)(8.34)}{(1980)(x)(8.34)}$

$0.59 = \frac{(3431.076)}{(x)(16513.2)}$

$x = \frac{(3431.076)}{(0.59)(16513.2)}$

$= \frac{3431.076}{9742.788}$

$\boxed{= 0.35}$

Finding x^2

21. $(0.785)(D^2) = 5024$

$$D^2 = \frac{5024}{0.785} = 6400$$

$$D = \sqrt{6400} = \boxed{80}$$

22. $(x^2)(10)(7.48) = 10{,}771.2$

$$(x^2)(74.8) = 10{,}771.2$$

$$x^2 = \frac{10{,}771.2}{74.8} = 144$$

$$x = \sqrt{144} = \boxed{12}$$

23. $51 = \dfrac{64{,}000}{(0.785)(D^2)}$

$$D^2 = \frac{64{,}000}{(0.785)(51)} = \frac{64{,}000}{40.035} = 1598.6012$$

$$D = \sqrt{1598.6012} = \boxed{39.98 \approx 40}$$

24. $(0.785)(D^2) = 0.54$

$$D^2 = \frac{0.54}{0.785} = 0.687898$$

$$D = \sqrt{0.687898} = \boxed{0.83}$$

25. $2.1 = \dfrac{(0.785)(D^2)(15)(7.48)}{(0.785)(80)(80)}$

$$\frac{2.1}{1} = \frac{(88.077)(D^2)}{5024}$$

$$(2.1)(5024) = (88.077)(D^2)$$

$$\frac{10550.4}{88.077} = D^2$$

$$119.786 = D^2$$

$$D = \sqrt{119.786} = \boxed{10.9}$$

Percent Practice Problems

Convert the following fractions to decimals:

1. ¾ $\frac{3}{4} = 0.75$
2. ⅝ $\frac{5}{8} = 0.625$
3. ¼ $\frac{1}{4} = 0.25$
4. ½ $\frac{1}{2} = 0.5$

Convert the following percents to decimals:

5. 35% $\frac{35}{100} = 0.35$
6. 99% $\frac{99}{100} = 0.99$
7. 0.5% $\frac{0.5}{100} = 0.005$
8. 30.6% $\frac{30.6}{100} = 0.306$

Convert the following decimals to percents:

9. 0.65 $(0.65)(100) = 65\%$
10. 0.125 $(0.125)(100) = 12.5\%$
11. 1.0 $(1.0)(100) = 100\%$
12. 0.05 $(0.05)(100) = 5\%$

Calculate the following: of means "multiply"; is means "equal to"

13. 15% of 125 $(0.15)(125) = 18.75$
14. 22% of 450 $(0.22)(450) = 99$
15. 473 is what % of 2365? $473 = (x)(2365) \rightarrow \frac{473}{2365} = x \rightarrow \underbrace{0.2}_{\text{decimal form}} = x = 20\%$
16. 1.3 is what % of 6.5? $1.3 = (x)(6.5) \rightarrow \frac{1.3}{6.5} = x \rightarrow 0.2 = x$

    $20\% = x$

APPLIED MATH FOR DISTRIBUTION
AREA, VOLUME, AND CONVERSIONS

Area, Volume and Conversions

AREA

1. A basin has a length of 45 feet and a width of 12 feet. Calculate the area in ft^2.

$$A = (\text{length})(\text{width})$$
$$= (45\,ft)(12\,ft)$$
$$\boxed{= 540\,ft^2}$$

2. A tank has a length of 90 feet, a width of 25 feet, and a depth of 10 feet. Calculate the surface area in ft^2.

$$A = (90\,ft)(25\,ft)$$
$$= \boxed{2250\,ft^2}$$

3. Calculate the cross-sectional area (in ft^2) for a 2 foot main that has just been laid.

$$A = (0.785)(\text{Diameter})^2$$
$$= (0.785)(2\,ft)^2$$
$$\boxed{= 3.14\,ft^2}$$

4. Calculate the cross-sectional area (in ft^2) for a 24" main that has just been laid.

$$\frac{24\,in \mid 1\,ft}{\mid 12\,in} = 2\,ft$$

$$A = (0.785)(2\,ft)^2$$
$$= \boxed{3.14\,ft^2}$$

5. Calculate the cross-sectional area (in ft^2) for a 2 inch line that has just been laid.

$$\frac{2\,in \mid 1\,ft}{\mid 12\,in} = 0.1667\,ft$$

$$A = (0.785)(0.1667\,ft)^2$$
$$\boxed{= 0.02\,ft^2}$$

VOLUME

6. Calculate the volume (in ft^3) of a tank that measures 10 feet by 10 feet by 10 feet.

$$V = (\text{length})(\text{width})(\text{depth})$$
$$= (10\,ft)(10\,ft)(10\,ft)$$
$$\boxed{= 1000\,ft^3}$$

7. Calculate the volume (in gallons) of a basin that measures 22 feet by 11 feet by 5 feet deep.

$$V = (22\,ft)(11\,ft)(5\,ft)$$
$$= \frac{1210\,\cancel{ft^3}}{} \left| \frac{7.48\,gal}{1\,\cancel{ft^3}} \right.$$
$$= \boxed{9050.8\,gal}$$

8. Calculate the volume (in gallons) of water in a tank that is 254 feet long, 62 feet wide, and 10 feet deep if the tank only contains 2 feet of water.

$$V = (254\,ft)(62\,ft)(2\,ft)(7.48\,gal/ft^3)$$
$$= \boxed{235590\,gal}$$

9. Calculate the volume of water in a tank (in gallons) that is 12 feet long by 6 feet wide by 5 feet deep and contains 8 inches of water.

$$\frac{8\,\cancel{in}}{} \left| \frac{1\,ft}{12\,\cancel{in}} \right. = 0.66667\,ft \qquad V = (12\,ft)(6\,ft)(0.66667\,ft)(7.48\,gal/ft^3)$$
$$= \boxed{359.04\,gal}$$

10. Calculate the maximum volume of water (in gallons) for a kids' swimming pool that measures 6 feet across and can hold 18 inches of water.

$$\frac{18\,\cancel{in}}{} \left| \frac{1\,ft}{12\,\cancel{in}} \right. = 1.5\,ft \qquad Vol. = (0.785)(D)^2(\text{depth})$$
$$= (0.785)(6\,ft)^2(1.5\,ft)(7.48\,gal/ft^3)$$
$$= \boxed{317\,gal}$$

11. How much water (in gallons) can a barrel hold if it measures 3.5 feet in diameter and can hold water to a depth of 4 feet?

$$V = (0.785)(3.5\,ft)^2(4\,ft)(7.48\,gal/ft^3)$$
$$= \boxed{287.7\,gal}$$

12. A water main has just been laid and needs to be disinfected. The main is 30" in diameter and has a length of 0.25 miles. How many gallons of water will it hold?

$\frac{30\cancel{in} \mid 1\,ft}{\mid 12\cancel{in}} = 2.5\,ft$

$\frac{0.25\cancel{mi} \mid 5280\,ft}{\mid 1\cancel{mi}} = 1320\,ft$

$V = (0.785)(2.5\,ft)^2(1320\,ft)(7.48\,gal/ft^3)$

$= \boxed{48{,}442\,gal}$

13. A water main is 10" in diameter and has a length of 5,000 feet. How many million gallons of water will it hold?

$\frac{10\cancel{in} \mid 1\,ft}{\mid 12\cancel{in}} = 0.8333\,ft$

$V = (0.785)(0.8333\,ft)^2(5{,}000\,ft)(7.48\,gal/ft^3)$

$= 20388\,gal = \boxed{0.02\,MG}$

14. A 3 million gallon water tank needs to be disinfected. The method you will use requires you to figure 5% of the tank volume. How many gallons will this be?

5% of $3\,MG \Rightarrow (0.05)(3\,MG) = 0.15\,MG$

$= \boxed{150{,}000\,gal}$

15. What is 5% of a 1.2 MG tank?

$(0.05)(1.2\,MG) = \boxed{0.06\,MG \text{ or } 60{,}000\,gal}$

CONVERSIONS

16. How many seconds in 1 minute? 60 sec/min

17. How many minutes in 1 hour? 60 min/hr

18. How many hours in 1 day? 24 hr/d

19. How many minutes in 1 day? 1440 min/d

20. The flow through a pipe is 3.6 cfs. What is the flow in gps?

$$\frac{3.6\,\cancel{ft^3}}{sec}\Big|\frac{7.48\,gal}{1\,\cancel{ft^3}} = 26.9 \text{ gps}$$

21. The flow through a pipe is 2.4 cfs. What is the flow in gpm?

$$\frac{2.4\,\cancel{ft^3}}{\cancel{sec}}\Big|\frac{7.48\,gal}{1\,\cancel{ft^3}}\Big|\frac{60\,\cancel{sec}}{1\,min} = 1077 \text{ gpm}$$

22. A pump produces 22 gpm. How many cubic feet per hour is that?

$$\frac{22\,\cancel{gal}}{\cancel{min}}\Big|\frac{1\,ft^3}{7.48\,\cancel{gal}}\Big|\frac{60\,\cancel{min}}{1\,hr} = 176.5\ ft^3/hr$$

23. A treatment plant produces a flow of 6.31 MGD. What is the flow in gpm?

$$\frac{6.31\,\cancel{MG}}{1\,\cancel{D}}\Big|\frac{1{,}000{,}000\,gal}{1\,\cancel{MG}}\Big|\frac{1\,\cancel{D}}{1440\,min} = 4382 \text{ gpm}$$

24. A pump produces 700 gpm. How many MGD will the pump flow?

$$\frac{700\,\cancel{gal}}{\cancel{min}}\Big|\frac{1\,MG}{1{,}000{,}000\,\cancel{gal}}\Big|\frac{1440\,\cancel{min}}{1\,D} = 1.008 \text{ MGD}$$

25. A three-eights mile segment of pipeline is to be repaired. How many feet of pipeline is this?

$3/8 = 0.375$

$$\frac{0.375\,\cancel{mile}}{}\Big|\frac{5280\,ft}{1\,\cancel{mile}} = 1980\,ft$$

26. If there is a 2,200 gallon tank full of water, how many pounds of water is in the tank?

$$\frac{2{,}200\,\cancel{gal}}{}\Big|\frac{8.34\,lbs}{1\,\cancel{gal}} = 18{,}348 \text{ lbs}$$

Applied Math for Distribution
Flow Conversions

1. Express a flow of 5 cfs in terms of gpm.

$$\frac{5\ \cancel{ft^3}}{\cancel{sec}} \left| \frac{7.48\ gal}{1\ \cancel{ft^3}} \right| \frac{60\ \cancel{sec}}{1\ min} = \boxed{2244\ gpm}$$

2. What is 38 gps expressed as gpd?

$$\frac{38\ gal}{\cancel{sec}} \left| \frac{60\ \cancel{sec}}{1\ \cancel{min}} \right| \frac{1440\ \cancel{min}}{1\ d} = \boxed{3{,}283{,}200\ gpd}$$

3. Convert a flow of 4,270,000 gpd to cfm.

$$\frac{4{,}270{,}000\ \cancel{gal}}{\cancel{day}} \left| \frac{1\ ft^3}{7.48\ \cancel{gal}} \right| \frac{1\ \cancel{d}}{1440\ min} = \boxed{396\ ft^3/min}$$

4. What is 5.6 MGD expressed as cfs? (round to nearest tenth)

$$\frac{5.6\ \cancel{MG}}{\cancel{D}} \left| \frac{1{,}000{,}000\ \cancel{gal}}{1\ \cancel{MG}} \right| \frac{1\ ft^3}{7.48\ \cancel{gal}} \left| \frac{1\ \cancel{d}}{1440\ \cancel{min}} \right| \frac{1\ \cancel{min}}{60\ sec} = \boxed{8.7\ ft^3/sec}$$

5. Express 423,690 cfd as gpm.

$$\frac{423{,}690\ \cancel{ft^3}}{\cancel{d}} \left| \frac{7.48\ gal}{1\ \cancel{ft^3}} \right| \frac{1\ \cancel{d}}{1440\ min} = \boxed{2201\ gpm}$$

6. Convert 2730 gpm to gpd.

$$\frac{2730\ gal}{\cancel{min}} \left| \frac{1440\ \cancel{min}}{d} \right. = \boxed{3{,}931{,}200\ gal/d}$$

Applied Math for Collections
Flow and Velocity

Velocity

1. A cork is placed in a channel and travels 370 feet in 2 minutes. What is the velocity of the wastewater in the channel, ft/min?

$$\text{Vel.} = \frac{\text{distance, ft}}{\text{time}} = \frac{370\text{ ft}}{2\text{ min}} = \boxed{185\text{ ft/min}}$$

2. A float travels 300 feet in a channel in 2 minutes and 14 seconds. What is the velocity in the channel, ft/sec? 2 min + 14 sec = 134 seconds total

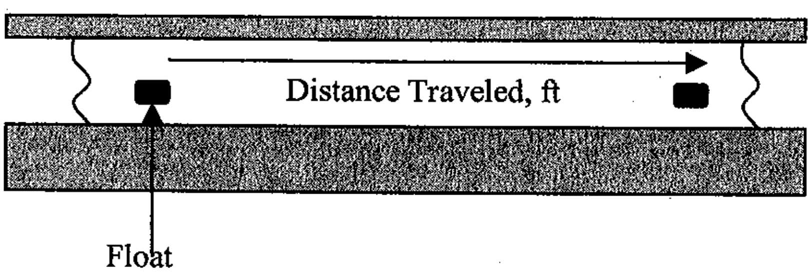
means we need time in seconds!!

$$\text{Vel} = \frac{300\text{ ft}}{134\text{ sec}} = \boxed{2.2\text{ ft/sec}}$$

3. The distance between manhole #1 and manhole #2 is 105 feet. A fishing bobber is dropped into manhole #1 and enters manhole #2 in 30 seconds. What is the velocity of the wastewater in the sewer in ft/min? 30 sec = 0.5 min

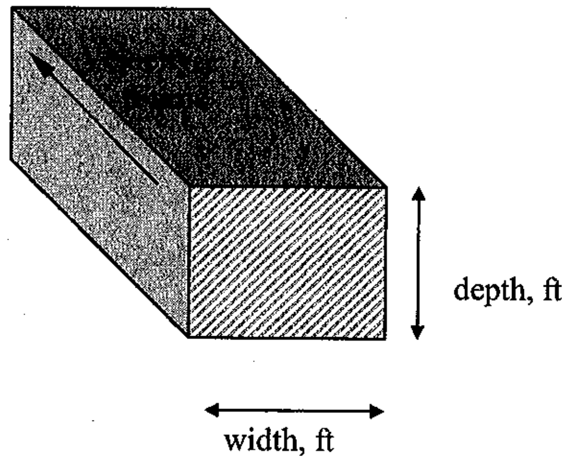
need time in minutes

$$\text{Vel} = \frac{105\text{ ft}}{0.5\text{ min}} = \boxed{210\text{ ft/min}}$$



$$\text{Velocity} = \frac{\text{Distance Traveled, ft}}{\text{Duration of Test, min}}$$

$$= \text{ft/min}$$



$$\underset{ft^3/time}{Q} = \underset{(ft)(ft)}{(A)} \quad \underset{(ft/time)}{(V)}$$

Flow in a channel

4. A channel 48 inches wide has water flowing to a depth of 1.5 feet. If the velocity of the water is 2.8 ft/sec, what is the flow in the channel in cu ft/sec?

w = 48 in = 4 ft
d = 1.5 ft
vel = 2.8 ft/sec

$Q = (w)(d)(vel)$
$= (4ft)(1.5ft)(2.8 ft/sec)$
$= \boxed{16.8\ ft^3/sec}$

5. A channel 3 feet wide has water flowing to a depth of 2.5 feet. If the velocity through the channel is 120 feet/min, what is the flow rate in cu ft/min? in MGD?

w = 3 ft
d = 2.5 ft
vel = 120 ft/min

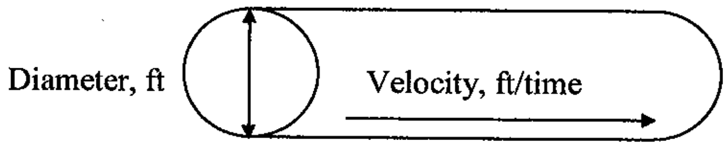
$Q = (3ft)(2.5ft)(120 ft/min) = \boxed{900\ ft^3/min}$

$\frac{(900 ft^3/min)(1440)(7.48)}{1,000,000} = \boxed{9.69\ MGD}$

6. A channel is 3 feet wide and has water flowing at a velocity of 1.5 ft/sec. If the flow through the channel is 8.1 ft^3/sec, what is the depth of the water in the channel in feet?

w = 3 ft
vel = 1.5 ft/sec
Q = 8.1 ft^3/sec

$Q = (w)(d)(vel)$
$\underset{ft^3/sec}{8.1} = \underset{ft}{(3)}\underset{ft}{(d)}\underset{ft/sec}{(1.5)}$
$8.1 = (4.5)(d)$
$\frac{8.1}{4.5} = d$
$\boxed{1.8 = d \text{ ft}}$



$$\underset{ft^3/time}{Q} = \underset{ft^2}{(A)} \quad \underset{(ft/time)}{(V)}$$

$$\underset{ft^3/time}{Q} = (0.785)\underset{(ft)(ft)}{(D)^2} \quad \underset{(ft/time)}{(vel)}$$

<u>Flow through full pipe</u>

7. The flow through a 2 ft diameter pipeline is moving at a velocity of 3.2 ft/sec. What is the flow rate in cu ft/sec?

D = 2 ft
vel = 3.2 ft/sec

$Q = (0.785)(D, ft)(D, ft)(vel)$
$= (0.785)(2 ft)(2 ft)(3.2 ft/sec)$
$= \boxed{10 \ ft^3/sec}$

8. The flow through a 6 inch diameter pipeline is moving at a velocity of 3 ft/sec. What is the flow rate in ft^3/sec?

D = 6 in = 0.5 ft
vel = 3 ft/sec

$Q = (0.785)(0.5 ft)(0.5 ft)(3 ft/sec)$
$= \boxed{0.59 \ ft^3/sec}$

9. An 8 inch diameter pipeline has water flowing at a velocity of 3.4 ft/sec. What is the flow rate in gpm?

D = 8 in = 0.6667 ft
vel = 3.4 ft/sec

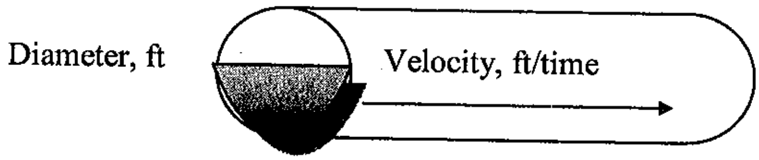
$Q = (0.785)(0.6667 ft)(0.6667 ft)(3.4 ft/sec)$
$= (1.1862 \ ft^3/sec)(60)(7.48) = \boxed{532 \ gpm}$

10. The flow through a pipe is 0.7 ft^3/sec. If the velocity of the flow is 3.6 ft/sec, and the pipe is flowing full, what is the diameter of the pipe in inches?

Q = 0.7 ft^3/sec
vel = 3.6 ft/sec

$Q = (0.785)(D, ft)(D, ft)(vel)$
$0.7 = (0.785)(D^2)(3.6)$
$0.7 = (2.826)(D^2)$
$\frac{0.7}{2.826} = D^2$
$\sqrt{0.25} = D^2$

0.50 = D
ft not inches
$\boxed{6 in} = 0.5 ft$



$$\underset{ft^3/time}{Q} = \underset{ft^2}{(A)} \quad \underset{(ft/time)}{(V)}$$

$$\underset{ft^3/time}{Q} = \text{(Factor from d/D Table)} \overbrace{\underset{(ft)(ft)}{(D)^2} \quad \underset{(ft/time)}{(vel)}}$$

<u>Flow through pipe flowing less than full</u>

11. A 12-inch diameter pipeline has water flowing at a depth of 6 inches. What is the gpm flow if the velocity of the wastewater is 300 fpm?

D = 12 in = 1 ft
d = 6 in
vel = 300 ft/min

$Q = (0.3927)(1\,ft)(1\,ft)(300\,ft/min)$
$= (117.81\,ft^3/min)(7.48) = \boxed{881\ gpm}$

$d/D = 6/12 = 0.5 \Rightarrow$ 0.3927 on chart

12. A 10-inch diameter pipeline has water flowing at a velocity of 3.2 fps. What is the gpd flow rate if the water is at a depth of 5 inches?

D = 10 in = 0.8333 ft
d = 5 in
vel = 3.2 ft/sec

$Q = (0.3927)(0.8333\,ft)(0.8333\,ft)(3.2\,ft/sec)$
$= (0.8727\,ft^3/sec)(60)(1440)(7.48)$
$= \boxed{563{,}980\ gpd}$

$d/D = 5/10 = 0.5 \Rightarrow$ 0.3927 on chart

13. An 8-inch pipeline has water flowing to a depth of 5 inches. If the flow rate is 415.85 gpm, what is the velocity of the wastewater in fpm? min – means flow needs to be in ft^3/min

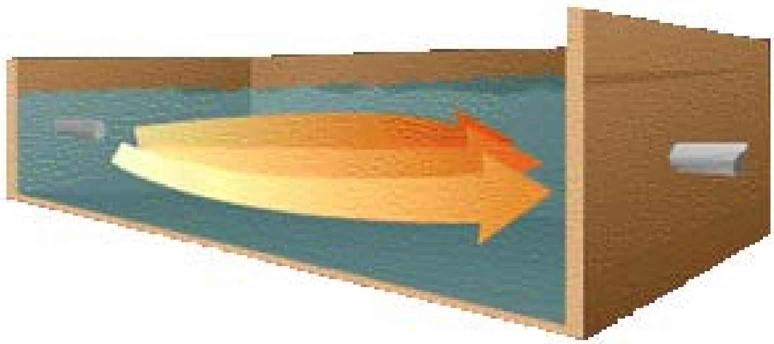
D = 8 in = 0.6667 ft
d = 5 in.

$Q = \frac{415.85\,gpm}{7.48} = 55.5949\ ft^3/min$

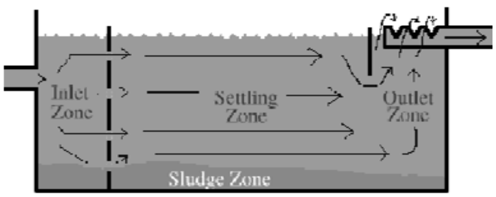
$d/D = 5/8 = 0.625 \approx 0.63 \Rightarrow$ 0.5212 on chart

$Q = (d/D\ \text{number})(D, ft)(D, ft)(vel)$
$55.5949\ ft^3/min = (0.5212)(0.6667\,ft)(0.6667\,ft)(vel)$
$55.5949 = (0.2316)(vel)$
$\frac{55.5949}{0.2316} = vel$
$\boxed{240\ ft/min = vel}$

Section 5
Sedimentation



Sedimentation & Flotation



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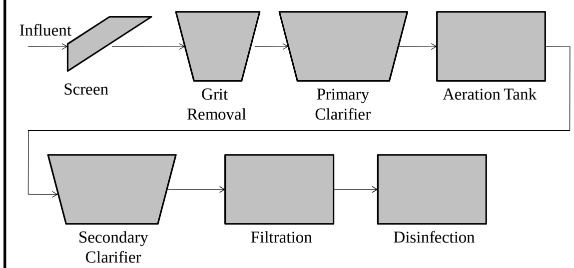
Wastewater Process Overview



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Sedimentation & Floatation

- Raw or untreated wastewater contains materials that easily settle to the bottom or float to the surface when the velocity is slowed
- Collection systems are designed to maintain a certain velocity to keep solids from settling out

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Sedimentation

- Settling of solids out of suspension due to gravity. Suspended particles include:
  - clay, silt, particles in natural state particles modified by treatment (biological floc/sloughings)
- Occurs in a rectangular, square or round basin.

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Sedimentation

- Water flows slowly though the basin with as little turbulence and short-circuiting as possible.
- Floatables (scum) removed at surface
- Sludge collects at the bottom of the basin.

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Sedimentation

- Other common names:
  - Settling tank
  - Sedimentation tank
  - Clarifier

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Factors Affecting Sedimentation

- Temperature
- Short circuits
- Detention time
- Weir overflow rates
- Surface loading rate
- Solids loading
- Toxic waste
- Storm flows
- Septic flows from collection system

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Temperature

- As water temperature increases, the settling of particles increases.
- As the water temperature decreases, so does the settling rate.

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Short Circuiting

- As wastewater enters a clarifier the flow should be dispersed evenly across the entire tank and should flow at the same velocity in all areas toward the outlet.
- Short circuiting may occur when the velocity is greater in some sections than others
  - Can be prevented by weir plates, port openings and proper design of the inlet channel

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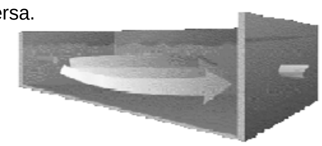
Short Circuiting

- Short circuiting also may be caused by turbulence and stratification due to temperature differences
- Different layers with different temperatures can cause short-circuiting when a warm influent flows across the top of cold water and vise-versa.



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Detention Time

- Wastewater should remain in the clarifier long enough to allow enough settling for solid particles to fall out
- Detention times are usually 2.0 to 3.0 hours

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Primary Clarifiers

- Immediately follows bar screen or grit chamber
- First clarifier in plant
  - TN Design Criteria says trickling filters will have one
- Some plants don't have one of these
- Sludge tends to be more dense
  - The primary clarifier settled sludge is wasted to the digesters, which puts a tremendous load of untreated volatile organic food to the digester

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Primary Clarifiers

- Long detention times cause:
  - Solids to become septic
  - Solids to float to the surface
  - High suspended solids level in primary effluent
  - Odors in primary effluent

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Primary Clarifiers

Water Quality Indicator	Expected Removal Efficiency
Settleable Solids	95 – 99 %
Suspended Solids	40 – 60 %
Total Solids	10 – 15 %
BOD	20 – 50 %
Bacteria	25 – 75 %

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Primary Clarifier

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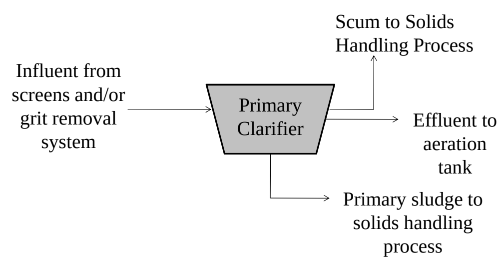
Primary Clarification



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Secondary Clarifiers

- Follows all other treatment processes
- Also called final clarifier
- Cleaner effluent than primary effluent
- Be sure to remove enough solids that are accumulating on the bottom before it becomes septic or gasification occurs

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Trickling Filter Clarifiers

- Settles out sloughings
- Loading rates for secondary clarifiers used after trickling filters:
  - Detention time – 2.0 to 3.0 hours
  - Surface loading – 800 to 1200 gpd/ft^2
  - Weir overflow – 5,000 to 15,000 gpd/ft

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Activated Sludge Clarifiers

- Designed to handle large volumes of sludge
- Loading rates for secondary clarifiers used after activated sludge:
  - Detention time – 2.0 to 3.0 hours
  - Surface loading – 300 to 1200 gpd/ft^2
  - Weir overflow – 5,000 to 15,000 gpd/ft
  - Solids loading – 24 to 30 lbs/day/ft^2

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Activated Sludge Clarifiers

- SVI indicates settleability:
  - SVI>100: light, fluffy; cone shaped blanket
  - SVI<100: more dense; bell shaped blanket
  - Desirable: 50-150 mL/g
- RAS to aeration tank & WAS to solids handling

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Gasification

- Denitrification is happening at the bottom of the clarifier and nitrogen gas bubbles are carrying up the sludge

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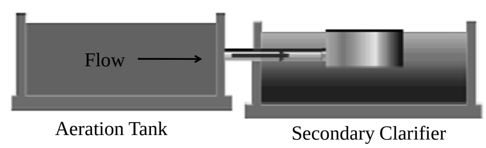
Activated Sludge Process Diagram



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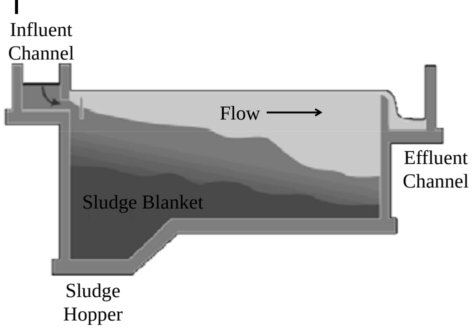
Rectangular Clarifier



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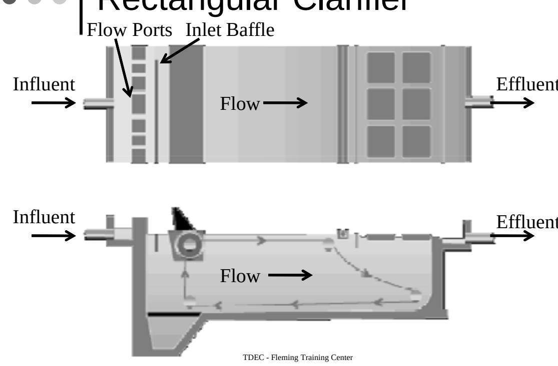
Rectangular Clarifier



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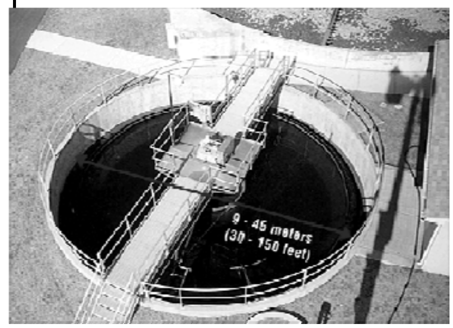
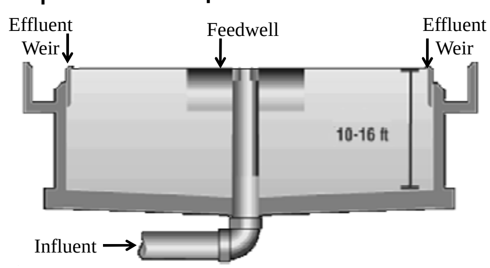
Wooden Baffles

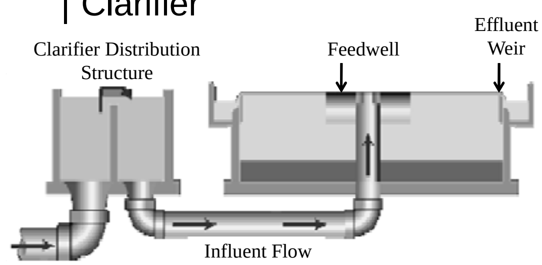
Circular Clarifier



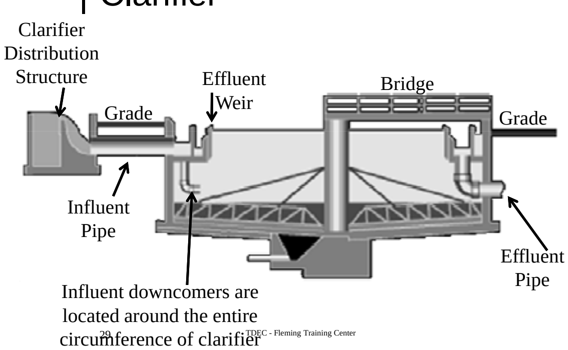
Circular Clarifier – Side Water Depth



Center-Feed Circular Clarifier



Peripheral-Feed Circular Clarifier



Feedwell

Effluent Launder

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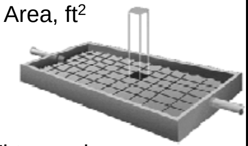
Overflow Flow Rate

- Surface Overflow Rate
  - SOR, gpd/ft^2 = $\frac{\text{Flow, gpd}}{\text{Area, ft}^2}$
- Weir Overflow Rate
  - WOR, gpd/ft = $\frac{\text{Flow, gpd}}{\text{Weir Length, ft}}$



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Solids Loading Rate and Detention Times

- SLR, lbs/day/ft^2 = $\frac{\text{(MLSS, mg/L)(Flow, MGD)(8.34)}}{\text{(0.785)(Diameter, ft)}^2}$
- DT, hrs = $\frac{\text{(Volume of Tank, gal)(24)}}{\text{Flow, gpd}}$

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Uneven Split of Flow

- The causes of uneven flow splitting include:
  - Poor design
  - Improper retrofit modifications

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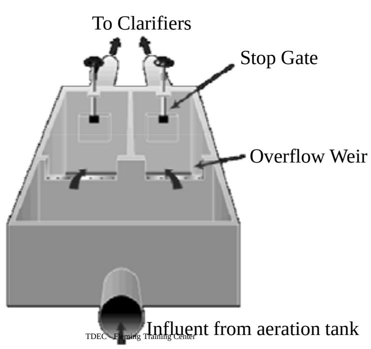
Distribution Box



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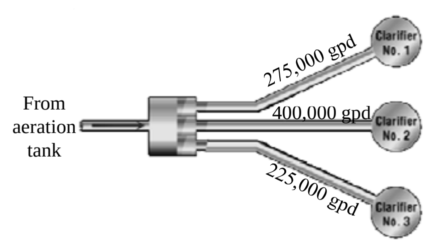
Uneven Flow



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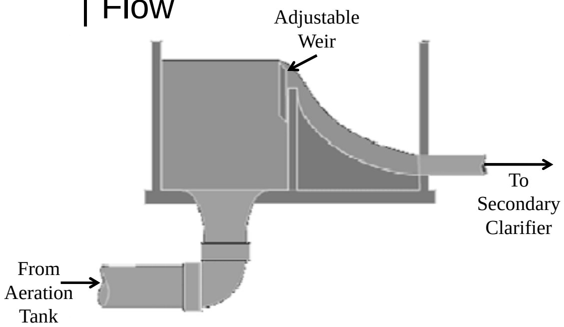
Cross Section of Clarifier Flow



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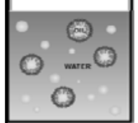
Dissolved Air Flotation



- Colloids and emulsions are two forms of solids that are difficult to remove by sedimentation
  - Colloids are very small, finely divided solids that remain dispersed in liquid for a long time
  - An emulsion is a liquid mixture of two or more liquid substances not normally dissolved in one another
    - Usually grease, oil or fat

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Dissolved Air Flotation

- Vacuum flotation
  - Aerated until saturated with dissolved air
  - Vacuum chamber then pulls air out and solids travel up with air bubbles
- Pressure flotation
  - Air is forced into wastewater
  - Dissolved air is then released because of change in pressure and solids are carried up with air bubbles

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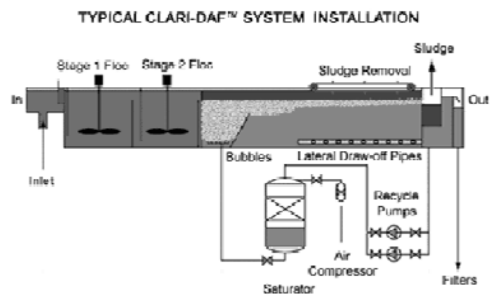
Pressure Flotation



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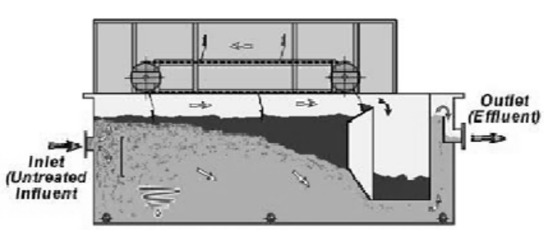
Dissolved Air Flotation



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Factors Effecting DAFs

- Type of sludge: heavier primary sludges harder to treat
- Age of feed sludge: older sludges float more readily
- Solids loading: 10-24 lbs/day/ft^2

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Factors Effecting DAFs

- Hydraulic loading: 0.5-1.5 gpm/ft^2
- Air to solids ratio: 0.01-0.10 lb/lb
- Recycle rate: 100-200%
- Blanket depth: decreasing scraper speed concentrates sludge

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Clarifier Solids Removal

- The mechanisms for clarifier solids removal include:
  - Mechanical transport
    - Continuous flight (chain and flight)
    - Traveling bridge
  - Siphon removal
  - Suction removal

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Mechanical Solids Removal

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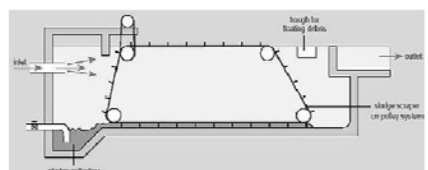
Chain and Flight

- Rectangular Basins – motor drives chain that pulls flight across basin floor, sweeps sludge to end of basin



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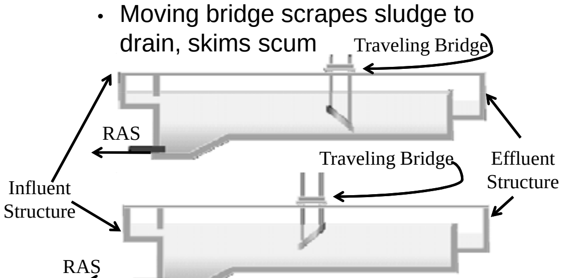
Traveling Bridge

- Moving bridge scrapes sludge to drain, skims scum



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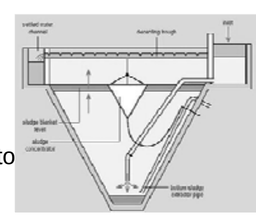
Floating Bridge Siphon Collector

- Uses suction pipes or submersible pump to withdraw sludge from basin
- Basin does not have to be taken out of service to clean



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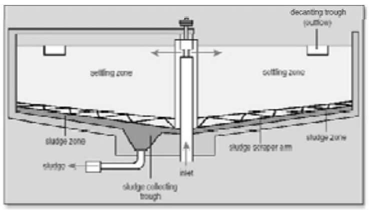
Circular or Square Basins

- Scrapers slant downward to center of basin
- Basin does not have to be taken out of service to clean



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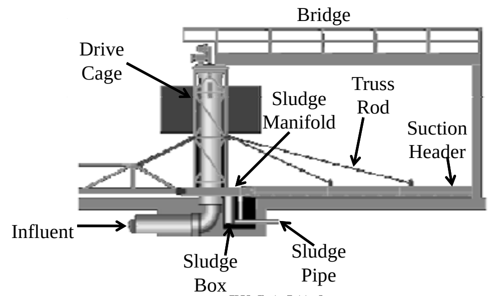
Solids Removal by Suction



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Scum

- Collected scum should be processed with the waste and primary sludges

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Scum Baffles

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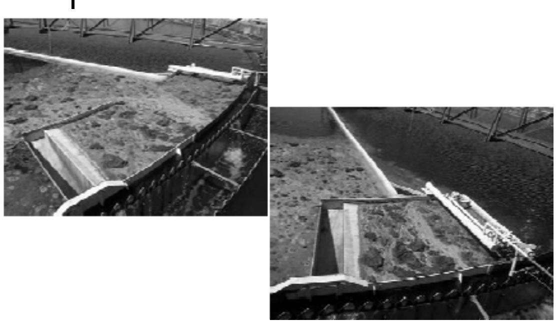
Scum Skimmer



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Scum Skimmer

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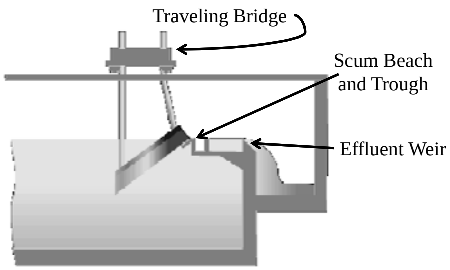
Scum Removal for Traveling Bridge



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Clarifier Monitoring

- Clarifier monitoring and control systems include sludge blanket monitoring and drive mechanism torque control.
- The continuous data being provided by these systems are very useful for process control.

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Clarifier Monitoring

- Sludge blanket levels
- Suspended solids concentration in clarifier effluent
- Control of return sludge flows
- Turbidity in clarifier effluent
- DO levels in clarifier effluent
- pH

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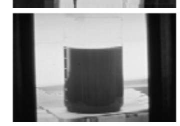
Monitoring the Process

- Primary clarifier: Imhoff cone
- Secondary clarifier: Settleometer; centrifuge spins
- Turbidity test also
- Visually checking for floc carry-over
- Visual check of how far floc particles are visible from inlet



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Manual Measurement of Sludge Blanket Depth

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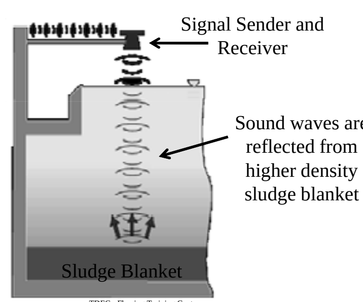
Sonic Measurement of Sludge Blanket Depth



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Flow Management

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Flow Management

- Activated sludge system components are sized for a specific design flow.
- Clarifiers can become overloaded

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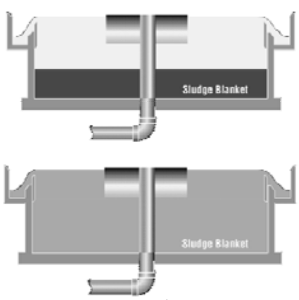
Clarifier "Washout"



Normal Clarifier

Clarifier "Washing Out"

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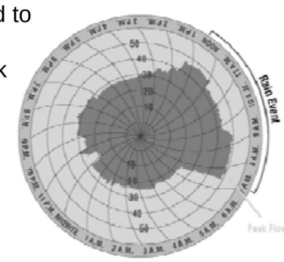
Peak Flows

- Operators need to minimize the impacts of peak flows on plant performance.



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Flow Management

- Operators must use:
  - Past history;
    - "March snow melts"
    - "August thunderstorms"
  - Weather forecasts
    - "Hurricane Henry to hit"
- to help them predict when high flows may occur.

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Flow Management

- High flows can be managed by using:
  - Flow-equalization basins
  - Storage lagoons
  - Alternate process modes such as contact stabilization or step feed.

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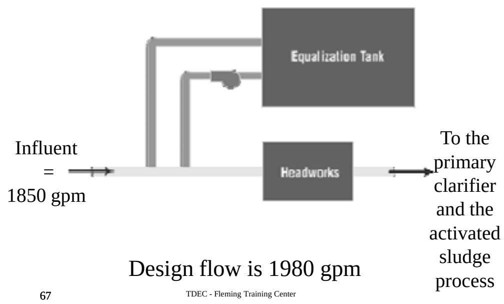
Flow Management



Design flow is 1980 gpm

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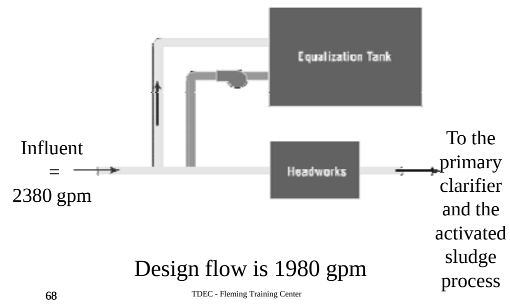
Flow Management



Design flow is 1980 gpm

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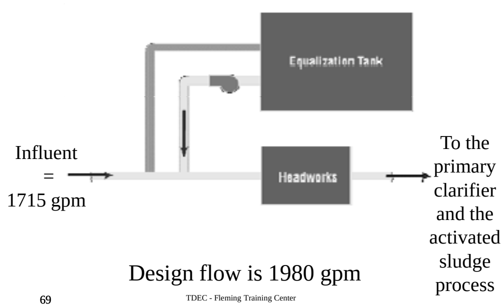
Flow Management



Design flow is 1980 gpm

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Flow Management

- Some plants have storage lagoons for wet weather flows.
- Stored wastewater is pumped to the head of the plant when flow rates decrease.

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CHAPTER 5

Clarifiers

5.1 General Criteria

5.1.1 Purpose
5.1.2 Number of Units
5.1.3 Arrangements
5.1.4 Tank Configurations
5.1.5 Flow Distribution

5.2 Design Loading

5.2.1 Primary Clarifiers
5.2.2 Intermediate Clarifiers
5.2.3 Final Clarifiers
5.2.4 Weir Loading Rates
5.2.5 Depth/Detention Time

5.3 Design Details

5.3.1 Inlets
5.3.2 Submerged Surfaces
5.3.3 Weir Troughs
5.3.4 Freeboard

5.4 Sludge and Scum Removal

5.4.1 Scum Removal
5.4.2 Sludge Removal
5.4.3 Sludge Removal Piping
5.4.4 Sludge Removal Control
5.4.5 Sludge Hopper

5.5 Protective and Service Facilities

5.5.1 Operator Protection
5.5.2 Mechanical Maintenance Access
5.5.3 Electrical Fixtures and Controls

5.6 Operability, Flexibility, and Reliability

5.6.1 Scum Removal
5.6.2 Overflow Weirs
5.6.3 Unit Dewatering
5.6.4 Hydraulics
5.6.5 Sludge Removal
5.6.6 Other Design Considerations

CLARIFIERS

5.1 General Criteria

5.1.1 Purpose

Clarifiers (sedimentation basins, settling tanks) are designed to perform three (3) functions in a treatment scheme:

A. Remove solids from liquids by sedimentation
B. Remove scum from liquid by flotation
C. Thicken solids for removal and further treatment

Specific application of clarifier functions will be dependent upon the treatment process employed. This chapter does not attempt to set criteria for all types of clarifiers. If a unique clarifier is proposed, the design engineer shall submit operational and design data justifying its use.

5.1.2 Number of Units

Multiple units capable of independent operation shall be provided in all facilities where design flows exceed 250,000 gallons per day. Otherwise, the number of units required shall satisfy reliability requirements (see Section 1.3.11). Facilities not having multiple units shall include other methods to assure adequate operability and flexibility of treatment.

5.1.3 Arrangements

Clarifiers shall be arranged for greatest operating and maintenance convenience, flexibility, economy, continuity of maximum effluent quality, and ease of installation of future units.

5.1.4 Tank Configurations

Consideration should be given to the probable flow pattern in the selection of tank size and shape and inlet and outlet type and location.

5.1.5 Flow Distribution

Effective flow measuring devices and control appurtenances (i.e., valves, gates, splitter boxes, etc.) shall be provided to permit proper proportion of flow to each unit (see Section 13.2.1).

5.2 Design Loading

5.2.1 Primary Clarifiers

Primary clarifier designs are primarily based upon surface overflow rate. The following criteria are recommended for
design:

Hydraulic Loading Rate	Surface Overflow Rate
Average Design Flow	800-1200 gpd/sq. ft.
Peak Design Flow	2000-3000 gpd/sq. ft.

If WAS is returned to the primary then

Hydraulic Loading Rate	Surface Overflow Rate

Average Design Flow	600-800 gpd/sq. ft.
Peak Design Flow	1200-1500 gpd/sq. ft.

Primary clarifier sizing shall be calculated for both flow conditions and the larger surface area derived shall be utilized. A properly designed primary clarifier should remove 30 to 35% of the influent BOD. However, anticipated BOD removal for wastewater containing high quantities of industrial wastewater should be determined by laboratory tests and considerations of the quantity and characteristics of the wastes.

5.2.2 Intermediate Clarifiers

Surface overflow rates for intermediate clarifiers should be based upon the following criteria:

Hydraulic Loading Rate	Maximum Surface Overflow Rate
Average Design Flow	1000 gpd/sq. ft.
Peak Design Flow	2500 gpd/sq. ft.

5.2.3 Final Clarifiers

Final clarifier designs shall be based upon the type of secondary treatment application used. Surface overflow and solids loading rates shall be the general basis for clarifier designs. Pilot studies of biological treatment is recommended when unusual wastewater characteristics are evident or when the proposed loading exceeds those noted in this section.

Table 5-1 depicts the criteria established for final clarifier surface overflow and solids loading rates. In activated sludge systems, the surface overflow rate for final clarifiers should be based on influent wastewater flows and not include return activated sludge flows (RAS). Solids loading rate criteria assume sludge recycle is 100% of the average design flow and the design mixed liquor suspended solids (MLSS) concentration.

TABLE 5-1
FINAL CLARIFIER DESIGN PARAMETERS

Type of Process	Maximum Surface Overflow Rate gpd/sq. ft.		Solids Loading Rate lb/day/sq. ft.	
	Average Design Flow	Peak Design Flow	Average Design Flow	Peak Design Flow
Trickling Filter	600	1200	25	40
Activated Sludge	800 (600 for plants less than 1 MGD)	1200	30	50
Extended Aeration	400	1000	25	35
Nitrification	400	800	25	35
Pure Oxygen	700	1200	25	40

5.2.4 Weir Loading Rates

Weir loadings should not exceed 15,000 gallons per day per linear feet (gpd/li ft).

5.2.5 Depth/Detention Time

The sidewater depth (SWD) for clarifier designs associated with design surface overflow rates should dictate the hydraulic detention time of the clarifier. For design purposes, the following criteria in Table 5-2 are established specific to clarifier application:

TABLE 5-2
CLARIFIER DEPTH

Type of Process	Diameter (ft)	Minimum Sidewater Depth (ft)
*Primary	-	8
Trickling Filter	-	10
**Activated Sludge	less than 40	11
	40 - 70	12
	71 - 100	13
	101 - 140	14
	over 140	15

*The hydraulic detention time in primary clarifiers is not recommended to be greater than 2.5 hours as a function of the surface overflow rate and SWD, since septic conditions resulting in poor performance and odor conditions can occur.

**For rectangular-shaped clarifiers following activated sludge treatment, the recommended SWD shall be no less than 12 feet at the shallow end.

5.3 Design Details

5.3.1 Inlets

Inlets should be designed to dissipate the influent velocity, to distribute the flow equally in both the horizontal and vertical vectors, and to prevent short-circuiting. Channels should be designed to maintain an inlet velocity of at least one (1) foot per second at one-half the design flow. Corner pockets and dead ends should be eliminated and corner fillets or channeling used where necessary. Provisions shall be made for elimination or removal of floating materials in inlet structures having submerged ports.

5.3.2 Submerged Surfaces

The tops of troughs, beams, and similar submerged construction elements shall have a minimum slope of 1.75 vertical to 1 horizontal. The underside of such structures should have a slope of 1 to 1 to prevent accumulation of scum and solids.

5.3.3 Weir Troughs

Weir troughs shall be designed to prevent submergence at maximum design flow, and to maintain a velocity of at least one (1) foot per second at one-half design flow.

5.3.4 Freeboard

Walls of clarifiers shall extend at least six (6) inches above the surrounding ground surface and shall provide not less than twelve (12) inches of freeboard.

5.4 Sludge and Scum Removal

5.4.1 Scum Removal

Effective scum collection and removal facilities, including baffling ahead of the outlet weirs, shall be provided for all clarifiers. Provisions may be made for discharge of scum with sludge; however, other provisions may be necessary to dispose of floating materials which may adversely affect sludge handling and disposal. The unusual characteristics of scum which may adversely affect pumping, piping, sludge handling and disposal, should be recognized in the design. Scum piping should be glass lined or equivalent. Precautions should be taken to minimize water content in the scum.

5.4.2 Sludge Removal

Sludge collection and withdrawal facilities shall be designed to assure rapid removal of the sludge. Provisions shall be made to permit continuous sludge removal from settling tanks. Final clarifiers in activated sludge plants shall be provided with positive scraping devices. Suction withdrawal should be provided for activated sludge plants designed for the reduction of nitrogenous oxygen demand.

5.4.3 Sludge Removal Piping

Each sludge hopper shall have an individually valved sludge withdrawal line at least six (6) inches in diameter if pumped and at least eight (8) inches in diameter if gravity flow is used. This does not apply to air lift methods of sludge removal, as this should be determined by the sludge removal rate. Static head available for sludge withdrawal shall be at least thirty (30) inches, as necessary, to maintain a three (3) feet per second velocity in the withdrawal pipe. Clearance between the end of the withdrawal line and the hopper walls shall be sufficient to prevent "bridging" of the sludge. Adequate provisions shall be made for rodding or back-flushing individual pipe runs.

***Air lift type sludge removal will not be approved for removal of primary sludges.

5.4.4 Sludge Removal Control

Sludge wells equipped with telescoping valves or other appropriate equipment shall be provided for viewing, sampling and controlling the rate of sludge withdrawal. A means for measuring the sludge removal rate and sludge return rate shall be provided. Sludge pump motor control systems shall include time clocks and valve activators for regulating the duration and sequencing of sludge removal. Gravity flow systems should have back-up pumping capabilities.

5.4.5 Sludge Hopper

The minimum slope of the side walls shall be 1.75 vertical to 1 horizontal. Hopper wall surfaces should be made smooth with rounded corners to aid in sludge removal. Hopper bottoms shall have a maximum dimension of two (2) feet. Extra-depth sludge hoppers for sludge thickening are not acceptable.

5.5 <u>Protective and Service Facilities</u>

5.5.1 Operator Protection

All clarifiers shall be equipped to enhance safety for operators. Such features shall appropriately include machinery cover lift lines, stairways, walkways, handrails and slip-resistant surfaces.

5.5.2 Mechanical Maintenance Access

The design shall provide for convenient and safe access to routine maintenance items such as gear boxes, scum removal mechanisms, baffles, weirs, inlet stilling baffle area, and effluent channels.

5.5.3 Electrical Fixtures and Controls

Electrical fixtures and controls in enclosed settling basins shall meet the requirement of the National Electrical Code. The fixtures and controls shall be located so as to provide convenient and safe access for operation and maintenance. Adequate area lighting shall be provided.

5.6 <u>Operability, Flexibility, and Reliability</u>

5.6.1 Scum Removal

5.6.1.1 A method of conveying scum across the water surface to a point of removal should be considered, such as water or air spray. Baffles should be designed to ensure capture of scum at minimum and maximum flow rates.

5.6.1.2 Facilities designed for flows of 0.1 MGD and greater should have mechanical scum removal equipment.

5.6.1.3. Scum holding tanks may be provided, with a method of removing excess water.

5.6.1.4 Large scum sumps should have a mixing device (pneumatic, hydraulic, or mechanical) to keep the scum mixed while being pumped.

5.6.1.5 Manual scum pump start-stop switches should be located adjacent to scum holding tanks.

5.6.2 Overflow Weirs

5.6.2.1 Since closely spaced multiple overflow weirs tend to increase hydraulic velocities, their spacing should be conservative.

5.6.2.2 Center-feed, peripheral draw-off clarifiers shall not have the overflow weir against the clarifier sidewall. Weir placement shall be 1/10 diameter or greater toward the center.

5.6.2.3 The up-flow rate shall not be greater than the surface overflow rate at any location within the solids separation zone of a clarifier.

5.6.2.4 Overflow weirs should be of the notched type; straight edged weirs will not be approved.

5.6.2.5 Overflow weirs shall be adjustable for leveling.

5.6.3 Unit Dewatering

5.6.3.1 The capacity of dewatering pumps should be such that the basin can be dewatered in 24 hours; eight hours is preferable.

5.6.3.2 The contents of the basin should be discharged to the closest process upstream from the unit being dewatered that can accept the flow.

5.6.3.3 Consideration shall be given to the need for hydrostatic pressure relief devices to prevent flotation of structures.

5.6.4 Hydraulics

5.6.4.1 Lift/pump stations located immediately upstream of secondary clarifiers shall have flow-paced controls to reduce shock loadings.

5.6.4.2 Square clarifiers with circular sludge withdrawal mechanisms shall be designed such that corner hydraulic velocities do not cause sludge carry-over.

5.6.5 Sludge Removal

5.6.5.1 When two or more clarifiers are used, provisions shall be made to control and measure the rate of sludge withdrawal from each clarifier.

5.6.5.2 Consideration should be given to removing activated sludge from the effluent end of rectangular clarifiers.

5.6.5.3 Consideration shall be given to chlorination of return activated sludge and digester supernate. Sufficient mixing and contact time should be provided.

5.6.6 Other Design Considerations

5.6.6.1 Designs should consider the possible need for future modifications to add chemicals such as flocculants.

5.6.6.2 A method of foam control should be considered for all inlet channels and feed wells in activated sludge systems.

Applied Math for Wastewater Treatment
Sedimentation

1. The flow to a circular clarifier is 3,940,000 gpd. If the clarifier is 75 ft in diameter and 12 feet deep, what is the clarifier detention time in hours? (Round to the nearest tenth.)

2. A circular clarifier has a diameter of 50 feet. If the primary clarifier influent flow is 2,260,000 gpd, what is the surface overflow rate in gpd/sq.ft.?

3. A rectangular clarifier has a total of 210 ft. of weir. What is the weir overflow rate in gpd/ft when the flow 3,728,000 gpd?

4. A secondary clarifier, 55-ft in diameter, receives a primary effluent flow of 1,887,000 gpd and a return sludge flow of 528,000 gpd. If the MLSS concentration is 2640 mg/L, what is the solids loading rate in lbs/day/sq.ft. on the clarifier? (Round to the nearest tenth.)

5. A circular primary clarifier has a diameter of 60 feet. If the influent flow to the clarifier is 2.62 MGD, what is the surface overflow rate in gpd/sq.ft.?

6. A secondary clarifier, 70 feet in diameter, receives a primary effluent flow of 2,740,000 gpd and a return sludge flow of 790,000 gpd. If the mixed liquor suspended solids concentration is 2815 mg/L, what is the solids loading rate in the clarifier in lbs/day/sq.ft.? (Round to the nearest tenth.)

7. The flow to a secondary clarifier is 5.1 MGD. If the influent BOD concentration is 216 mg/L and the effluent BOD concentration is 103, how many lbs/day BOD are removed daily?

8. The flow to a sedimentation tank 80 feet long, 30 feet wide and 14 feet deep is 4.05 MGD. What is the detention time in the tank, in hours? (Round to the nearest tenth.)

Answers:

1. 2.4 hours
2. 1152 gpd/sq.ft.
3. 17,752 gpd/ft
4. 22.4 lbs/day/sq.ft.
5. 927 gpd/sq.ft.
6. 21.5 lbs/day/sq.ft.
7. 4806 lbs/day
8. 1.5 hrs

Section 5

Applied Math for Wastewater Treatment
Sedimentation

1. The flow to a circular clarifier is 3,940,000 gpd. If the clarifier is 75 ft in diameter and 12 feet deep, what is the clarifier detention time in hours? (Round to the nearest tenth.)

$$\text{Detention Time, hrs} = \frac{(\text{Vol, gal})(24\ \text{hr/day})}{\text{Flow, gpd}}$$

$$\text{Vol.} = (0.785)(75\text{ft})^2(12\text{ft})(7.48) = 396346.5\ \text{gal}$$

$$= \frac{(396346.5\ \text{gal})(24)}{3{,}940{,}000\ \text{gpd}} = \boxed{2.4\ \text{hrs}}$$

2. A circular clarifier has a diameter of 50 feet. If the primary clarifier influent flow is 2,260,000 gpd, what is the surface overflow rate in gpd/sq.ft.?

$$\text{SOR, gpd/ft}^2 = \frac{\text{flow, gpd}}{\text{area, ft}^2}$$

$$= \frac{2{,}260{,}000\ \text{gpd}}{(0.785)(50\text{ft})^2} = \boxed{1151.6\ \text{gpd/ft}^2}$$

3. A rectangular clarifier has a total of 210 ft. of weir. What is the weir overflow rate in gpd/ft when the flow 3,728,000 gpd?

$$\text{WOR, gpd/ft} = \frac{\text{flow, gpd}}{(2)(l,\text{ft}) + (2)(w,\text{ft})} \quad \text{or} \quad \frac{\text{flow, gpd}}{\text{weir length, ft}}$$

$$= \frac{3{,}728{,}000\ \text{gpd}}{210\ \text{ft}} = 17{,}752\ \text{gpd/ft}$$

4. A secondary clarifier, 55-ft in diameter, receives a primary effluent flow of 1,887,000 gpd and a return sludge flow of 528,000 gpd. If the MLSS concentration is 2640 mg/L, what is the solids loading rate in lbs/day/sq.ft. on the clarifier? (Round to the nearest tenth.)

$$\text{SLR, lbs/day/ft}^2 = \frac{(\text{MLSS, mg/L})(\text{P.E.} + \text{RAS flow, MGD})(8.34)}{(0.785)(D,\text{ft})^2}$$

$$= \frac{(2640\ \text{mg/L})(\overbrace{1.887 + 0.528}^{2.415}\ \text{MGD})(8.34)}{(0.785)(55\text{ft})^2}$$

$$= \frac{53172.504\ \text{lbs/day}}{2374.625\ \text{ft}^2} = 22.4\ \text{lbs/day/ft}^2$$

Section 5

5. A circular primary clarifier has a diameter of 60 feet. If the influent flow to the clarifier is 2.62 MGD, what is the surface overflow rate in gpd/sq.ft.?

$$SOR, gpd/ft^2 = \frac{2{,}620{,}000 \text{ gpd}}{(0.785)(60 ft)^2}$$

$$= \boxed{927 \text{ gpd}/ft^2}$$

6. A secondary clarifier, 70 feet in diameter, receives a primary effluent flow of 2,740,000 gpd and a return sludge flow of 790,000 gpd. If the mixed liquor suspended solids concentration is 2815 mg/L, what is the solids loading rate in the clarifier in lbs/day/sq.ft.? (Round to the nearest tenth.)

$$SLR, lbs/day/ft^2 = \frac{(2815 \text{ mg/L})(\overbrace{2.74 + 0.79}^{3.53} \text{ MGD})(8.34)}{(0.785)(70 ft)^2}$$

$$= \frac{82874.163 \text{ lbs/day}}{3846.5 ft^2} = \boxed{21.5 \text{ lbs/d/ft}^2}$$

7. The flow to a secondary clarifier is 5.1 MGD. If the influent BOD concentration is 216 mg/L and the effluent BOD concentration is 103, how many lbs/day BOD are removed daily?

$$\text{Removed} = \text{Influent} - \text{Effluent} = 216 \text{ mg/L} - 103 \text{ mg/L} = 113 \text{ mg/L}$$

$$lbs/d = (\text{Removed, mg/L})(\text{Flow, MGD})(8.34)$$

$$= (113 \text{ mg/L})(5.1 \text{ MGD})(8.34) = \boxed{4806 \text{ lbs/d}}$$

8. The flow to a sedimentation tank 80 feet long, 30 feet wide and 14 feet deep is 4.05 MGD. What is the detention time in the tank, in hours? (Round to the nearest tenth.)

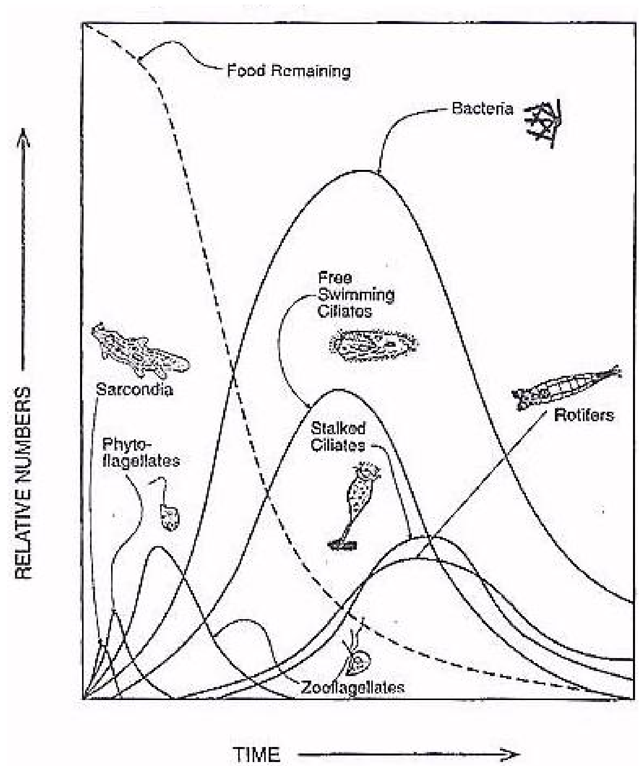
$$DT, hrs = \frac{(80 ft)(30 ft)(14 ft)(7.48)(24)}{4{,}050{,}000 \text{ gpd}}$$

$$= \boxed{1.5 \text{ hrs}}$$

Answers:

1. 2.4 hours
2. 1152 gpd/sq.ft.
3. 17,752 gpd/ft
4. 22.4 lbs/day/sq.ft.
5. 927 gpd/sq.ft.
6. 21.5 lbs/day/sq.ft.
7. 4806 lbs/day
8. 1.5 hrs

Section 6
Activated Sludge



Activated Sludge

Intro to Wastewater

Activated Sludge Process

- This fundamental process is the heart of activated sludge treatment.
- Organics + O_2 + nutrients + inert matter → CO_2 + H_20 + new microorganisms + additional inert matter

Design Parameters for Various Activated Sludge Processes

Process	MCRT, days	F:M ratio, lbs BOD applied/d / lb MLVSS	MLSS, mg/L
Conventional	5 – 15	0.2 – 0.4	1500 – 3000
Complete Mix	5 – 15	0.2 – 0.6	2500 – 4000
Step Feed	5 – 15	0.2 – 0.4	2000 – 3500
Modified Aeration	0.2 – 0.5	1.5 – 5.0	200 – 1000
Contact Stabilization	5 – 15	0.2 – 0.6	1000 – 3000 4000 – 10000
Extended Aeration	20 – 30	0.05 – 0.15	3000 – 6000
High Rate Aeration	5 – 10	0.4 – 1.5	4000 – 10000
High Purity Aeration	3 – 10	0.25 – 1.0	2000 – 5000
Oxidation Ditch	10 – 30	0.05 – 0.30	3000 – 6000
Single Stage Nitrification	8 – 20	0.10 – 0.25	2000 – 3500
Separate Stage Nitrification	15 – 100	0.05 – 0.20	2000 – 3500

This page is enlarged at the end of this section.

Performance problems can be caused by

- Changes in influent characteristics
- Hydraulic overloading
- Mechanical equipment failures
- Insufficient operator training

System Components

- Biological Reactors - The tanks where aerobic, anaerobic, or anoxic conditions are created to produce healthy mixed liquor and facilitate biological treatment processes.
- Clarifiers - Sedimentation tanks used to remove settleable solids in water or wastewater.

- Mixed Liquor - A mixture of raw or settled wastewater and activated sludge contained in an aeration tank or biological reactor.
- Suspended Solids - Insoluble solids that either float on the surface of, or are in suspension in, water, wastewater, or other liquid.
- Mixed Liquor Suspended Solids (MLSS) – The concentration (mg/L) of suspended solids in activated sludge mixed liquor.

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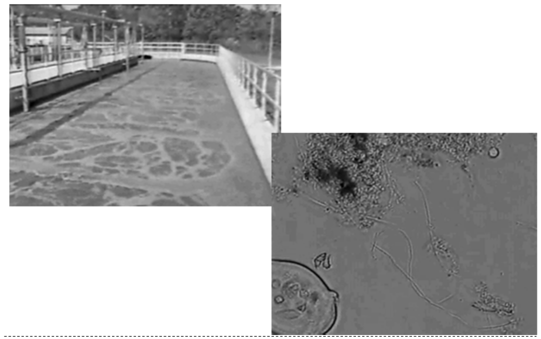
Biological Reactor and Micrograph of Floc Particle



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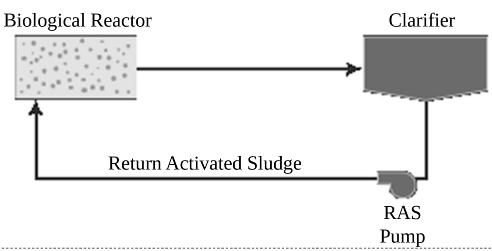
Return Activated Sludge (RAS)

- Return Activated Sludge (RAS) - Settled activated sludge returned to mix with incoming raw or primary settled wastewater.



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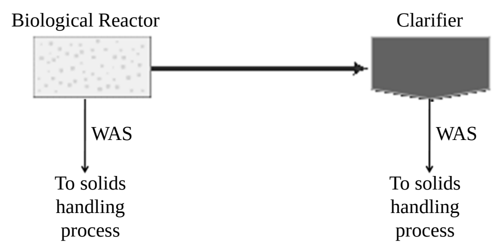
Waste Activated Sludge (WAS)

- Waste Activated Sludge (WAS) - Solids removed from the activated sludge process.



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- Solids Retention Time (SRT) - The average time suspended solids are held in a biological wastewater treatment system.
  - Also called Mean Cell Residence Time (MCRT)
- Mixed Liquor Volatile Suspended Solids (MLVSS) - The organic fraction of the suspended solids in activated sludge mixed liquor that can be driven off by combustion at 550 °C.

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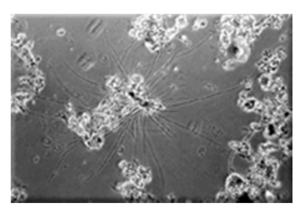

Microbiology

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Microorganisms

- Types of microorganisms present in activated sludge depend on
  - Composition of the wastewater
  - Length of the system's MCRT
  - pH
  - Temperature
  - DO concentration
- Microorganism population type affects both activated sludge characteristics and treatment potential.

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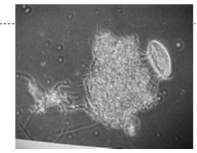
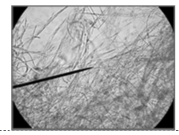
What are Microbes?

- Bacteria
- Protozoa
- Viruses
- Algae
- Metazoa- worms, rotifers
- Fungi



Crawling ciliate on activated sludge floc



Cyanobacteria

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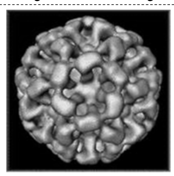
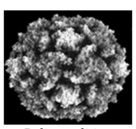
Why are they important?



Norwalk virus



Poliomyelitis

- Can cause disease
  - Most immediate importance
- Role in environment
  - Major decomposers in nature
  - Essential in a balanced ecosystem

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Why are they important?

- Role in treatment systems
  - Removed in water treatment
  - Key role in wastewater treatment
  - Major role in problems & solutions to solid waste

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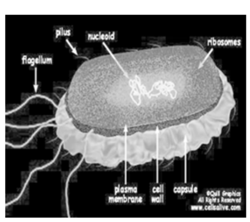
Viruses and Bacteria

- Viruses
  - Genetic material + protein coat
  - Reproduce only by infecting cells of other organisms
  - Pathogenic
- Bacteria
  - Most important



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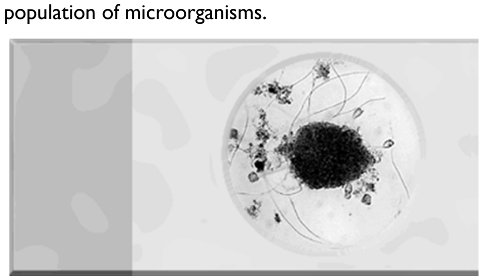
- A single drop of healthy mixed liquor contains a diverse population of microorganisms.



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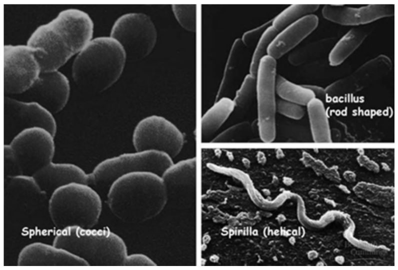
Examples of Bacteria Found in Wastewater



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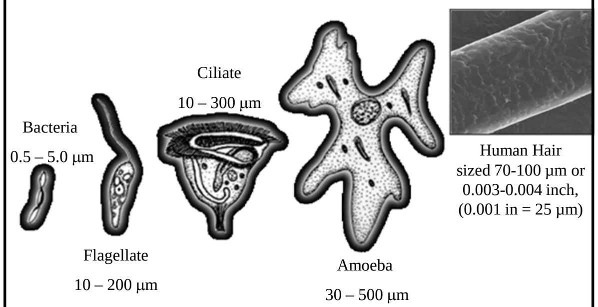
Size Range of Microorganisms



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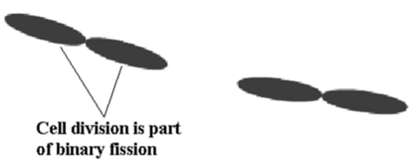
Bacteria

- Binary fission is the process by which one mature cell divides into two new cells.
- Bacteria Reproducing



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Two Types of Bacteria

- Heterotrophic and autotrophic bacteria differ in the source of nutrition they require.
- Heterotrophic:
  - CBOD removers
  - Denitrifiers
- Autotrophic
  - Nitrifiers
  - Algae
  - Higher plants

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Heterotrophic

- Need organic carbon as their food source.
  - Humans
  - Protozoa
  - Most wastewater bacteria
- All animals are heterotrophs, as are most microorganisms (the major exceptions being microscopic algae and blue-green bacteria).

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Heterotrophic

- Oxygen requirements:
  - Aerobes require free DO to function
  - Anoxic use nitrate (NO_3^-) and nitrite (NO_2^-), no free DO
  - Anaerobes thrive in the absence of free DO, use sulfate (SO_4^-) or carbon dioxide (CO_2)
  - Facultative bacteria prefer free DO but can function in its absence

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Autotrophic

- Use carbon dioxide (inorganic) as a carbon source
- Autotrophic organisms take inorganic substances into their bodies and transform them into organic nourishment.
- Autotrophic bacteria make their own food, either by photosynthesis (which uses sunlight, carbon dioxide and water to make food) or by chemosynthesis (which uses carbon dioxide, water and chemicals like ammonia to make food - these bacteria are called nitrogen fixers and include the bacteria found living in legume roots and in ocean vents).

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Food

- Two types of "food"
  - Dissolved
    - Example: sugar in oatmeal
  - "Chunky"
    - Example: oats in oatmeal
- Our body uses both "foods"
- We eat and our stomach and gut breaks the "chunky food" down into smaller dissolved food that our cells in our bodies can use.
- If you had to stay in the hospital and could not eat, they would "feed" you dissolved food in the form of sucrose, a sugar water.

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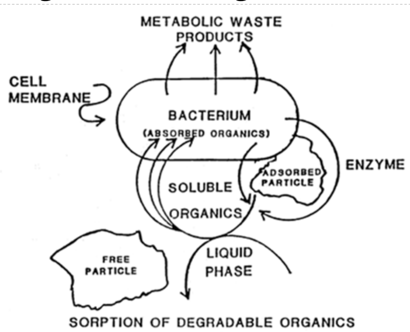
Microorganisms "Eating"



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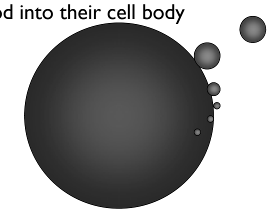
Microorganisms

- We use our stomachs and gut to break down food, but microorganisms break down "chunky food" on the outside with their cell wall.
- Once the food is small enough, the microorganisms can bring the food into their cell body



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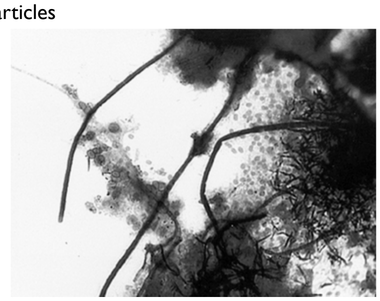
- Micrograph of Bacteria and Filaments Bound Together in Floc Particles



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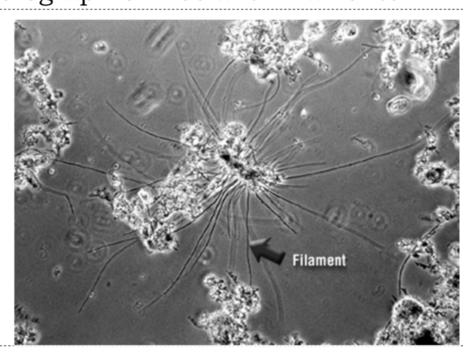
Micrograph of Floc and Filaments



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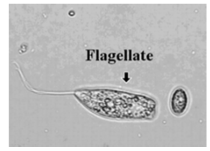
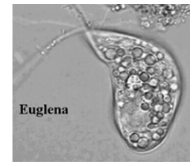
Protozoa

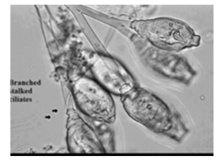
- Single-celled animals that also reproduce by binary fission
- Have complex digestive systems that ingest organic matter which they use as an energy and carbon source
- Graze on bacteria
- Form cysts
- Beneficial in wastewater treatment
- Indicators of health of system

- Examples:
  - Paramecium
  - Stalked Ciliates
  - Amoeba
  - Euglena
  - Flagellate

Protozoa Found in the Activated Sludge Process

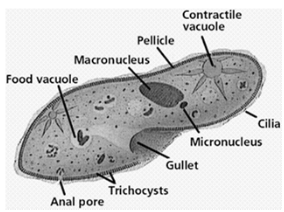






Protozoa

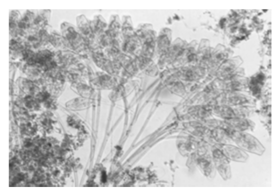
Free Swimming Ciliate - Paramecium

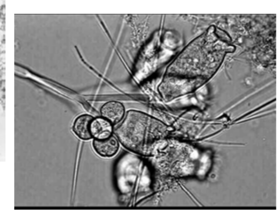


<u>Paramecium eating</u>

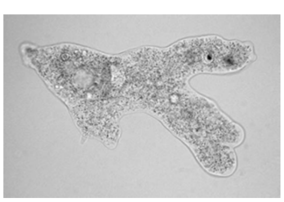
Protozoa

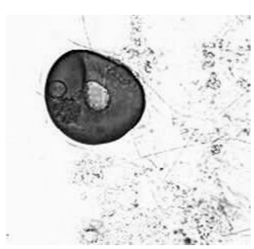
<u>Stalked Ciliates</u>





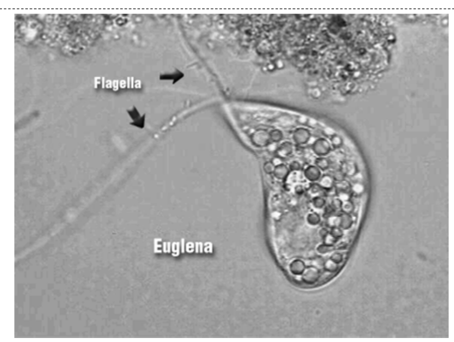
Protozoa





<u>Amoeba eating</u>

Protozoa



Fungi and Algae

- Fungi
  - Soil organisms
  - Degrade dead organic matter (saprophytic)
- Algae
  - Photosynthetic
  - Eutrophication can cause algal blooms in receiving streams
  - Key in operation of wastewater ponds: produce oxygen needed by bacteria
  - Nuisance in clarifiers, basins, etc.

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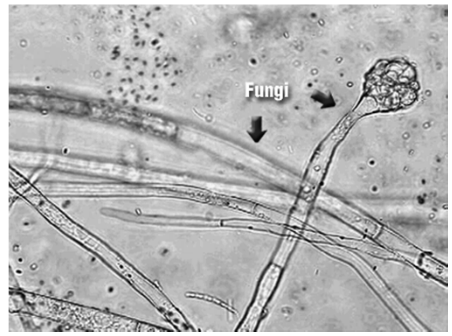
Fungi



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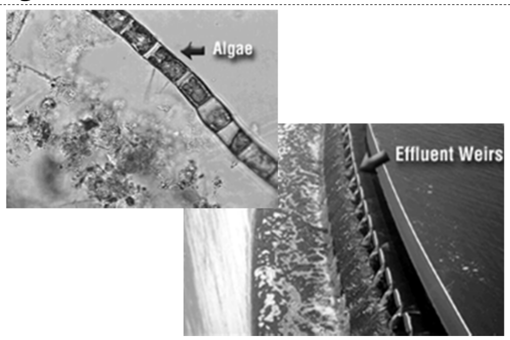
Algae



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Worms

- Multicellular organisms
- Diseases (tapeworms, roundworms)
- Beneficial in trickling filters (increase air penetration in biofilm and help in sloughing)

Ascaris and egg

Trickling filter

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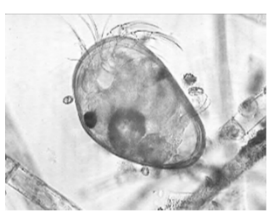
Metazoa

- Multi-cellular animals
- Examples:
  - Rotifer
  - Water Mite
  - Water Bear
  - Nematodes
  - Ostracods



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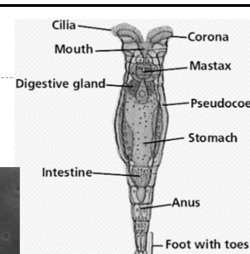
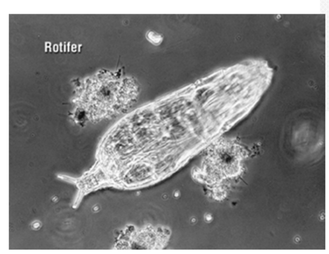
Rotifer





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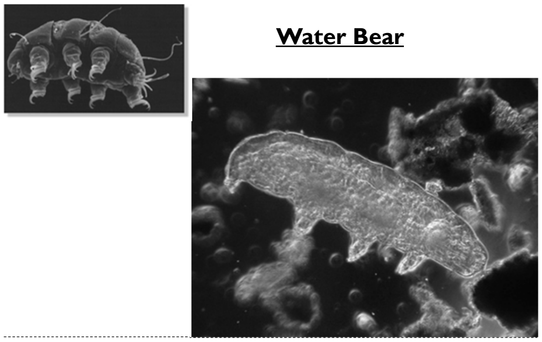
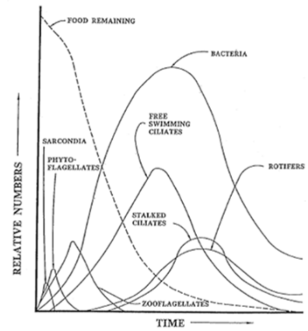
Water Bear



Bacteria Population vs. Sludge Age



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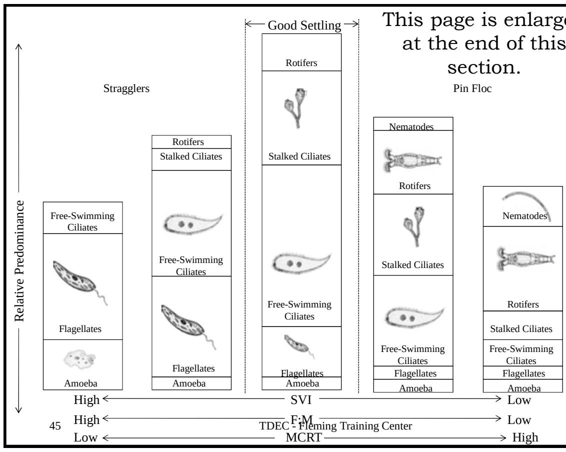

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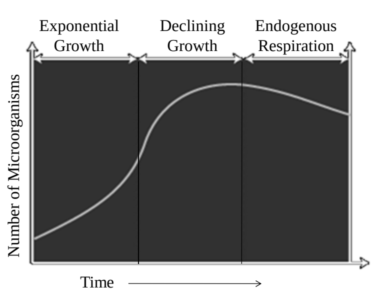
Microorganisms Predominance

- If conventional plant and you start to see more rotifers and less free-swimming ciliates, you need to increase wasting to make old sludge go away/
- If extended aeration plant and you have pin floc and nematodes, you are holding your sludge too long.

Phases of Microorganism's Life



Phases of Microorganism's Life

- Exponential Growth – The number of microorganisms in a culture broth will grow exponentially until an essential nutrient is exhausted. Typically the first organism splits into two daughter organisms, who then each split to form four, who split to form eight, and so on
- Declining Growth – As food supply declines, the microorganisms work harder to get their food. Reproduction rates gradually slow down.
- Endogenous Respiration – There is inadequate food to maintain the biomass. Some microorganisms starve and die others use their own stored energy to live.

- Food-to-Microorganism Ratio (F:M) - The ratio of organic loading to microorganisms in the activated sludge system

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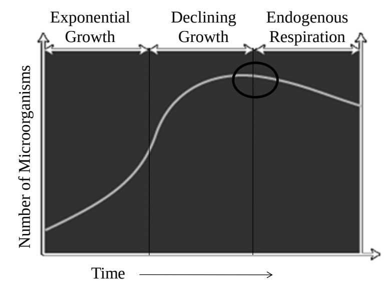
- Most plants operate right before endogenous respiration



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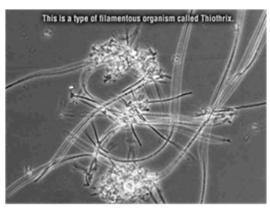
Filaments

- *Thiothrix* filaments are usually attached to the flocs.
- The sulphur globules are very characteristic.
- The sulphides are oxidised and elementary sulphur is temporarily stored in the cell as an intermediary product.
  - These are the bright globules that can be microscopically observed.



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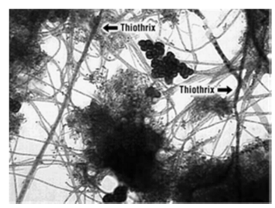
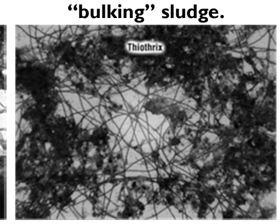
Filaments

Microorganisms act as a kind of skeleton for the floc.



An overabundance of filamentous microorganisms can cause "bulking" sludge.



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Filaments

- Specific conditions can allow a particular filamentous organism to dominate.

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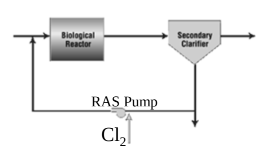
Filaments

- Conditions that promote filamentous organism growth:
  - Consistently low DO in biological reactors ~ 0.4 – 0.7
  - High-BOD wastewater (for example, high-sugar industrial wastewater)
  - Low pH
- Chlorination may be used for temporary control of filamentous organisms.
  - Dose of 1 – 10 mg/L and so that chlorine will be in contact with RAS for ~ 1 min before mixing with incoming settled WW



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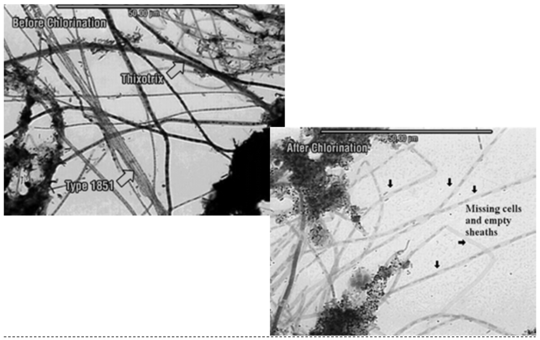
Filaments



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Foaming Problems

- White, billowy foam is often caused by surfactants.
- Development of white, billowy foam is also common under start-up conditions.

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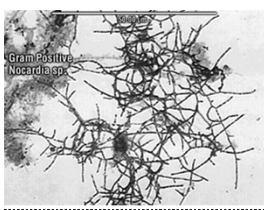
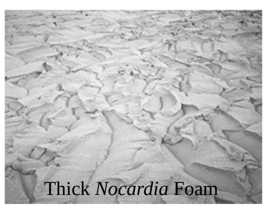
Foaming Problems

- Filamentous bacteria also cause foaming.
- *Nocardia*
  - Identified by true branching
  - FOG encourages growth





Thick *Nocardia* Foam

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Nocardia

- Nocardia can be controlled by
  - Maintaining an MCRT <1 day in warm weather
    - Works with pure oxygen systems
    - Can be very difficult in nitrifying plants
  - Physical removal and disposal by skimming and disposal
  - Spray with chlorine

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Process Goals

Successful activated sludge process performance is judged by effluent quality.

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Activated Sludge Process Goals

- CBOD removal
- Nitrification (where required)
- TSS removal
- Maintaining neutral pH
- Minimizing the amount of solids produced
- Optimizing the energy used

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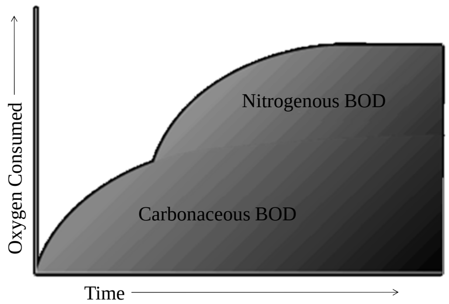
BOD Distribution



- Biochemical Oxygen Demand (BOD) – Measure of quantity of oxygen used in biochemical oxidation of organic matter.
- Can be divided into:
  - CBOD – carbon-based compounds
  - NBOD – nitrogen-based compounds

CBOD

- Conventional activated sludge processes are designed to remove only CBOD from wastewater.

Nitrification Reaction

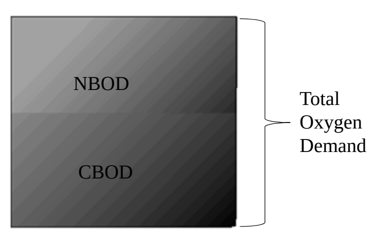
- $\underset{\text{Ammonia}}{NH_4} + \underset{\text{Oxygen}}{1.5\ O_2} \xrightarrow{\text{Nitrosomonas}} \underset{\text{Nitrite}}{NO_2^-} + \underset{\text{Acid}}{2\ H^+} + \underset{\text{Water}}{H_2O} + \text{Energy}$
- $\underset{\text{Nitrite}}{NO_2^-} + \underset{\text{Oxygen}}{0.5\ O_2} \xrightarrow{\text{Nitrobacter}} \underset{\text{Nitrate}}{NO_3^-} + \text{Energy}$

Design Criteria – Suspended Growth Systems

- 8.1.1.2 Special Details
  - A. Use 4.6 pounds of Oxygen per pound total Kjeldalh nitrogen to calculate the oxygen requirements for nitrification, in addition to the oxygen needed for BOD removal
  - B. Aeration basin design dissolved oxygen shall be greater than or equal to 2.0 mg/L
  - D. The pH levels must be controlled within the range of 6.5-8.4
    - Nitrification is optimized in the upper portion of this range (7.9-8.4)
  - E. Nitrification requires alkalinity, 7.1 pounds as $CaCO_3$ per pound NH_3-H oxidized

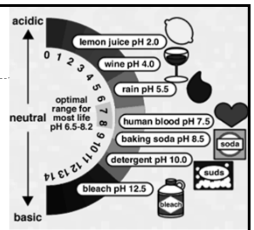
Total Oxygen Demand

- NBOD + CBOD = Total Oxygen Demand



pH

- A measure of the hydrogen ion concentration in a solution.
- The pH scale typically runs 0 to 14, with 7 being neutral.



- When neutral pH levels are not maintained, there may be
  - Inability to maintain a healthy biomass;
  - Potential damage to process equipment; and/or
  - Increased cost because of chemical addition.
- During nitrification, alkalinity is needed to buffer the pH.

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Typical Activated Sludge Values

Parameter	Influent	Effluent
BOD_5	100 – 300 mg/L	5 – 20 mg/L
TSS	100 – 300 mg/L	5 – 30 mg/L
Ammonia	10 – 30 mg/L	< 2 mg/L
pH	6.5 – 8.5	~ 7.0

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Activated Sludge Process Modes

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Activated Sludge Process Modes

- Plug-flow (conventional)
- Complete mix
- Contact stabilization
- Step feed
- Extended aeration
- Oxidation ditches
- High-rate aeration
- High-purity oxygen
- Sequencing batch reactors

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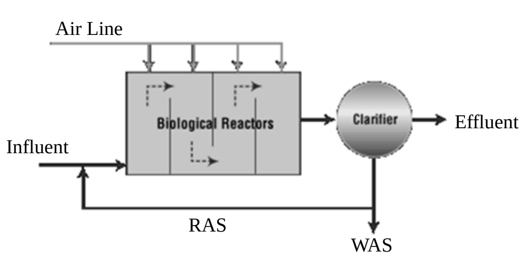
Plug Flow



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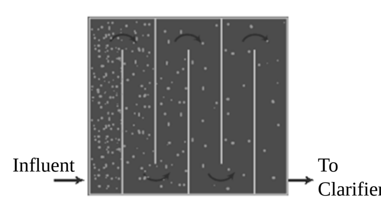
Criteria for a Plug-Flow Reactor

- High length-to width ratio;
- Air flow rate minimized to meet specific treatment needs; and
- Fairly high wastewater velocity through the reactor.



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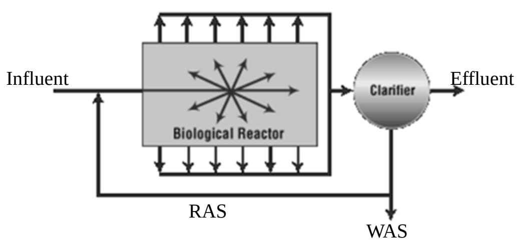
Plug Flow

- Raw wastewater goes in as a "plug" and leaves as a "plug"
- Smaller foot print needed
- Highest DO requirement at inlet
- Highest F:M at inlet
- F:M decreases as you go through the process
- You must have a primary clarifier, State won't let you otherwise

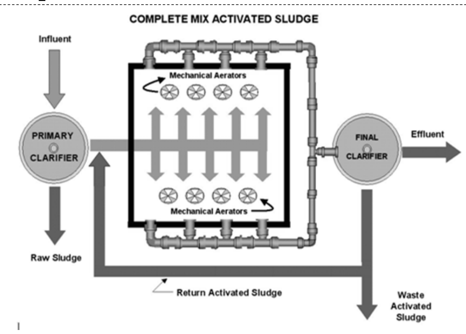
Plug Flow Design Parameters

Application	Domestic and Industrial
BOD Removal Efficiency	85 – 95%
Aeration Type	Diffused or Mechanical
MCRT	5 – 15 days
Aeration Time	4 – 12 hours
MLSS	1500 – 3000 mg/L
RAS Flow	25 – 75% of influent
F:M	0.2 – 0.4 lbs BOD/d/lbs MLVSS
Organic Loading	20 – 40 lbs BOD/d/1000 ft^3

Complete Mix



Complete Mix



Criteria for a Complete-Mix Reactor

- Low length-to-width ratio
- High air flow rate or mixing power
- Low velocity through the reactor

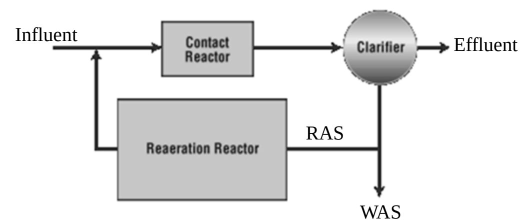
Complete-mix

- Conventional plant – but modified
- If you take an MLSS sample at one corner, it should be the same at the opposite corner
- Can handle toxic loads or organic loads – dilutes them out
  - Primary reason to have one of these
- Oxygen demand same throughout
- Needs lots of air and/or mixing
- Susceptible to growth of filamentous bacteria due to nutrient deficiency
  - If organic loads stop coming in, this could become a problem

Complete Mix Design Parameters

Application	Domestic and Industrial
BOD Removal Efficiency	85 – 95%
Aeration Type	Mechanical
MCRT	5 – 15 days
Aeration Time	3 – 10 hours
MLSS	2500 – 4000 mg/L
RAS Flow	25 – 100% of influent
F:M	0.2 – 0.6 lbs BOD/d/lbs MLVSS
Organic Loading	50 – 120 lbs BOD/d/1000 ft^3

Contact Stabilization



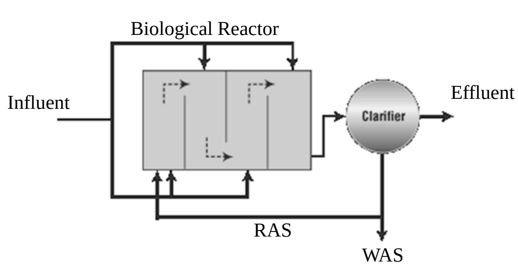
Contact Stabilization Design Parameters

Application	Modification of Existing Plant
BOD Removal Efficiency	80 – 90%
Aeration Type	Diffused or Mechanical
MCRT	5 – 15 days
Aeration Time	0.5 – 1 hour Contact 3 – 6 hours Reaeration
MLSS	1000 – 3000 mg/L Contact 4000 – 10000 mg/L Reaeration
RAS Flow	50 – 150% of influent
F:M	0.2 – 0.6 lbs BOD/d/lbs MLVSS
Organic Loading	60 – 75 lbs BOD/d/1000 ft^3

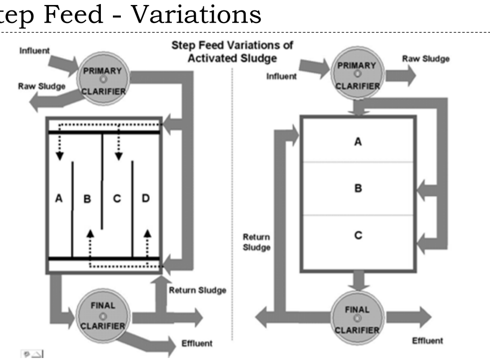
Contact Stabilization

- If toxic load comes in, it will shock the contact tank and not affect the stabilization tank
- Both contact tank and reaeration tank are aerated
  - Reaeration tank is for RAS.
    - No new food is added
    - Organisms must use stored energy, once used up, they begin searching for more food, this is when they are moved on to the contact tank
  - Contact tank is where the organic load is applied
    - Attempts to have microorganisms take in and store large portions of influent waste in a short period of time (30-90 minutes)
    - Can avoid a complete wash-out when high flows or toxic load comes in

Step Feed



Step Feed - Variations



Step Feed Design Parameters

Application	Domestic and Industrial
BOD Removal Efficiency	85 – 95%
Aeration Type	Diffused
MCRT	5 – 15 days
Aeration Time	3 – 6 hours Flow 5 – 7.5 hours Solids
MLSS	2500 – 3500 mg/L
RAS Flow	25 – 75% of influent
F:M	0.2 – 0.4 lbs BOD/d/lbs MLVSS
Organic Loading	40 – 60 lbs BOD/d/1000 ft^3

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Step Feed

- Advantages over conventional operation:
  - Less aeration volume to treat same volume of wastewater
  - Better control in handling shock loads
  - Potential for handling lower applied solids to the secondary clarifier

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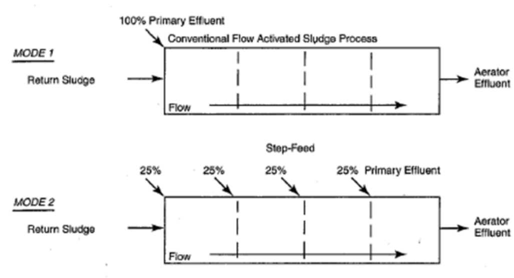
Step Feed



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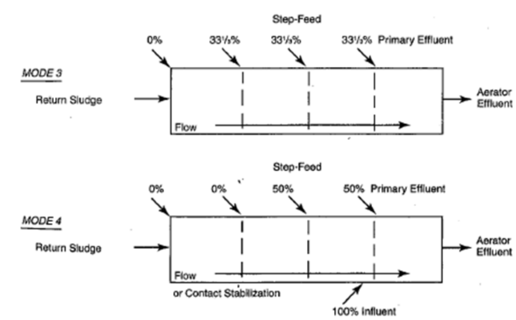
Step Feed



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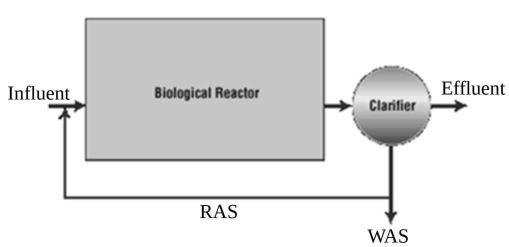
Extended Aeration



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Extended Aeration Design Parameters

Application	Smaller Communities and Package Plants
BOD Removal Efficiency	85 – 95%
Aeration Type	Diffused or Mechanical
MCRT	20 – 30 days
Aeration Time	18 – 36 hours
MLSS	3000 – 6000 mg/L
RAS Flow	50 – 150% of influent
F:M	0.05 – 0.15 lbs BOD/d/lbs MLVSS
Organic Loading	10 – 25 lbs BOD/d/1000 ft^3

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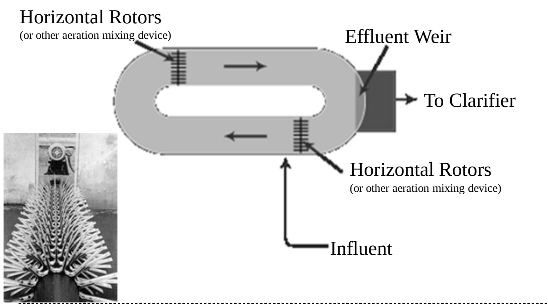
Oxidation Ditch

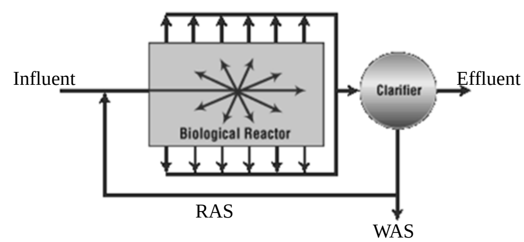


Oxidation Ditch

- Brush rotor – first oxidation ditch
  - To control DO, play with depth of water
  - Some brush rotors were covered to keep down air-borne diseases
- Velocity of 1 ft/sec
- Very low effluent BOD
- Large tank volume and high oxygen demand are disadvantages
- High MCRT and low F:M

Murfreesboro Wastewater Treatment Plant

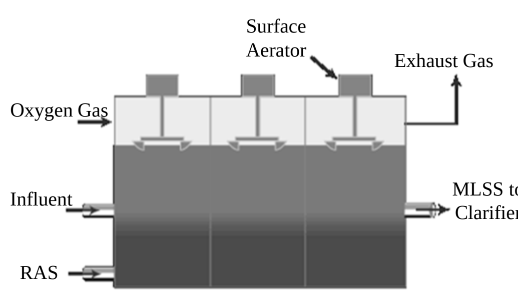
High Rate Aeration



High Rate Aeration Design Parameters

Application	Industrial
BOD Removal Efficiency	75 – 85%
Aeration Type	Mechanical or Diffused (rare)
MCRT	5 – 10 days
Aeration Time	2 – 4 hours
MLSS	4000 – 10000 mg/L
RAS Flow	100 – 500% of influent
F:M	0.4 – 1.5 lbs BOD/d/lbs MLVSS
Organic Loading	100 – 1000 lbs BOD/d/1000 ft^3

High Purity Oxygen



High Purity Aeration Design Parameters

Application	Domestic and Industrial
BOD Removal Efficiency	85 – 95%
Aeration Type	Mechanical
MCRT	3 – 10 days
Aeration Time	1 – 3 hours
MLSS	2000 – 5000 mg/L
RAS Flow	25 – 50% of influent
F:M	0.25 – 1.0 lbs BOD/d/lbs MLVSS
Organic Loading	100 – 200 lbs BOD/d/1000 ft^3

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High-Purity Oxygen Facility

- Oxygen for this process can be supplied by:
  - Trucked-in liquid oxygen (LOX)
  - Cryogenic oxygen generation
  - Pressure-swing adsorption generation

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High-Purity Oxygen Facility

- Liquid oxygen is a fire hazard, comes delivered at -300°F
- Continuously control oxygen feed rate depending on how active the microorganisms are
- Always has a covered tank to prevent costly pure oxygen from going off into the atmosphere, keeps it in the tank
- Nitrification ability limited due to accumulation of CO_2 in gas headspace which causes low pH in mixed liquor

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Sequencing Batch Reactor (SBR)

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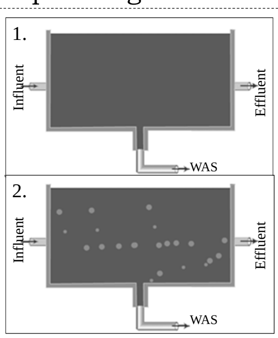
Sequencing Batch Reactor (SBR)



1. Fill – reactor is filled with wastewater.

2. React – the wastewater is aerated.

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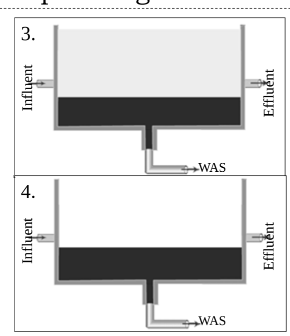
Sequencing Batch Reactor (SBR)



3. Settle – MLSS is separated.

4. Decant – treated wastewater is removed.

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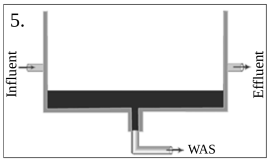
Sequencing Batch Reactor (SBR)



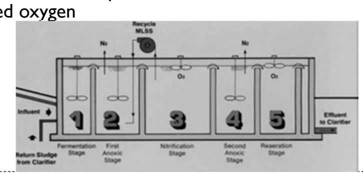
5. Idle – a portion of the waste sludge is removed with adequate sludge left in the tank to provide biomass for the next treatment cycle.

Sequencing Batch Reactor Design Parameters

Application	Smaller Communities
BOD Removal Efficiency	85 – 95%
Aeration Type	Diffused
MCRT	N/A
Aeration Time	12 – 50 hours
MLSS	1500 – 5000 mg/L
RAS Flow	N/A
F:M	0.05 – 0.3 lbs BOD/d/lbs MLVSS
Organic Loading	25 lbs BOD/d/1000 ft^3

Bardenpho Process

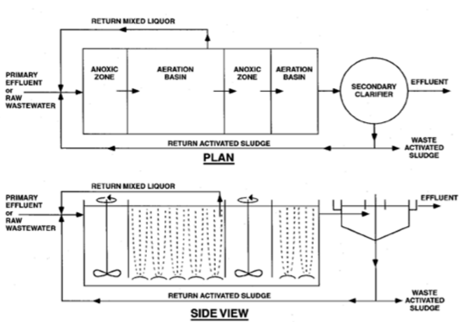
- Bardenpho process is named by Dr. James L. **Bar**nard for **den**itrification and **pho**sphorus removal
- Used to remove between 90-95 percent of all the nitrogen present in the raw wastewater by recycling nitrate-rich mixed liquor from the aeration basin to an anoxic zone located ahead of the aeration basin
- Denitrification takes place in the anoxic zone in the absence of dissolved oxygen



Bardenpho Process

- The degree of nitrate removal depends on the recycle rate
  - Some plants have 2x, 4x and even 6x the average dry weather flow back to the anoxic zone
  - Usually 4x the average dry weather flow is sufficient
  - If the nitrate in the effluent rises above 1 mg/L, the recycle rate is too high because not enough detention time is provided in the anoxic zone for denitrification to occur
- If phosphorus removal is desired, a fermentation stage is added before the first anoxic zone

Bardenpho Process



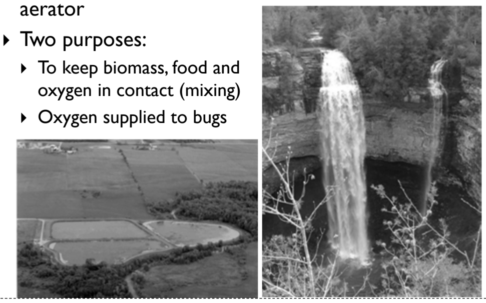
Criteria for choosing the optimal activated sludge process variation:

- Construction capital availability
- Land availability
- Influent flow and loading considerations
- Operational expertise available

Aeration

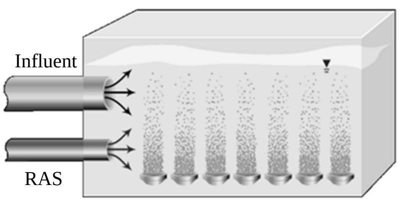
Aeration

- Aeration is a process that occurs naturally, not just in an aerator
- Two purposes:
  - To keep biomass, food and oxygen in contact (mixing)
  - Oxygen supplied to bugs



Biological Reactors

- Biological reactors provide oxygen and promote contact with waste.
- RAS maintains the microorganism population



Biological Reactors

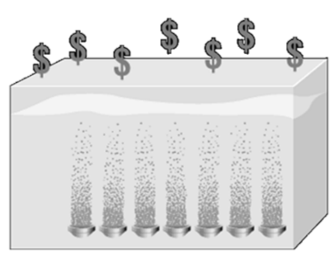
Biological Reactors

- In biological reactors, adequate DO must be maintained. The typical concentration range for most reactors is:

1.0 to 4.0 mg/L

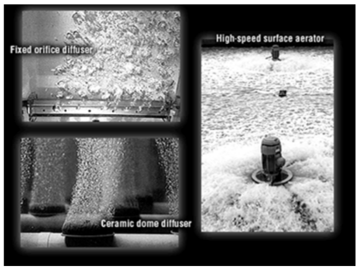
Over Aeration

- Adding dissolved oxygen to the mixed liquor creates the highest single electrical demand at most activated sludge facilities



Aeration Systems

- Surface aerators
- Diffused aeration systems
- Hybrid devices

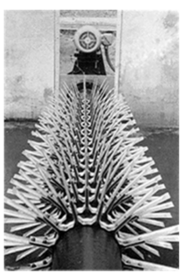


High Purity Oxygen System

- High purity oxygen systems use aeration equipment similar to a conventional plant

Surface Aerators

Horizontal Rotor Surface Aerator



Surface Aerator

Surface Aerators

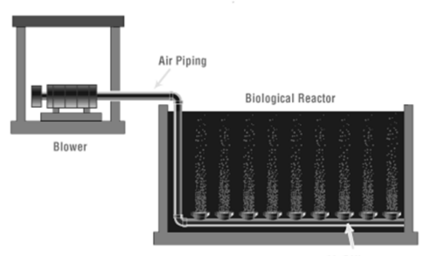
- Surface aerators generate a lot of splashing and mist

- Deflector plate keeps most spray from going up

Surface Aerators

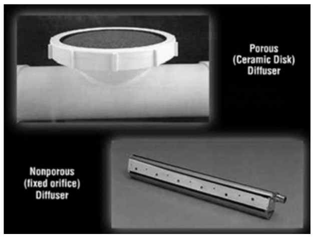
- For surface aerators, the most common way to control the DO and mixing is through the use of variable-speed motors.
- Typically, a two-speed motor is used.

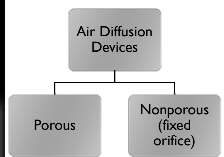
Diffused Aeration System



Diffused Aeration System

- Because the terms "fine bubble diffuser" and "coarse bubble" diffuser are often not clearly defined, the use of these designations can be very confusing





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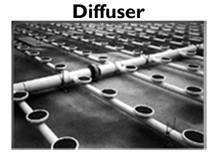
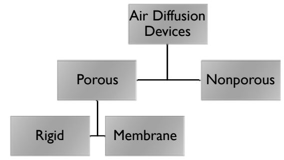
Diffused Aeration System

Ceramic Diffuser

Flexible Membrane Diffuser





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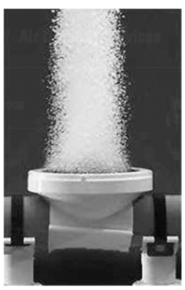
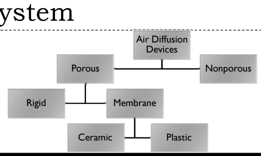
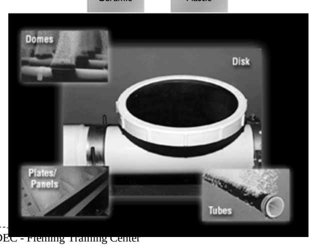
Diffused Aeration System

- Membrane Diffuser







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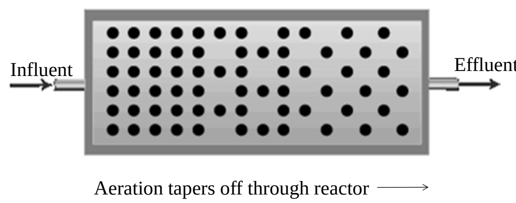
Plan View of Biological Reactor



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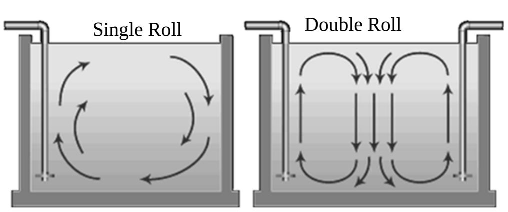
Mixing with Aeration



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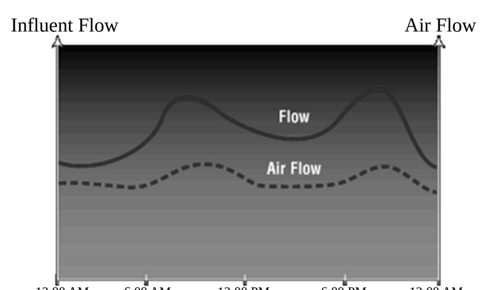
Influent Flow vs. Air Flow



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High Purity Oxygen System

- An advantage of high-purity oxygen systems is that a smaller reactor size is required
- Disadvantages of high-purity oxygen processes:
  - Higher capital costs
  - Higher operating costs
  - Systems are more prone to operational problems
  - Additional safety concerns

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Sources of High-Purity Oxygen:

- Trucked-in liquid
- Onsite generation via
  - Pressure-swing adsorption
  - Vacuum pressure-swing adsorption
  - Cryogenic system

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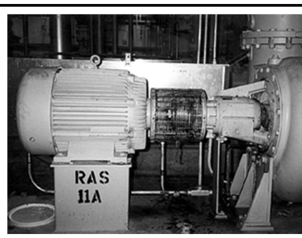

Return Activated Sludge Systems

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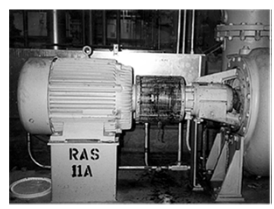
Centrifugal RAS Pump



- It is very important to have the RAS enter the biological reactors at a point where thorough mixing occurs.

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Waste Activated Sludge Systems

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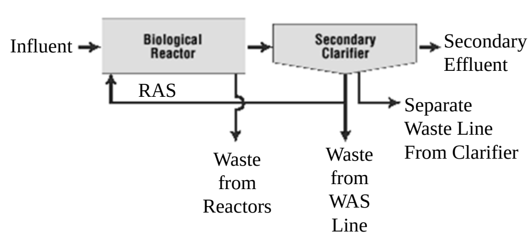
Waste Sludge Options



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Waste Sludge Options

- Increasing the wasting rate will:
  - Decrease the MLSS concentration
  - Decrease the MCRT
  - Increase the F:M ratio
  - Increase the SVI

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Wasting Rates

- The most important feature of a WAS pumping system is its flexibility to allow different wasting rates.
- Develop a wasting strategy that works best for your facility.

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Chemical Feed Systems

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Chemical Addition

- In the activated sludge process, chemical addition may be used to:
  - Improve settling
  - Correct nutrient deficiencies
  - Raise alkalinity levels
- Caustic soda and lime are added to the activated sludge process to control pH and raise alkalinity levels.

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Process Control

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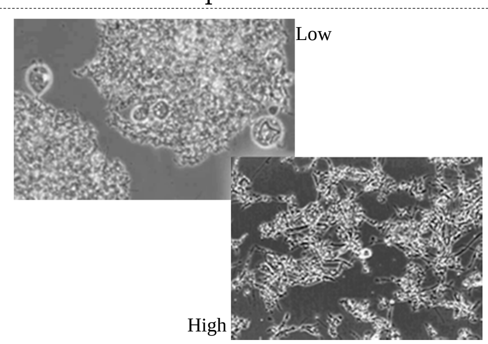
Filamentous Populations



Low

High

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Organic Tests

- CBOD/BOD tests provide a good indication of the organic strength of a wastewater.
- Because of fairly long detention times, BOD/COD variations are typically only of concern if they last 24 hours or longer.
- Correlation between BOD and COD

Date	BOD, mg/L	COD, mg/L
10/1/2007	125	240
10/2/2007	120	231
10/3/2007	145	279
10/4/2007	136	262
10/5/2007	110	212
10/6/2007	100	192
10/7/2007	94	181
10/8/2007	112	215
10/9/2007	117	225
10/10/2007	119	229
10/11/2007	128	246
10/12/2007	138	265
10/13/2007	155	282

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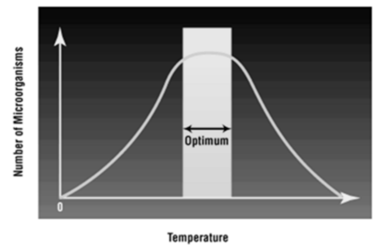
Temperature vs. Population

- Temperature affects the size of the microorganism population.



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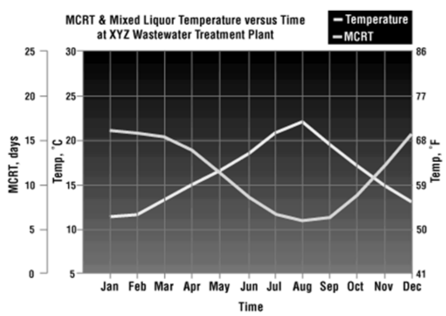
MCRT and Temperature



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pH

- Optimum pH ranges:
  - Conventional Process: 6.5 – 8.5
  - Nitrifying Process: 7.0 – 8.0

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Nitrification

- Nitrification consumes bicarbonate alkalinity
- To convert 1 mg of ammonia to nitrite, approximately 7 mg of alkalinity are consumed.
- Minimum alkalinity levels
  - 50 mg/L where pH is adjusted automatically
  - 100 mg/L pH is adjusted manually

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Effluent Alkalinity

- To determine the alkalinity of you need for your secondary influent (coming out of your primary clarifier):

$$Alk_{inf} = Alk_{eff} + (7.14)(N)$$

Where N = ammonia concentration, mg/L
Alk_{eff} = effluent alkalinity, mg/L as $CaCO_3$
Alk_{inf} = secondary influent alkalinity, mg/L as $CaCO_3$

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Effluent Alkalinity Example

- Example:
  - Desired effluent alkalinity = 60 mg/L
  - Influent Ammonia Concentration = 14 mg/L
  - Required influent alkalinity = ?

$$\begin{aligned} Alk_{inf} &= Alk_{eff} + (7.14)(N) \\ &= 60 + (7.14)(14) \\ &= 60 + 99.96 \\ &= 159.96 \text{ mg/L} \end{aligned}$$

Secondary Influent Alkalinity

Secondary Influent Alkalinity	Action
Equal to or greater than 160 mg/L	No correction needed
< 160 mg/L	Add chemicals to prevent pH drop

BOD ratios

- The minimum ratio of BOD to nitrogen to phosphorus is 100:5:1.
- This is very critical:

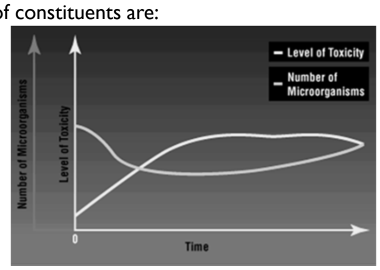
BOD:N:P = 100:5:1

Nutrient Deficiencies

- When essential nutrient ratios drop, less-desirable microorganisms begin to dominate.

Toxins

- Influent wastewater may contain constituents that can be toxic to activated sludge microorganisms.
- These types of constituents are:
  - Metals
  - Inorganics
  - Organics



Dissolved Oxygen Control

DO Requirements

- For low-BOD wastewater, the minimum airflow rate is often based on mixing rather than DO requirements.
- Typically, oxygen requirements are met when the DO in the mixed liquor is at 2 mg/L or more.

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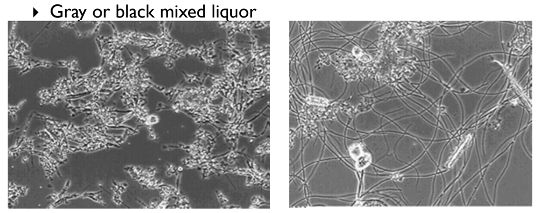
Low DO

- Signs that low-DO conditions may be present:
  - Dominance of "low-DO" filamentous bacteria
  - Turbid effluent
  - Gray or black mixed liquor



Filamentous bacteria may indicate low DO conditions.

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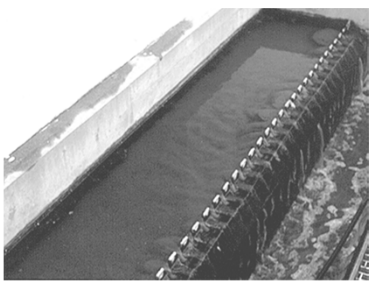
Turbid Effluent



Low DO can lead to effluent turbidity.

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Black Mixed Liquor

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Uniform Mixing

- Reactors should be monitored to ensure mixing is uniform

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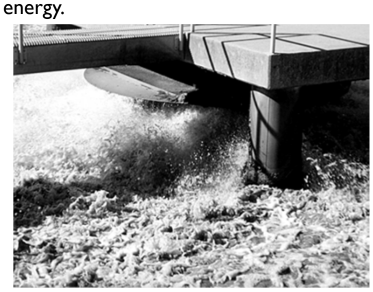
Over Aeration

- Overaeration can ensure adequate DO is available but wastes energy.



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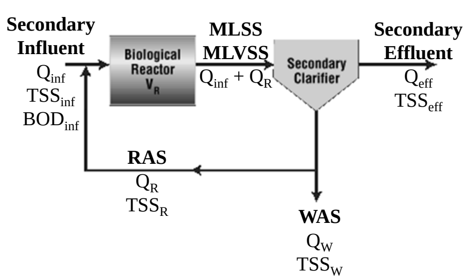
Solids Inventory and Control

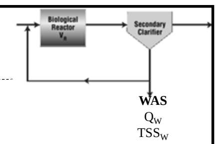
Solids

- It is important to account for and control the solids in the activated sludge process.
- As BOD is reduced, additional microorganisms are produced.
- Measuring flow and solids concentration allows calculation of mass balances.

Solids Inventory



Solids Wasted



- WAS, lbs/day = (TSS_W, mg/L)(Q_W, MGD)(8.34 lbs/gal)
- Example: WAS flow of 200 gpm with a WAS TSS of 8050 mg/L

(200 gpm)(1440 min/day) /1,000,000 = 0.288 MGD

- WAS, lbs/day = (8050 mg/L)(0.288 MGD)(8.34 lbs/gal)

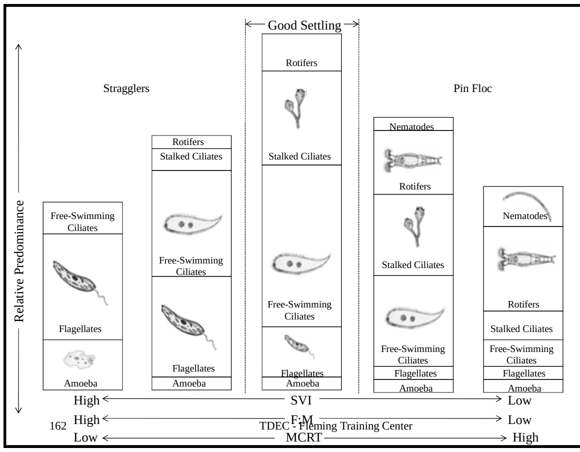
= 19,335 lbs/day WAS

F:M Ratio

- One of the most important process control parameters is maintaining the optimum amount of solids to remove BOD from influent wastewater.
- BOD = "food"
- Activated sludge solids = "microorganisms"

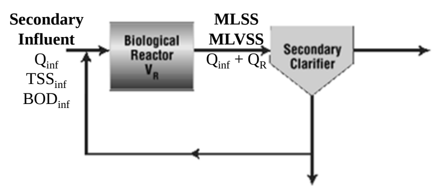
F:M Ratio

- Food (BOD, lbs/day) divided by Microorganisms (MLVSS, lbs)



F:M Ratio

- F:M = $\frac{(BOD_{inf}, mg/L)(Q_{inf}, MGD)(8.34\ lbs/gal)}{(MLVSS, mg/L)(Aerator\ Vol, MG)(8.34\ lbs/gal)}$



F:M Ratio

- Target F:M values
  - Conventional = 0.2 – 0.5
  - Nitrifying less than or equal to 0.10
- F:M based on BOD measurements does not give immediate process control feedback
- Running averages of F:M provide useful monitoring input
- F:M can be based on COD measurements when immediate process feedback is required
  - Target $F{:}M_{COD} = \frac{Target\ F{:}M_{BOD}}{BOD{:}COD}$

F:M Example

BOD_{inf}	145 mg/L
Q_{inf}	15 MGD
MLVSS	2500 mg/L
Aerator Volume	2 MG

- F:M = $\frac{(BOD_{inf}, mg/L)(Q_{inf}, MGD)(8.34\ lbs/gal)}{(MLVSS, mg/L)(Aerator\ Vol, MG)(8.34\ lbs/gal)}$
- F:M = $\frac{(145\ mg/L)(15\ MGD)(8.34\ lbs/gal)}{(2500\ mg/L)(2\ MG)(8.34\ lbs/gal)} = 0.44$

F:M Ratio

Calculated F:M	Result	Action
Less than target F:M	Too many microorganisms in process	Increase wasting rate
Greater than target F:M	Not enough microorganisms in process	Reduce wasting rate

- Excess sludge to waste:
  - Excess M to waste = Current M – $\frac{F\ (Food)}{F{:}M\ Target}$
    (Microorganisms)

F:M Ratio

- Excess sludge to waste:
  - Excess M to waste = Current M – $\frac{F\ (Food)}{F{:}M\ Target}$
    (Microorganisms)
- Wastewater formula book, pg. 10 has this as three different formulas:
  - Desired MLVSS, lbs = $\frac{BOD\ or\ COD,\ lbs}{Desired\ F{:}M\ ratio}$
  - Desired MLSS, lbs = $\frac{Desired\ MLVSS,\ lbs}{\%\ Vol.\ Solids,\ as\ decimal}$
  - SS, lbs to waste = Actual MLSS, lbs – Desired MLSS, lbs

Excess Sludge to Waste Example

- Given the following data, use the desired F:M ratio to determine the lbs SS to be wasted:
  Aeration Vol = 1,300,000 gal MLSS = 2980 mg/L
  Q_{inf} = 3,190,000 gpd %VS = 70%
  COD = 115 mg/L
  Desired F:M = 0.15 lbs COD/day/lb MLVSS
- Desired MLVSS, lbs = $\frac{BOD\ or\ COD,\ lbs}{Desired\ F{:}M\ ratio}$
  $= \frac{(115\ mg/L)(3.19\ MGD)(8.34)}{0.15}$
  = 20,396.86 lbs desired MLVSS

Excess Sludge to Waste Example

- Given the following data, use the desired F:M ratio to determine the lbs SS to be wasted:

  Aeration Vol = 1,300,000 gal MLSS = 2980 mg/L
  Q_{inf} = 3,190,000 gpd %VS = 70%
  COD = 115 mg/L Desired MLVSS = 20,396.86 lbs
  Desired F:M = 0.15

- Desired MLSS, lbs = $\frac{\text{Desired MLVSS, lbs}}{\text{\% Vol. Solids, as decimal}}$

  = $\frac{20{,}396.86 \text{ lbs}}{0.70}$

  = 29,138.37 lbs desired MLSS

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Excess Sludge to Waste Example

- Given the following data, use the desired F:M ratio to determine the lbs SS to be wasted:

  Aeration Vol = 1,300,000 gal MLSS = 2980 mg/L
  Qinf = 3,190,000 gpd %VS = 70%
  COD = 115 mg/L Desired MLVSS = 20,396.86 lbs
  Desired F:M = 0.15 Desired MLSS = 29,138.37 lbs

- SS, lbs to waste = Actual MLSS, lbs – Desired MLSS, lbs

  = (2980 mg/L)(1.3 MG)(8.34) – 29,138.37 lbs
  = 32,309.16 lbs – 29,138.37 lbs
  = 3170.79 lbs to waste

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MCRT

- Mean Cell Residence Time
  - The average time a given unit of cell mass stays in the biological reactor.
  - Higher MCRT's create higher MLSS concentrations
  - Lower MCRT's create lower MLSS concentrations

- MCRT, days = $\frac{\text{Suspended Solids in System, lbs}}{\text{SS Leaving System, lbs/day}}$

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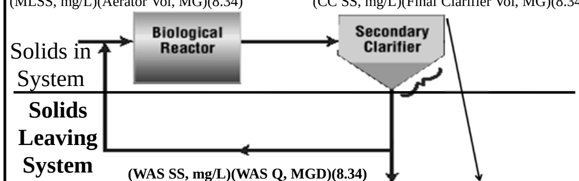
MCRT

* CCSS is the average clarifier core SS concentration of the entire water column sampled by a core sampler.

MLSS, lbs + CCSS*, lbs

(MLSS, mg/L)(Aerator Vol, MG)(8.34) (CC SS, mg/L)(Final Clarifier Vol, MG)(8.34)



WAS SS, lbs + S.E. SS, lbs

(SE SS, mg/L)(Plant Q, MGD)(8.34)

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MCRT

- Given the following data, use the information below to determine the MCRT, days:

  Aeration Vol = 1.5 MG MLSS = 2460 mg/L
  Final Clar.Vol = 0.11 MG WAS SS = 8040 mg/L
  PE Flow = 3.4 MGD SE SS = 18 mg/L
  WAS Pump Rate = 60,000 gpd CC SS = 1850 mg/L

- MCRT = $\frac{(2460 \text{ mg/L})(1.5 \text{ MG})(8.34) + (1850 \text{ mg/L})(0.11 \text{ MG})(8.34)}{(8040 \text{ mg/L})(0.06 \text{ MGD})(8.34) + (18 \text{ mg/L})(3.4 \text{ MGD})(8.34)}$

  = $\frac{30774.6 \text{ lbs MLSS} + 1697.19 \text{ lbs CCSS}}{4023.216 \text{ lbs/d WAS} + 510.408 \text{ lbs/d SE SS}}$ = $\frac{32471.79 \text{ lbs}}{4533.624 \text{ lbs/d}}$

  = 7.2 days

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MCRT

- Note that when using this equation, the highly variable solids concentration throughout the clarifier sludge blanket can make this calculation difficult
- If Clarifier Core Suspended Solids (CCSS) sample is not taken, but you are given the clarifier volume, add that to your aerator volume before figuring your MLSS lbs.
- Target MCRT
  - High Rate = 5 – 10 days
  - Conventional = 5 – 15 days
  - Nitrifying = 8 – 20 days
  - Extended Aeration = 20+

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MCRT

- Given the following data, use the information below to determine the MCRT, days(same as previous, just missing the CCSS sample:

  Aeration Vol = 1.5 MG MLSS = 2460 mg/L
  Final Clar. Vol = 0.11 MG WAS SS = 8040 mg/L
  PE Flow = 3.4 MGD SE SS = 18 mg/L
  WAS Pump Rate = 60,000 gpd

- $MCRT = \frac{(2460\ mg/L)(1.5\ MG + 0.11\ MG)(8.34)}{(8040\ mg/L)(0.06\ MGD)(8.34) + (18\ mg/L)(3.4\ MGD)(8.34)}$

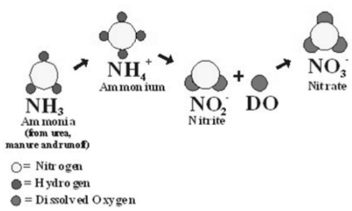
  $= \frac{(2460\ mg/L)(1.61\ MG)(8.34)}{4023.216\ lbs/d\ WAS + 510.408\ lbs/d\ SE\ SS} = \frac{33031.404\ lbs}{4533.624\ lbs/d}$

  = 7.3 days

MCRT

- MCRT/solids inventory must be adjusted as temperatures change.
- Temperature changes affect
  - Metabolic rates of microorganisms
  - Oxygen transfer rates
  - Solids settling rates

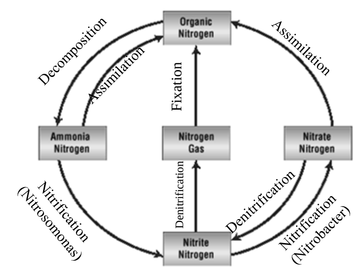
MCRT	RAS Rate
Low	30 – 40% of influent
High	Up to 150% of influent



Nitrification

Nitrogen Cycle

- The activated sludge process can also be operated to remove nitrogen and/or phosphorus.



Nutrients

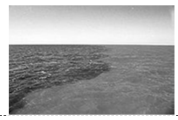
- Algal blooms can be caused by excess nutrient levels.
- Aquatic and marine dead zones can be caused by an increase in chemical nutrients in the water, known as eutrophication.
- Chemical fertilizer is considered the prime cause of dead zones around the world

Eutrophication

- Eutrophication is an increase in chemical nutrients (compounds containing nitrogen or phosphorus) in an ecosystem, and may occur on land or in water.
- However, the term is often used to mean the resultant increase in the ecosystem's primary productivity (excessive plant growth and decay), and further effects including lack of oxygen and severe reductions in water quality, fish, and other animal populations.
- Once algae blooms, it will die off and as the algae decay bacteria will consume it and use up all the oxygen.

Eutrophication

- Gulf of Mexico
  - Currently the most notorious dead zone is a 8,543 mi² region in the Gulf of Mexico, where the Mississippi River dumps high-nutrient runoff from its vast drainage basin, which includes the heart of U.S. agribusiness, the Midwest.
  - The drainage of these nutrients are affecting important shrimp fishing grounds.
  - This is equivalent to a dead zone the size of New Jersey.



Eutrophication Video

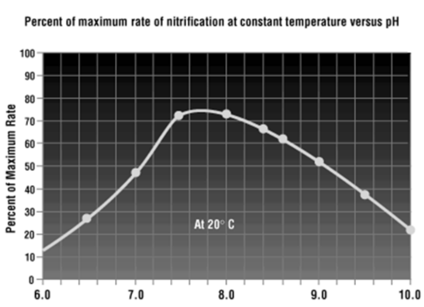
Reversal of Dead Zones

- Dead zones are reversible.
- The Black Sea dead zone, previously the largest dead zone in the world, largely disappeared between 1991 and 2001 after fertilizers became too costly to use following the collapse of the Soviet Union and the demise of centrally planned economies in Eastern and Central Europe.
- Fishing has again become a major economic activity in the region

Nitrification

- A bacterial process that converts ammonia nitrogen to nitrate and consumes alkalinity.
- $NH_4 + 1.5\ O_2 \xrightarrow{\text{Nitrosomonas}} NO_2^- + 2\ H^+ + H_2O$ + Energy
  Ammonia Oxygen Nitrite Acid Water
- $NO_2^- + 0.5\ O_2 \xrightarrow{\text{Nitrobacter}} NO_3^-$ + Energy
  Nitrite Oxygen Nitrate

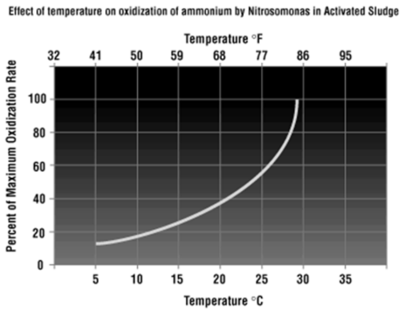
Nitrification vs. pH



Alkalinity and pH

- Alkalinity is a key parameter in nitrifying systems.
- To adequately control pH
  - Calculate the total amount of alkalinity required
  - Calculate the additional alkalinity that must be added

Nitrification vs. Temperature



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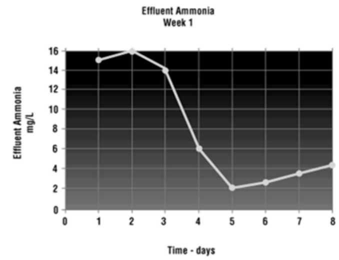
Nitrification

- Most processes will require an MCRT of 8 days or more to nitrify.



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Nitrification

- Nitrification typically requires 25% more oxygen than conventional processes.
- Factors influencing nitrification:
  - DO
  - Alkalinity/pH
  - MCRT
  - Temperature

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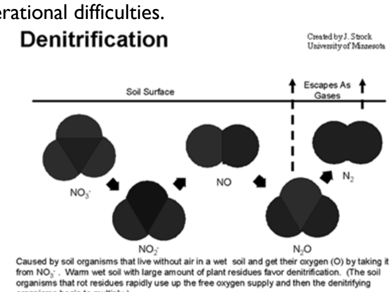
Denitrification

- Denitrification can occur unintentionally causing operational difficulties.



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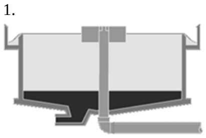
Denitrification

1.



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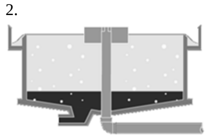

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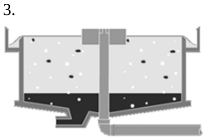

- Denitrification can cause rising sludge problems.

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Denitrification

- Advantages of denitrification:
  - Use of nitrate returns some of the extra oxygen needed
  - A portion of the alkalinity removed by nitrification is returned

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Foaming

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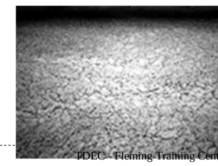
Foam and Scum

Stiff White Foam

Very Dark or Black Foam



Thick Scummy Dark Foam

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White Foam

- Stiff white foam is typically an indication of a high F:M, possibly caused by:
  - High influent BOD, low MLSS – high F:M
  - Detergents (surfactants) not being fully metabolized
- Excessive stiff white foam can become a nuisance and hazard for your facility.

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White Foam

- For a long-term solution to stiff white foam:
  - Find the cause of the problem
  - Figure out a way to alter or eliminate the cause

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White Foam Scenario 1

- Cause: High F:M ratio from a new process startup
- Solution: Build up the biomass in the aerators as quickly as possible by:
  - Maximizing the RAS rate
  - Reducing WAS rate
  - Maintaining adequate DO levels throughout the aerators

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White Foam Scenario 2

- Cause: High F:M ratio due to toxic slug in the influent causing biomass to die off
- Solution: Rebuild biomass as soon as possible
  - Maximizing the RAS rate
  - Reducing WAS rate
  - Maintaining adequate DO levels throughout the aerators
  - Also, investigate the source of the toxic load to prevent future problems

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White Foam Scenario 3

- Cause: High F:M ratio due to nutrient deficiencies
- Solution: Adjust ratio of BOD:N:P to maintain 100:5:1

White Foam Scenario 4

- Cause: High F:M caused by high or low pH
- Solution:
  - Short-term: correct pH by adding chemicals
  - Long-term: determine the cause and correct it

White Foam Scenario 5

- Cause: High F:M due to cold temperatures
- Solution: Raise MLSS in aerators by:
  - Reducing WAS rate
  - Increasing the RAS rate

White Foam Scenario 6

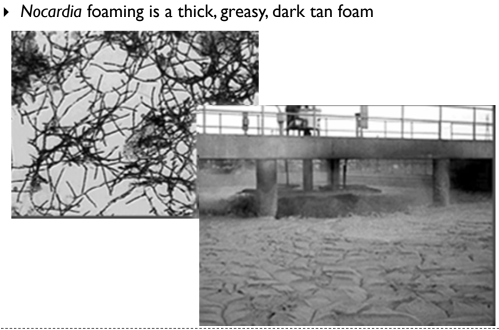
- Cause: High F:M due to solids loss in effluent
- Solution: Rebuild biomass as soon as possible
  - Maximizing the RAS rate
  - Reducing WAS rate
  - Maintaining adequate DO levels throughout the aerators

White Foam Scenario 7

- Cause: High F:M by insufficient RAS to aerators
- Solution:
  - Make sure RAS flow is going to aerators
  - Make sure RAS pumps are operating
  - Make sure RAS flow meter is working
  - Check clarifier sludge blanket level

Nocardia Foam

- *Nocardia* foaming is a thick, greasy, dark tan foam



Nocardia Foam

- *Nocardia* foam is caused by a longer MCRT and low F:M ratio
- To correct a *Nocardia* foam problem in a conventional system, increase wasting to raise F:M.
- *Nocardia* already present in your system must be physically removed
- *Nocardia* foam can cause problems with aerobic digesters and be returned to the reactors through recycled water.

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Dark Foam

- Dark or black foam is typically the result of insufficient aeration or industrial wastes.

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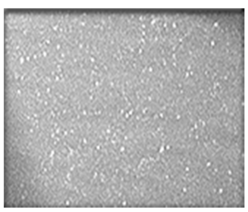

Ashing

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Ashing

- Ashing may occur when:
  - Denitrification is beginning to occur in the clarifier
  - F:M is extremely low and beyond normal extended aeration
  - Mixed liquor contains excessive levels of grease

  - Ashing may be a symptom of overoxidized (overaerated) mixed liquor.

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Pinpoint and Straggler Floc

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Pinpoint Floc

- Possible Causes of Pinpoint Floc:
  - Old sludge with poor floc-forming characteristics
  - Excessive turbulence shearing the floc
- Straggler floc is indicative of a low SRT.
- Pinpoint Floc Strategy
  - If tests indicate your sludge is old, decrease SRT by increasing the WAS flow rate

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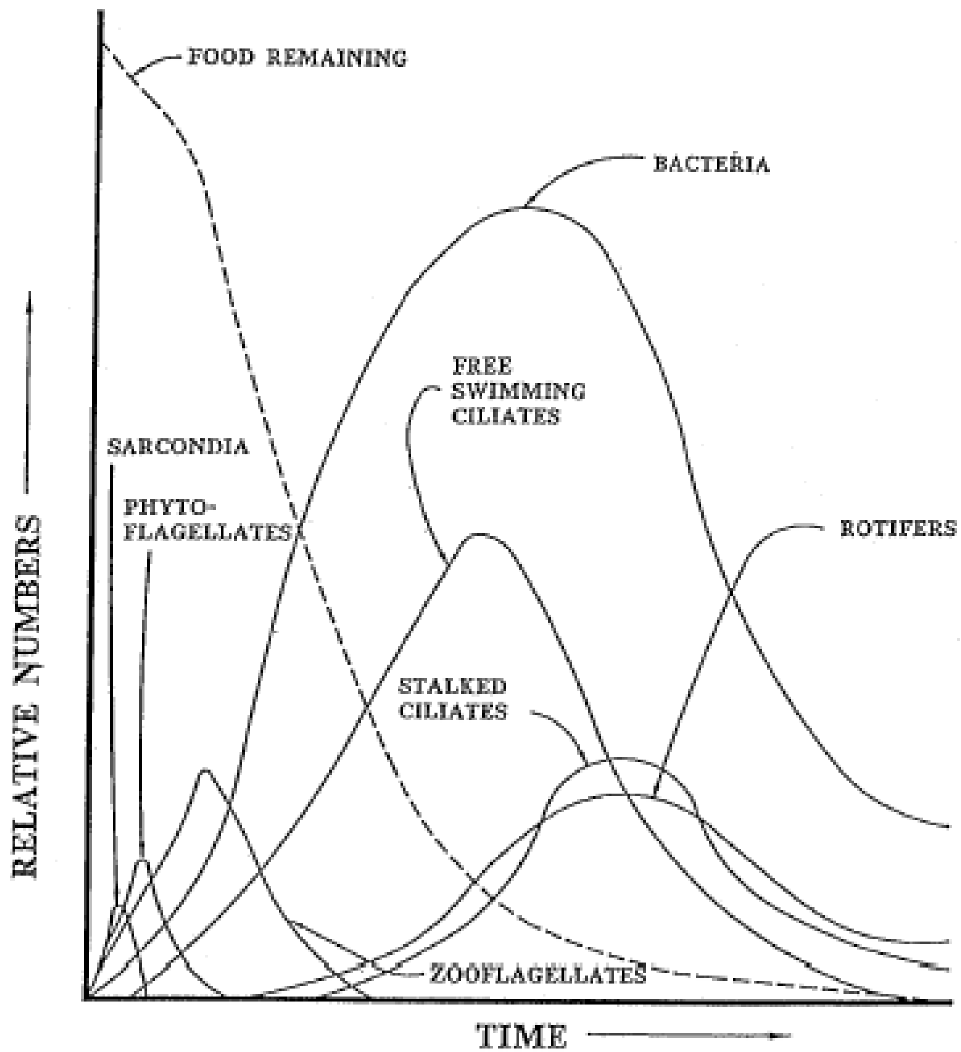
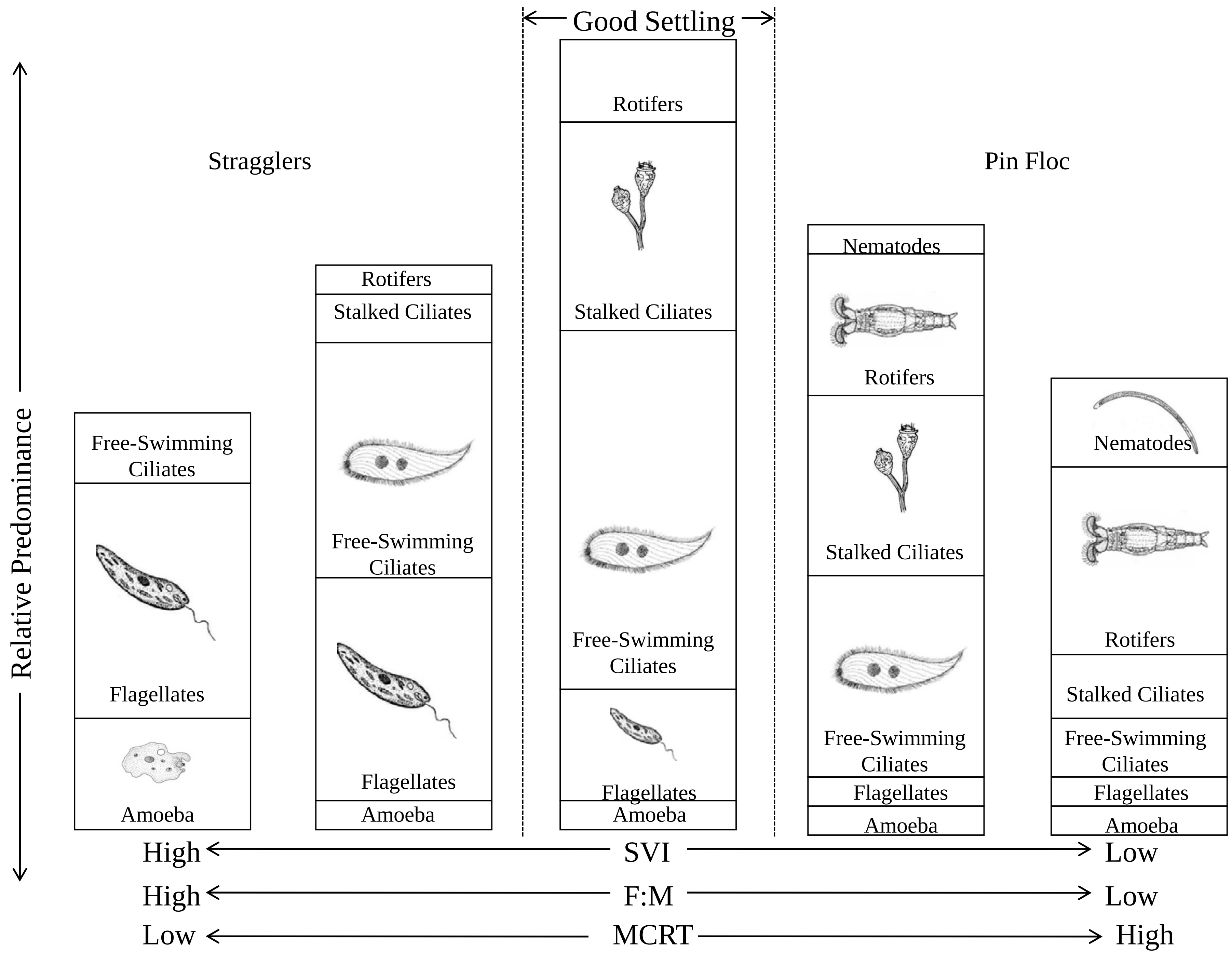
Design Parameters for Various Activated Sludge Processes

Process	MCRT, days	F:M ratio, lbs BOD applied/d / lb MLVSS	MLSS, mg/L
Conventional	5 – 15	0.2 – 0.4	1500 – 3000
Complete Mix	5 – 15	0.2 – 0.6	2500 – 4000
Step Feed	5 – 15	0.2 – 0.4	2000 – 3500
Modified Aeration	0.2 – 0.5	1.5 – 5.0	200 – 1000
Contact Stabilization	5 – 15	0.2 – 0.6	1000 – 3000 4000 – 10000
Extended Aeration	20 – 30	0.05 – 0.15	3000 – 6000
High Rate Aeration	5 – 10	0.4 – 1.5	4000 – 10000
High Purity Aeration	3 – 10	0.25 – 1.0	2000 – 5000
Oxidation Ditch	10 – 30	0.05 – 0.30	3000 – 6000
Single Stage Nitrification	8 – 20	0.10 – 0.25	2000 – 3500
Separate Stage Nitrification	15 – 100	0.05 – 0.20	2000 – 3500

Bacteria Population vs. Sludge Age




Good Settling
Stragglers
Pin Floc
Relative Predominance
Free-Swimming Ciliates
Flagellates
Amoeba
Rotifers
Stalked Ciliates
Free-Swimming Ciliates
Flagellates
Amoeba
Rotifers
Stalked Ciliates
Free-Swimming Ciliates
Flagellates
Amoeba
Nematodes
Rotifers
Stalked Ciliates
Free-Swimming Ciliates
Flagellates
Amoeba
Nematodes
Rotifers
Stalked Ciliates
Free-Swimming Ciliates
Flagellates
Amoeba
High SVI Low
High F:M Low
Low MCRT High

Activated Sludge Vocabulary

_______1. Absorption
_______2. Activated Sludge Process
_______3. Adsorption
_______4. Aeration Tank
_______5. Aerobes
_______6. Anaerobes
_______7. Anoxic
_______8. Biomass
_______9. Bulking
_______10. Coagulation
_______11. Denitrification
_______12. Diffuser
_______13. Endogenous Respiration
_______14. Facultative
_______15. Filamentous Bacteria
_______16. Floc
_______17. F/M Ratio
_______18. Mean Cell Residence Time (MCRT)
_______19. Mechanical Aeration
_______20. Mixed Liquor
_______21. Mixed Liquor Suspended Solids (MLSS)
_______22. Mixed Liquor Volatile Suspended Solids (MLVSS)
_______23. Nitrification
_______24. Oxidation
_______25. Protozoa
_______26. Reduction
_______27. Septic
_______28. Sludge Age
_______29. Supernatant
_______30. Zoogleal

A. Clumps of bacteria and particles or coagulants and impurities that have come together and formed a cluster. Found in aeration tanks, secondary clarifiers and chemical precipitation processes.
B. When the activated sludge in an aeration tank is mixed with primary effluent or the raw wastewater and return sludge, this mixture is then referred to as mixed liquor as long as it is in the aeration tank.
C. Bacteria that must have molecular (dissolved) oxygen (DO) to survive. Aerobes are aerobic bacteria.
D. The clumping together of very fine particles into larger particles (floc) caused by the use of chemicals (coagulants).
E. The organic or volatile suspended solids in the mixed liquor of an aeration tank. This volatile portion is used as a measure or indication of the microorganisms present.
F. The taking in or soaking up of one substance into the body of another by molecular or chemical action (as tree roots absorb dissolved nutrients in the soil)
G. The addition of oxygen, removal of hydrogen, or the removal of electrons from an element or compound. In wastewater treatment, organic matter is oxidized to more stable substances.
H. A device (porous plate, tube, bag) used to break the air stream from the blower system into fine bubbles in an aeration tank or reactor.
I. Oxygen deficient or lacking sufficient oxygen, but nitrate is available.
J. A condition produced by anaerobic bacteria. If sever, the wastewater produces hydrogen sulfide, turns black, gives off foul odors, contains little or no dissolved oxygen and the wastewater has a high oxygen demand.

K. These bacteria can use either dissolved molecular oxygen or oxygen obtained from food materials such as sulfate or nitrate ions. In other words, these bacteria can live under aerobic or anaerobic conditions.
L. Bacteria that do not need molecular (dissolved) oxygen (DO) to survive.
M. Suspended solids in the mixed liquor of an aeration tank.
N. A situation where living organisms oxidize some of their own cellular mass instead of new organic matter they adsorb or absorb from their environment.
O. An expression of the average time that a microorganism will spend in the activated sludge process.
P. Clouds of billowing sludge that occur throughout secondary clarifiers and sludge thickeners when the sludge does not settle properly. In the activated sludge process, this is usually caused by filamentous bacteria or bound water.
Q. A measure of the length of time a particle of suspended solids has been retained in the activated sludge process.
R. A biological wastewater treatment process that speeds up the decomposition of wastes in the wastewater being treated. Activated sludge is added to the wastewater and the mixture (mixed liquor) is aerated and agitated. After some time in the aeration tank, the activated sludge is allowed to settle out by sedimentation and is disposed of (wasted) or reused (returned to aeration tank) as needed. The remaining wastewater then undergoes more treatment.
S. Food to microorganism ratio. A measure of food provided to bacteria in an aeration tank.
T. Liquid removed from settle sludge. This liquid is usually returned to the influent wet well or to the primary clarifier.
U. The tank where raw or settled wastewater is mixed with return sludge and aerated.
V. A group of motile microscopic organisms (usually single-celled and aerobic) that sometimes cluster into colonies and often consume bacteria as an energy source.
W. The use of machinery to mix air and water so that oxygen can be absorbed into the water.
X. A mass or clump or organic material consisting of living organisms feeding on the wastes in wastewater, dead organisms and other debris.
Y. Jelly-like masses of bacteria found in both the trickling filter and activated sludge processes.
Z. The gathering of a gas, liquid or dissolved substance on the surface or interface zone of another material.
AA. Bacteria that grown in a thread or filamentous form. A common cause of sludge bulking in the activated sludge process.
BB. An aerobic process where bacteria change the ammonia and organic nitrogen in wastewater into oxidized nitrogen (usually nitrate). The second-stage BOD is sometimes referred to as the “nitrogenous BOD” (first stage is called the “carbonaceous BOD”)

CC. The anoxic biological reduction of nitrate nitrogen to nitrogen gas. An anoxic process that occurs when nitrite or nitrate ions are reduced to nitrogen gas and nitrogen bubbles are formed as a results of this process. The bubbles attach to the biological floc in the activated sludge process and float the floc to the surface of the secondary clarifiers. This condition is often the cause of rising sludge observed in secondary clarifiers or gravity thickeners.

DD. The addition of hydrogen, removal of oxygen, or the addition of electrons to an element or compound. Under aerobic conditions (no dissolved oxygen present), sulfur compounds are reduced to odor-producing hydrogen sulfide (H_2S) and other compounds.

Review Questions

1. In the activated sludge process, microorganisms convert organic matter to _______.
    a. New cells, carbon dioxide and water
    b. New cells, ammonia and water
    c. Carbon dioxide, water and nitrate
    d. Carbon dioxide, water and chlorine

2. The basic components of the activated sludge process are _______.
    a. Thickeners and digesters
    b. Screens and clarifiers
    c. Sand filters and chlorine contact chambers
    d. Biological reactors and clarifiers

3. Solids that settle to the bottom of clarifiers and are pumped back to the head of biological reactors are referred to as _______.
    a. RAS
    b. WAS
    c. TSS
    d. Total residual chlorine

4. The amount of time that microorganisms spend in the activated sludge process before they are wasted is called the _______.
    a. Total residual chlorine
    b. MLSS
    c. MCRT
    d. WAS

5. The process of reproduction where one mature cell divides into two new cells is known as _______.
    a. Cellular deduction
    b. Binary fission
    c. Bacterial degradation
    d. Resectioning

6. Protozoans are _______.
    a. Bacteria
    b. Microscopic plants
    c. Single-celled animals
    d. Worms

7. Conventional activated sludge processes are designed to remove soluble carbonaceous BOD from wastewater.
    a. True
    b. False

8. Return activated sludge is typically pumped back to which of the following?
    a. The headworks
    b. Primary clarifier
    c. Influent side of a biological reactor
    d. Effluent side of a biological reactor

9. The measure of biochemical or organic strength of wastewater is referred to as _______.
    a. Total residual chlorine
    b. TSS
    c. BOD
    d. F:M

10. At pH levels lower than _______ and higher than 10.0, the activated sludge process will completely stop.
    a. 2.0
    b. 6.0
    c. 4.0
    d. 5.0

11. Potential visual indicators of low DO concentrations include _______.
    a. Presence of filamentous bacteria
    b. Turbid effluent
    c. Dark gray to black mixed liquor
    d. All of the above

12. The mean cell residence time for most conventional activated sludge processes is typically _______.
    a. 5 – 15 days
    b. 5 – 15 hours
    c. 20 – 30 days
    d. 20 – 30 hours

13. Return activated sludge flow is typically a percentage of plant influent flow that is based on _______.
    a. Temperature and pH levels
    b. BOD and nutrient concentrations
    c. Mean cell residence time
    d. Inert solids and metal concentrations

14. Nitrification is a two step process. At the end of the second and final step, to what has ammonia been oxidized?
    a. Nitrite
    b. Nitrate
    c. Ammonium hydroxide
    d. Nitric acid

15. The required ratio of BOD:N:P:Fe in an activated sludge process is 100:10:5:0.5.
    a. True
    b. False

Answers to Vocabulary

1.	F	11.	CC	21.	M
2.	R	12.	H	22.	E
3.	Z	13.	N	23.	BB
4.	U	14.	K	24.	G
5.	C	15.	AA	25.	V
6.	L	16.	A	26.	DD
7.	I	17.	S	27.	J
8.	X	18.	O	28.	Q
9.	P	19.	W	29.	T
10.	D	20.	B	30.	Y

Answers to Review Questions

1.	A	6.	C	11.	D
2.	D	7.	A	12.	A
3.	A	8.	C	13.	C
4.	C	9.	C	14.	B
5.	B	10.	A	15.	B

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CHAPTER 7

Activated Sludge

ACTIVATED SLUDGE

7.1 General

7.1.1 Applicability

The activated sludge process and its various modifications may be used where sewage is amenable to biological treatment. This process requires close attention and more competent operator supervision than some of the other biological processes. A treatability study may be required to show that the organics are amendable to the proposed treatment. For example, industrial wastewaters containing high levels of starches and sugars may cause interferences with the activated sludge process due to bulking.

Toxic loadings from industries and excessive hydraulic loadings must be avoided to prevent the loss or destruction of the activated sludge mass. If toxic influents are a possibility, a properly enforced industrial pretreatment program will prove extremely beneficial to the WWTP and will be required. It takes days and sometimes weeks for the plant to recover from a toxic overload and will likely result in permit violations. Flow equalization, as detailed in Chapter 4, may be required in some instances. These requirements shall be considered when proposing this type of treatment.

7.1.2 Process Selection

The activated sludge process and its several modifications may be employed to accomplish varied degrees of removal of suspended solids and reduction of BOD and ammonia. Choice of the process most applicable will be influenced by the proposed plant size, type of waste to the treated, and degree and consistency of treatment required. All designs should provide for flexibility to incorporate as many modes of operation as is reasonably possible.

Calculations and/or documentation shall be submitted to justify the basis of design for the following:

a. Process efficiency
b. Aeration tanks
c. Aeration equipment (including oxygen and mixing requirements)
d. Operational rationale (including maintenance)
e. Costs (capital and operating)

In addition, the design must comply with any requirements set forth in other chapters such as clarifiers, sludge processing, etc.

7.1.3 Pretreatment

Where primary settling tanks are not used, effective removal or exclusion of grit, debris, excessive oil or grease, and comminution or screening of solids shall be accomplished prior to the activated sludge process.

Where primary settling is used, provisions should be made for discharging raw sewage directly to the aeration tanks to facilitate plant start-up and operation during the initial stages of the plant's design life. Also, primary effluents are often low in D.O. This should be planned for in the design.

7.2 Types of Processes

Figure 7.1 shows the flow schematics of the major types of activated sludge processes, excluding pretreatment. The types that are simply modifications of these processes are not shown.

7.2.1 Conventional

Conventional activated sludge is characterized by introduction of influent wastewater and return activated sludge at one end of the aeration tank, a plug-flow aeration tank, and diffused aeration.

7.2.2 Complete Mix

Complete mix activated sludge is characterized by introduction of influent wastewater and return activated sludge throughout the aeration basin and the use of a completely mixed aeration tank. Complete mix aeration tanks may be arranged in series to approximate plug flow and conventional activated sludge.

7.2.3 Step Aeration

Step aeration activated sludge is characterized by introduction of the influent wastewater at two or more points in the aeration tank, use of a plug-flow aeration tank, and diffused aeration.

7.2.4 Tapered Aeration

Tapered aeration is similar to conventional activated sludge except that the air supply is tapered to meet the organic load within the tank. More air is added to the influent end of the tank where the organic loading and oxygen demand are the greatest.

7.2.5 Contact Stabilization

Contact stabilization activated sludge is characterized by the use of two aeration tanks for each process train, one to contact the influent wastewater and return activated sludge (contact tank) and the other to aerate the return activated sludge (stabilization tank) and promote the biodegradation of the organics absorbed to the bacterial flocs.

7.2.6 Extended Aeration

Extended aeration activated sludge is characterized by a low F/M ratio, long sludge age, and long aeration tank detention time (greater than 18 hours). For additional details on oxidation ditches see Section 7.7).

7.2.7 High-Rate Aeration

High-rate aeration activated sludge is characterized by high F/M ratio, low sludge age, short aeration tank detention time, and high mixed-liquor suspended solids. High-rate aeration should be followed by other BOD and suspended solids removal processes to provide secondary treatment.

7.2.8 High-Purity Oxygen

High-purity oxygen activated sludge is characterized by the use of high-purity oxygen instead of air for aeration.

7.2.9 Kraus Process

Kraus process activated sludge is characterized by use of an aeration tank to aerate a portion of the return activated sludge, digester supernatant, and digested sludge in order to provide nitrogen (ammonia) to a nitrogen-deficient wastewater.

7.2.10 Sequencing Batch Reactors (SBR)

The SBR process is a fill-and-draw, non-steady state activated sludge process in which one or more reactor basins are filled with wastewater during a discrete time period, and then operated in a batch treatment mode. SBR's accomplish equalization, aeration, and clarification in a timed sequence. For additional details see Section 7.6.

7.3 Aeration Tanks

7.3.1 Required Volume

The size of the aeration tank for any particular adaptation of the process shall be based on the food-to-microorganism (F/M) ratio, using the influent BOD (load per day) divided by the mixed-liquor volatile suspended solids. Alternatively, aeration tanks may be sized using sludge age. The calculations using the F/M ratio or sludge age shall be based on the kinetic relationships.

APPENDIX 7A shows the permissible range of F/M ratio, sludge age, mixed-liquor suspended solids, aeration tank detention time, aerator loading, and activated sludge return ratio for design of the various modifications of the activated sludge process. All design parameters shall be checked to determine if they fall within the permissible range for the selected F/M ratio or sludge area and the aeration tank size. Diurnal load variations and peak loadings must be considered when checking critical parameters.

7.3.2 Shape and Mixing

The dimensions of each independent mixed-liquor aeration tank or return sludge reaeration tank should be such as to maintain effective mixing and utilization of air when diffused air is used. Liquid depths should not be less than 10 feet or more than 30 feet except in special design cases. For plug-flow conditions using very small tanks or tanks with special configuration, the shape of the tank and/or the installation of aeration equipment should provide for elimination of short-circuiting through the tank.

Aerator loadings should be considered and the horsepower per 1,000 cubic feet of basin volume required for oxygen transfer should be limited to prevent excessive turbulence in the aeration basins, which might reduce activated sludge settleability.

7.3.3 Number of Units

Multiple tanks capable of independent operation may be required for operability and maintenance reasons, depending on the activated sludge process, size of the plant, and the reliability classification of the sewerage works (refer to Section 1.3.11).

7.3.4 Inlets and Outlets

7.3.4.1 Controls

Inlets and outlets for each aeration tank unit in multiple tank systems should be suitably equipped with valves, gates, stop plates, weirs, or other devices to permit control of the flow and to maintain reasonably constant liquid level. The hydraulic properties of the system should permit the maximum instantaneous hydraulic load to be carried with any single aeration tank unit out of service.

7.3.4.2 Conduits

Channels and pipes carrying liquids with solids in suspension should be designed to maintain self-cleaning velocities or should be agitated to keep such solids in suspension at all rates of flow within the design limits.

7.3.4.3 Hydraulics

Where multiple aeration tanks and secondary clarifiers are used, provisions should be made to divide the flow evenly to all aeration tanks in service and then recombine the flows, and to divide the flow evenly to all secondary clarifiers in service and then recombine the flows. Treatments plants using more than four aeration tanks and secondary clarifiers may divide the activated sludge systems into two or more process trains consisting of not less than two aeration tanks and secondary clarifiers per process train.

7.3.4.4 Bypass

When a primary settling tank is used, provisions shall also be made for discharging raw wastewater directly to the aeration tanks following pretreatment for start-ups.

7.3.5 Measuring Devices

For plants designed for less than 250,000 gallons per day, devices shall be installed for indicating flow rates of influent sewage, return sludge, and air to each aeration tank. For plants designed for greater than 250,000 gallons per day, devices shall be installed for totalizing, indicating, and recording influent sewage and returned sludge to each aeration tank. Where the design provides for all returned sludge to be mixed with the raw sewage (or

primary effluent) at one location, the mixed-liquor flow rate to each aeration tank shall be measured, and the flow split in such a manner to provide even loading to each tank, or as desired by operations.

7.3.6 Freeboard and Foam Control

Aeration tanks shall have a freeboard of at least 18 inches. Freeboards of 24 inches are desirable with mechanical aerators.

Consideration shall be given for foam control devices on aeration tanks. Suitable spray systems or other appropriate means will be acceptable. If potable water is used, approved backflow prevention shall be provided on the water lines. The spray lines shall have provisions for draining to prevent damage by freezing.

7.3.7 Drain and Bypass

Provisions shall be made for dewatering each aeration tank for cleaning and maintenance. The dewatering system shall be sized to permit removal of the tank contents within 24 hours. If a drain is used, it shall be valved. The dewatering discharge shall be upstream of the activated sludge process.

Provisions shall be made to isolate each aeration tank without disrupting flow to other aeration tanks.

Proper precautions shall be taken to ensure the tank will not "float" when dewatered.

7.3.8 Other Considerations

Other factors that might influence the efficiency of the activated sludge process should be examined. Septic and/or low pH influent conditions are detrimental, particularly where primary clarifiers precede the activated sludge process or when the collection system allows the sewage to go septic. Often, the pH is buffered by the biological mass, but wide variations in the influent should be avoided and, if present, chemical addition may be necessary.

Aerobic organisms require minimum quantities of nitrogen and phosphorus. Domestic wastewater usually has an excess of nitrogen and phosphorus; however, many industrial wastewaters are deficient in these elements. A mass balance should be performed to see if the combined industrial and domestic influent contains sufficient nitrogen and phosphorus or if nutrient levels will have to be supplemented.

7.4 <u>Aeration Equipment</u>

7.4.1 General

Oxygen requirements generally depend on BOD loading, degree of treatment, and level of suspended solids concentration to be maintained in the aeration tank mixed liquor. Aeration equipment shall be designed to supply sufficient oxygen to maintain a minimum dissolved oxygen concentration of 2 milligrams per liter (mg/l) at average design load and 1.0 mg/l at peak design loads throughout the mixed liquor. In the absence of experimentally determined values, the design oxygen requirements for all activated sludge processes shall be 1.1 lbs oxygen per lb peak BOD_5 applied to the aeration tanks, with the exception of the extended aeration process, for which the value shall be 2.35. Aeration equipment shall be of sufficient size and arrangement to maintain velocities greater than 0.5 foot per second at all points in the aeration tank.

The oxygen requirements for an activated sludge system can be estimated using the following relationship:

O_2 = (a) (BOD) + b (MLVSS)

O_2 = pounds of oxygen required per day

BOD = pounds of BOD removed per day (5-day BOD)*

MLVSS= pounds of mixed liquor volatile suspended solids contained in the aeration basin

a = amount of oxygen required for BOD synthesis. "a" will range from 0.5 to 0.75 pound of oxygen per pound of BOD removed

b = amount of oxygen required for endogenous respiration or decay. "b" will range from 0.05 to 0.20 pound of oxygen per pound of MLVSS

*BOD removal shall be calculated as influent BOD_5 minus soluble effluent BOD_5.

For preliminary planning before process design is initiated, a rough estimate can be obtained by using 1.0 to 1.2 pounds of oxygen per pound of BOD removed (assuming no nitrification).

7.4.2 Diffused Air Systems

7.4.2.1 Design Air Requirements

The aeration equipment shall be designed to provide the oxygen requirements set forth above. Minimum requirements for carbonaceous removal are shown below. (Oxygen requirements for nitrification are in addition to that required for carbonaceous removal where applicable; i.e., low F/M.)

Process	Cubic Feet of Air Available per Pound of BOD Load Applied to Aeration Tank
Conventional	1,500
Step Aeration	1,500
Contact Stabilization	1,500
Modified or "High Rate"	400 to 1,500 (depending upon BOD removal expected)
Extended Aeration	2,100

Air required for channels, pumps, or other air-use demand shall be added to the air volume requirements.

Manufacturers' specifications must be corrected to account for actual operation conditions (use a worst case scenario). Corrections shall be made for
temperatures other than 20^{o}C and elevations greater than 2,000 feet.

7.4.2.2 Special Details

The specified capacity of blowers or air compressors, particularly centrifugal blowers, shall take into account that the air intake temperature might reach extremes and that pressure might be less than normal. Motor horsepower shall be sufficient to handle the minimum and maximum ambient temperatures on record.

The blower filters shall be easily accessible. Spare filters should be provided.

The blowers shall be provided in multiple units, arranged and in capacities to meet the maximum air demand with the single largest unit out of service. The design shall also provide for varying the volume of air delivered in proportion to the load demand of the plant.

The spacing of diffusers shall be in accordance with the oxygen and mixing requirements in the basin. If only one aeration tank is proposed, arrangement of diffusers should permit their removal for inspection, maintenance, and replacement without de-watering the tank and without shutting off the air supply to other diffusers in the tank.

Individual units of diffusers shall be equipped with control valves, preferably with indicator markings, for throttling or for complete shutoff. Diffusers in each assembly shall have substantially uniform pressure loss. The adjustment of one diffuser should have minimal influence on the air supply rate to any other diffusers.

Flow meters and throttling valves shall be placed in each header. Air filters shall be provided as part of the blower assembly to prevent clogging of the diffuser system. Means shall be provided to easily check the air filter so that it will be replaced when needed.

7.4.3 Mechanical Aeration Equipment

Power input from mechanical aerators should range from 0.5 to 1.3 horsepower per 1,000 cubic feet of aeration tank.

The mechanism and drive unit shall be designed for the expected conditions of the aeration tank in terms of the proven performance of the equipment.

Due to the high heat loss, consideration shall be given to protecting subsequent treatment units from freezing where it is deemed necessary. Multiple mechanical aeration unit installations shall be designed to meet the maximum oxygen demand with the largest unit out of service. The design shall normally also provide for varying the amount of oxygen transferred in proportion to the load demand on the plant.

A spare aeration mechanism shall be furnished for single-unit installations. Access to the aerators shall be provided for routine maintenance.

7.4.4 Flexibility and Energy Conservation

The design of aeration systems shall provide adequate flexibility to vary the oxygen transfer capability and power consumption in relation to oxygen demands. Particular attention should be given to initial operation when oxygen demands may be significantly less that the design oxygen demand. The design shall always maintain the minimum mixing levels; mixing may control power requirements at low oxygen demands.

Dissolved oxygen probes and recording should be considered for all activated sludge designs. Consideration will be given to automatic control of aeration system oxygen transfer, based on aeration basin dissolved oxygen concentrations, provided manual back-up operation is available. A dissolved oxygen field probe and meter is to be provided for all activated sludge installations.

Watt-hour meters shall be provided for all aeration system drives to record power usage.

Energy conservation measures shall be considered in design of aeration systems. For diffused aeration systems, the following shall be considered:

a. Use of small compressors and more units

b. Variable-speed drives on positive-displacement compressors

c. Intake throttling on centrifugal compressors

d. Use of timers while maintaining minimum mixing and D.O. levels (consult with manufacturer's recommendations for proper cycling)

e. Use of high-efficiency diffusers

f. Use of separate and independent mixers and aerators

For mechanical aeration systems, the following shall be considered:

a. Use of smaller aerators

b. Variable aeration tank weirs

c. Multiple-speed motors

d. Use of timers

7.5 Additional Details

7.5.1 Lifting Equipment and Access

Provisions shall be made to lift all mechanical equipment and provide sufficient access to permit its removal without modifying existing or proposed structures.

7.5.2 Noise and Safety

Special consideration shall be given to the noise produced by air compressors used with diffused aeration systems and mechanical aerators. Ear protection may be required. Silencers for blowers may be required in sensitive areas.

Handrails shall be provided on all walkways around aeration tanks and clarifiers.

The following safety equipment shall be provided near aeration tanks and clarifiers:

Safety vests
Lifelines and rings
Safety poles

Walkways near aeration tanks shall have a roughened surface or grating to provide safe footing and be built to shed water.

Guards shall be provided on all moving machinery in conformance with OSHA requirements.

Sufficient lighting shall be provided to permit safe working conditions near aerations tanks and clarifiers at night.

7.6 Sequencing Batch Reactors (SBRs)

SBRs shall be designed to meet all the requirements set forth in preceding sections on activated sludge. Special consideration shall be given to the following:

7.6.1 A pre-aeration, flow-equalization basin is to be provided for when the SBR is in the settle and/or draw phases. If multiple SBR basins are provided, a pre-aeration basin will not be needed if each SBR basin is capable of handling all the influent peak flow while another basin is in the settle and/or draw phase.

7.6.2 When discharging from the SBR, means need to be provided to avoid surges to the succeeding treatment units. The chlorine contact tank shall not be hydraulically overloaded by the discharge.

7.6.3 The effluent from the SBRs shall be removed from just below the water surface (below the scum level) or a device which excludes scum shall be used. All decanters shall be balanced so that the effluent will be withdrawn equally from the effluent end of the reactor.

7.6.4 Prevailing winds must be considered in scum control.

7.7 Oxidation Ditch

7.7.1 General

The oxidation ditch is a complete-mixed, extended aeration, activated sludge process which is operated with a long detention time. Brush-rotor (or disk type) aerators are normally used for mixing and oxygen transfer. All requirements set forth in previous sections and/or chapters must be met, with the exception of those items addressed below.

7.7.2 Special Details

7.7.2.1 Design Parameters

The design parameters shall be in the permissible range as set forth in Table 7.1 for F/M, sludge age, MLSS, detention time, aerator loading, and activated sludge return ratio.

7.7.2.2 Aeration Equipment

Aeration equipment shall be designed to transfer 2.35 pounds of oxygen per pound of BOD at standard conditions. The oxygen requirement takes into account nitrification in a typical wastewater. Also, a minimum average velocity of one foot per second shall be maintained, based on the pumping rate of the aeration equipment and the aeration basin cross-sectional area.

A minimum of two aerators per basin is required.

7.7.2.3 Aeration Tank Details

a. Influent Feed Location

Influent and return activated sludge feed to the aeration tank should be located just
upstream of an aerator to afford immediate mixing with mixed liquor in the channel.

b. Effluent Removal Location

Effluent from the aeration channel shall be upstream of an aerator and far enough upstream from the injection of the influent and return activated sludge to prevent short-circuiting.

c. Effluent Adjustable Weir

Water level in the aeration channel shall be controlled by an adjustable weir or other means. In calculating weir length, use peak design flow plus maximum recirculated flow to prevent excessive aerator immersion.

d. Walkways and Splash Control

Walkways must be provided across the aeration channel to provide access to the aerators for maintenance. The normal location is above the aerator. Splash guards shall be provided to prevent spray from the aerator on the walkway. Bridges should not be subject to splash from the rotors.

e. Baffles

Horizontal baffles, placed across the channel, may be used on all basins with over 6 feet liquid depth, and may be used where the manufacturer recommends them to provide proper mixing of the entire depth of the basin.

Baffles should be provided around corners to ensure uniform velocities.

7.7.3 45-Degree Sloping Sidewall Tanks

7.7.3.1 Liquid Depth

Liquid depth shall be 7 to 10 feet, depending on aerator capability, as stated by the manufacturer.

7.7.3.2 Channel Width at Water Level

The higher ratios (channel width at water level divided by aerator length) are to be used with smaller aerator lengths.

3- to 15-foot-long rotors, ratio 3.0 to 1.8.

16- to 30-foot-long rotors, ratio 2.0 to 1.3

Above 30-foot-long rotors, ratio below 1.5

7.7.3.3 Center Island

When used, the minimum width of center island at liquid level, based on aerator length, should be as follows (with center islands below minimum width, use return flow baffles at both ends):

3- to 5-foot-long rotor, 14 feet

6- to 15-foot-long rotor, 16 feet

16- to 30-foot-long rotor, 20 feet

Above 30-foot-long rotors, 24 feet

7.7.3.4 Center Dividing Walls

Center dividing walls can be used but return flow baffles at both ends are required. The channel width, W, is calculated as flat bottom plus 1/2 of sloping sidewall. Baffle radius is W/2. Baffles should be offset by W/8, with the larger opening accepting the flow and the smaller opening downstream compressing the flow.

7.7.3.5 Length of Straight Section

Length of straight section of ditch shall be a minimum of 40 feet or at least two times the width of the ditch at liquid level.

7.7.3.6 Preferred Location of Aerators

Aerators shall be placed just downstream of the bend, normally 15 feet, with the long straight section of the ditch downstream of the aerator.

7.7.4 Straight Sidewall Tanks

7.7.4.1 Liquid Depth

Liquid depth shall be 7 to 12 feet, depending on aerators.

7.7.4.2 Aerator Length

Individual rotor length shall span the full width of the channel, with necessary allowances required for drive assembly and outboard bearing.

7.7.4.3 Center Island

Where center islands are used, the width should be the same as with 45-degree sloping sidewalls, or manufacturer's recommendation.

7.7.4.4 Center Dividing Walls

When a center dividing wall is used, return flow baffles are required at both ends. Return flow baffle radius is width of channel, W, divided by 2, W/2. Baffles should be offset by W/8, with the larger opening accepting the flow and the smaller opening downstream compressing the flow.

7.7.4.5 Length of Straight Section

Length of straight section downstream of aerator shall be near 40 feet or close to two times the aerator length. In deep tanks with four aerators, aerators should be placed to provide location for horizontal baffles.

7.7.4.6 Preferred Location of Aerators

Aerators should be placed just downstream of the bend with the long straight section of the tank downstream of the aerator. Optimal placement of rotors will consider maintaining ditch center line distance between rotors close to equal.

APPENDIX 7-A

CHAPTER 8

Nitrification

8.1 General

8.1.1 Applications
8.1.2 Process Selection

8.2 Suspended Growth Systems

8.2.1 Single - Stage Activated Sludge
8.2.2 Two - Stage with Activated Sludge Nitrification

8.3 Fixed - Film Systems

8.3.1 Trickling Filters
8.3.2 Activated Biofilter (ABF) Process
8.3.3 Submerged Media
8.3.4 Rotating Biological Contactors

NITRIFICATION

8.1 General

8.1.1 Applications

Nitrogen exists in treated wastewater primarily in the form of ammonia which is oxidized to nitrate by bacteria. This process requires oxygen and can exert a significant oxygen demand on the receiving water.

Nitrification shall be considered when ammonia concentrations in the effluent would cause the receiving water to exceed the limitations established to prevent ammonia toxicity to aquatic life, or when the effluent ammonia quantity would cause the dissolved oxygen level of the receiving stream to deplete below allowable limits. The degree of treatment required will be determined by the NPDES permit limit.

8.1.2 Process Selection

Calculations shall be submitted to support the basis of design. The following factors should be considered in the evaluations of alternative nitrification processes:

a. Ability to meet effluent requirements under all environmental conditions to be encountered, with special emphasis on temperature, pH, alkalinity, and dissolved oxygen.

b. Cost (total present worth)

c. Operational considerations, including process stability, flexibility, operator skill required, and compatibility with other plant processes.

d. Land requirements.

8.2 Suspended Growth Systems

8.2.1 Single - Stage Activated Sludge

This section details the requirements for activated sludge systems designed to both remove carbonaceous matter and oxidize ammonia.

8.2.1.1 Process Design

Design must provide adequate solids retention time in the activated sludge system for sufficient growth of nitrifying bacteria. A safety factor of 2.5 or greater should be used to calculate the design mean cell residence time or sludge age. This safety factor must be large enough to provide enough operational flexibility to handle diurnal, peak, and transient loadings. The calculation of the solids retention time shall consider influent BOD, TSS, BOD_5/TKN (Total Kjeldahl Nitrogen) ratio and kinetic parameters. The kinetic parameters can be taken from the literature, similar installations, or pilot plant studies. The effect of temperature on the kinetics must be considered since nitrification will not proceed as rapidly during winter months.

8.2.1.2 Special Details

The following requirements are in addition to those included in Chapter 5, "Clarifiers", and Chapter 7, "Activated Sludge":

a. Sufficient oxygen must be provided for both carbonaceous BOD oxidation and ammonia oxidation. Use 4.6 pounds O_2 per pound total Kjeldahl nitrogen to calculate the oxygen requirements for nitrification, in addition to the oxygen needed for BOD removal.

b. Aeration basin design dissolved oxygen shall be greater than or equal to 2.0 mg/l.

c. Diurnal peak mass flow rates of BOD and total Kjeldahl nitrogen must be considered in the aeration system design.

d. The pH levels must be controlled within the range of 6.5 to 8.4. Nitrification is optimized in the upper portion of this range (7.9 to 8.4) but pH levels in the range of 7.6 to 7.8 are recommended since CO_2 produced will be released from the wastewater.

e. Nitrification requires alkalinity, 7.1 pounds as $CaCO_3$ per pound NH_3-N oxidized. The wastewater must be shown to have sufficient alkalinity or chemical treatment must be considered to provide adequate alkalinity.

f. Clarifier and return sludge pumping must be designed with the capability to allow operation over a range of solids retention times. Flexibility should be provided to prevent denitrification in the clarifier from low D.O. levels in the sludge blanket. This could cause violations of other effluent limits (i.e., suspended solids).

8.2.2 Two-Stage with Activated Sludge Nitrification

This section details the requirements for systems in which carbonaceous BOD is removed in the first stage and ammonia is oxidized by activated sludge in the second stage. BOD removal in the first stage could be by activated sludge, trickling filters, or physical - chemical treatment.

8.2.2.1 Process Design

The first stage shall be designed using the requirements of the appropriate chapters, such as activated sludge, trickling filters, and clarifiers. To promote a sludge with good settling characteristics in the second stage clarifier, some carbonaceous BOD shall enter the second stage aeration basin. This allows a less conservative design of the first stage as long as total BOD removal is sufficient. The requirements for the process design of the second stage are the same as those presented previously for the single-stage nitrification system.

8.2.2.2 Special Details

The following details are in addition to those in Chapter 5, "Clarifiers," Chapter 6, "Fixed Film Reactors," and Chapter 7, "Activated Sludge."

a. Sufficient oxygen must be provided for both carbonaceous BOD oxidation and ammonia oxidation. Use 4.6 pounds O_2 per pound total Kjeldahl nitrogen to calculate the oxygen requirements for nitrification, in addition to the oxygen needed nitrogen to calculate the oxygen requirements for nitrification, in addition to the oxygen needed for BOD removal.

b. Aeration basin design dissolved oxygen shall be greater than or equal to 2.0 mg/l.

c. Diurnal peak mass flow rates of BOD and total Kjeldahl nitrogen must be considered in the aeration system design.

d. The pH levels must be controlled within the range of 6.5 to 8.4. Nitrification is optimized in the upper portion of this range (7.9 to 8.4) but pH levels in the range of 7.6 to 7.8 are recommended since CO_2 produced will be released from the wastewater.

e. Nitrification requires alkalinity, 7.1 pounds as $CaCO_3$ per pound NH_3-N oxidized. The wastewater must be shown to have sufficient alkalinity or chemical treatment must be considered to provide adequate alkalinity.

f. Clarifier and return sludge pumping must be designed with the capability to allow operation over a range of solids retention times. Flexibility should be provided to prevent denitrification in the clarifier from low D.O. levels in the sludge blanket. This could cause violations of other effluent limits (i.e., suspended solids).

8.3 <u>Fixed - Film Systems</u>

8.3.1 Trickling Filters

8.3.1.1 Process Design

Recirculation is required to provide a constant hydraulic loading on the medium.

a. Single - Stage

This section details the requirements for a trickling filter that is designed for both carbonaceous BOD removal and ammonia oxidation. Design shall be based on the organic loading expressed as pounds BOD per 1,000 cubic feet. The design loading rate shall by justified from literature, similar installations, or pilot plant data for a particular depth and type of filter medium. Design shall consider temperature effects on ammonia removal and organic loading rates, and any proposal to attain nitrification in a single-stage rock media trickling filter will be more closely scrutinized than with other types of media.

b. Two - Stage

This section details the requirements of using a trickling filter for nitrification which is preceded by a trickling filter, activated sludge system, or physical - chemical

treatment for carbonaceous BOD removal. Design must be based on either a surface area loading expressed as square feet per pound NH_4-N oxidized per day or a volumetric loading expressed as pounds NH_4-N per 1,000 cubic feet per day. Loading rates must be justified from literature, similar plants, or
pilot plant data. The effects of temperature on loading rates and ammonia oxidation must be considered in the design.

8.3.1.2 Special Details

The following requirements are in addition to those in Chapter 5, "Clarifiers," and Chapter 6, "Fixed Film Reactors."

a. Clarifiers will be required for second-stage trickling filters for nitrification.

b. Higher specific surface area and lower void ratio media may be used for second-stage trickling filters providing nitrification.

8.3.2 Activated Biofilter (ABF) Process

8.3.2.1 Process Design

Process design shall be based on the literature, similar installations, or pilot plant data. The design shall consider the effects of temperature, pH, and aeration basins.

8.3.2.2 Special Details

a. Sufficient oxygen must be provided for both carbonaceous BOD oxidation and ammonia oxidation. Use 4.6 pounds O_2 per pound total Kjeldahl nitrogen to calculate the oxygen requirement for nitrification, in addition to the oxygen needed for BOD removal.

b. Aeration basin design dissolved oxygen shall be greater than or equal to 2.0 mg/l.

c. Diurnal peak mass flow rates of BOD and total Kjeldahl nitrogen must be considered in the aeration system design.

d. The pH levels must be controlled within the range of 6.5 to 8.4. Nitrification is optimized in the upper portion of this range (7.9 to 8.4) but pH levels in the range of 7.6 to 7.8 are recommended since CO_2 produced will be released from the wastewater.

e. Nitrification requires alkalinity, 7.1 pounds as $CaCO_3$ per pound NH_3-N oxidized. The wastewater must be shown to have sufficient alkalinity or chemical treatment must be considered to provide adequate alkalinity.

f. Clarifier and return sludge pumping must be designed with the capability to allow operation over a range of solids retention times. Flexibility should be provided to prevent denitrification in the clarifier from low D.O. in the sludge blanket. This could cause violations of other effluent limits (i.e., suspended solids).

8.3.3 Submerged Media

8.3.3.1 General

This section includes all designs for fixed-film reactors using stones, gravel, sand, anthracite coal, or plastic media or combinations thereof in which the medium is submerged and air or oxygen is used to maintain aerobic conditions. Pilot plant testing or a similar full-scale installation with a minimum of 1 year of operation is required before consideration will be given to a submerged design. No design will be considered unless the following can be demonstrated:

a. Reliable operation

b. Ability to transfer sufficient oxygen

c. Ability to handle peak flows without washout of medium

d. Methods of separating suspended solids from effluent, removing waste sludge, and stabilization and dewatering of waste sludge

e. Media resistance to plugging

8.3.3.2 Process Design

Data for design and calculations shall be submitted upon request to justify the basis of design.

8.3.4 Rotating Biological Contactors

8.3.4.1 Process Design

Process design shall be based on the surface area loading expressed as gallons per day per square foot. Design surface area loading shall consider the number of stages, temperature, BOD concentration entering and leaving each stage, and ammonia concentration entering and leaving each stage. Calculations shall be submitted upon request to justify the basis of design.

8.3.4.2 Special Details

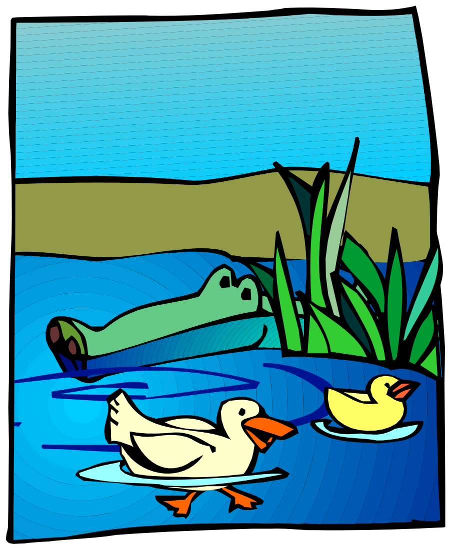
The following requirements are in addition to those set forth in Chapter 5, "Clarifiers," and Chapter 6, "Fixed Film Reactors."

a. Standard media (100,000 square feet per shaft or less) shall be used until influent BOD concentration is less than manufacturer's recommendation for high-density media (150,000 square feet per shaft or more). High-density media may be used for influent BOD concentrations less than manufacturer's recommendation for high-density media.

b. Clarifiers will be required following rotating biological contactors that follow a secondary process.

Section 7

Ponds



Wastewater Ponds & Lagoons

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Advantages of Ponds

- Economical to operate
- Capable of handling high flows
- Adaptable to changing loads
- Accumulate sludge at a rate of 0.2 lbs per lb of BOD (much lower than conventional facilities where the accumulation rate is 0.5 lbs to 1.0 lbs of solids per lb of BOD removed.)

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Advantages of Ponds

- Have an increased potential design life
- Serve as wildlife habitat
- Consume little energy
- Adaptable to land application
- Does not require highly trained personnel

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Disadvantages of Ponds

- May produce odors
- Require large land areas
- Are effected by climactic conditions
- May have high suspended solids levels in effluent
- Might contaminate groundwater

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Types of Bacteria in Lagoons

- Aerobic bacteria
  - Need D.O. to live and grow
- Anaerobic bacteria
  - Live only where there is no D.O.
- Facultative bacteria
  - Can live with or without D.O.

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Aerobic Decomposition

- Organics + O_2 + nutrients + inert matter → CO_2 + H_2O + new microorganisms + additional inert matter

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Anaerobic Decomposition

- Organics + nutrients + inert matter → CH_4 + CO_2 + NH_4 + H_2S + other products

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Types of Lagoons

- Aerobic
- Anaerobic
- Facultative
- Aerated

Types of Bacteria in Stabilization Lagoons

8
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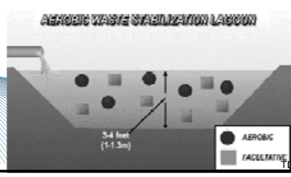
Aerobic Pond

- Shallow: 3-4 ft deep
- D.O. throughout water column
- Flat terrain with much sunshine
- D.O. due to photosynthesis



9
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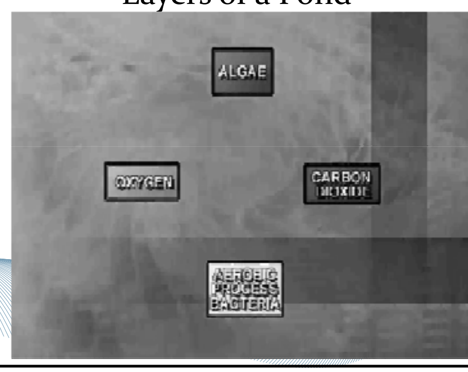
Decomposition in Aerobic Layers of a Pond



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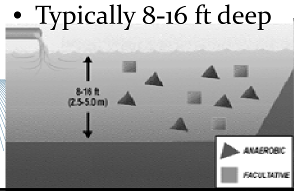
Anaerobic Pond

- No dissolved oxygen
- Treatment due to fermentation of sludge on bottom
- Highly efficient removal organic wastes
- Typically 8-16 ft deep



11
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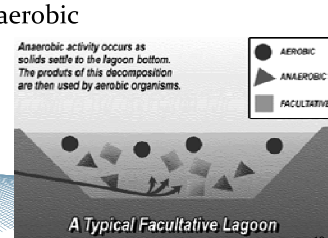
Facultative Lagoon

- Most common
- Upper portion aerobic due to algae
- Sludge layer anaerobic
- Depth: 4-8 ft
- DT: 5-30 day+



12
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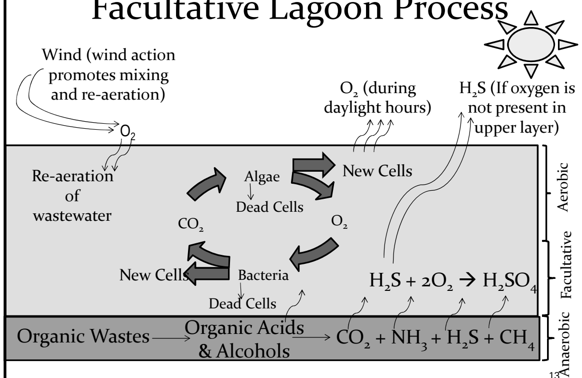
Facultative Lagoon Process



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Aerated Lagoons

Aerated compared to Facultative

- Shorter detention times
- Heavier loadings

Detention Times

- Aerated Lagoons: 3-10 d
- Facultative Lagoons:
  - 5-30 days (typical)
  - 180 days (in cold climates)

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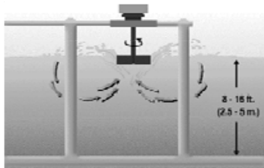
Mechanically Aerated Ponds

Stationary or floating aerators

Allows for higher organic loading or shorter detention time in lagoon



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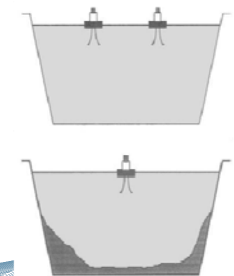
Aerated Lagoons: Partial vs. Complete Mix

- Less land; constructed deeper
- Uniform D.O or partial mix
- Not dependent for D.O by sun/photosynthesis
- More maintenance required
- Greater energy costs to supply oxygen to bacteria
- Easily affected by temp.
- Require sedimentation unit after lagoon (complete mix)



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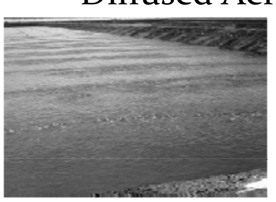
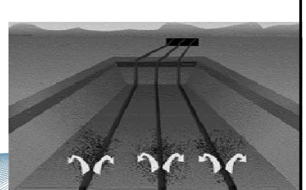
Diffused Aeration Lagoons



Less mixing; more efficient oxygen transfer



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Typical Lagoon Design

Parameter	Aerobic	Facultative	Anaerobic	Aerated
Size, ac	<10, multiples	2-10 multiples	0.5-2.0	2-10, multiples
Operation	Series or Parallel	Series or Parallel	Series	Series or Parallel
Detention Time, days	10-40	5-30*	20-50	3-10
Depth, ft	3-4	4-8	8-16	6-20
pH	6.5-10.5	6.5-8.5	6.5-7.2	6.5-8.0
Temperature Range, °C	0-30	0-50	6-50	0-30
Optimum Temperature, °C	20	20	30	20
BOD5 Loading, lb/ac/d	54-110	45-160	180-450	——
BOD5 Removal, %	80-95	80-95	50-85	80-95

*180 days in cold climates

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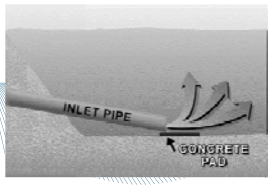
Pond Structures: Inlet

- Force main vs. gravity
- Single vs. multiple inlets
- Below surface best: prevents freezing



19
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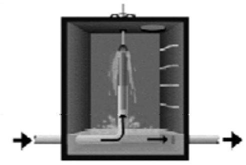
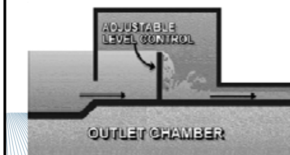
Pond Structures: Outlet

- Just below surface with scum baffle to minimize transfer of algae





Above: telescoping tube.

Left: flash boards

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•Synthetic liner
•Packed clay liner
•Berm or levee: grass and/or rip rap

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Factors Effecting Pond Operation

- Physical:
  - Surface area
  - Depth
  - Hydraulic load
  - Type of aeration
  - Temperature
  - Flow variations

22
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Factors Effecting Pond Operation

- Biochemical:
  - Organic loading rate
  - pH
  - Dissolved oxygen
  - Alkalinity
- Microbiological: bacteria, algae, etc.

23
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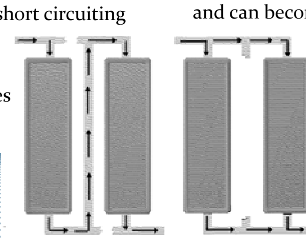
Lagoons in Series

Advantages
- Few algae and bacteria in final effluent
- Reduces short circuiting

Disadvantages
- First lagoon in series experiences heavy load and can become anaerobic

Series



Parallel

24
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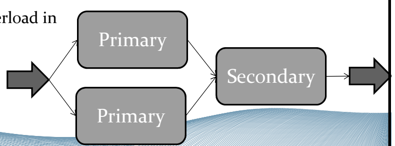
Lagoons in Parallel

Advantages

- Can take heavier loads without becoming anaerobic
- One lagoon can be closed for cleaning and maintenance
- Prevents organic overload in winter

Disadvantages

- May not produce as good an effluent as series arrangement



25
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Microorganisms in Wastewater Treatment Lagoons

- Single Celled:
  - Bacteria: treat wastewater
  - Algae
  - Protozoa:
    - Flagellates
    - Free Swimming Ciliates
    - Stalked Ciliates
- Multi Celled:
  - Metazoa:
    - Rotifers
    - Crustaceans

26
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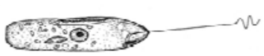
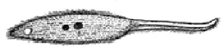
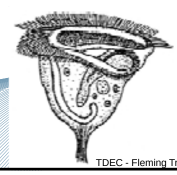
Protozoa

- Flagellates
  - Consume organic matter
  - Compete with bacteria
- Ciliates
  - Consume bacteria and algae in wastewater







27
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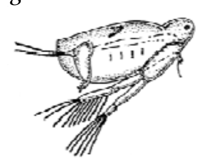
Metazoa

- Rotifers
  - Filter organic waste & bacteria
  - Indicate effective biological treatment
- Crustaceans feed on algae.



28
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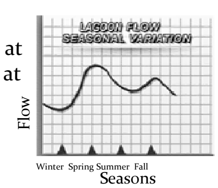
Monitoring Performance

- D.O. and pH: diurnal variation at several points in each cell and at several depths
  - Highest values in p.m.
- Seasonal flow variation
- Sludge production
- Actual detention time vs. design
- Spring overturn: bottom water becomes warmer & rises up



29
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Daily Operation & Maintenance

Control of scum & mats of blue-green bacteria	Block sunlight; reduce green algae activity; odors; avian botulism	Agitation with water jets & rakes manually
Weeds	Mosquito breeding ground; scum accumulation; hinders circulation	Pull out young plants; maintain min. 3 ft depth; riprap; raise & lower water level
Insects	Nuisance; disease	Mosquito larvicide; surface aeration; addition *Gambusia* (mosquito fish)
Muskrats, groundhogs, turtles	Destroy berm walls by burrowing	Trap out; shoot; lower water level to expose den

30
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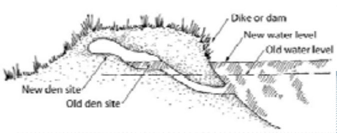
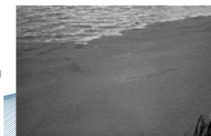
Daily O & M



31
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Causes of Poor Quality Effluent

- Aeration equipment failure
- Organic overload
- High total suspended solids (green algae)
- Toxic influent
- Loss of volume
- Short circuiting

32
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Low D.O. in Lagoon

- Low algae growth
- Excess scum
- Aeration problems
- Organic overload
- Short circuiting


33
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Odors in Lagoons

- Causes: overloading; poor housekeeping
- Treatment methods:
  - Add aeration
  - Feed sodium nitrate as oxygen source
  - Housekeeping- manual scum and algae removal
  - Masking agents

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Lagoon Safety

- Never work around a lagoon alone
- Never perform maintenance from a boat
- Never take a boat onto the lagoon alone

35
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Lagoon Safety



36
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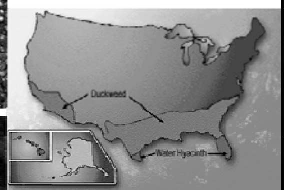
Lagoon Effluent Polishing with Duckweed



- Duckweed covers surface of polishing pond
- Prevents sunlight penetration, killing green algae

37
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Polishing Pond

- Design Criteria:
- Organic Loading:
  - 20-25 lbs BOD/ac/day
- Hydraulic Loading:
  - 2350-2990 gpd/ac
- Water Depth
  - 5-6.5 ft
- Secondary Effluent Quality:
- BOD
  - < 30 ppm
- SS
  - < 30 ppm
- Total Nitrogen
  - < 15 ppm
- Total Phosphorous
  - < 6 ppm

38
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CHAPTER 9

Ponds and Aerated Lagoons

PONDS AND AERATED LAGOONS

9.1 General

This chapter describes the requirements for the following biological treatment processes:

a. Stabilization ponds

b. Aerated lagoons

Additionally, this chapter describes the requirements for use of hydraulic control release lagoons for effluent disposal.

A guide to provisions for lagoon design is the EPA publication Design Manual - Municipal Wastewater Stabilization Ponds, EPA-625/1-83-015.

9.1.1 Applicability

In general, ponds and aerated lagoons are most applicable to small and/or rural communities where land is available at low cost and minimum secondary treatment requirements are acceptable. Advantages include potentially lower capital costs, simple operation, and low O&M costs.

9.1.2 Supplement to Engineering Report

The engineering report shall contain pertinent information on location, geology, soil conditions, area for expansion, and any other factors that will affect the feasibility and acceptability of the proposed treatment system.

The following information should be submitted in addition to that required in the Chapter 1 section titled "Engineering Report and Preliminary Plans":

a. The location and direction of all residences, commercial development, and water supplies within 1/2 mile of the proposed pond

b. Results of the geotechnical investigation performed at the site

c. Data demonstrating anticipated seepage rates of the proposed pond bottom at the maximum water surface elevation

d. A description, including maps showing elevations and contours, of the site and adjacent area suitable for expansion

e. The ability to disinfect the discharge is required.

9.1.3 Effluent Requirements

See Chapter 1, Section 1.1.

9.2 Design Loadings

9.2.1 Stabilization Ponds

Stabilization ponds are facultative and are not artificially mixed or aerated. Mixing and aeration are provided by natural processes. Oxygen is supplied mainly by algae.

Design loading shall not exceed 30 pounds BOD per acre per day on a total pond area basis and 50 pounds BOD per acre per day to any single pond (from Middlebrooks).

9.2.2 Aerated Lagoons

An aerated lagoon may be a complete-mix lagoon or a partial-mix aerated lagoon. Complete-mix lagoons provide enough aeration or mixing to maintain solids in suspension. Power levels are normally between 20 and 40 horsepower per million gallons. The partial-mix aerated lagoon is designed to permit accumulation of settleable solids on the lagoon bottom, where they decompose anaerobically. The power level is normally 4 to 10 horsepower per million gallons of volume.

BOD removal efficiencies normally vary from 80 to 90 percent, depending on detention time and provisions for suspended solids removal.

The aerated lagoon system design for minimum detention time may be estimated by using the following formula; however, for the development of final parameters, it is recommended that actual experimental data be developed.

$$\frac{Se}{So} = \frac{1}{1 + 2.3K_1 t}$$

where:

t = detention time, days
K_1= reaction coefficient, complete system per day, base 10. For complete treatment of normal domestic sewage, the K_1 value will be assumed to be:
K_1 = 1.087 @20^{o}C for complete mix
K_1 = 0.12 @20^{o}C for partial mix
Se = effluent BOD_5, mg/l
So = influent BOD_5, mg/l

The reaction rate coefficient for domestic sewage that includes significant quantities of industrial wastes, other wastes, and partially treated sewage should be determined experimentally for various conditions that might be encountered in the aerated ponds. Conversion of the reaction rate coefficient to temperatures other than 20 degrees C should be according to the following formula:

$K_1 = K_{20}\, 1.036^{(T-20)}$ (T = temperature in degrees C)

The minimum equilibrium temperature of the lagoon should be used for design of the aerated lagoon. The minimum equilibrium temperature should be estimated by using heat balance equations, which should include factors for influent wastewater temperature, ambient air temperature, lagoon surface area, and heat transfer effects of aeration, wind, and humidity. The minimum 30-day average ambient air temperature obtained from climatological data should be used for design.

Additional storage volume shall be considered for sludge storage and partial mix in aerated lagoons.

Sludge processing and disposal should be considered.

9.3 Special Details

9.3.1 General

9.3.1.1 Location

a. Distance from Habitation

A pond site should be located as far as practicable from habitation or any area that may be built up within a reasonable future period, taking into consideration site specifics such as topography, prevailing winds, and forests. Buffer zones between the lagoon and residences or similar land use should be at least 300 feet to residential property lines, and 1000 feet to existing residence structures.

b. Prevailing Winds

If practical, ponds should be located so that local prevailing winds will be in the direction of uninhabited areas. Preference should be given to sites that will permit an unobstructed wind sweep across the length of the ponds in the direction of the local prevailing winds.

c. Surface Runoff

Location of ponds in watersheds receiving significant amounts of runoff water is discouraged unless adequate provisions are made to divert storm water around the ponds and protect pond embankments from erosion.

d. Water Table

The effect of the ground water location on pond performance and construction must be considered.

e. Ground Water Protection

Ground Water Protection's main emphasis should be on site selection and liner construction, utilizing mainly compacted clay. Proximity of ponds to water supplies and other facilities subject to contamination and location in areas of porous soils and fissured rock formations should be critically evaluated to avoid creation of health hazards or other undesirable conditions. The possibility of chemical pollution may merit appropriate consideration. Test wells to monitor potential ground water pollution may be required and should be designed with proper consideration to water movement through the soil as appropriate.

An approved system of ground water monitoring wells or lysimeters may be required around the perimeter of the pond site to facilitate ground water monitoring. The use of wells and/or lysimeters will be determined on a case-by-case basis depending on proximity of water supply and maximum ground water levels. This determination will be at the site approval phase (see Section 1.1).

A routine ground water sampling program shall be initiated prior to and during the pond operation, if required.

f. Floodwaters

Pond sites shall not be constructed in areas subject to 25-year flooding, or the ponds and other facilities shall be protected by dikes from the 25-year flood.

9.3.1.2 Pond Shape

The shape of all cells should be such that there are no narrow or elongated portions. Round, square, or rectangular ponds should have a length to width ratio near 1:1 for complete mix ponds. Rectangular ponds with a length not exceeding three times the width are considered most desirable for complete mix aerated lagoons. However, stabilization ponds should be rectangular with a length exceeding three times the width, or be baffled to ensure full utilization of the basin. No islands, peninsulas, or coves are permitted. Dikes should be rounded at corners to minimize accumulations of floating materials. Common dike construction should be considered whenever possible to minimize the length of exterior dikes.

9.3.1.3 Recirculation

Recirculation of lagoon effluent may be considered. Recirculation systems should be designed for 0.5 to 2.0 times the average influent wastewater flow and include flow measurement and control.

9.3.1.4 Flow Measurement

The design shall include provisions to measure, total, and record the wastewater flows.

9.3.1.5 Level Gauges

Pond level gauges should be located on outfall structures or be attached to stationary structures for each pond.

9.3.1.6 Pond Dewatering

All ponds shall have emergency drawdown piping to allow complete draining for maintenance.

Sufficient pumps and appurtenances should be available to facilitate draining of individual ponds in cases where multiple pond systems are constructed at the same elevation or for use if recirculation is desired.

9.3.1.7 Control Building

A control building for laboratory and maintenance equipment should be provided.

9.3.1.8 General Site Requirements

The pond area shall be enclosed with an adequate fence to keep out livestock and discourage trespassing, and be located so that travel along the top of the dike by maintenance vehicles is not obstructed. A vehicle access gate of width sufficient to accommodate mowing equipment and maintenance vehicles should be provided. All access gates shall be provided with locks.

Cyclone-type fences, 5 to 6 feet high with 3 strands of barbed wire, are desirable, with appropriate warning signs required.

9.3.1.9 Provision for Sludge Accumulation

Influent solids, bacteria, and algae that settle out in the lagoons will not completely decompose and a sludge blanket will form. This can be a problem if the design does not include provisions for removal and disposal of accumulated sludge, particularly in the cases of anaerobic stabilization ponds and aerated lagoons. The design should include an estimate of the rate of sludge accumulation, frequency of sludge removal, methods of sludge removal, and ultimate sludge handling and disposal. Abandoning and capping of the lagoon is an acceptable solution (Re: The Division of Solid Waste Management guidelines for abandonment of a lagoon). However, the design life shall be stated in the report.

9.3.2 Stabilization Ponds

9.3.2.1 Depth

The primary (first in a series) pond depth should not exceed 6 feet. Greater depths will be considered for polishing ponds and the last ponds in a series of 4 or more.

9.3.2.2 Influent Structures and Pipelines

a. Manholes

A manhole should be installed at the terminus of the interceptor line or the force main and should be located as close to the dike as topography permits; its invert should be at least 6 inches above the maximum operating level of the pond to provide sufficient hydraulic head without surcharging the manhole.

b. Influent Pipelines

The influent pipeline can be placed at zero grade. The use of an exposed dike to carry the influent pipeline to the discharge points is prohibited, as such a structure will impede circulation.

c. Inlets

Influent and effluent piping should be located to minimize short-circuiting and stagnation within the pond and maximize use of the entire pond area.

Multiple inlet discharge points shall be used for primary cells larger than 10 acres.

All gravity lines should discharge horizontally onto discharge aprons. Force mains should discharge vertically up and shall be submerged at least 2 feet when operating at the 3-foot depth.

d. Discharge Apron

Provision should be made to prevent erosion at the point of discharge to the pond.

9.3.2.3 Interconnecting Piping and Outlet Structures

Interconnecting piping for pond installations shall be valved or provided with other arrangements to regulate flow between structures and permit variable depth control.

The outlet structure can be placed on the horizontal pond floor adjacent to the inner toe of the dike embankment. A permanent walkway from the top of the dike to the top of the outlet structure is required for access.

The outlet structure should consist of a well or box equipped with multiple-valved pond drawoff lines. An adjustable drawoff device is also acceptable. The outlet structure should be designed so that the liquid level of the pond can be varied from a 3.0- 5.0 foot depth in increments of 0.5 foot or less. Withdrawal points shall be spaced so that effluent can be withdrawn from depths of 0.75 foot to 2.0 feet below pond water surface, irrespective of the pond depth.

The lowest drawoff lines should be 12 inches off the bottom to control eroding velocities and avoid pickup of bottom deposits. The overflow from the pond shall be taken near but below the water surface. A two-foot deep baffle may be helpful to keep algae from the effluent. The structure should also have provisions for draining the pond. A locking device should be provided to prevent unauthorized access to level control facilities. An unvalved overflow placed 6 inches above the maximum water level shall be provided.

Outlets should be located nearest the prevailing winds to allow floating solids to be blown away from effluent weirs.

The pond overflow pipes shall be sized for the peak design flow to prevent overtopping of the dikes.

9.3.2.4 Minimum and Maximum Pond Size

No pond should be constructed with less than 1/2 acre or more than 40 acres of surface area.

9.3.2.5 Number of Ponds

A minimum of three ponds, and preferably four ponds, in series should be provided (or baffling provided for a single cell lagoon design configuration) to insure good hydraulic design. The objective in the design is to eliminate short circuiting.

9.3.2.6 Parallel/Series Operation

Designs, other than single ponds with baffling, should provide for operation of ponds in parallel or series. Hydraulic design should allow for equal distribution of flows to all ponds in either mode of operation.

9.3.3 Aerated Lagoons

9.3.3.1 Depth

Depth should be based on the type of aeration equipment used, heat loss considerations, and cost, but should be no less than 7 feet. In choosing a depth, aerator erosion protection and allowances for ice cover and solids accumulation should be considered.

9.3.3.2 Influent Structures and Pipelines

The same requirements apply as described for facultative systems, except that the discharge locations should be coordinated with the aeration equipment design.

9.3.3.3 Interconnecting Piping and Outlet Structures

a. Interconnecting Piping

The same requirements apply as described for facultative systems.

b. Outlet Structure

The same requirements apply as described for facultative systems, except for variable depth requirements and arrangement of the outlet to withdraw effluent from a point at or near the surface. The outlet shall be preceded by an underflow baffle.

9.3.3.4 Number of Ponds

Not less than three basins should be used to provide the detention time and volume required. The basins should be arranged for both parallel and series operation. A settling pond with a hydraulic detention time of 2 days at average design flow must follow the
aerated cells, or an equivalent of the final aerated cell must be free of turbulence to allow settling of suspended solids.

9.3.3.5 Aeration Equipment

A minimum of two mechanical aerators or blowers shall be used to provide the horsepower required. At least three anchor points should be provided for each aerator. Access to aerators should be provided for routine maintenance which does not affect mixing in the lagoon. Timers will be required.

9.4 <u>Pond Construction Details</u>

9.4.1 Liners

9.4.1.1 Requirement for Lining

The seepage rate through the lagoon bottom and dikes shall not be greater than a water surface drop of 1/4 inch per day. (Note: The seepage rate of 1/4 inch per day is 7.3 x 10^{-6} cm/sec coefficient of permeability seepage rate under pond conditions.) If the native soil cannot be compacted or modified to meet this requirement, a pond liner system will be required.

If a lagoon is proposed to be upgraded, it must be shown that it currently meets the 1/4-inch per day seepage rate before approval will be given.

9.4.1.2 General

Pond liner systems that should be evaluated and considered include (1) earth liners, including native soil or local soils mixed with commercially prepared bentonite or comparable chemical sealing compound, and (2) synthetic membrane liners. The liner should not be subject to deterioration in the presence of the wastewater. The geotechnical recommendations should be carefully considered during pond liner design.
Consideration should also be given to construct test wells when required by the Department in any future regulations, or when industrial waste is involved.

9.4.1.3 Soil Liners

The thickness and the permeability of the soil liners shall be sufficient to limit the leakage to the maximum allowable rate of 1/4 inch per day. The evaluation of earth for use as a soil liner should include laboratory permeability tests of the material and laboratory compaction tests. The analysis should take into consideration the expected permeability of the soil when compacted in the field. All of the soil liner material shall have essentially the same properties.

The analysis of an earth liner should also include evaluation of the earth liner material with regard to filter design criteria. This is required so that the fine-grained liner material does not infiltrate into a coarser subgrade material and thus reduce the effective thickness of the liner.

If the ponds are going to remain empty for any period of time, consideration should be given to the possible effects on the soil liners from freezing and thawing during cold weather or cracking from hot, dry weather. Freezing and thawing will generally loosen the soil for some depth. This depth is dependent on the depth of frost penetration.

The compaction requirements for the liner should produce a density equal to or greater than the density at which the permeability tests were made. The minimum liner thickness should be 12 inches, to ensure proper mixing of bentonite with the native soil. The soil should be placed in lifts no more than 6 inches in compacted thickness. The moisture content at which the soil is placed should be at or slightly above the optimum moisture content.

Construction and placement of the soil liner should be inspected by a qualified inspector. The inspector should keep records on the uniformity of the earth liner material, moisture contents, and the densities obtained.

Bentonite and other similar liners should be considered as a form of earth liner. Their seepage characteristics should be analyzed as previously mentioned, and laboratory testing should be performed using the mixture of the native or local soil and bentonite or similar compound. In general, the requirements for bentonite or similar compounds should include the following: (1) The bentonite or similar compound should be high swelling and free flowing and have a particle size distribution favorable for uniform application and minimizing of wind drift; (2) the application rate should be least 125 percent of the minimum rate found to be adequate in laboratory tests; (3) application rates recommended by a supplier should be confirmed by an independent laboratory; and (4) the mixtures of soil and bentonite or similar compound should be compacted at a water content greater than the optimum moisture content.

9.4.1.4 Synthetic Membrane Liners

Requirements for the thickness of synthetic liners may vary due to the liner material, but it is generally recommended that the liner thickness be no less than 20 mils; that is, 0.020 inch. There may be special conditions when reinforced membranes should be considered. These are usually considered where extra tensile strength is required. The membrane liner material should be compatible with the wastewater in the ponds such that no damage results to the liner. PVC liners should not be used where they will be exposed directly to sunlight. The preparation of the subgrade for a membrane liner is important. The subgrade should be graded and compacted so that there are no holes or exposed angular rocks or pieces of wood or debris. If the subgrade is very gravelly and contains angular rocks that could possibly damage the liner, a minimum bedding of 3 inches of sand should be provided directly beneath the liner. The liner should be covered with 12 inches of soil. This includes the side slope as well. No equipment should be allowed to operate directly on the liner. Consideration should be given to specifying that the manufacturer's representative be on the job supervising the installation during all aspects of the liner placement. An inspector should be on the job to monitor and inspect the installation.

Leakage must not exceed 1/4-inch per day.

9.4.1.5 Other Liners

Other liners that have been successfully used are soil cement, gunite, and asphalt concrete. The performance of these liners is highly dependent on the experience and skill of the designer. Close review of the design of these types of liners is recommended.

9.4.2 Pond Construction

9.4.2.1 General

Ponds are often constructed of either a built-up dike or embankment section constructed on the existing grade, or they are constructed using a cut and fill technique. Dikes and embankments shall be designed using the generally accepted procedures for the design of small earth dams. The design should attempt to make use of locally available materials for the construction of dikes. Consideration should also be given to slope stability and seepage through and beneath the embankment and along pipes.

9.4.2.2 Top Width

The minimum recommended dike top width should be 12 feet on tangents and 15 feet on curves to permit access of maintenance vehicles. The minimum inside radius of curves of the corners of the pond should be 35 feet.

9.4.2.3 Side Slopes

Normally, inside slopes of either dikes or cut sections should not be steeper than 3 horizontal to 1 vertical. Outer slopes should not be steeper than 2 horizontal to 1 vertical. However, in many instances, the types of material used, maintenance considerations, and seepage conditions can indicate that other slopes should be used.

9.4.2.4 Freeboard

There should be sufficient freeboard to prevent overtopping of the dike from wave action and strong winds. A minimum of one foot is required.

9.4.2.5 Erosion Control

Erosion control should be considered for the inside slopes of the dike to prevent the formation of wavecut beaches in the dike slope. In the event that earth liners or membrane liners with earth cover are used, consideration should be given to erosion protection directly beneath aeration units. If the currents are strong enough, considering the type of material used for the earth cover, erosion pads may be necessary beneath the aeration units. Erosion control should also be considered wherever influent pipes empty into the pond. If a grass cover for the outer slopes is desired, they should be fertilized and seeded to establish a good growth of vegetative cover. This vegetative cover will help control erosion from runoff. Consideration should also be given to protection of the outer slopes in the event that flooding occurs. The erosion protection should be able to withstand the currents from a flood.

9.4.3 Prefilling

The need to prefill ponds in order to determine the leakage rate shall be determined by the Department and incorporated into the plans and specifications. The strongest consideration for prefilling ponds will be given to ponds with earth liners. Ponds in areas where the surrounding homes are on wells will also be given strong consideration for prefilling.

9.4.4 Utilities and Structures Within Dike Sections

Pipes that extend through an embankment should be bedded up to the springline with concrete. Backfill should be with relatively impermeable material. No granular bedding material should be used. Cutoff collars should be used as required. No gravel or granular base should be used under or around any structures placed in the embankment within the pond. Embankments should be constructed at least 2 feet above the top of the pipe before excavating the pipe trench.

9.5 Hydrograph Controlled Release (HCR) Lagoons

All lagoons requirements apply to HCR lagoons with the following additional concerns:

HCR lagoons control the discharge of treated wastewater in accordance with the stream's assimilative capacity. Detention times vary widely and must be determined on a case-by-case basis.

HCR sites require much receiving stream flow pattern characterization. For this purpose, EPA Region IV has developed a computer design program. The Division of Water Pollution Control can assist in sizing the HCR basin using this program. HCR sites may be more economical if the design is combined with summertime land application. Their design is more economical if summer/winter or monthly standards are available.

The design and construction of the in-stream flow measurement equipment are critical components of an HCR system. The United States Geological Survey (USGS) should be contacted during the design phase. The USGS also has considerable construction experience concerning in-stream monitoring stations, although construction need not necessarily be done or supervised by the USGS.

9.6 Polishing Lagoons

Polishing lagoons following activated sludge are not permissible in Tennessee due to the one-cell algae interference.

9.7 Operability

Once a pond is designed, little operation should be required. However, to avoid NPDES permit violations, pond flexibility is needed. Operation flexibility is best facilitated by the addition of piping and valves to each pond which allows isolation of its volume during an algal bloom.

9.8 Upgrading Existing Systems

There are approximately sixty existing lagoons in Tennessee which were built utilizing standards and criteria from the 1960 period. Most are single- or double-cell units which need upgrading. Many are required to meet tertiary standards. The upgrade case should, in general, utilize the guidance in this chapter or proven configurations. It is noted, however, that there are many lagoon combinations available, such as complete-mix pond, partial-mix pond, stabilization pond, HCR pond and marsh-pond (wetlands)concepts. The combination of these alternatives
should be based upon the effluent permit design standards as well as site economics.

Wastewater Lagoons
Review Questions

1. A pond that has dissolved oxygen distributed throughout the pond.
   a. Aerobic
   b. Anaerobic
   c. Facultative

2. A pond that contains no dissolved oxygen near the bottom and does contain dissolved oxygen near the surface.
   a. Aerobic
   b. Anaerobic
   c. Facultative

3. A pond that contains no dissolved oxygen.
   a. Aerobic
   b. Anaerobic
   c. Facultative

4. Algae produce ____________________ from the water molecule through photosynthesis.
   a. Oxygen
   b. Carbon Dioxide
   c. Methane
   d. all of the above
   e. none of the above

5. Pond efficiency is affected by biological factors, which one is not a biological factor?
   a. The type of bacteria present
   b. The type and quantity of algae
   c. The activity of the organisms present
   d. Nutrient Deficiencies
   e. The temperature

6. A pond is not functioning properly when ______________________________.
   a. it creates a visual or odor nuisance
   b. it has a high BOD or suspended solids in its effluent
   c. it has a high coliform bacteria concentration in its effluent
   d. all of the above
   e. none of the above

7. A definite ____________ color in a pond indicates a flourishing algae population and is a good sign.
    a. green
    b. black
    c. gray
    d. all of the above
    e. none of the above

8. Most odors in ponds are caused by overloading and poor housekeeping.
    a. True
    b. False

9. The outlet of a pond should be submerged to prevent the discharge of floating materials.
    a. True
    b. False

10. The inlet of a pond should be submerged to distribute the heat of the influent as much as possible and to minimize the occurrence of floating materials.
    a. True
    b. False

11. When the pH and dissolved oxygen drop dangerously low, the loading should be:
    a. increased.
    b. left unchanged.
    c. decreased or stopped.
    d. all of the above
    e. none of the above

12. Ponds should be started in winter to take advantage of the increased efficiency associated with low temperatures.
    a. True
    b. False

13. Weeds are objectionable around a pond because ______________________.
    a. they provide a place for the breeding of insects
    b. they allow for scum accumulation
    c. they hinder pond circulation
    d. all of the above
    e. none of the above

14. An operator can use ________________ to break up accumulation of scum.
    a. rakes
    b. jets of water
    c. outboard motors
    d. all of the above
    e. none of the above

15. A drop in pH and dissolved oxygen may be caused by ________________.
    a. overloading
    b. lack of circulation
    c. wave action
    d. A & B
    e. A & C

16. Odors in ponds can be reduced by ___________________________.
    a. recirculation from aerobic units
    b. the use of floating aerators.
    c. chlorination
    d. all of the above
    e. none of the above

17. Suspended vegetation in a pond can be controlled by all of the following methods except ____________________.
    a. mowing regularly during the growing season
    b. keeping a few ducks in the pond
    c. mechanical harvesting
    d. skimming with rakes or boards
    e. keeping the pond exposed to a clean sweep of the wind

18. Herbicides can be used to control emergent weeds, suspended vegetation, and dike vegetation, but only as a last resort.
    a. True
    b. False

19. Emergent weeds can be controlled by lowering the water level, cutting or burning the weeds, and raising the water level.
    a. True
    b. False

20. Emergent weeds can be controlled by keeping the water more than _______ feet deep.
    a. 1.5
    b. 2.0
    c. 3.0
    d. all of the above

21. Excessive BOD loadings can occur when
    a. influent loads exceed design capacity due to population increases
    b. due to industrial growth
    c. industrial dumps or spills
    d. all of the above
    e. none of the above

22. Large amounts of brown or black scum on the surface of a pond is an indication that the pond is overloaded.
    a. True
    b. False

Answers:

1. A
2. C
3. B
4. A
5. E
6. D
7. A
8. A
9. A
10. A
11. C
12. B
13. D
14. D
15. D
16. D
17. A
18. A
19. A
20. C
21. D
22. A

Section 8

Safety

Safety

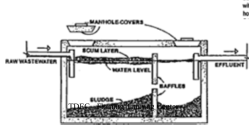
Confined Space Conditions

- Large enough and so configured that an employee can bodily enter and perform assigned work
- Limited or restricted means of entry or exit
- Not designed for continuous employee occupancy

Confined Space Examples

- Storage tanks
- Manholes
- Hoppers
- Vaults
- Septic tanks
- Inside filters
- Basins
- Sewers

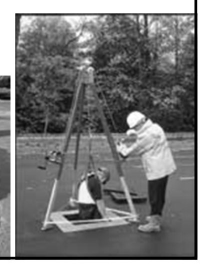
Submersible lift stations are designed to blend readily with natural surroundings, since there is no pump house and there is a minimum of above-ground equipment. ...dvantages to below-ground installations are noise ...ons and less safety-hazard concerns.



Equipment Needed for Confined Spaces

- Safety harness with lifeline, tripod and winch
- Electrochemical sensors
- Ventilation blower with hose





Equipment Needed for Confined Spaces

- PPE
- Ladder
- Rope
- Breathing Apparatus




Permit Required Confined Space

- Contains or has potential to contain hazardous atmosphere
- Contains material with potential to engulf an entrant
- Entrant could be trapped or asphyxiated

Atmospheric Hazards

- Need to have atmosphere monitored!!!
  - Explosive or flammable gas or vapor
    - These can develop in the collection system or sewer plant duel to legal, illegal or accidental sources
  - Toxic or suffocating gases
    - Comes from natural breakdown of organic matter in wastewater or toxic discharges
  - Depletion or elimination of breathable oxygen
    - Oxygen deficient atmosphere

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Hydrogen Sulfide – H_2S

- Detected by the smell of rotten eggs
- Loss of ability to detect short exposures
  - Olfactory fatigue
- Not noticeable at high concentrations
- Poisonous, colorless, flammable, explosive and corrosive
- Exposures to .07% to 0.1% will cause acute poisoning and paralyze the respiratory center of the body
- At the above levels, death and/or rapid loss of consciousness occur
- S.G. = 1.19

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Hydrogen Sulfide – H_2S

%	PPM	Hazard
46	460,000	Upper Explosive Limit (UEL)
4.3	43,000	Lower Explosive (LEL)
0.1	1,000	DEAD
0.07	700	Rapid loss of consciousness
0.01	100	IDLH
0.005	50	Eye tissue damage
0.002	20	Eye, nose irritant
0.001	10	Alarm set point

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Hydrogen Sulfide – H_2S

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Methane Gas – CH_4

- Product of anaerobic waste decomposition
- Leaks in natural gas pipelines
  - Odorless unless natural gas supplied through pipeline, has mercaptans added, but soil can strip the odor
- Explosive at a concentration of 5% or 50,000 ppm
- Spaces may contain concentrations above the Lower Explosive Limits (LEL) and still have oxygen above the 19.5% allowable
- Colorless, odorless, tasteless
- Does not decrease oxygen content
- Acts as an asphyxiant
- Coal miners used canaries as early alarms; if bird died, it was time to get out
- S.G.= 0.55
- Alarm set point is 10% LEL = 5000 ppm

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Methane Gas – CH_4

%	PPM	Hazard
85	850,000	Amount in natural gas
65	650,000	Amount in digester gas
15	150,000	Upper Explosive Limit (UEL)
5	50,000	Lower Explosive Limit (LEL)
0.5	5,000	Alarm set point (10% of LEL)

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Carbon Monoxide - CO

- Decreases amount oxygen present
  - Hazardous because it readily binds with hemoglobin in blood, starving the person's body of oxygen
- ALWAYS VENTILATE
- 0.15% (1500 ppm) → DEAD
- Will cause headaches at .02% in two hour period
- Maximum amount that can be tolerated is 0.04% in 60 minute period
- Colorless, odorless, tasteless, flammable and poisonous
- Manufactured fuel gas
- S. G. = 0.97
- Alarm set point at 35 ppm

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Carbon Monoxide - CO

%	PPM	Hazard
74	740,000	Upper Explosive Limit (UEL)
12.5	125,000	Lower Explosive (LEL)
0.2	2,000	Unconscious in 30 minutes
0.15	1,500	IDLH
0.05	500	Sever headache
0.02	200	Headache after 2-3 hours
0.0035	35	8-hour exposure limit
0.0035	35	Alarm set point

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Carbon Monoxide - CO

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Oxygen – O_2

- ALWAYS ventilate – normal air contains ~ 21%
- Oxygen deficient atmosphere if less than 19.5%
- Oxygen enriched at greater than 23.5%
  - Speeds combustion
  - Could be from pure oxygen being used to oxidize hydrogen sulfide
- Leave area if oxygen concentrations approach 22%
- Early warning signs that an operator is not getting enough oxygen:
  - Shortness of breath
  - Chest heaving
  - Change from usual responses

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Oxygen – O_2

%	PPM	Hazard
23.5	235,000	Accelerates combustion
20.9	209,000	Oxygen content of normal air
19.5	195,000	Minimum permissible level
8	8,000	**DEAD** in 6 minutes
6	6,000	Coma in 40 seconds, then **DEAD**

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Oxygen – O_2

- When O_2 levels drop below 16%, a person experiences
  - Rapid fatigue
  - Inability to think clearly
  - Poor coordination
  - Difficulty breathing
  - Ringing in the ears
  - Also, a false sense of well-being may develop

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Oxygen – O_2

- In a confined space, the amount of oxygen in the atmosphere may be reduced by several factors
  - Oxygen consumption
    - During combustion of flammable substances
    - Welding, heating, cutting or even rust formation
  - Oxygen displacement
    - Carbon dioxide can displace oxygen
  - Bacterial action

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Atmospheric Alarm Units

- Continuously sample the atmosphere
- Test atmospheres from manhole areas prior to removing the cover if pick holes available
- Remove manhole covers with non sparking tools
- **Test for oxygen first**
- **Combustible gases second (methane at 5000 ppm)**

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Atmospheric Alarm Units

- Alarms set to read:
  - Flammable gasses exceeding 10% of the LEL
  - H_2S exceeds 10 ppm and/or
  - O_2 percentage drops below 19.5%
  - CO alarm set point is 35 ppm
- Calibrate unit before using
- Most desirable units: simultaneously sample, analyze and alarm all three atmospheric conditions

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Atmospheric Alarm Units

- Some physical and environmental conditions that could affect the accuracy of gas detection instruments include:
  - Caustic gases
  - Temperature
  - Dirty air
  - Humidity
  - Air velocity
  - Vibration

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Safety Procedures if Explosive Atmosphere Discovered

- Immediately notify supervisor
- Do not remove manhole cover
- Turn off running engines in area
- Route vehicles around area
- Inspect up and downstream of manhole
- Route traffic off the street
- Notify waste and or pretreatment facility
- Cautiously ventilate
- NO SMOKING IN AREA

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Ventilation

- Blowers need to be placed upwind of manhole and at least 10 feet from opening
- Gas driven engine – exhaust must be downwind of manhole
- Air intake should be 2-5 feet above ground service

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Infectious Disease Hazards

- Many diseases may be transmitted by wastewater: hepatitis A, cholera, bacterial dysentery, polio, typhoid, amoebic dysentery
- Ingestion (splashes); inhalation (aerosols); contact (cuts or burns)
- Wash hands frequently
- Avoid touching face
- Never eat, drink or smoke without first washing hands

Lockout / Tagout

General Requirements

- Written program
- Utilize tagout system if energy isolating device not capable of being locked out
- Lockout/tagout hardware provided
- Devices used only for intended purposes
- Tagout shall warn **DO NOT START, DO NOT ENERGIZE, DO NOT OPERATE**
- Only trained employees shall perform lockout/tagout

Requirements When Lockout of Equipment

- Notify employees
- Employees notified after completion of work and equipment re-energized

Recommend Steps for Lockout/Tagout

- Notify employees that device locked and tagged out
- Turn off machine normally
- De-activate energy
- Use appropriate lockout/tagout equipment
- Release any stored energy
- Try to start machine by normal means

Steps for Restoring Equipment

- Check area for equipment or tools
- Notify all employees in the area
- Verify controls are in neutral
- Remove lockout/tagout devices and re-energize device
- Notify employees maintenance and/or repairs are complete and equipment is operationally

Training Requirements

- Employer shall train all employees
- All new employees trained
- Recognition of applicable hazardous energy
- Purpose of program
- Procedures
- Consequences
- ANNUAL REQUIREMENT

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Inspections

- Conduct periodic inspection at least annually
- Shall include review between the inspector and each authorized employee
- Recommendation: Frequent walk through of work areas and observation of Maintenance and Operation area

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Required Record Keeping

- Written Lockout/Tagout Program
- Training: Annual and New Employees
- Inspections: Annual including new equipment, inspection of devices, and procedures

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Most Cited Industry Standards By TOSHA

- No written Hazard Communication Program
- Inadequate Hazard Communication Training
- PPE Hazard Assessment not Done
- No Energy Control Program - Lockout/Tagout
- No MSDS on Site
- No one Trained in First Aid
- No Emergency Action Plan
- Metal Parts of Cord and Plug Equipment Not Grounded
- Unlabeled Containers of Hazardous Chemicals

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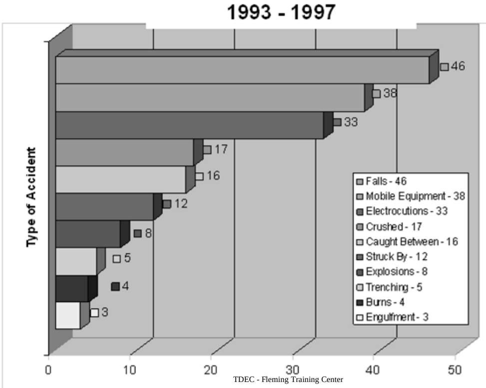

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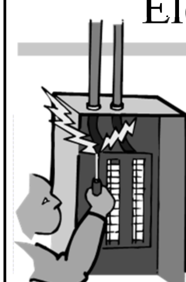
Electrical Safety



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OSHA Says

- Any electrical installations shall be done by a professionally trained electrician.
- Any employee who is in a work area where there is a danger of electric shock shall be trained.
- Employees working on electrical machinery shall be trained in lockout/tagout procedures

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Fire Protection

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Fire Protection Equipment

- Fire extinguishers shall be located where they are readily accessible.
- Shall be fully charged and operable at all times.
- All fire fighting equipment is to be inspected at least annually.

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Fire Protection Equipment

- Portable fire extinguishers inspected at least monthly and records kept.
- Hydrostatic testing on each extinguisher every five years.
- Fire detection systems tested monthly if batter operated.

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Types of Fire Extinguishers

- Class A 
  - Used on combustible materials such as wood, paper or trash
  - Can be water based.
- Class B 
  - Used in areas where there is a presence of a flammable or combustible liquid
  - Shall not be water based
  - Example is dry chemical extinguisher
  - An existing system can be used but not refilled.

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Types of Fire Extinguishers

- Class C 
  - Use for areas electrical
  - Best is carbon dioxide extinguisher.
  - Using water to extinguish a class C fire risks electrical shock
- Class D
  - Used in areas with combustible metal hazards
  - Dry powder type
  - Use no other type for this fire.

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Types of Fire Extinguishers

Class	Material	Method
A	Wood, paper	Water
B	Flammable liquids (oil, grease, paint)	Carbon dioxide, foam, dry chemical or Halon
C	Live electricity	Carbon dioxide, dry chemical, Halon
D	Metals	Carbon dioxide

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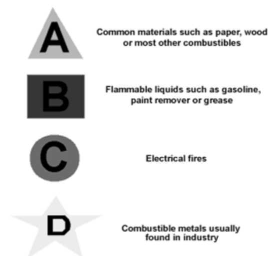
Types of Fire Extinguishers

- Combination ABC are most common
- Have the types of extinguishers available depending upon analyses performed in each area



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Fire Extinguishers

- To operate a fire extinguisher, remember the word PASS
  - **P**ull the pin. Hold the extinguisher with the nozzle pointing away from you
  - **A**im low. Point the extinguisher at the base of the fire.
  - **S**queeze the lever slowly and evenly.
  - **S**weep the nozzle from side-to-side.

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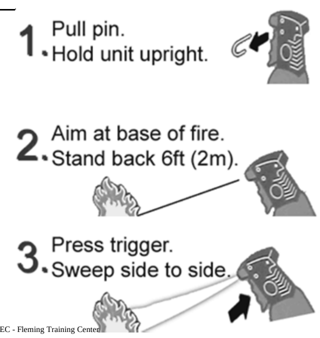
Fire Extinguishers

Combo Extinguisher



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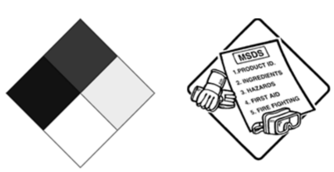
Chemical Safety



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Personal Protective Equipment

- Gloves
- Coveralls / Overalls
- Face Shield / Goggles
- Respirator / SCBA
- Boots
- Ear Plugs / Muffs

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Material Safety Data Sheets

- Also called MSDS
- Lists:
  - Common and chemical name
  - Manufacturer info
  - Hazardous ingredients
  - Health hazard data
  - Physical data
  - Fire and explosive data
  - Spill or leak procedures
  - PPE
  - Special precautions

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NFPA

- National Fire Protection Association
- Chemical hazard label
  - Color coded
  - Numerical system
    - Health
    - Flammability
    - Reactivity
  - Special precautions
- Labels are required on all chemicals in the lab

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RTK Labels

- "Right to Know"
  - In 1983, OSHA instituted Hazard Communication Standard 1910-1200, a rule that gives employees the right to know the hazards of chemicals to which they may be exposed in the workplace.

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Degrees of Hazard

- Each of the colored areas has a number in it regarding the degree of hazard
  - 4 → extreme
  - 3 → serious
  - 2 → moderate
  - 1 → slight
  - 0 → minimal

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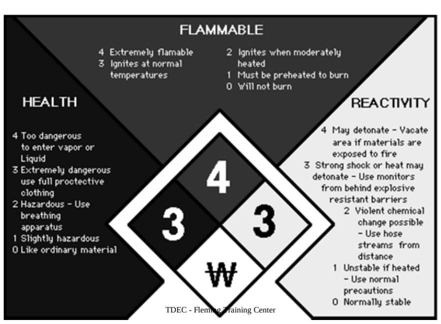
Chemical Label



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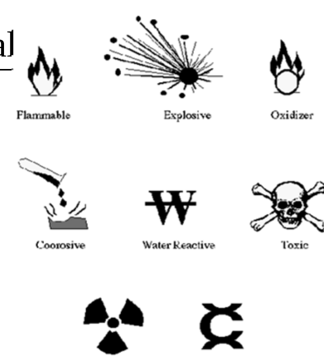
Special



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Terms

- Lower Explosive Level (LEL) – minimum concentration of flammable gas or vapor in air that supports combustion
- Upper Explosive Limit (UEL) – maximum concentration of flammable gas or vapor in air that will support combustion
- Teratogen – causes structural abnormality following fetal exposure during pregnancy
- Mutagen – capable of altering a cell's genetic makeup

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Name of Gas and Chemical Formula	Spec. Gravity	Explosive Range		Common Properties	Physiological Effects	Most Common Source in Sewers	Method of Testing
		Lower Limit	Upper Limit				
Oxygen, O_2	1.11	Not flammable		Colorless, odorless, tasteless, non-poisonous gas. Supports combustion	Normal air contains 20.93% of O_2. If it becomes less than 19.5%, do not enter space without respiratory protection.	Oxygen depletion from poor ventilation and absorption or chemical consumption of available O_2.	Oxygen deficiency indicator.
Carbon Monoxide, CO	0.97	12.5	74.2	Colorless, odorless, nonirritating, tasteless, flammable, explosive	Hemoglobin of blood has strong affinity for gas causing oxygen starvation. 0.2-0.25% causes unconsciousness in 30 minutes.	Manufactured fuel gas.	CO ampoules.
Methane, CH_4	0.55	5.0	15.0	Colorless, tasteless, odorless, non-poisonous, flammable, explosive	Acts mechanically to deprive tissues of oxygen. Does not support life. A simple asphyxiant.	Natural gas, marsh gas, manufactured fuel gas, gas found in sewers.	1. Combustible gas indicator. 2. Oxygen deficiency indicator.
Hydrogen Sulfide, H_2S	1.19	4.3	46.0	Rotten egg odor in small concentrations, but sense of smell rapidly impaired. Odor not evident at high concentrations. Colorless, flammable, explosive, poisonous	Death in a few minutes at 0.2%. Paralyzes respiratory center.	Petroleum fumes, from blasting, gas found in sewers.	1. Hydrogen sulfide analyzer 2. Hydrogen sulfide ampoules.
Carbon Dioxide, CO_2	1.53	Not flammable		Colorless, odorless, nonflammable. Not generally present in dangerous amounts unless there is already a deficiency of oxygen	10% can't be tolerated for more than a few minutes. Acts on nerves of respiration.	Issues from carbonaceous strata. Gas found in sewers.	Oxygen deficiency indicator.
Chlorine, Cl_2	2.5	Not flammable Not explosive		Greenish yellow gas or amber color liquid under pressure. Highly irritating and penetrating odor. Highly corrosive in presence of moisture.	Respiratory irritant, irritating to eyes and mucous membranes. 30 ppm causes coughing. 40-60 ppm dangerous in 30 minutes. 1,000 ppm apt to be fatal in a few breaths.	Leaking pipe connections. Overdosage.	Chlorine detector. Odor. Strong ammonia on swab gives off white fumes.
Sulfur Dioxide, SO_2	2.3	Not flammable Not explosive		Colorless compressed liquefied gas with a highly pungent odor. Highly corrosive in presence of moisture.	Respiratory irritant, irritating to eyes, skin and mucous membranes. Only slightly less toxic than chlorine.	Leaking pipe and connections.	Sulfur dioxide detector. Odor. Strong ammonia on swab gives off white fumes.

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Trenching & Excavation Safety Checklist

Site Location ______________________ Date ______________ Time ________ a.m. p.m.

GENERAL INSPECTION

1.	Has the "Competent Person" had specific training in—and is knowledgeable about—soil analysis, use of protective systems, and the requirements of 29CFR1926-Subpart P: Excavations and Trenches?	❑ YES	❑ NO	❑ N/A
2.	Does the "Competent Person" have the authority to remove workers from the excavation immediately?	❑ YES	❑ NO	❑ N/A
3.	Are excavations, adjacent areas, and protective systems inspected by a Competent Person: **A.** Daily prior to the start of work, **B.** As needed throughout the shift, and **C.** After every rainstorm or other occurrence that could increase the hazard?	❑ YES	❑ NO	❑ N/A
4.	Are ALL surface encumbrances removed or supported?	❑ YES	❑ NO	❑ N/A
5.	Are ALL employees protected from loose rock or soil that could pose a hazard by falling or rolling into the excavation?	❑ YES	❑ NO	❑ N/A
6.	Are hard hats worn by ALL employees?	❑ YES	❑ NO	❑ N/A
7.	Are spoils, materials, and equipment set back at least 2 feet from the edge of the excavation?	❑ YES	❑ NO	❑ N/A
8.	Are barriers provided at all remotely located excavations, wells, pits, shafts, etc.?	❑ YES	❑ NO	❑ N/A
9.	Are walkways and bridges over excavations 6 feet or more in depth and 30 inches or more in width equipped with standard guard rails and toe boards?	❑ YES	❑ NO	❑ N/A
10.	Are warning vests or other highly visible clothing provided and worn by all employees exposed to vehicular traffic?	❑ YES	❑ NO	❑ N/A
11.	Are employees required to stand away from vehicles being loaded or unloaded?	❑ YES	❑ NO	❑ N/A
12.	Are warning systems established and used when mobile equipment is operating near the edge of an excavation?	❑ YES	❑ NO	❑ N/A
13.	Are employees prohibited from going under suspended loads?	❑ YES	❑ NO	❑ N/A
14.	Are employees prohibited from working on the faces of sloped or benched excavations above other employees?	❑ YES	❑ NO	❑ N/A

UTILITIES

15.	Are utilities companies contacted and/or utilities located as required by local, state, and federal law?	❑ YES	❑ NO	❑ N/A
16.	Are the exact locations clearly marked?	❑ YES	❑ NO	❑ N/A
17.	Are underground installations protected, supported, or removed when an excavation is open?	❑ YES	❑ NO	❑ N/A

ACCESS & EGRESS

18.	Are ladders or other means of access and egress in place in all trenches 4 feet or more deep?	❑ YES	❑ NO	❑ N/A
19.	Are all workers within 25 feet of a means of access and egress?	❑ YES	❑ NO	❑ N/A
20.	Are the ladders that are used in excavations secured and extended 3 feet above edge of the excavation?	❑ YES	❑ NO	❑ N/A
21.	Are ALL structural ramps used by employees designed by a "Competent Person?"	❑ YES	❑ NO	❑ N/A
22.	Are ALL structural ramps used for equipment designed by a Registered Professional Engineer?	❑ YES	❑ NO	❑ N/A
23.	Are ALL ramps constructed of materials of uniform thickness, cleated together, equipped with no-slip surfaces?	❑ YES	❑ NO	❑ N/A
24.	Are employees protected from cave-ins when entering or exiting excavation?	❑ YES	❑ NO	❑ N/A

WET CONDITIONS

25.	Are precautions taken to protect employees from water accumulation?	❑ YES	❑ NO	❑ N/A
26.	Is water removal equipment monitored by "Competent Person?"	❑ YES	❑ NO	❑ N/A
27.	Is surface water or runoff diverted after every rainstorm or other hazard-increasing occurrence?	❑ YES	❑ NO	❑ N/A

continued on back...

HAZARDOUS ATMOSPHERES

28. Is the atmosphere within ALL excavations tested when there is a reasonable possibility of an oxygen-deficient, oxygen-enriched, combustible, toxic, or other harmful contaminant? ❑ YES ❑ NO ❑ N/A

29. Are adequate precautions taken to protect employees from exposure to an atmosphere containing less than 19.5% oxygen and/or other hazardous atmosphere? ❑ YES ❑ NO ❑ N/A

30. Is verification provided to protect employees from an atmosphere containing flammable gas in excess of 10% of the lower explosive limit of the gas? ❑ YES ❑ NO ❑ N/A

31. Is emergency equipment available when hazardous atmospheres could or do exist? ❑ YES ❑ NO ❑ N/A

32. Are employees trained to use personal protective equipment and other rescue equipment? ❑ YES ❑ NO ❑ N/A

SOILS

33. Has the Competent Person classified the soil using one manual test and one visual test, as specified by the standard? ❑ YES ❑ NO ❑ N/A

Visual Test ______________________ (Type) Manual Test ______________________ (Type)

Soil Classified as: ❑ Solid Rock ❑ Type A ❑ Type B ❑ Type C

SUPPORT SYSTEMS

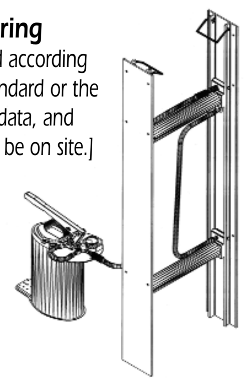
3 Primary Options are Available:

Note: *If an excavation is deeper than 5 feet (4 feet in some states), a support system is required by federal law, except for excavations entirely in stable rock (very rare!). If an excavation is less than 5 feet deep (4 feet in some states), a support system is required if there is a potential for a cave-in, as determined by the "Competent Person."*

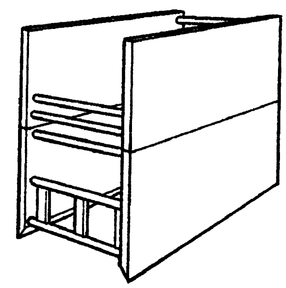
❑ Option #1– Sloping
[For excavations less than 20 feet deep.]

Soil Type	Maximum Allowable Slope (H:V)
Stable Rock	Vertical **or** 90˚
Type A	¾:1 **or** 53˚
Type B	1:1 **or** 45˚
Type C	1½ : 1 **or** 34˚

❑ Option #2 – Shoring
[Shoring must be installed according to charts in the OSHA standard or the manufacturer's tabulated data, and these charts or data must be on site.]



❑ Option #3 – Shielding
[Shielding must be installed according to the manufacturer's tabulated data, and this data must be on site.]



Note: A 4th option always available is a system designed by a Registered Professional Engineer
[Designs must be in writing, they must meet OSHA's requirement, and must be on site.]

34. Are materials and/or equipment chosen based upon soils analysis, trench depth and expected loads? ❑ YES ❑ NO ❑ N/A

35. Are materials and equipment that are used for protective systems inspected and in good condition? ❑ YES ❑ NO ❑ N/A

36. Are damaged materials and equipment immediately removed from service? ❑ YES ❑ NO ❑ N/A

37. Are damaged materials and equipment inspected by a Registered Professional Engineer after repairs are made and before being placed back in service? ❑ YES ❑ NO ❑ N/A

38. Are protective systems installed without exposing employees to hazards of cave-ins, collapses, or threat of being struck by materials or equipment? ❑ YES ❑ NO ❑ N/A

39. Are ALL members of support systems securely fastened together to prevent failure? ❑ YES ❑ NO ❑ N/A

40. Are support systems provided to insure stability of adjacent structures, buildings, roadways, sidewalks, etc.? ❑ YES ❑ NO ❑ N/A

41. Are excavations below the level of the base or footing supported, and approved by a Registered Professional Engineer? ❑ YES ❑ NO ❑ N/A

42. Does back-filling progress with the removal of the support system? ❑ YES ❑ NO ❑ N/A

43. Is a shield system installed to prevent lateral movement? ❑ YES ❑ NO ❑ N/A

44. Are employees prohibited from remaining in a shield system during vertical movement? ❑ YES ❑ NO ❑ N/A

Job Notes: ____

Inspected by:

Construction techniques and equipment usage must be in accordance with all governmental regulations and manufacturers' instruction. All orders placed with TrenchSafety are subject to the terms, conditions, and warranty limitations contained in TrenchSafety's Rental and Sales Agreements.

Safety Vocabulary

______1. Aerobic
______2. Ambient
______3. Anaerobic
______4. Competent Person
______5. Confined Space
______6. Confined Space, Non-Permit
______7. Confined Space, Permit-Required (Permit Space)
______8. Decibel
______9. Engulfment
______10. Fit Test
______11. IDLH
______12. Mercaptans
______13. Olfactory Fatigue
______14. Oxygen Deficiency
______15. Oxygen Enrichment
______16. Septic
______17. Sewer Gas
______18. Spoil

A. A condition where atmospheric or dissolved molecular oxygen is not present in the aquatic (water) environment.
B. A unit for expressing the relative intensity of sounds on a scale from zero for the average least perceptible sound to about 130 for the average level where sound causes pain to humans. Abbreviated dB.
C. A space which is large enough and so configured that an employee can bodily enter and perform assigned work; has limited or restricted means for entry or exit and it not designed for continuous employee occupancy.
D. Compounds containing sulfur that have an extremely offensive skunk-like odor; also sometimes described as smelling like garlic or onions.
E. The use of a procedure to qualitatively or quantitatively evaluate the fit of a respirator on an individual.
F. An atmosphere containing oxygen at a concentration of less than 19.5% by volume.
G. A condition where atmospheric or dissolved molecular oxygen is present in the aquatic (water) environment.
H. A condition produced by anaerobic bacteria. If severe, the wastewater produces hydrogen sulfide, turns black, gives off foul odors, contains little or no dissolved oxygen and the wastewater has a high oxygen demand.
I. Immediately Dangerous to Life or Health. The atmospheric concentration of any toxic, corrosive or asphyxiant substance that poses an immediate threat to life or would cause irreversible or delayed adverse health effects or would interfere with an individual's ability to escape from a dangerous atmosphere.
J. Gas in collection lines (sewers) that result from the decomposition of organic matter in the wastewater. When testing for gases found in sewers, test for lack of oxygen and also for explosive and toxic gases.
K. A person capable of identifying existing and predictable hazards in the surroundings, or working conditions that are unsanitary, hazardous or dangerous to employees, and who has authorization to take prompt corrective measures to eliminate the hazards.
L. Excavated material such as soil from the trench of a sewer.

M. The surrounding and effective capture of a person by a liquid or finely divided (flowable) solid substance that can be aspirated to cause death by filling or plugging the respiratory system or that can exert enough force on the body to cause death by strangulation, constriction or crushing.
N. A condition where a person's nose, after exposure to certain odors, is no longer able to detect the odor.
O. A confined space that does not contain or, with respect to atmospheric hazards, have the potential to contain any hazard capable of causing death or serious physical harm.
P. An atmosphere containing oxygen at a concentration of more than 23.5% by volume.
Q. Surrounding. Ambient or surrounding atmosphere.
R. A confined space that has one or more of the following characteristics: contains or has the potential to contain a hazardous atmosphere; contains a material that has the potential for engulfing an entrant; has an internal configuration such that an entrant could be trapped or asphyxiated by inwardly converging walls or by a floor that slopes downward and tapers to a smaller cross section; or contains any other recognized serious safety of health hazard.

Safety Questions

1. How can traffic be warned of your presence in the street?

2. How can explosive or flammable atmosphere develop in a collection system?

3. What types of hazardous atmospheres should an atmospheric test unit be able to detect in confined spaces?

4. If operators are scheduled to work in a manhole, when should the atmosphere in the manhole be tested?

5. When a blower is used to ventilate a manhole, where should the blower be located?

6. List the safety equipment recommended for use when operators are required to enter a confined space.

7. What are some early signs that an operator working in a manhole or other confined space is not getting enough oxygen?

8. How can collection system operators be protected from injury by the accidental discharge of stored energy?

9. How can collection system operators protect their hearing from loud noises?

10. How would you extinguish a fire?

Answers to Vocabulary and Questions

Vocabulary:

1. G	7. R	13. N
2. Q	8. B	14. F
3. A	9. M	15. P
4. K	10. E	16. H
5. O	11. I	17. J
6. D	12. D	18. L

Questions:

1. Traffic can be warned of your presence in a street by signs, flags or flashers and vehicles with rotating flashing lights. Vehicle-mounted traffic guides are also helpful. Flaggers can be used to alert drivers and to direct traffic around a work site.
2. Explosive or flammable atmospheres can develop at any time in the collection system. Flammable gases or vapors may enter a sewer or manhole from a variety of legal, illegal or accidental sources.
3. An atmospheric test unit should be able to detect flammable and explosive gases, toxic gases and oxygen deficiency.
4. If operators are scheduled to work in a manhole, the atmosphere in the manhole should be tested before anyone enters it, preferably before the cover is even removed, and atmospheric testing should continue for the entire time anyone is working in the manhole.
5. The blower used to ventilate a manhole should be located in an area upwind of the manhole and at least 10 feet from the manhole opening. If the blower has a gas-driven engine, the exhaust must be downwind from the manhole. The air intake to the blower should be 2-5 feet above the ground surface, depending on conditions (higher for dusty conditions).
6. SCBA (self-contained breathing apparatus); safety harness with lifeline, tripod and winch; portable atmospheric alarm unit; ventilation blower with hose; manhole enclosure (if entering a manhole); ladder or tripod with winch; ropes and buckets; hard hats; protective clothing; cones and barricades; firs-aid kit; soap, water, paper towels and a trash bag
7. The early warning signs that an operator is not getting enough oxygen include: labored breathing (shortness of breath), chest heaving and change from usual responses
8. Operators can be protected from injury due to the accidental discharge of stored energy by following prescribed lockout/ tagout procedures.
9. Collection system operators can protect their hearing from loud noises by use of approved earplugs, earmuffs and/or person protective equipment.
10. To extinguish a fire, first identify the material burning (class or category) and then use the appropriate method to put out the fire.

Section 9

Disinfection


Wastewater Disinfection and Chlorination

TENNESSEE DEPARTMENT OF ENVIRONMENT AND CONSERVATION

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Removal of Pathogenic Microorganisms

- Wastewater treatment removes some of the pathogenic microorganisms through these processes:
  - Physical removal through sedimentation and filtration
  - Natural die-off in an unfavorable environment
  - Destruction by chemicals introduced for treatment purposes

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Disinfection vs. Sterilization

- Disinfection is the destruction of all pathogenic microorganisms
  - Chlorination of wastewater is considered adequate when the
    - fecal coliform count has been reduced to 200 cfu/100 mL or less
    - E. coli count has been reduced to 126 cfu/100 mL or less
- Sterilization is the destruction of ALL microorganisms

**cfu = colony forming unit

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Pathogenic Organisms

- Diseases that are spread through water are:
  - Viral
    - Polio
    - Hepatitis A
  - Protozoa
    - Amebic Dysentary
    - Giardiasis
    - Cryptosporidiosis
  - Bacterial
    - Choler
    - Typhoid
    - Salmonellosis
    - Shigellosis, a bacillary dysentery
    - Gastroenteritis from enteropathogenic Escherichia coli

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Disinfection

- The main objective of disinfection is to prevent the spread of disease by protecting:
  - Public water supplies
  - Receiving waters used for recreational purposes
    - Protect water where human contact is likely
  - Fisheries and shellfish growing areas
  - Irrigation and agricultural waters

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Chlorine Chemicals

- Elemental chlorine
  - Yellow-green gas or amber liquid
  - 100% chlorine
- Sodium hypochlorite - bleach
  - Clear, pale yellow liquid
  - 5-15% chlorine
- Calcium hypochlorite - HTH
  - White, pale yellow granules or tablets
  - 65% chlorine
- Chlorine dioxide
  - Green-yellow gas generated on-site

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Chlorine

- Reacts with:
  - Organic matter
  - Hydrogen sulfide (H_2S)
  - Iron
  - Phenols
  - Manganese
  - Nitrite
  - Ammonia
  - And lastly used for disinfection

Chemistry of Chlorination

$Cl_2 + H_2O \rightarrow HOCl + HCl$

hypochlorous acid hydrochloric acid

- Hypochlorous acid
  - Most effective disinfectant
  - Prevalent at pH less than 7
    Dissociates at higher pH:

    $HOCl \rightarrow H+ + OCl-$

    hypochlorite ion
  - Hypochlorite ion is only 1% as effective as hypochlorous acid.

Chemistry of Hypochlorination

$NaOCl + H_2O \rightarrow HOCl + NaOH$

hypochlorous acid

- Sodium hypochlorite will slightly raise the pH because of the sodium hydroxide (NaOH)

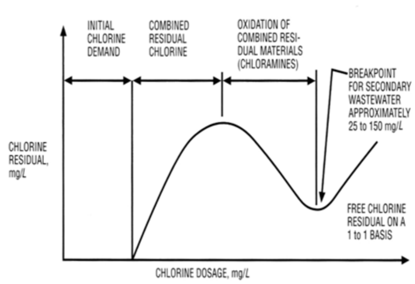
$Ca(OCl)_2 + 2H_2O \rightarrow Ca(OH)_2 + 2HOCl$

- Calcium hypochlorite does the same

Chlorine Dioxide (ClO_2): Chemistry

- Made onsite and very unstable
- $2NaClO_2 + Cl_2 \rightarrow 2NaCl + 2ClO_2$
  Sodium Chlorite, Chlorine, Sodium Chloride, Chlorine Dioxide
- $2ClO_2 + H2O \rightarrow ClO_3^- + ClO_2^- + 2H^+$
  Chlorine dioxide, Water, Chlorate Ion, Chlorite Ion, Hydrogen Ion

Breakpoint Chlorination Curve



Factors Influencing Disinfection

- Injection point and method of mixing
- Design or shape of contact chamber
- Contact time
  - Most contact chambers are designed to give 30 min contact time
- Effectiveness of upstream processes
  - The lower the SS, the better the disinfection
- Temperature
- Dose and type of chemical
- pH
- Numbers and types of microorganisms

Chlorine Demand

- Chlorine demand can be caused by environmental factors such as:
  - Temperature
  - pH
  - Alkalinity
  - Suspended solids
  - Biochemical and chemical oxygen demand
  - Ammonia nitrogen compounds

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Application Points for Chlorination

- Collection system
- Prechlorination
- Plant chlorination
- Chlorination before filtration
- Post-chlorination

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Collection System

- Odor control
  - Aeration may be most cost efficient
- Corrosion control
- BOD control
  - Decrease the load imposed on the STP

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Prechlorination

- The addition of chlorine to wastewater at the entrance to the treatment plant, ahead of settling units and prior to the addition of other chemicals
  - Aids in:
    - Odor control
    - Decrease BOD load
    - Settling
    - Oil removal

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Plant Chlorination

- Chlorine can be added to wastewater during treatment
  - The point of application depends on the desired results
- Emergency measure only, use extreme care when chlorinating in the treatment process because you may interfere or inhibit biological treatment processes
- Aids in:
  - Control of odors
  - Corrosion
  - Sludge bulking
  - Digester foam
  - Filter flies
  - Trickling Filter Ponding

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Chlorination Before Filtration

- Kills algae and other large biological organisms in water or in filters
  - Biological growth may cause filters to clog which would cause the need to backwash more frequently

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Post-chlorination

- Post-chlorination is defined as the addition of chlorine to municipal or industrial wastewater following other treatment processes
  - Point of application should be called a Chlorine Contact Chamber or Basin
  - Sole purpose is disinfection

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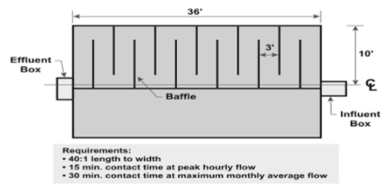
Typical Layout – Contact Basin



- Requirements:
  - 30:1 length to width
    - The total length of the channel created by the baffles should be 30 times the distance between the baffles
  - 15 min. contact time at peak hourly flow
  - 30 min. contact time at max monthly avg. flow

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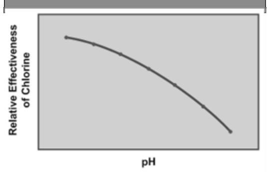
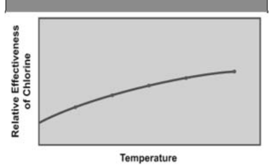
Relative Effectiveness

vs. pH



The lower the ph (<7), the disinfection action increases because hypochlorous acid is formed from chlorine and has 40 to 80 times greater disinfection potential.

vs. Temperature



When the temperature increases the disinfection action of chlorine increases.

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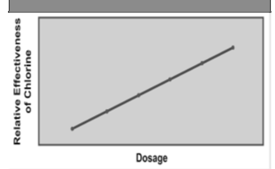
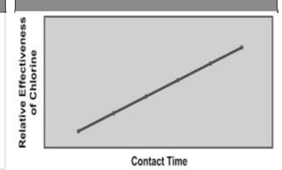
Relative Effectiveness

vs. Dosage



vs. Contact Time



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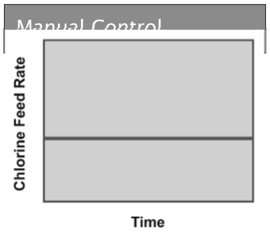
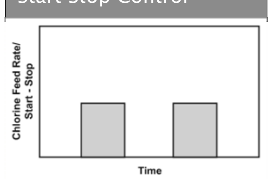
Types of Feed Control

Manual Control



Start Stop Control



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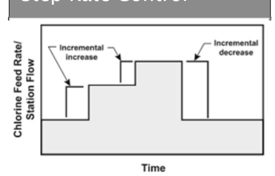
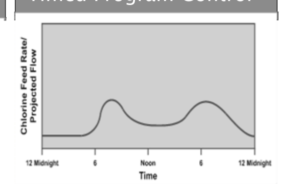
Types of Feed Control

Step Rate Control



Timed Program Control



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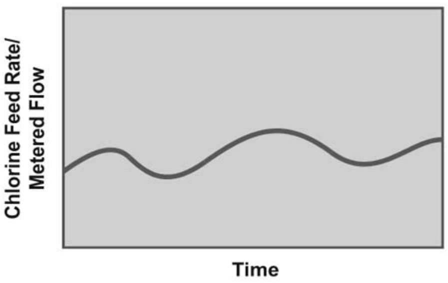
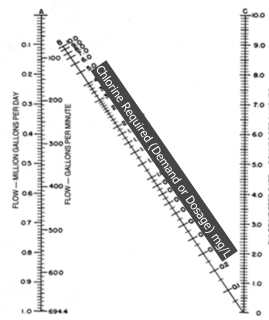
Flow Proportional Control



Chlorination Control Nomograph

- Nomogram is a chart or diagram containing three or more scales used to solve problems with three or more variables



Chlorine Hazards

- Chlorine gas is:
  - 2.5 times heavier than air
  - Extremely toxic
  - Corrosive in moist atmospheres

Chlorine Leaks

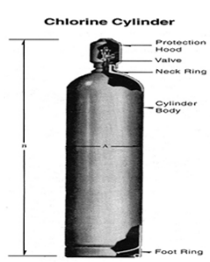
- To locate chlorine leaks you should use a commercial ammonia water
  - The ammonia water can be put in a polyethylene squeeze bottle about half full and squeeze the ammonia vapors around potential Cl_2 leak.
  - When ammonia vapor comes in contact with chlorine, a white cloud of ammonia chloride is formed.
  - A ammonia soaked rag wrapped around a stick will also do.
  - Household ammonia is not strong enough.
- Never put water on a chlorine leak
- because the mixture of water and chlorine will increase the rate of corrosion at the leak.

Physiological Response to Chlorine Gas

Effect	Parts of Chlorine Gas per Million Parts of Air by Volume (ppm)
Slight symptoms after several hours' exposure	1*
Detectable odor	0.08 - 0.4
60-min inhalation without serious effects	4
Noxiousness	5
Throat irritation	15
Coughing	30
Dangerous from ½ - 1 hour	40
Death after a few deep breaths	1,000

*OSHA regs specify that exposure to chlorine shall at NO time exceed 1 ppm.

Chlorine Cylinder (100 or 150 lb.)

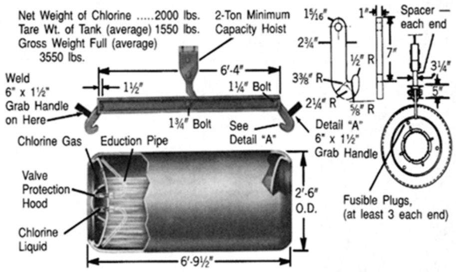


- The fusible plug melts at 158-165 F to prevent build-up of excessive pressure and possible rupture
- Cylinders must be kept away from direct heat

Net Cylinder Contents	Approx. Tare, Lbs.*	Dimensions, Inches	
		A	B
100 Lbs.	73	8¼	54½
150 Lbs.	92	10¼	54½

* Stamped tare weight on cylinder shoulder does not include valve protection hood.

Ton Container



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Ton Container

- Ton tanks weigh ~ 3,700 pounds
- Most ton tanks have 6-8 fusible plugs that are designed to melt at the same temperature range as the safety plug in the cylinder valve
- Ton tanks should be stored and used on their sides, above the floor or ground on steel or concrete supports
- Ton tanks should be placed on trunnions
- The upper valve will discharge chlorine gas and he lower valve will discharge liquid chlorine

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Chlorine Repair Kits

Kit B

Kit A

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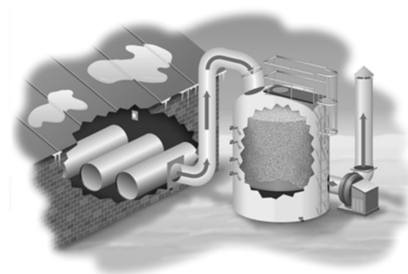
Chlorine Scrubber



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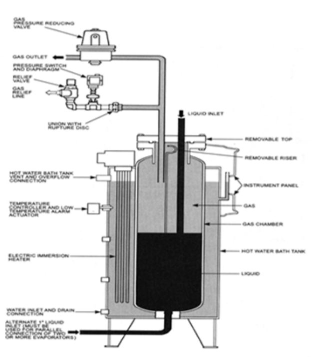
Evaporator

- Installed where large amounts of chlorine are fed
- An evaporator is a hot water heater surrounding a steel tank and the liquid chlorine is evaporated to gas at 110-120 F



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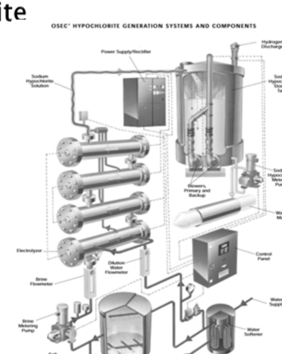
Hypochlorite Generator



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Dechlorination

- Dechlorination is the physical or chemical removal of all traces of residual chlorine remaining after the disinfection process and prior to the discharge of the effluent to the receiving waters
- Removal methods:
  - Aeration
  - Sunlight
  - Long detention time
  - Chemicals

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Chemicals Used for Dechlorination

- Sulfur dioxide
  - SO_2
  - One-to-one basis
  - Most popular
- Sodium sulfite
  - Na_2SO_3
- Sodium bisulfate
  - $NaHSO_3$
- Sodium metabisulfite
  - $Na_2S_2O_5$
- Sodium Thiosulfate
  - $Na_2S_2O_3$

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Sulfur Dioxide

- Colorless gas with a characteristic pungent odor
- Not flammable or explosive
- Not corrosive unless in a moist environment it can form sulfuric acid

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Application Point

- The typical application point is just before discharge into receiving stream
- This allows for maximum time for disinfection to take place

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Physiological Response to Sulfur Dioxide

Effect	Concentration
Lowest concentration detectable by odor	3-5 ppm
Lowest concentration immediately irritating to throat	8-12 ppm
Lowest concentration immediately irritating to eyes	20 ppm
Lowest concentration causing coughing	20 ppm
Maximum allowable concentration for 8-hr exposure	10 ppm
Maximum allowable concentration for 1-hr exposure	50-100 ppm
Tolerable (briefly)	150 ppm
Immediately dangerous concentration	400-500 ppm
OSHA 8-hour TWA (Time Weighted Average) is 2 ppm and the 15-minute STEL (Short Term Exposure Limit) is 5 ppm	

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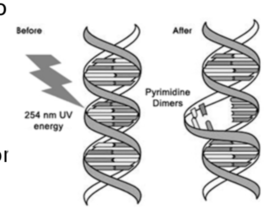
Ultraviolet Radiation

- Ultraviolet radiation is commonly referred to as ultraviolet light or UV
- When UV is absorbed by the cells of microorganisms, it damages the genetic material so that they can no longer grow or reproduce
  - This will ultimately kill them



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Ultraviolet Radiation

- With growing concern with safety of chlorine handling and the possible health effects of chlorination by-products, UV is gaining popularity
- UV disinfection may become a practical alternative to chlorine disinfection at STP

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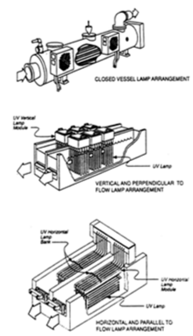
Typical UV Lamp Configurations

- Closed vessel lamp arrangements are more typically found in drinking water plants
- Wastewater plants normally have UV bulbs placed in an open channel either horizontal or perpendicular to flow



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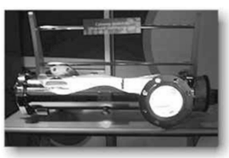
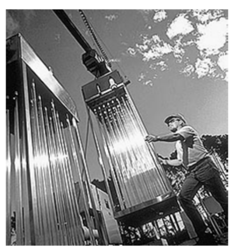
Typical UV Lamp Configurations





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Safety with Ultraviolet Light Systems

- The light from a UV lamp can cause serious burns to your eyes and skin
- Always take precautions to protect your eyes and skin
- NEVER look into the uncovered sections of the UV chamber without protective glasses
- UV lamps contain mercury vapor, which is a hazardous substance that can be released if the lamp is broken

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UV Operation

- Lamp output declines as they age
  - Operators must monitor output and replace bulbs that no longer meet design standards
- Turbidity and flow must be monitored
  - Suspended particles can shield microorganisms from the UV light
  - Flows should be somewhat turbulent to ensure complete exposure of all organisms to the bulbs

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UV Operation

- UV light does NOT leave a residual like chlorine
  - Bacteriological tests must be run frequently to ensure adequate disinfection is taking place
  - Microorganisms that were not killed may be able to heal themselves

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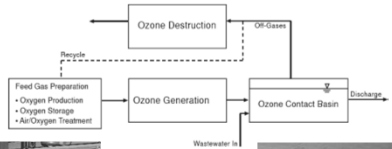
Process of Ozone Disinfection



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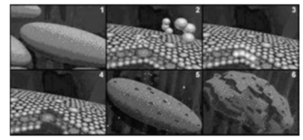
Effects of Ozone on Bacteria



Ozone disinfection steps:
1 – Computer animation of a bacterial cell
2 – Close-up of an ozone molecule on the bacterial cell wall
3 – Ozone penetrates the cell wall and causes corrosion
4 – Close-up of the effect of ozone on the cell wall
5 – Bacterial cell after it has come in contact with a number of ozone molecules
6 – Cell destruction (lysis)

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Design Criteria

http://www.tn.gov/environment/wpc/publications/

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Chapter 10 – Disinfection

- 10.1.1 – Disinfection as a minimum shall
  - A. Protect public water supply
  - B. Protect fisheries and shellfish waters
  - C. Protect irrigation and agricultural waters
  - D. Protect water where human contact is likely

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Chapter 10 – Disinfection

- 10.1.2.1 – Chlorination
  - Chlorination using dry chlorine is the most commonly applied method of disinfection and should be used unless other factors, including chlorine availability, costs, or environmental concerns, justify an alternative method

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Chapter 10 – Disinfection

- 10.1.3 – Dechlorination
  - Capability to add dechlorination should be considered in all new treatment plants. Dechlorination of chlorinated effluents shall be provided when permit conditions dictate the need

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Chapter 10 – Disinfection

- 10.2.1.4 – Chlorine Gas Withdrawal Rates
  - The maximum withdrawal rate for 100- and 150-pound cylinders should be limited to 40 pounds per day per cylinder
  - When gas is withdrawn from 2,000-pound containers, the withdrawal rate should be limited to 400 pounds per day per container

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Chapter 10 – Disinfection

- 10.2.2.4 – Contact Period
  - Contact chambers shall be sized to provide a minimum of 30 minutes detention at average design flow and 15 minutes detention at daily peak design flow, whichever is greater. Contact chambers should be designed so detention times are less than 2 hours for initial flows.

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Chapter 10 – Disinfection

- 10.2.2.5 – Contact Chambers
  - The contact chambers should be baffled to minimize short-circuiting and backmixing of the chlorinated wastewater to such an extent that plug flow is approached.
  - Provision shall be made for removal of floating and settleable solids from chlorine contact tanks or basins without discharging inadequately disinfected effluent

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Chapter 10 – Disinfection

- 10.2.2.5 – Contact Chambers (continued)
  - A readily accessible sampling point shall be provided at the outlet end of the contact chamber

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Chapter 10 – Disinfection

- 10.2.2.6 (a) – Dechlorination with Sulfur Dioxide
  - Sulfur dioxide can be purchased, handled and applied to wastewater in the same way as chlorine
  - Sulfur dioxide dosage required for dechlorination is 1 mg/L of SO_2 for 1 mg/L of chlorine residual expressed as Cl_2

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Chapter 10 – Disinfection

- 10.2.2.8 – Residual Chlorine Testing
- Equipment should be provided for measuring chlorine residual.
- There are five EPA accepted methods for analysis of total residual chlorine and they are
  - 1) Ion Selective Electrode
  - 2) Amperometric End Point Titration Method
  - 3) Iodometric Titration Methods I & II
  - 4) DPD Colormetric Method
  - 5) DPD Ferrous Titrimetric Method

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Chapter 10 – Disinfection

- 10.2.2.8 – Residual Chlorine Testing (continued)
- Where the discharge occurs in critical areas, the installation of facilities for continuous automatic chlorine residual analysis and recording systems may be required.

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Chapter 10 – Disinfection

- 10.2.3.1(a) – Design Details (Housing – General)
  - An enclosed structure shall be provided for the chlorination equipment
  - Chlorine cylinder or container storage area shall be shaded from direct sunlight

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Chapter 10 – Disinfection

- 10.2.3.1(a) – Design Details (Housing – General) (continued)
  - Chlorination systems should be protected from fire hazards and water should be available for cooling cylinders or containers in case of fire
  - If gas chlorination equipment and chlorine cylinders or containers are to be in a building used for other purposes, a gastight partition shall separate this room from any other portion of the building

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Chapter 10 – Disinfection

- 10.2.3.1(b) – Design Details (Housing – Heat)
  - Chlorinator rooms should have a means of heating and controlling the room air temperature above a minimum of 55°F
  - A temperature of 65° F is recommended

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Chapter 10 – Disinfection

- 10.2.3.1(b) – Design Details (Housing – Heat) (continued)
  - The room housing chlorine cylinders or containers in use should be maintained at a temperature less than the chlorinator room, but in no case less than 55 F unless evaporators are used and liquid chlorine is withdrawn
  - All rooms containing chlorine should also be protected from excess heat

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Chapter 10 – Disinfection

- 10.2.3.1(c) – Design Details (Housing – Ventilation)
  - All chlorine feed rooms and rooms where chlorine is stored should be force-ventilated, providing one air change per minute except "package" buildings with less than 16 ft^2 of floor space
  - The entrance to the air exhaust duct from the room should be near the floor and the point of discharge should be so located as not to contaminate the air inlet to any building or inhabited areas

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Chapter 10 – Disinfection

- 10.2.3.1(e)
  - Dechlorination equipment (SO_2) shall not be placed in the same room as the Cl_2 equipment. SO_2 equipment is to be located such that the safety requirements of handling Cl_2 are not violated in any form or manner

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Chapter 10 – Disinfection

- 10.2.3.6 – Handling Equipment
  - Handling equipment should be provided as follows for 100- and 150-pound cylinders:
    - A hand truck specifically designed for cylinders
    - A method for securing cylinders to prevent them from falling over

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Chapter 10 – Disinfection

- 10.2.3.6 – Handling Equipment (continued)
  - Handling equipment should be provided as follows for 2,000-pound container:
    - Two-ton capacity hoist
    - Cylinder lifting bar
    - Monorail or hoist with sufficient lifting height to pass one cylinder over another
    - Cylinder trunnions to allow rotating the cylinders for proper connection

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Chapter 10 – Disinfection

- 10.2.4.1 – Leak Detection and Controls
  - A bottle of 56% ammonium hydroxide solution shall be available for detecting chlorine leaks
  - All installations utilizing 2,000-pound containers and having less than continuous operator attendance shall have suitable continuous chlorine leak detectors

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Chapter 10 – Disinfection

- 10.2.4.2 – Breathing Apparatus
  - At least <u>two</u> gas masks in good operating condition and of a type approved by the National Institute for Occupational Safety and Health (NIOSH) as suitable for high concentrations of chlorine gas shall be available at all installations where chlorine gas is handled and shall be stored outside of any room where chlorine is used or stored

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Chapter 10 – Disinfection

- 10.3.2 – Ultraviolet Disinfection – Application
  - UV disinfection may be substituted for chlorination, particularly whenever chlorine availability, cost or environmental benefits justify its application. For tertiary treatment plants where dechlorination is required for chlorine toxicity is suspected, UV disinfection is a viable alternative

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Disinfection Vocabulary

______1. Breakpoint	______8. Free Chlorine Residual
______2. Chlorination	______9. Organic Substance
______3. Combined Residual	______10. Ozone Generator
______4. CxT Value	______11. Sterilization
______5. Disinfection Residual	______12. Trihalomethane
______6. Disinfection	______13. UV Disinfection
______7. Disinfection By-Product	______14. Waterborne Disease

A. The process of destroying all organisms in water.
B. The product of the residual disinfectant concentration C and the corresponding disinfectant contact time T.
C. The water treatment process that kills disease-causing organisms in water.
D. A device that produces ozone by passing an electrical current through air or oxygen.
E. The point at which the chlorine dose has met the demand.
F. A chemical substance of animal or vegetable origin, having carbon in its molecular structure.
G. Disinfection using ultraviolet light.
H. The process of adding chlorine to water to kill disease-causing organisms.
I. The residual formed after the chlorine demand has been satisfied.
J. An excess of chlorine left in water after treatment. Indicates that an adequate amount of disinfectant has been added to ensure complete disinfection.
K. Compound formed when organic substances such as humic and fulvic acids react with chlorine.
L. Chemical compounds that are formed by the reaction of disinfectants with organic compounds in water.
M. The chlorine residual produced by the reaction of chlorine with substances in the water. It is not as effective as free residual.
N. A disease caused by waterborne organism.

Disinfection Review Questions

1. List four infectious diseases that can be transmitted by water:
   -
   -
   -
   -

2. What are limitations of UV disinfection?

3. Name the three types of chlorine commonly used in wastewater treatment and give a short description of each:
   -
   -
   -

4. Define breakpoint.

5. When chlorine is added to water, it breaks down into two products. Name them:
   -
   -

6. Which of the two products (in #5) is the most effective disinfectant?

7. Why is chlorination less effective at a higher pH?

Answers to Vocabulary and Questions

Vocabulary:

1. E
2. H
3. M
4. B
5. J
6. C
7. L
8. I
9. F
10. D
11. A
12. K
13. G
14. N

Questions:

1. Typhoid fever, infectious hepatitis, dysentery, cholera
2. Water must pass close to lamp; water must be of good quality; no residual
3.
   - gas – greenish-yellowish gas; pungent, noxious odor; toxic if inhaled; 2.5x heavier than air
   - NaOCl – Sodium hypochlorite, liquid, bleach; can cause burns on skin; 5-15% strength
   - $Ca(Ocl)_2$ – Calcium hypochlorite, solid; 65% strength, fire hazard, can cause burns
4. Addition of chlorine to water or wastewater until the chlorine demand has been satisfied. At this point, further additions of chlorine result in a residual that is directly proportional to the amount of chlorine added beyond the breakpoint.
5. HOCl (hypochlorous acid) and OCl^- (hypochlorite ion)
6. HOCl (hypochlorous acid)
7. Hypochlorous acid breaks down into hypochlorite ion, which is only 1% as effective

Wastewater Disinfection Math

(Round to the nearest tenth)

1. Calculate the chlorine feed rate in lbs/day for a chlorine dosage of 6 mg/L at a flow of 100,000 gal/day.

2. A chlorine contact tank with a volume of 20,000 gallons receives an average flow of 1000 gal/min. If the minimum contact time is 15 minutes, is this tank above or below the minimum time?

3. What is the chlorinator feed rate in lbs/day if the chlorine dosage is 8 mg/L and the flow is 500,000 gal/day?

4. How many pounds of HTH (65% available chlorine) are required to make 35 gallons of 5% available chlorine bleach? (Assume bleach is 8.34 lbs/gal)

5. What is the demand of your wastewater if you are feeding 133 lbs/day of chlorine and the flow rate is 2 MGD? The chlorine residual after a 30 minutes contact time is 1.5 mg/L.

Section 6

Wastewater Disinfection Math

(Round to the nearest tenth) pg. 9 formula book

1. Calculate the chlorine feed rate in lbs/day for a chlorine dosage of 6 mg/L at a flow of 100,000 gal/day.

$$\text{lbs/d} = (6\,\text{mg/L})(0.1\,\text{MGD})(8.34)$$
$$= \boxed{5\ \text{lbs/d}}$$

2. A chlorine contact tank with a volume of 20,000 gallons receives an average flow of 1000 gal/min. If the minimum contact time is 15 minutes, is this tank above or below the minimum time?

pg. 8 in Sedimentation

$$\text{DT, min} = \frac{(\text{Vol, gal})(24\ \text{hrs/d})(60\ \text{min/hr})}{\text{flow, gpd}} \quad \text{OR} = \frac{(\text{Vol., gal})}{\text{flow, gpm}}$$
$$= \frac{20{,}000\,\text{gal}}{1000\,\text{gpm}} = \boxed{20\ \text{min} \rightarrow \text{above DT}}$$

3. What is the chlorinator feed rate in lbs/day if the chlorine dosage is 8 mg/L and the flow is 500,000 gal/day?

$$\text{lbs/d} = (8\,\text{mg/L})(0.5\,\text{MGD})(8.34)$$
$$= \boxed{33.4\ \text{lbs/d}}$$

4. How many pounds of HTH (65% available chlorine) are required to make 35 gallons of 5% available chlorine bleach? (Assume bleach is 8.34 lbs/gal)

HTH, lbs (solution mix)

$$\text{HTH, lbs} = \frac{(0.05)(35\,\text{gal})(8.34)}{0.65}$$
$$= \boxed{22.5\ \text{lbs}}$$

5. What is the demand of your wastewater if you are feeding 133 lbs/day of chlorine and the flow rate is 2 MGD? The chlorine residual after a 30 minutes contact time is 1.5 mg/L.

$$Cl_2\ \text{dose} = \frac{(133\ \text{lbs/d})}{(2\,\text{MGD})(8.34)} = 8.0\,\text{mg/L}$$

$$\text{Demand} = 8.0\,\text{mg/L} - 1.5\,\text{mg/L} = \boxed{6.5\,\text{mg/L}}$$

Disinfection