Advanced Wastewater Treatment

Course #3201

Fleming Training Center
February 27 – March 3, 2017

Advanced Wastewater

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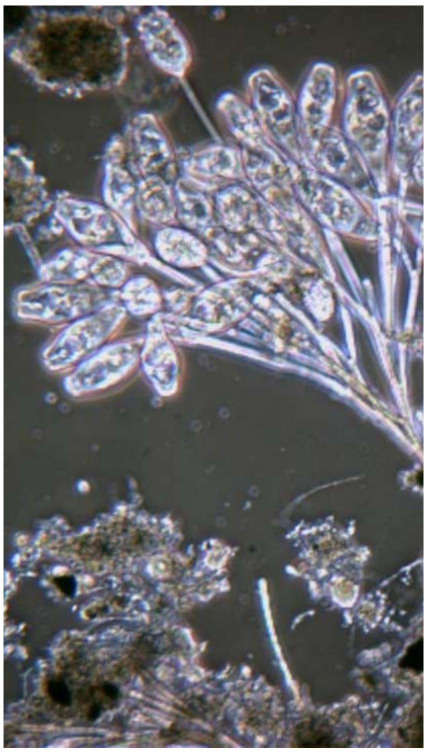

Monday, February 27 :

8:30	Nutrient Removal	Brett Ward
11:00	LUNCH	UT-MTAS
12:15	Nutrient Removal Cont'd	brett.ward@tennessee.edu
2:00	Fats, Oil and Grease Control	

Tuesday, February 28:

8:30	Activated Sludge	Dr. Larry Moore
11:00	LUNCH	University of Memphis
12:15	Residual Solids Management	lwmoore@memphis.edu
2:15	Solids Removal from Secondary Effluents	

Wednesday, March 1:

8:30	BOD Presentation	Barbara Loudermilk
12:00	LUNCH	Division of Water Resources
1:15	BOD "workout" reviewing real data	Barbara.loudermilk@tn.gov
2:00	E. coli presentation	

Thursday, March 2:

8:30	Reclamation and Reuse	John Strickland
10:00	Odor and Corrosion Control	Sinking Creek WWTP
11:00	LUNCH	jstrickland@murfreesborotn.gov
12:15	Spring Hill WWTP plant tour	

Friday, March 3:

8:30	Review	Ben Rodriquez
11:00	LUNCH	
12:15	Exam and Course Evaluation	

State of Tennessee

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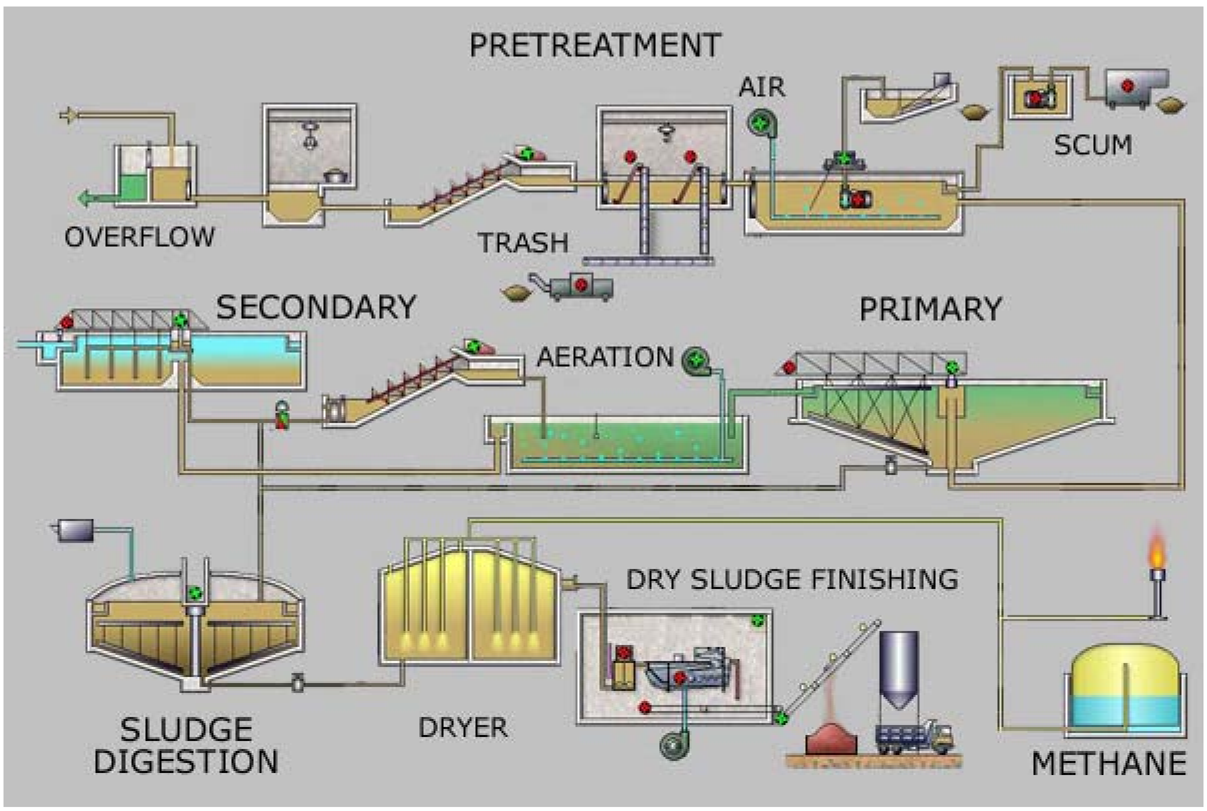
Advanced Wastewater Treatment

Section 1

Activated Sludge



Activated Sludge

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Activated Sludge Process

- The term "Activated Sludge" comes from the sludge particles teeming with active bacteria, fungi and protozoans.
- 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

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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
Pure Oxygen	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

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Performance problems can be caused by

- Changes in influent characteristics
  - Septic flows
  - Toxic loads
  - Organic overloads
- Hydraulic overloading
  - Storm water infiltration does NOT improve plant efficiency
- Mechanical equipment failures
  - Aeration equipment
  - Pump or lift stations
  - Valves
- Insufficient operator training

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System Components

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- 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.

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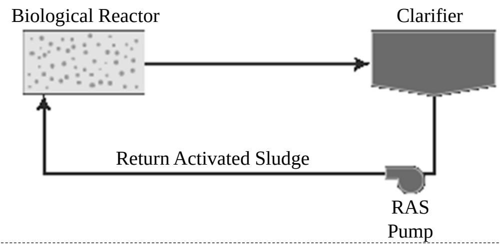
- Mixed Liquor - A mixture of raw or settled wastewater and activated sludge contained in an aeration tank or biological reactor.
- Suspended Solids - Insoluble solids that either float on the surface of, or are in suspension in, water, wastewater, or other liquid.
- Mixed Liquor Suspended Solids (MLSS)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

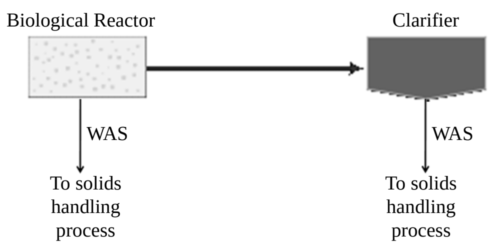
Return Activated Sludge (RAS)

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

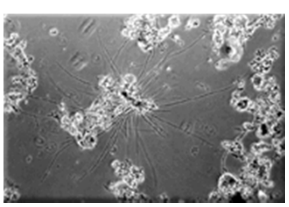


Waste Activated Sludge (WAS)

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



- 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.



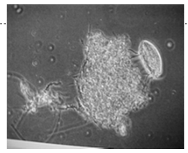
Microbiology

Microorganisms

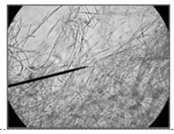
- Types of microorganisms present in activated sludge depend on
  - Composition of the wastewater
  - Length of the system's MCRT
  - pH
  - Temperature
  - DO concentration
- Microorganism population type affects both activated sludge characteristics and treatment potential.

What are Microbes?

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



Crawling ciliate on activated sludge floc



Cyanobacteria

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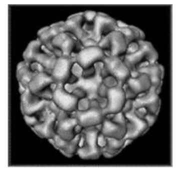
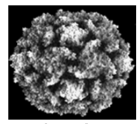
Why are they important?



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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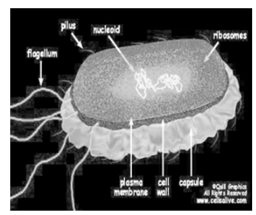
Viruses and Bacteria

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



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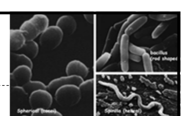
Examples of Bacteria Found in Wastewater



- Most are soil bacteria.
- For WW Treatment, bacteria are the most important microorganisms in the process.
  - Bacteria are the main workers in wastewater treatment
- They are one of the simplest forms of life, use soluble food and are capable of self-reproduction
- Individual cells come in sphere (coccus), rod (bacillus) and spiral (spirillum) shapes and range in size from 0.5 to 5.0 microns
- About 95% of microorganisms in mixed liquor for activated sludge systems are the bacteria.
- Don't want to see many spiral, they are disease-causing bacteria

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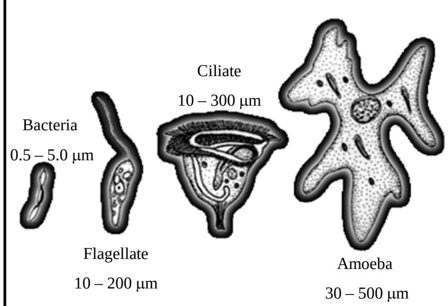
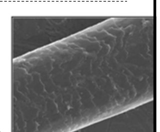
Size Range of Microorganisms





Human Hair sized 70-100 µm or 0.003-0.004 inch, (0.001 in = 25 µm)

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Bacteria

- Binary fission is the process by which one mature cell divides into two new cells.
  - Under ideal conditions, a bacterium can grow to maturity and reproduce by binary fission in less than 30 min.
- Generation Time: replication in PURE culture:
  - Bacillus sp. (BOD eating bacteria) 20-30 minutes
  - Nitrifiers 22-48 hours
  - Methanogens 10-30 days
- Video of Bacteria Reproducing

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

Heterotrophic

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

Heterotrophic

- Nutrients
  - Nitrogen, Phosphorus, micronutrients
  - Source is the Sewage and wastewater
  - Ideal Balance
    - BOD:TKN:P
    - 100:5:1
  - Domestic waste generally provides a good balance for the microorganisms, industrial waste may not, which could lead to filament growth.

Heterotrophic

- Heterotrophs can also be further classified based ont their oxygen requirements:
  - Aerobes require free DO to function
  - Anoxic use nitrogen bound oxygen like 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

Biochemistry

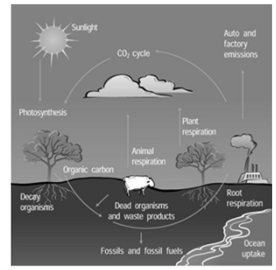
- Rotting, by heterotrophic bacteria:
- $\underset{\text{Glucose}}{C_6H_{12}O_6}$ + Bugs + $O_2 \longrightarrow$ More Bugs + CO_2 + H_2O (Energy and Nutrients)
- What is the formula backwards?
- $C_6H_{12}O_6 + O_2 \longleftarrow CO_2 + H_2O$ + energy

Autotrophic

- Use carbon dioxide (inorganic) as a carbon source
- Autotrophic organisms take inorganic substances into their bodies and transform them into organic nourishment.
  - Nitrifiers like Nitrosomonas and Nitrobacter are important autotrophic bacteria.
- 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).

Photosynthesis!

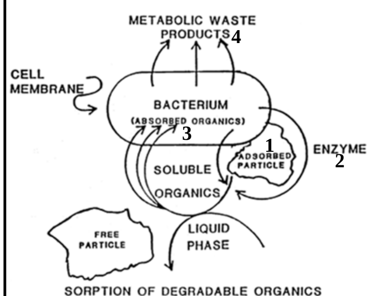
- The Carbon Cycle
  - Matter is not created or destroyed, but its form is changed.
  - Carbon goes from Carbon dioxide to organic carbon (food) and back in a treatment plant.



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.

Microorganisms "Eating"



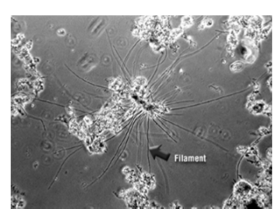
- Step 1 – Adsorb
- Step 2 – Enzymes break down organic matter into soluble particles
- Step 3 – Absorb
- Step 4 – Waste products (nitrogen gas for some, carbon dioxide, water and stable matter) and reproduce

Microorganisms

- Bacteria have a little tail, they swim around and eat food
- Once food runs low, they loose their tail and start leaving behind waste product that is sticky (polysaccharide slime)
- This sticky waste makes them stick to other bacteria and creates heavy floc
- If high slug of BOD, they don't loose their tail, they continue to swim around and don't have sticky stuff to attach to them, therefore, the don't floc and settle out.

Micrograph of Floc and Filaments

- Filamentous bacteria are not "floc formers" but are also of interest in WW treatment.
- Small amounts of them can improve floc structure, acting as a back bone, providing mass to help in settling after treatment.
- Large amounts can negatively affect performance of activated sludge systems by keeping floc apart and which makes it light and fluffy, therefore, not settling well.



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
- Protozoans are much larger than bacteria, their size ranges from 10-500 microns
- They are an important link in the activated sludge food chain because they consume bacteria to fill a large part of their nutritional needs.
  - This seems not only to remove excess bacteria from WW, but appears to stimulate the growth of healthy bacteria, which produce floc more quickly and aid in the clarification of the effluent
- Form cysts
- Beneficial in wastewater treatment
- Indicators of health of system

- Examples:
  - Amoeba
  - Free-Swimming Ciliates - Paramecium
  - Crawling Ciliates
  - Stalked Ciliates
  - Suctoria

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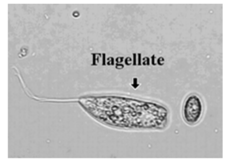
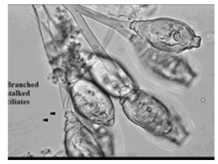
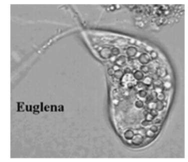
Protozoa Found in the Activated Sludge Process



- Much less abundant than bacteria, but very important.
- Require DO
- Flagellate has a whip-like tail and competes with bacteria
  - Indicative of young sludge
- Stalked ciliates – as adults, attach to something; as a "baby", has little hairs (cilia) to move around and move water and food into "mouth"
- Euglena – has green algae in it that makes oxygen when the sun shines.





Video of MLSS

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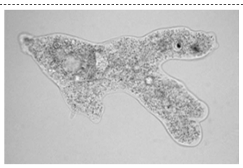
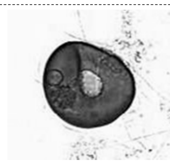
Protozoa - Amoeba





Video of Amoeba eating

- Amoebas don't like being in WW, they encyst themselves to make it through the system
- Look like donuts
- Can be found during plant start up or after a plant is recovering from an upset.

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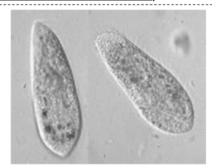
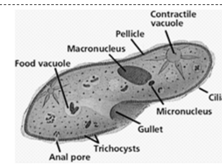
Protozoa – Free Swimming Ciliate (Paramecium)





- Free swimming ciliates generally are younger biomass organisms but are common in many plants.
- Cilia covers entire shape
- Sufficient D.O.
- Asexually & Sexually
- Paramecium- 4.7 hours growth rate

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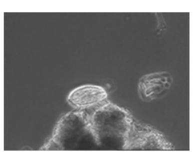
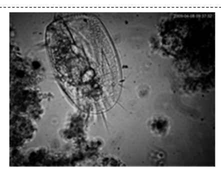
Protozoa – Crawling Ciliates





- Resemble crabs or ladybugs
- May have some cilia but majority of body does not contain any
- Croppers of biomass
- Cirri (A bundle or tuft of cilia serving as foot or tentacle in certain ciliate protozoa) are 4-5 cilia fused together
- Very efficient feeders

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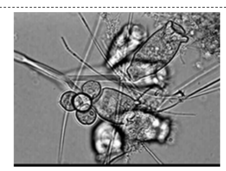
Protozoa – Stalked Ciliates



- They feed by drawing cells into their "mouth" with small cilia that create a visible twirling motion in the sample.
- Can be sessile or colonial
- Length of stalk indicates age
- Some will have a myenome (contractile muscle fiber with in stalk)
- Some species will produce a daughter cell which resembles a free-swimming ciliate
- Size of oral opening may indicate health of system / more bacteria smaller opening and less bacteria larger opening
- Single (vorticella) vs colonial (epystylis) does not mean one is better than other, they are all individual species and grow based on the environment

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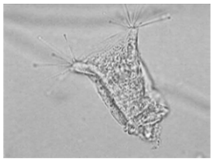
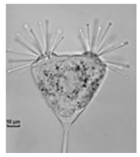
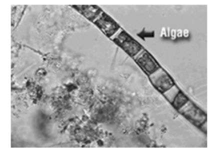
Protozoa – Suctoria

- These are the true vampires of the wastewater world
- Tentacles may recoil in presence of increased ammonia
- Some will have a stalk and others may not

Fungi and Algae

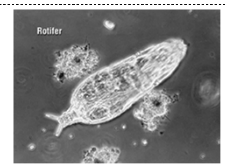
- Fungi
  - Soil organisms
  - Degrade dead organic matter (saprophytic)
- Algae
  - Photosynthetic
  - Eutrophication can cause algal blooms in receiving streams
  - Key in operation of wastewater ponds: produce oxygen needed by bacteria
  - Nuisance in clarifiers, basins, etc.

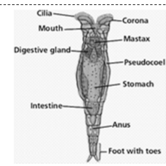


Metazoa

- Multi-cellular animals
- Multicellular
- Slower growing
- Typically larger than protozoa
- Sexual and asexual reproduction
- Heterotrophic
- All are motile
  - Unless there has been an upset to the plant
- Examples:
  - Rotifer
  - Water Mite
  - Water Bear
  - Nematodes
  - Ostracods

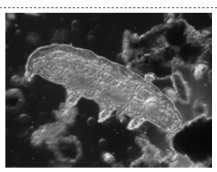
Metazoa - Rotifer





- Simple multi-celled organisms
- Need aerobic environment
- Consume solid food including bacteria
- In lagoons, they eat lots of algae
- Means happy, healthy population
- Over 80% are female
- Longer Sludge age
- Low BOD, Sufficient D.O.
- Tardigrade food*
- Some move like snails others resemble free-swimming ciliates

Metazoa – Water Bear (Tardigrade)




- Old sludge organism
- Feeds on smaller protozoa
- Does not like ammonia
  - Not found in presence of ammonia above 5ppm
- Extremely aerobic
- 8 legs- with 2 claws on each for holding
  - Prefer rotifers as a food source
- Water bears are typically not seen in industrial waste treatment systems
- They have been sent to space as part of the NASA program

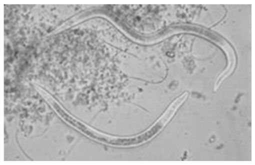
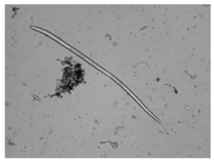
Metazoa – Worms

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

Ascaris and egg


Trickling filter

Metazoa – Nematode

- Aquatic earthworms.
- Fast moving.
- The poke around the floc.
- Older sludge organisms that reproduce slowly.

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Metazoa – Bristle Worm


- Aquatic earthworm
- They eat bacteria and protozoa.
- They are relative active. They have red spot that are not visible here but can turn biomass red colored.
- They have the capacity to make your biomass disappear.

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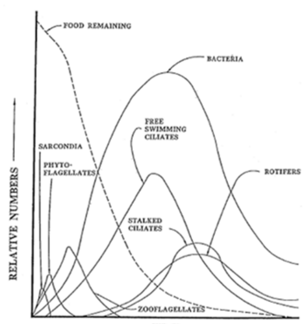
Bacteria Population vs. Sludge Age



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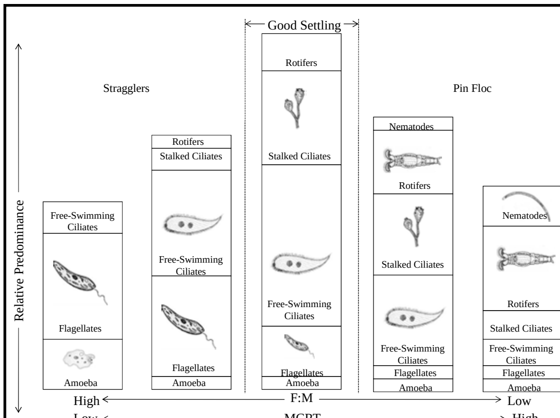

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Microorganisms Predominance

- 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.
- If you see a predominance of amoebas and flagellates in the microbial population, this is an indication of young or recovering sludge.

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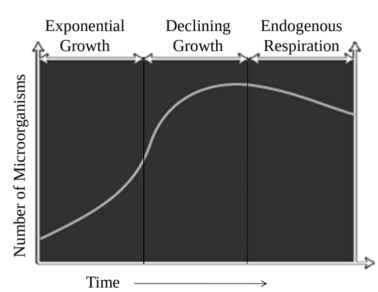
Phases of Microorganism's Life



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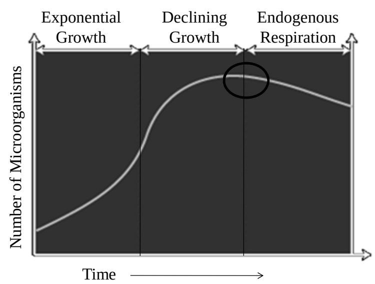
Phases of Microorganism's Life

- 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

$$\text{F/M Ratio} = \frac{\text{BOD or COD, lbs/day}}{\text{Mixed Liquor Volatile Suspended Solids, lbs}}$$

- Most plants operate right before endogenous respiration

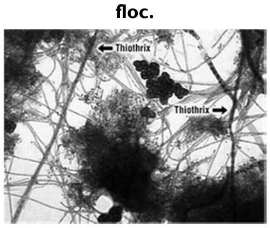


Bulking

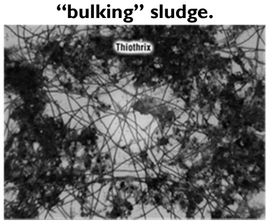
- Clouds of billowing sludge that occur throughout the secondary clarifiers and sludge thickeners when the sludge does not settle properly.
  - In the activated sludge process, bulking is usually caused by filamentous bacteria or bound water.
- Bulking activated sludges can be caused by:
  - Elevated levels of hydrogen sulfide
  - Low F/M
  - Nutrient deficiencies

Filaments

Microorganisms act as a kind of skeleton for the floc.



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



Filaments

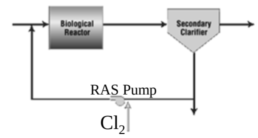
- Some filamentous organisms are good, but too many are bad
- Filamentous organisms can form a network or backbone upon which clumps of activated sludge can gather
  - This produces a floc with excellent settling characteristics
- If filaments become excessive, a bridging mechanism forms and prevents the numerous small clumps of sludge from gathering or packing together
  - If they are prevented from clumping together, sufficient particle mass will not be produced to achieve good settling rates
- Activated sludge with good settling characteristics do not have a predominance of filamentous bacteria.

Filaments

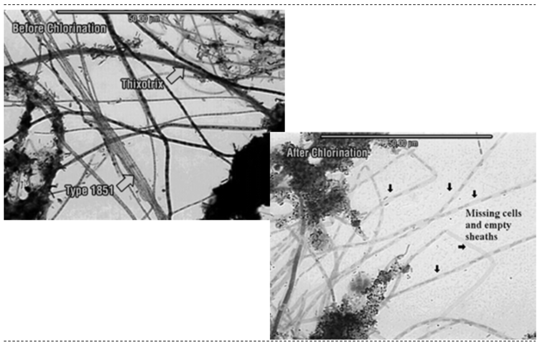
- Specific conditions can allow a particular filamentous organism to dominate.

Filaments

- Conditions that promote filamentous organism growth:
  - Consistently low DO in biological reactors ~ 0.4 – 0.7
  - High-BOD wastewater (for example, high-sugar, low nutrient industrial wastewater)
  - Low F:M
  - Elevated levels of H_2S
  - 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



Filaments



Filaments

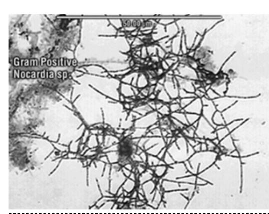
- *Thiothrix* filaments are usually attached to the flocs.
- The sulphur globules are very characteristic.
- The sulphides are oxidised and elementary sulphur is temporarily stored in the cell as an intermediary product.
  - These are the bright globules that can be microscopically observed.

Foaming Problems

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

Foaming Problems

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



Thick *Nocardia* Foam

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

Process Goals

Successful activated sludge process performance is judged by effluent quality.

Activated Sludge Process Goals

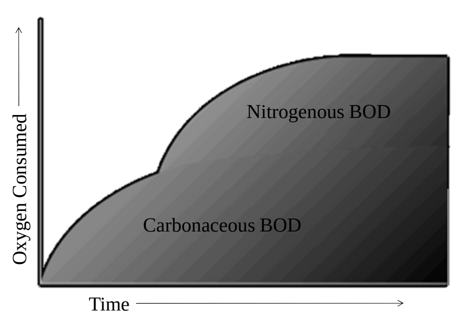
- CBOD removal
- Nitrification (where required)
- TSS removal
- Maintaining neutral pH
- Minimizing the amount of solids produced
- Optimizing the energy used

(CBOD removal, Nitrification, TSS removal:) May have oxygen demand if it bypasses the plant or makes it through plant and into receiving stream

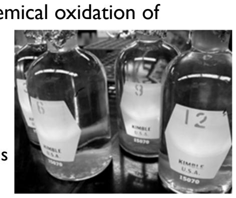
Activated Sludge Process Goals

- How do we accomplish this?
  - cBOD removal
    - Aerate with adequate RAS
  - Nitrification (where required)
    - Aerate with adequate RAS and MCRT
  - TSS removal
    - Good settling characteristics
    - May have to add chemicals
  - Maintaining neutral pH
    - May have to add chemicals
  - Minimizing the amount of solids produced
  - Optimizing the energy used

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



Organic Matter Tests

- BOD – Biochemical Oxygen Demand
  - 5-day test on organic matter than can be biologically metabolized by bacteria in a 300 mL bottle
- COD – Chemical Oxygen Demand
  - A 2-hour test that measures all organic carbon with the exception of certain aromatics (benzene, toluene, phenol, etc.) which are not completely oxidized in the reaction.
  - COD is a chemically chelated/thermal oxidation reaction, and therefore, other reduced substances such as sulfides, sulfites, and ferrous iron will also be oxidized and reported as COD.
  - NH_3-N (ammonia) will NOT be oxidized as COD.
- TOC – Total Organic Carbon
  - A quick (less than 15 min) test to more accurately measure low levels of organic matter.
  - TOC doesn't differentiate between that portion of organic carbon, which can be metabolized (assimilated) and which cannot.

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Nitrification Reaction

- $NH_4 + 1.5\ O_2 \xrightarrow{\text{Nitrosomonas}} NO_2^- + 2\ H^+ + H_2O + \text{Energy}$
  Ammonia, Oxygen → Nitrite, Acid, Water

- $NO_2^- + 0.5\ O_2 \xrightarrow{\text{Nitrobacter}} NO_3^- + \text{Energy}$
  Nitrite, Oxygen → Nitrate

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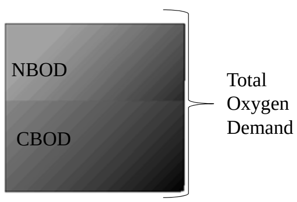
Total Oxygen Demand

- NBOD + CBOD = Total Oxygen Demand
  - Nitrogenous oxygen demand is a measure of the oxygen required by the nitrifying bacteria to convert ammonia nitrogen to nitrite and nitrate.
  - The combined requirement to decrease CBOD and nitrogenous BOD makes up the total oxygen requirement for the nitrifying activated sludge process.



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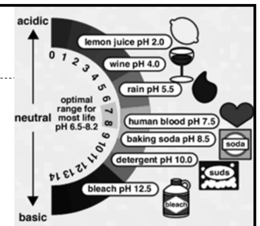
pH



- 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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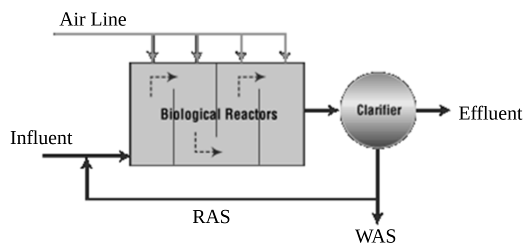
Activated Sludge Process Modes

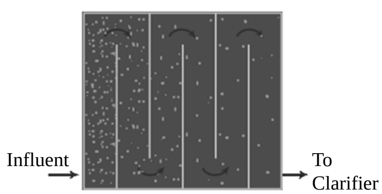
- Plug-flow (conventional)
- Complete mix
- Contact stabilization
- Step feed
- Extended aeration
- Oxidation ditches
- High-rate aeration
- High-purity oxygen
- Sequencing batch reactors

Plug Flow



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.



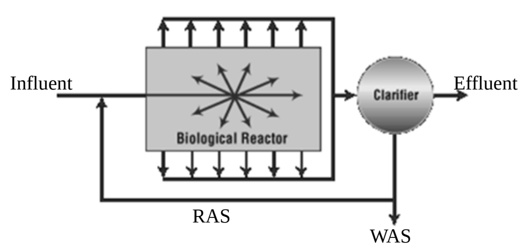
Plug Flow

- 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

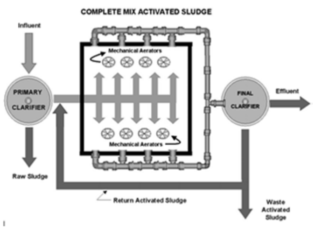
Application	Domestic and Industrial
BOD Removal Efficiency	85 – 95%
Aeration Type	Diffused or Mechanical
MCRT	5 – 15 days
Aeration Time	4 – 12 hours
MLSS	1500 – 3000 mg/L
RAS Flow	25 – 75% of influent
F:M	0.2 – 0.4 lbs BOD/d/lbs MLVSS
Organic Loading	20 – 40 lbs BOD/d/1000 ft^3

Complete Mix



Criteria for a Complete-Mix Reactor

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



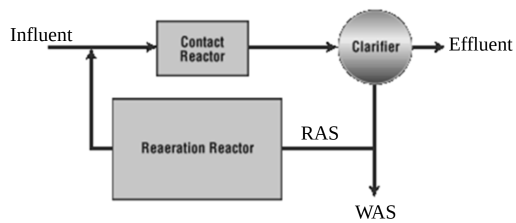
Complete-mix

- 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



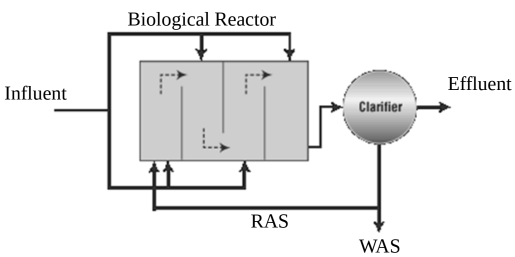
Contact Stabilization Design Parameters

Application	Modification of Existing Plant
BOD Removal Efficiency	80 – 90%
Aeration Type	Diffused or Mechanical
MCRT	5 – 15 days
Aeration Time	0.5 – 1.5 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

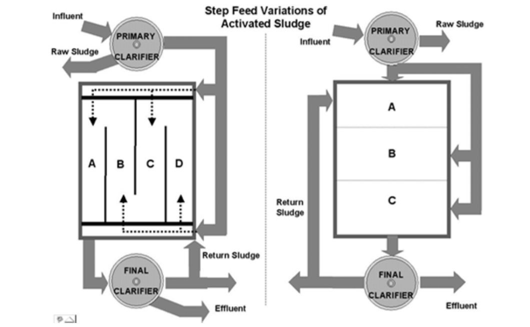
Contact Stabilization

- 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



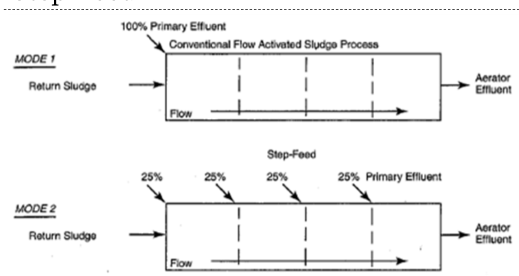
Step Feed Design Parameters

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

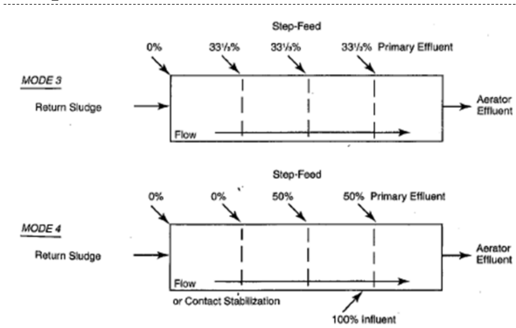
Step Feed

- 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
- Mode 1 works more like a conventional activated sludge process to handle ordinary domestic flows
  - Then you have the flexibility to switch to Mode 2, 3 or 4 depending on the quantity of industrial waste flows, seasonal WW or temperature variations
  - Mode 1 should provide the best treatment with the longest detention time for microorganisms to have contact with food and aeration
- Mode 4 works more like a contact stabilization plant during peak flows resulting from storms or when treating strong industrial wastes

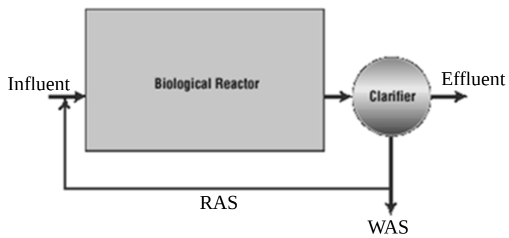
Step Feed



Step Feed



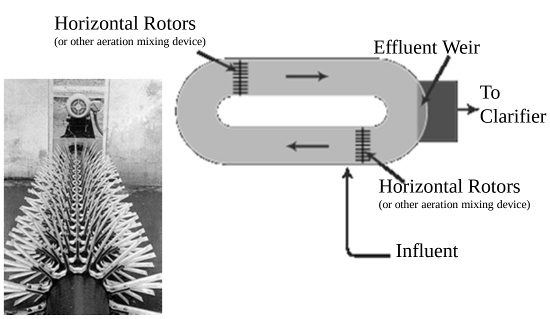
Extended Aeration



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

Oxidation Ditch

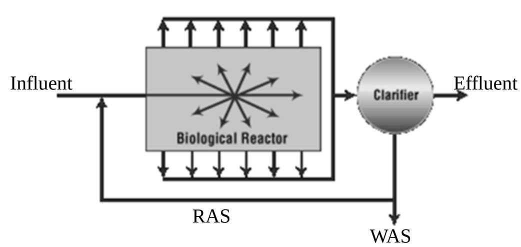


Oxidation Ditch

- Brush rotor – first oxidation ditch
  - To control DO, play with depth of water
  - Some brush rotors were covered to keep down air-borne diseases
- Simple to operate
- Velocity of 1 ft/sec
- Large tank volume and high oxygen demand are disadvantages
  - Requires more aeration energy than conventional or complete mix
- High MCRT and low F:M
  - Well stabilized sludge
  - Very low effluent BOD
  - Adaptable to nutrient removal

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	12 – 24 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

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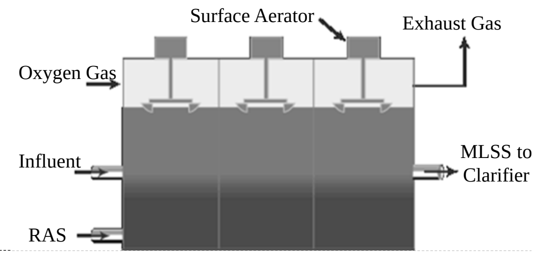
Pure Oxygen

- AKA – High Purity Oxygen
- The modification of the activated sludge process which allows the closest match between the amount of oxygen supplied and the oxygen uptake rate of the mixed liquor



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Pure Oxygen 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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Pure 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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Pure 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)

- Compact, simplified process
- Flexible; operational changes for nutrient removal
- Higher maintenance skills for instruments, automatic valves and monitoring devices

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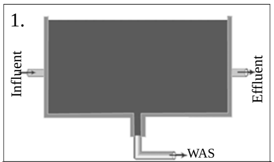
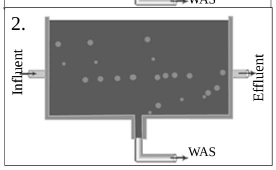
Sequencing Batch Reactor (SBR)



1. Fill – reactor is filled with wastewater.



2. React – the wastewater is aerated.

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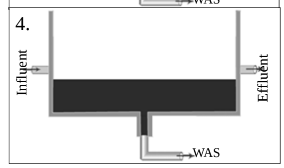
Sequencing Batch Reactor (SBR)

3. Settle – MLSS is separated.



4. Decant – treated wastewater is removed.

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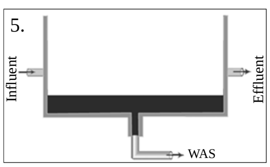
Sequencing Batch Reactor (SBR)



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.

** Some degree of treatment is taking place in any phase. **

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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

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Criteria for choosing the optimal activated sludge process variation:

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

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Aeration

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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

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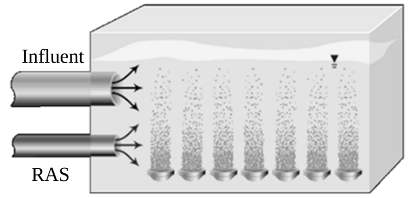
Biological Reactors

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



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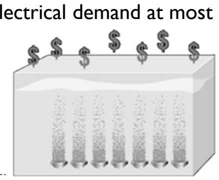
Aeration

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

1.0 to 4.0 mg/L

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



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Pure Oxygen System

- Pure oxygen systems use aeration equipment similar to a conventional plant

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Pure Oxygen System

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

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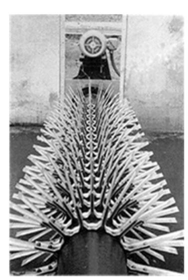
Surface Aerators

Horizontal Rotor Surface Aerator



Surface Aerator

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Surface Aerators

- Surface aerators generate a lot of splashing and mist

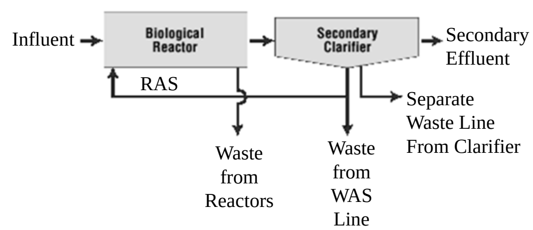
- Deflector plate keeps most spray from going up

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.

Waste Activated Sludge Systems

Waste Sludge Options



Waste Sludge Options

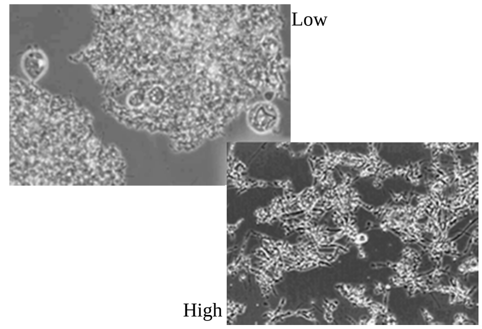
- Increasing the wasting rate will:
  - Decrease the MLSS concentration
  - Decrease the MCRT
  - Increase the F:M ratio
  - Increase the SVI
- If WAS rates are constant and BOD increases in the plant influent, the F:M ratio will increase as well.

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.
- Objective of wasting is to maintain a balance between the bugs under aeration and the amount of food coming in.

Process Control

Filamentous Populations



Low

High

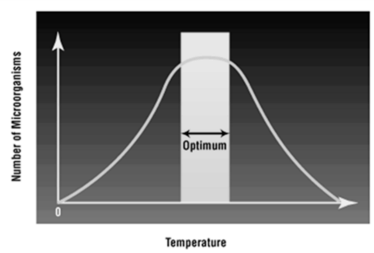
Organic Tests

- 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

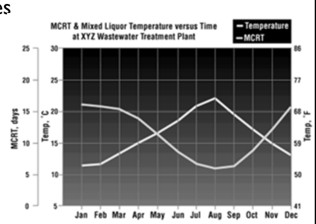
Temperature vs. Population

- Temperature affects the size of the microorganism population.



MCRT and Temperature

- During cold weather, treatment quality degrades because of the slower growth rates of microorganisms.
- This can be remedied by the increase MCRT to allow microorganisms more time in the system to grow and reproduce.
  - Increase MLSS will increase the MCRT



Sludge Volume Index

- The SVI is a measure of sludge settleability
- Acceptable SVI target levels are no greater than 150 mL/g and ideally less than 100 mL/g
- High SVI's are associated with:
  - Filamentous bacteria
  - Young sludge
  - Industrial wastewaters, with nutrient deficiencies

$$SVI = \frac{SSV_{30}, \text{ mL/L} \times 1000}{\text{MLSS, mg/L}}$$

pH

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

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

BOD ratios

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

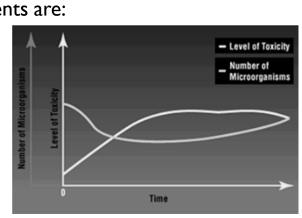
BOD:N:P = 100:5:1

Nutrient Deficiencies

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

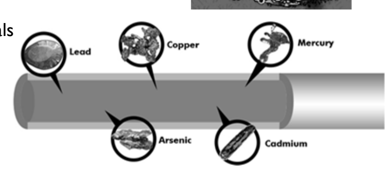
Toxins

- Influent wastewater may contain constituents that can be toxic to activated sludge microorganisms.
  - Biological treatment processes cannot easily adjust to great fluctuations of flows and waste
- These types of constituents are:
  - Metals
  - Inorganics
  - Organics



Industrial Wastes

- Industrial wastes could inhibit the activity of microorganisms in a treatment plant
- Examples of industrial wastes:
  - Heavy metals
  - Toxic wastes
  - Low pH
  - Organic Materials



Recognition of a Toxic Waste Load

- The first indication of a toxic waste load within the treatment plant is recognized by observing the aeration basin DO levels.
  - As the toxic load moves into and through the aeration basin, the DO will increase significantly.
  - A DO increase without an increase in air input indicates that a toxic waste load is killing the microorganisms in the aeration tank, thus reducing the oxygen uptake by the microorganisms
- The second indication of a toxic waste reaching the plant may be observed in the secondary clarifier effluent.
  - The effluent will be to have floc carryover (an indication of cell death)
  - The degree of carryover will depend on the substance and quantity of the toxic waste.

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Operational Strategy for Toxic Wastes

- The operator's primary mission in the case of toxic wastes is to save the activated sludge system.
- When the operator at the plant recognizes a toxic waste condition, the RAS flow rate is reduced significantly.
  - If this action is taken promptly, it isolates in the secondary clarifiers most of the bacteria affected by the toxic waste
- The operator then significantly increases the WAS flow to purge the activated sludge process of the toxic waste and the sick or dead microorganisms.

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Recognition of a High Organic Load

- The first indication of a high organic waste load within the treatment plant is recognized by observing the aeration basin DO levels.
  - As the high organic load moves into and through the aeration basin, the DO will decrease significantly.
  - A DO decrease without an air input decrease indicates that the high organic waste load is too great for the available microorganisms to properly assimilate and metabolize the waste (food to microorganism ratio is out of balance because of greater BOD (food)).
- A second indication of high organic waste reaching the plant may be observed in the secondary clarifier effluent.
  - The effluent will be more turbid (less clear) indicating that the waste flow has not been adequately treated.

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Operational Strategy for High Organic Loads

- The operator's primary mission in the case of high organic loads is to improve the microorganisms treatment efficiency.
- The RAS flow must be significantly increase to provide more microorganisms to the aeration contact basin to adequately treat the high organic waste.
- The rate of RAS increase must be accomplished gradually so that both design hydraulic and solids loading rates for the secondary clarifiers are not exceeded.
- In addition, every attempt should be made to increase the air or oxygen input to maintain proper DO levels in the aeration basins.

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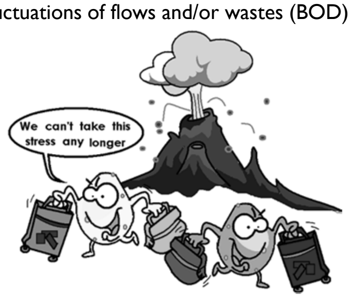
Biological Treatment

- Biological treatment processes can not easily adjust to great fluctuations of flows and/or wastes (BOD)



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Dissolved Oxygen Control

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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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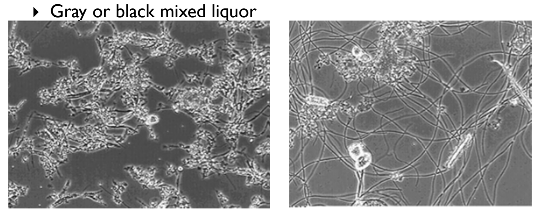
Low DO

- 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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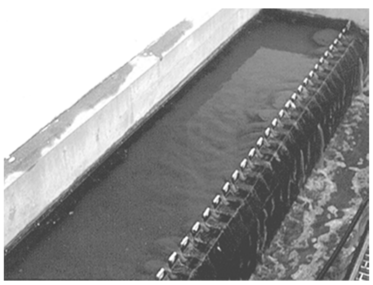
Turbid Effluent



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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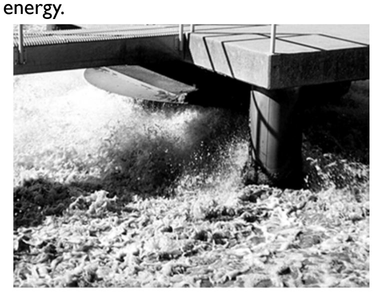
Over Aeration

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



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Solids Inventory and Control

Solids

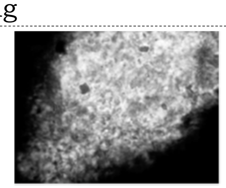
- It is important to account for and control the solids in the activated sludge process.
- As BOD is reduced, additional microorganisms are produced.
- Measuring flow and solids concentration allows calculation of mass balances.

Settleability

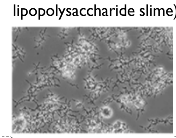
- The settleability test conducted on the MLSS is an estimate of how well solids will settle in the secondary clarifier
- Two types:
  - Controllable Settling
    - Hydraulic Overload
    - Inadequate Sludge Return
  - Uncontrollable Settling

Uncontrollable Settling

- Good Settling with Diluted Settleometer
  - Excess Old Sludge
  - Glutted System
- Poor Settling with Diluted Settleometer
  - Bulking Sludge
    - Slime
    - Filamentous

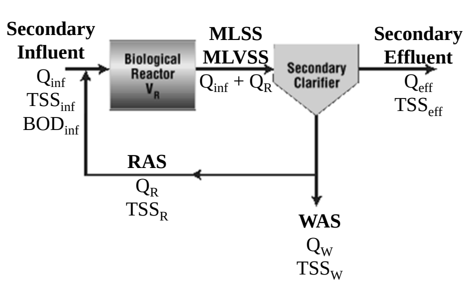


India ink stain shows slime bulking due to nutrient deficient waste (exocellular lipopolysaccharide slime)

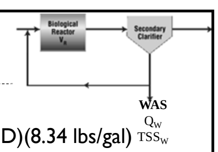


[...]dia Foam (200X)

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)

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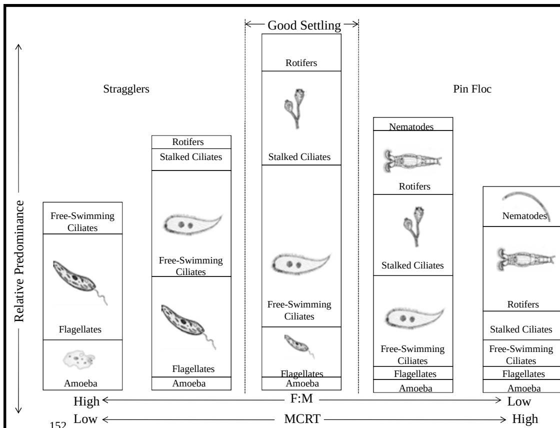

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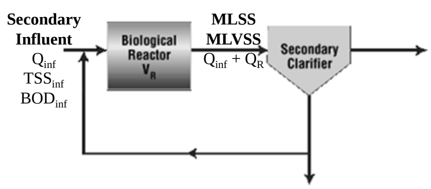
F:M Ratio

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



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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 $F{:}M_{COD} = \frac{Target\ F{:}M_{BOD}}{BOD{:}COD}$

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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 = $\frac{(145\ mg/L)(15\ MGD)(8.34\ lbs/gal)}{(2500\ mg/L)(2\ MG)(8.34\ lbs/gal)} = 0.44$

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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 (Microorganisms) = Current M – $\frac{F\ (Food)}{F{:}M\ Target}$

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F:M Ratio

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

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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
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 = BOD or COD, lbs / Desired F:M ratio

= (115 mg/L)(3.19 MGD)(8.34) / 0.15

= 20,396.86 lbs desired MLVSS

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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
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 = Desired MLVSS, lbs / % Vol. Solids, as decimal

= 20,396.86 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 = Suspended Solids in System, lbs / SS Leaving System, lbs/day

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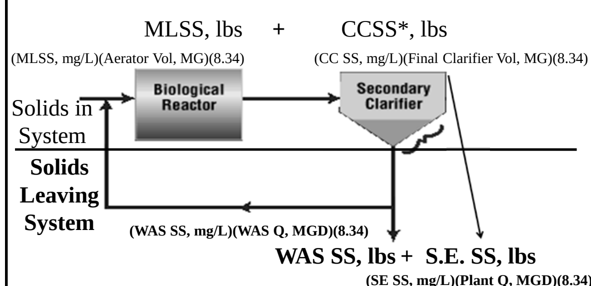
MCRT

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



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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 = (2460 mg/L)(1.5 MG)(8.34) + (1850 mg/L)(0.11 MG)(8.34) / (8040 mg/L)(0.06 MGD)(8.34) + (18 mg/L)(3.4 MGD)(8.34)

= 30774.6 lbs MLSS + 1697.19 lbs CCSS / 4023.216 lbs/d WAS + 510.408 lbs/d SE SS = 32471.79 lbs / 4533.624 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 = (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)

= (2460 mg/L) (1.61 MG) (8.34) / 4023.216 lbs/d WAS + 510.408 lbs/d SE SS = 33031.404 lbs / 4533.624 lbs/d

= 7.3 days

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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

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Conditions to Avoid in Activated Sludge

- Temperature > 35°C
- TDS > 50,000 mg/L
- Ammonia-N > 480 mg/L
- Sulfide > 25 mg/L
- Surfactants > 100 mg/L

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Effects of Temperature on Activated Sludge

>35°C	Deterioration of biological floc
>40°C	Protozoa disappear
>43°C	Dispersed floc dominated by filaments
>35°C	Sharp decrease in zone settle velocity of activated sludge

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Foaming

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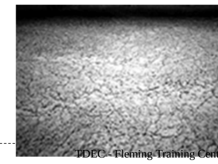
Foam and Scum

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

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Bad Day at the Plant

- 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

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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

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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

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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

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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

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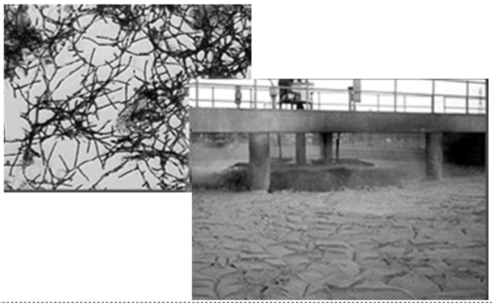
Nocardia Foam

- *Nocardia* foaming is a thick, greasy, dark tan foam

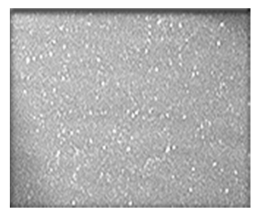


Nocardia Foam

- *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.

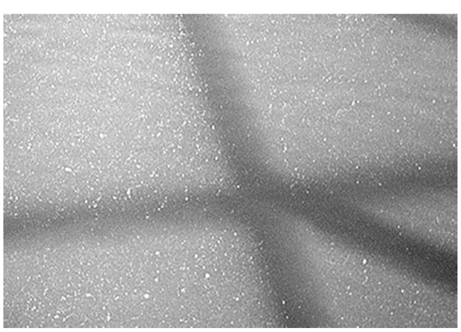
Dark Foam

- Dark or black foam is typically the result of insufficient aeration or industrial wastes.



Ashing

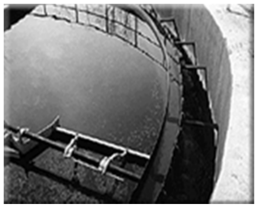
Clarifier Covered in "Ash"



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.



Pinpoint and Straggler Floc

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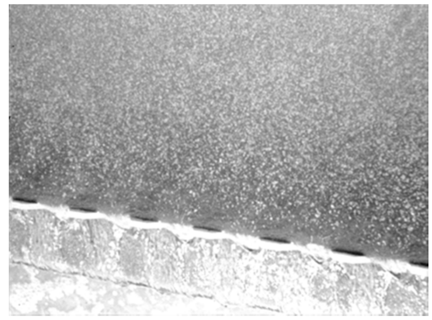
Clarifier with Dense Pin Floc



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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 MCRT.
- Pinpoint Floc Strategy
  - If tests indicate your sludge is old, decrease MCRT by increasing the WAS flow rate

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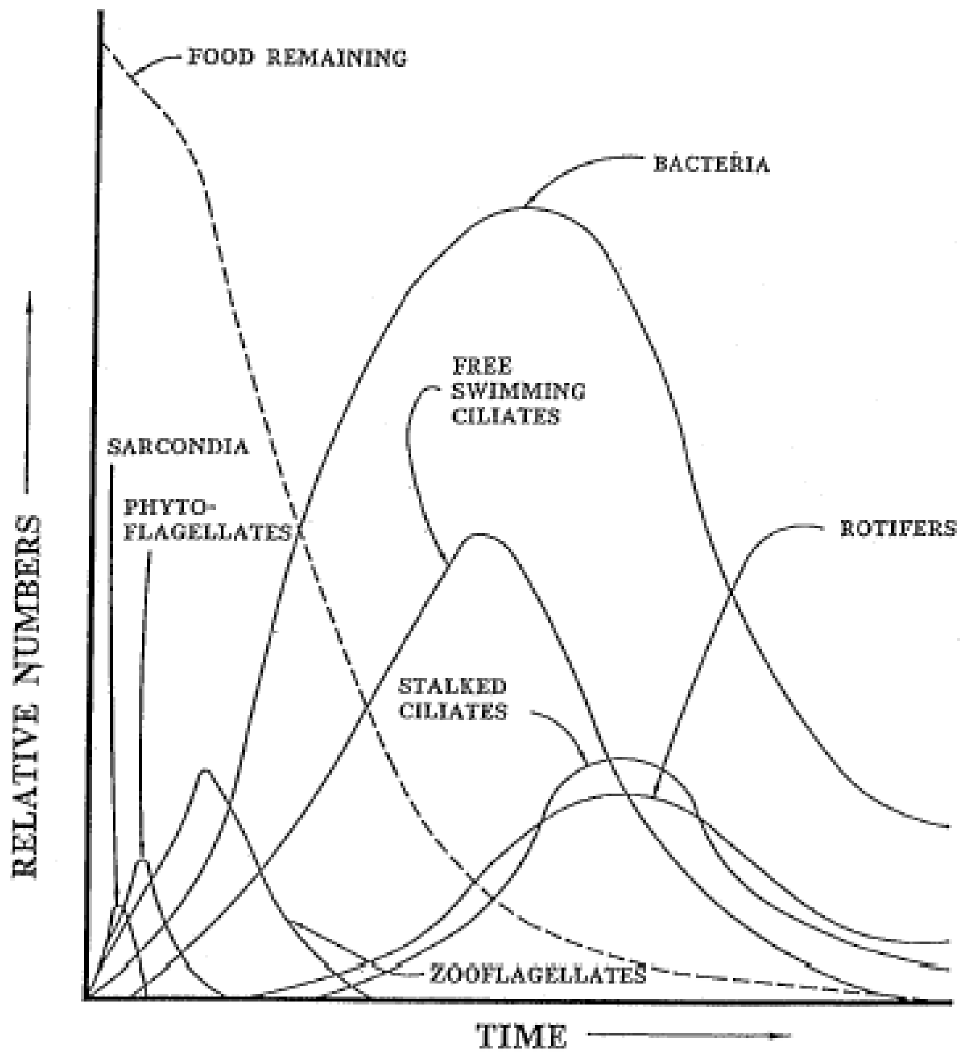
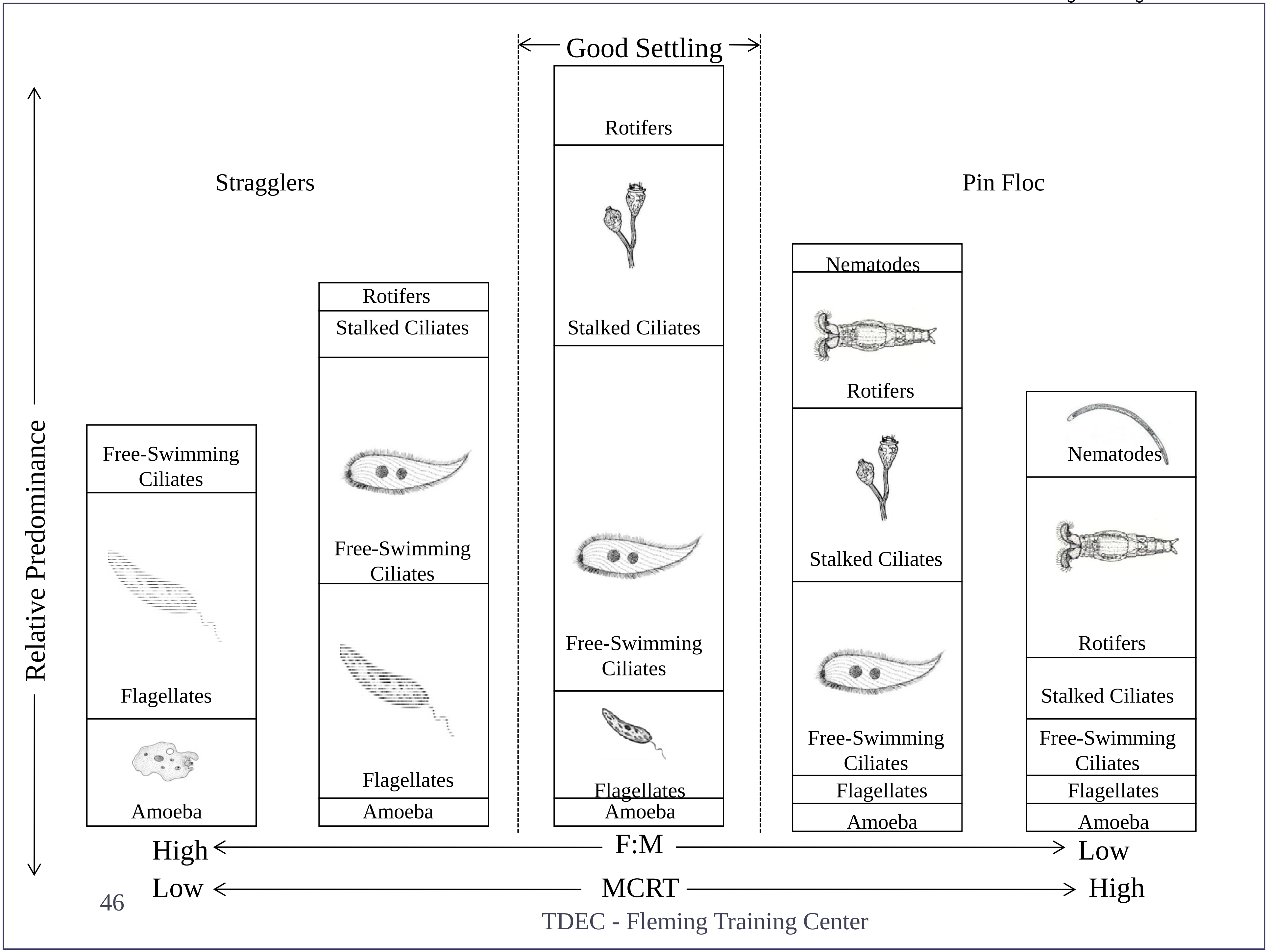
Design Parameters for Various Activated Sludge Processes

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
Pure Oxygen	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 F:M Low
Low MCRT High
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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. Ciliates
_______12. Composite Sample
_______13. Denitrification
_______14. Diffuser
_______15. Endogenous Respiration
_______16. Facultative
_______17. Filamentous Bacteria
_______18. Floc
_______19. F/M Ratio
_______20. Heterotrophic
_______21. Mean Cell Residence Time (MCRT)
_______22. Mechanical Aeration
_______23. Mixed Liquor
_______24. Mixed Liquor Suspended Solids (MLSS)
_______25. Mixed Liquor Volatile Suspended Solids (MLVSS)
_______26. Nitrification
_______27. Oxidation
_______28. Protozoa
_______29. Reduction
_______30. Rotifer
_______31. Septic
_______32. Sludge Age
_______33. Sludge Volume Index
_______34. Supernatant
_______35. 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. This test is a measure of the volume of sludge compared to its weight. The volume occupied by one gram of sludge after 30 minutes settling.
F. 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.
G. Describes the organisms that use organic matter for energy and growth. Animals, fungi and most bacteria are these.
H. 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)
I. 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.

J. 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.
K. Oxygen deficient or lacking sufficient oxygen, but nitrate is available.
L. 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.
M. Microscopic animals characterized by short hairs on their front ends.
N. 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.
O. Bacteria that do not need molecular (dissolved) oxygen (DO) to survive.
P. Suspended solids in the mixed liquor of an aeration tank.
Q. A situation where living organisms oxidize some of their own cellular mass instead of new organic matter they adsorb or absorb from their environment.
R. An expression of the average time that a microorganism will spend in the activated sludge process.
S. 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.
T. A measure of the length of time a particle of suspended solids has been retained in the activated sludge process.
U. A class of protozoans distinguished by short hairs on all or part of their bodies.
V. 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.
W. Food to microorganism ratio. A measure of food provided to bacteria in an aeration tank.
X. Liquid removed from settle sludge. This liquid is usually returned to the influent wet well or to the primary clarifier.
Y. The tank where raw or settled wastewater is mixed with return sludge and aerated.
Z. A group of motile microscopic organisms (usually single-celled and aerobic) that sometimes cluster into colonies and often consume bacteria as an energy source.
AA. The use of machinery to mix air and water so that oxygen can be absorbed into the water.
BB. A mass or clump or organic material consisting of living organisms feeding on the wastes in wastewater, dead organisms and other debris.
CC. Jelly-like masses of bacteria found in both the trickling filter and activated sludge processes.
DD. The gathering of a gas, liquid or dissolved substance on the surface or interface zone of another material.

EE. Bacteria that grown in a thread or filamentous form. A common cause of sludge bulking in the activated sludge process.

FF. 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”)

GG. A collection of individual samples obtained at regular intervals, usually every one or two hours during a 24-hour period. Each individual sample is combined with others in proportion to the rate of flow when the sample was collected.

HH. 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.

II. 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. 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

11. The MCRT for most conventional activated sludge processes is typically _______.
    a. 5 – 15 days
    b. 5 – 15 hours
    c. 20 – 30 days
    d. 20 – 30 hours

12. RAS 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

13. 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

Answers to Vocabulary

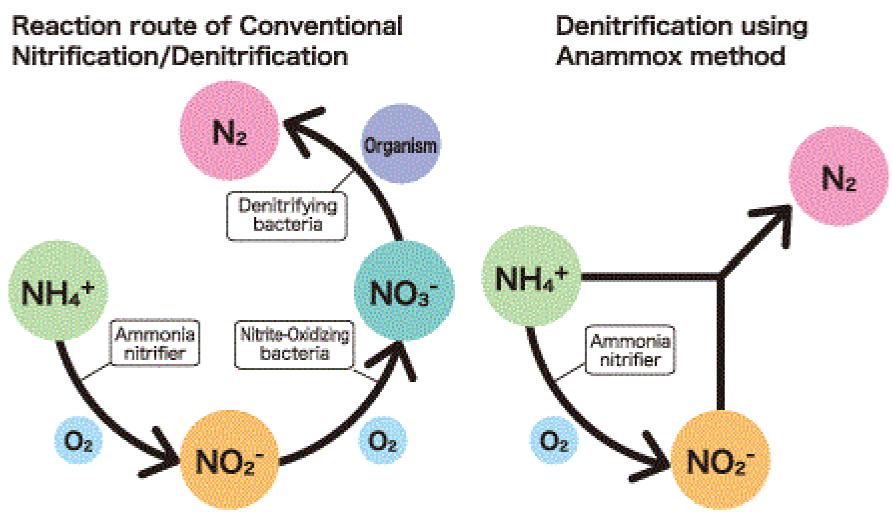
1.	H	10.	D	19.	W	28.	Z
2.	V	11.	U	20.	G	29.	II
3.	DD	12.	GG	21.	R	30.	M
4.	Y	13.	HH	22.	AA	31.	L
5.	C	14.	J	23.	B	32.	T
6.	O	15.	Q	24.	P	33.	E
7.	K	16.	N	25.	F	34.	X
8.	BB	17.	EE	26.	FF	35.	CC
9.	S	18.	A	27.	I		

Answers to Review Questions

1.	A	10.	D
2.	D	11.	A
3.	A	12.	C
4.	C	13.	B
5.	B		
6.	C		
7.	A		
8.	C		
9.	C		

Section 2

Nutrient Removal



Nutrient Removal

Phosphorus and Nitrogen

- Phosphorus and nitrogen provide a nutrient or food source for algae to grow
  - Combined with inorganic nitrogen greatly increases algae growth
- Algae in water is considered unsightly and can cause taste and odor problems in drinking water supplies
- Dead and decaying algae can cause serious oxygen depletion problems in receiving streams
  - This can in turn cause fish kills

Oxygen Control

- Oxygen control is the key to operating biological nutrient removal processes
- The microorganisms always require some type of oxygen to support their growth and reproduction
  - This oxygen can be free dissolved oxygen or oxygen bound in other substances like nitrate, nitrite or sulfate

Oxygen Availability

- Aerobic
  - Also called oxic
  - Free dissolved oxygen available
- Anoxic
  - No free dissolved oxygen available
  - Chemically bound oxygen is present, such as nitrite and nitrate
- Anaerobic
  - Does not contain free or bound oxygen compounds
  - Though, sulfate is considered to be in this group

Nutrients

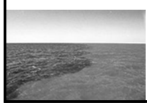
- Algal blooms can be caused by excess nutrient levels.
- Aquatic and marine dead zones can be caused by an increase in chemical nutrients in the water, known as eutrophication.
- Chemical fertilizer is considered the prime cause of dead zones around the world
- The growth of excess algae in receiving streams is not desirable. Algae can cause the following except
  - Fish kill
  - Unsightly appearance
  - Serious oxygen depletion
  - Taste and odor problems for drinking water supplies

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.



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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

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Phosphorus Removal

Generally speaking, phosphorous levels in wastewater have dropped due to phosphate detergent bans

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Systems for Phosphorus Removal

- Biological phosphorus removal
- Lime precipitation
- Filtration following aluminum sulfate

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Biological Phosphorus Removal

- Microorganisms found in conventional activated sludge processes use phosphorus within their cell makeup
  - Most bacteria contain 1-2% Phosphorus in their cell bodies
  - Phosphate accumulating organisms can contain up to 5-7%

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Biological Phosphorus Removal

- Phosphorus is stored as a polyphosphate.
- The organisms store the maximum amount of phosphorus in their cells when they are in the aerobic zone
- Then they are transferred to an anaerobic zone

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Biological Phosphorus Removal

- To survive under anaerobic conditions, the microorganisms must chemically convert some of the carbon materials in their cells to get the oxygen they need for metabolism
- The energy used in this process comes from the polyphosphates they stored in their cells
  - As a result, phosphorus is released from the cell

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Biological Phosphorus Removal

- After releasing phosphorus, the microorganisms are returned to the aeration tank where food, oxygen and phosphorus is plentiful
- Since the bugs just used up phosphorus to stay alive in the anaerobic environment, the first thing they want to do is take up and store a large amount of phosphorus

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Biological Phosphorus Removal

- They store much more than they need for their life processes
- This is called "luxury uptake" because they take in more than they need
- Then:
  - The sequence is repeated
  - Organisms are transferred to an anaerobic stripping tank
  - Settled out in clarifiers and wasted with biosolids

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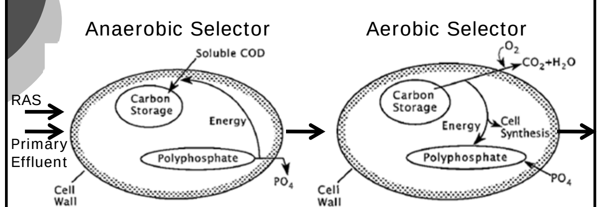
Biological Phosphorus Removal



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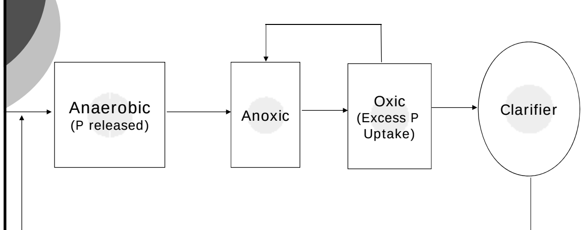
Luxury Uptake of Phosphorus



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Lime Precipitation

- Lime is also known as calcium hydroxide or $Ca(OH)_2$
- When lime is mixed with effluent waters in a high enough concentration to raise the pH to 11 or higher, a chemical compound is formed consisting of phosphorus, calcium and the hydroxyl ion (OH^-)
- This compound can be flocculated to form a heavier solid that can settle out in a clarifier for phosphorous removal

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Lime Precipitation Sampling

- Daily phosphorus tests should be run on composite samples of chemical clarifier effluent and also secondary clarifier effluent to compare results to determine:
  - Which pH setting works best?
  - Does the treatment plant meet effluent discharge requirement for P?
  - Are you achieving your desired removal efficiency?

Lime Feed System

- The lime feed system must operate very reliably
- Make frequent checks (several times each shift) on the automatic dry lime feed system, the mixing of dry lime and water, the slurry transfer to the rapid-mix basin and the grit removal system that removes sand from the lime slurry

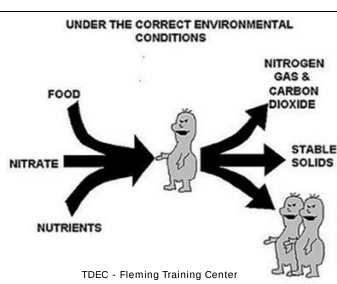
Aluminum Sulfate Flocculation

- Aluminum sulfate can flocculate effluent waters the same as lime
- The compound that is created is aluminum phosphate particles that attach to each other and settle out
  - The alum floc is difficult to settle out and needs to be run through a pressure filter or sand or mixed-media filter to remove any remaining floc that does not settle in the clarifier

Aluminum Sulfate Flocculation

- When using aluminum sulfate as a filtration aid, dosages must be precise
- Operators must rely on jar test to accurately dose their plant

Nitrogen Removal



Nitrogen

- Nitrogenous compounds not only need to be controlled to prevent algae growth, but also:
  - To prevent adverse impact from ammonia toxicity to fish life
  - Reduction of chlorine disinfection efficiency
  - Increase in DO depletion in receiving waters
  - Adverse public health effects
    - Mainly in groundwater being used for drinking water where high levels of nitrate can hurt newborn babies
  - Reduction in the water's suitability for reuse

Systems for Nitrogen Removal

- Nitrogen removal can be accomplished by a variety of:
  - Physical
  - Chemical and
  - Biological process
- Most common:
  - Nitrification/denitrification
  - Ammonia stripping
  - Breakpoint chlorination

Systems for Nitrogen Removal

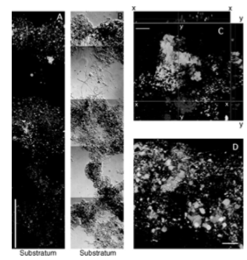
System	Operation Consideration
Physical Treatment Methods	Expensive
• Sedimentation	
• Gas Stripping	
Chemical Treatment Methods	Expensive
• Breakpoint Chlorination	
• Ion Exchange	
Biological Treatment Methods	
• Activated Sludge Process	• Operational control. • Additional cost for oxygen to produce nitrification.
• Trickling Filter Process	
• Rotating Biological Contactor Process	
• Oxidation Pond Process	
• Land Treatment Process (Overland Flow)	• Land Requirements. • Suitable Temperatures. • Control of plants.
• Wetland Treatment Systems	

Nitrification

- The conversion of ammonia to nitrate requires a large amount of oxygen
- Nitrification is a biological process accomplished by two main types of microorganisms
  - *Nitrosomonas*
  - *Nitrobacter*

Genera of Nitrifying Bacteria

- Ammonia Oxidizers
  - *Nitrosomonas*
  - *Nitrosococcus*
  - *Nitrosospira*
  - *Nitrosorbio*
- Nitrite Oxidizers
  - *Nitrobacter*
  - *Nitrospira*
  - *Nitrococcus*
  - *Nitrospina*



C - Ammonia oxidizers appear red and Nitrospira appear green

Nitrification

- These microorganisms are autotrophic, which means they get their food source from inorganic sources, such as carbon dioxide (CO_2) and bicarbonate (HCO_3^-) alkalinity

Nitrification

- Step 1 – Ammonia (NH_3) or ammonium (NH_4^+) gets converted to nitrite (NO_2^-) by the N*itrosomonas* bacteria.

$$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 2H_2O + 4H$$

Ammonia Oxygen Nitrite Water Strong Acid

Nitrification

- Step 2 – The second step is conversion of nitrite to nitrate (NO_3^-) by the *Nitrobacter* bacteria.

$$2NO_2^- + O_2 \rightarrow 2NO_3^-$$

Nitrite Oxygen Nitrate

Nitrification

- The proper conditions must exist for *Nitrosomonas* to be able to separate the nitrogen from the hydrogen in the ammonium molecule and replace the hydrogen with oxygen molecules.
- There needs to be plenty of oxygen, correct temperature and food for this process to occur
- *Nitrobacter* also rely on oxygen to complete the stabilization of the nitrite molecule into the more stable nitrate substance

Effect of pH on the Rate of Nitrification

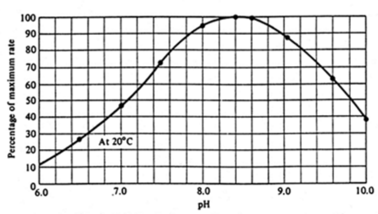


FIGURE 13-18 Rate of nitrification versus pH at constant temperature. [Source: H. E. Wild, Jr., C. N. Sawyer, and T. C. McMahon, "Factors Affecting Nitrification Kinetics," *J. Water Poll. Control Fed.* 43, no. 9 (1971) : 1852.]

Optimum pH about 7.5 to 9.

Effect of Temperature on the Rate of Nitrification

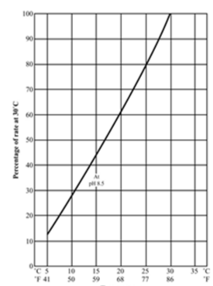
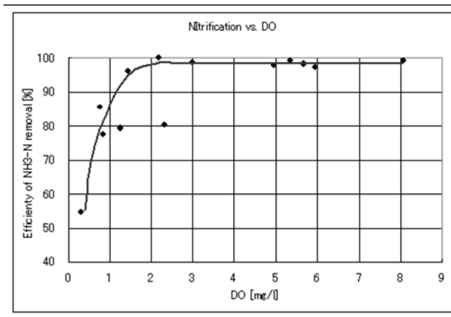


FIGURE 13-17 Rate of nitrification at all temperatures compared to the rate at 30°C. [Source: H. E. Wild, Jr., C. N. Sawyer, and T. C. McMahon, "Factors affecting Nitrification Kinetics," *J. Water Poll. Control Fed.* 43, no. 9 (1971): 1852.]

- Growth rate increases exponentially with temperature
  - Maximum at 30-35°C
  - Declines at 40°C
- Process variables that an operator does can adjust to compensate for slower winter growth rates in the nitrification process
  - Adjust pH to higher levels
  - Increase the MCRT
  - Increase the MLVSS

Effect of Dissolved Oxygen on the Rate of Nitrification



Nitrification

- 4.6 mg oxygen required per mg nitrogen oxidized
- 7.1 mg $CaCO_3$ alkalinity depleted per mg nitrogen oxidized
  - Can cause a pH drop if sufficient alkalinity is not present
- 60-95°F is optimum temperature for good nitrification
  - At lower temperatures, up to five times as much detention time may be needed to accomplish complete nitrification
  - Increase MLSS, MCRT and pH can help during winter months
- Alkalinity is the best water quality indicator to monitor an enhanced nitrogen oxidation process

Nitrification

- Troubleshooting Example:
  - You ran tests on your effluent and you have the following results:
    - Ammonia – 3 mg/L
    - Nitrate – 4 mg/L
    - Nitrite – 21 mg/L
  - What do you think is happening here?

$$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 2H_2O + 4H$$

Ammonia, Oxygen, Nitrite, Water, Strong Acid

$$2NO_2^- + O_2 \rightarrow 2NO_3^-$$

Nitrite, Oxygen, Nitrate

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Denitrification

- Biological denitrification is the process where microorganisms reduce nitrate (NO_3^-) to nitrogen gas that is released to the atmosphere
- These bacteria are heterotrophic

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Denitrification

- When these microorganisms are placed into an environment where dissolved oxygen is not present but there is food (BOD), they will reduce nitrate to nitrogen gas by breaking the bond between nitrogen and oxygen
- This is how they get their oxygen
- This reduction or breaking down is also called microorganism dissimilation

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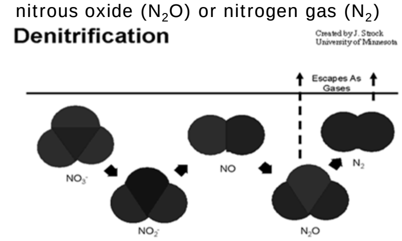
Denitrification

- Step 1 – Nitrate is reduced to nitrite
- Step 2 – Nitrite is reduced to nitric oxide (NO), nitrous oxide (N_2O) or nitrogen gas (N_2)



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Denitrification

- This nitrogen gas is the released to the atmosphere once it gets to an aerated tank
- This can also occur in primary or secondary clarifiers

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Denitrification

- Optimum pH for denitrification is 7.5 to 9.0
- Over the range of 5-30°C, rate of denitrification increases exponentially with temperature increases.
- Denitrification can occur in thermophilic range (50-60°C).
- Food concentration strongly influences denitrification rate.

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Denitrification

- 2.9 mg oxygen released per mg oxidized nitrogen removed
- 3.6 mg $CaCO_3$ alkalinity recovered

Nitrification vs Denitrification

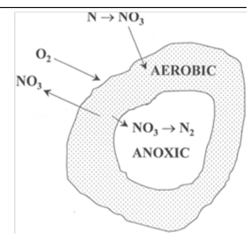
- Nitrification
  - $NH_4 + O_2 \rightarrow NO_2$ + acid
  - $NO_2 + O_2 \rightarrow NO_3$
  - Uses 4.6 mg of O_2 and 7.1 mg of Alk
- Denitrification
  - NO_3 + cBOD $\rightarrow N_2\uparrow$
  - Get back 2.9 mg of O_2 and 3.6 mg Alk

Denitrification Methods

- Pre-anoxic zone with nitrate recycle from aeration tank
- On-Off aeration
- Low D.O. operation
  - D.O. of 0.1 - 0.4 mg/L
  - D.O. of 0.4 mg/L appears below that required by obligate aerobic low D.O. filaments
  - Typical D.O. for low D.O. filaments is 0.5 – 1.0 mg/L

Factors Effecting Simultaneous Nitrification/Denitrification (SNdN)

- Organic carbon source with TCOD:TKN 7:1; 9:1 if P removal also.
- Dissolved oxygen concentration: optimal N removal when rate of nitrification equals rate of denitrification at 0.5 mg/L
- Floc size produces separate zones within the floc



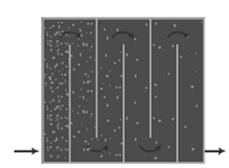
- D.O. penetrates floc, theoretically to the center at 2.0 mg/L
- Less D.O. provides anaerobic center; anoxic if NO_3^- is available

Process Modes for Biological Nitrification/Denitrification

- Conventional or plug flow aeration system
- Complete mix activated sludge process
- Contact stabilization
- Extended aeration
- Step-feed aeration
- SBR
- Attached Growth
- Overland Flow

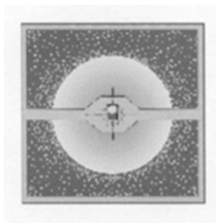
Conventional or Plug Flow

- This process is good because of the flow configuration and detention time
- pH levels may drop during this detention time because nitrification destroys alkalinity



Complete Mix

- Provides a uniform dissolved oxygen within the reactor
- May be more sensitive to pH drops



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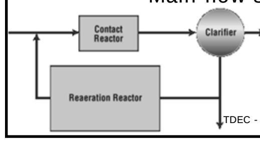
Contact Stabilization

- This process is not ideal for nitrification because:
  - An insufficient number of nitrifying bacteria may be left in biomass from separate RAS used in contact stabilization
  - Main flow stream reactor is too small



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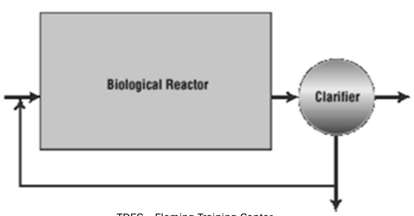
Extended Aeration

- Well suited for nitrification due to long aeration time and the long sludge age maintained



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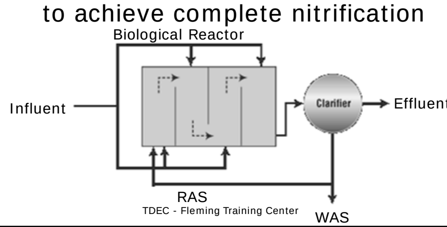
Step Feed Aeration

- This can be used to accomplish partial nitrification
- Detention time is usually too short to achieve complete nitrification



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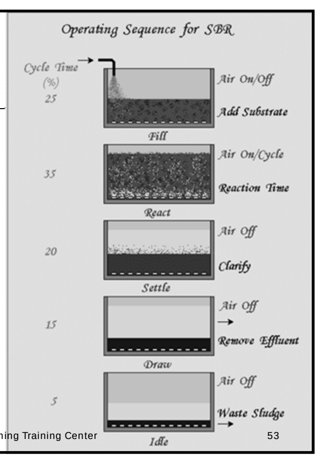
SBR Stages Operation



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SBR Operating Guidelines

Flow	1.2 to 2 times ADF
Reactors	2 or more
Reactor Depth	10 to 20 ft (TWL)
Cycles/Day	2 to 6
F/M Ratio	0.02 to 0.05
MLSS Concentration	2000 to 6000 mg/L
SRT	25-45 days
D.O. During React	1.0 to 3.0 mg/L

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SBR Advantages

- Simplified process (final clarification and RAS pumping not necessary)
- Treatment occurring at all stages
- Operating flexibility and control (PLCs)
- Compact-minimal footprint
- Variety of WWTP sizes
- Can retrofit existing WWTPs

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SBR Advantages

- Very stable due to high sludge age with long solids retention times
- Quiescent settling enhances solids separation (low effluent SS)
- Operate as selector to minimize sludge bulking potential
- Reduced capital costs

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SBR Limitations

- Process control more complicated
- Higher maintenance skills required for instruments, monitoring devices, valves, switches, etc.
- Batch discharge may require equalization before disinfection

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SBRs for Nitrogen Removal

- Mixing during fill cycles is added
- Preanoxic denitrification using BOD in influent wastewater
- Mixing during fill also improves sludge settleability
- Nearly all nitrate removed during settle and decant steps (< 5 mg/L)

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SBRs for Phosphorus Removal

- Nitrate concentration minimized before settling
- If enough nitrate is removed, an anaerobic period can develop during and after fill cycle
- Readily degradable organics also available for uptake and storage by PAOs from influent wastewater

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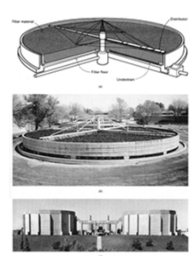
Nitrification using Attached Growth Reactors: Trickling Filters



- Most trickling filters not designed for nitrification
- BOD must be low (often 2-stage system)
- Aerobic conditions essential
- Natural ventilation often supplemented with forced air ventilation
- Cover can decrease temperature effects and increase cold weather performance.
- BOD:N:P 100:5:1 key.

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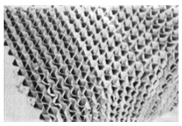
Packed Tower for Nitrification



- Tall trickling filter with synthetic media
- Recirculation allows for constant & even distribution of WW
- Constant flow & appropriate oxygen levels must be monitored closely

Diagram excerpted from Chapter 6: Nitrogen Remvoal. In *Advance Waste Treatment*.

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Denitrification with Attached Growth Systems

- Food source is needed for denitrification units
  - High carbon food
    - Acetic acid
    - Citric acid
    - Methanol
    - Methane gas
    - Ethanol
  - Primary effluent

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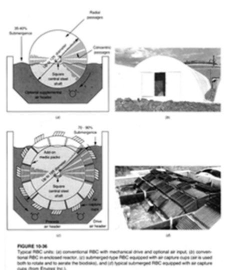
Rotating Biological Contactors



- Rotating shaft surrounded by HDPE media (D=12 ft)
- Zoogleal mass grows on media surface
- Usually, nitrification in last unit(s) of train

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Rotating Biological Contactors

- Covers keep media insulated, protect biofilm from rain, control odors
- Monitor oxygen, alkalinity & nitrogen throughout reactors
- Nitrification takes place in the last stage or final contactor in a series of contactors
- Minimum 1-2 mg/L D.O. in solution at all times

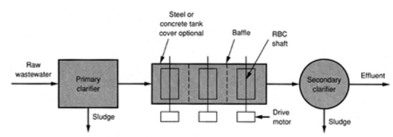

FIGURE 10-37
Typical RBC schematic for secondary treatment.

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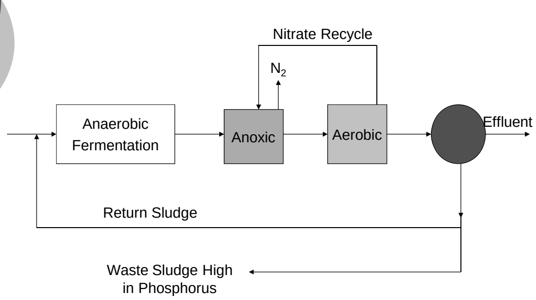
Typical Biological Nutrient Removal System



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Overland Flow

- The water flows or trickles as sheet flow through water-tolerant grass at the soil surface effectively reduce BOD and cause both nitrification and denitrification to occur.

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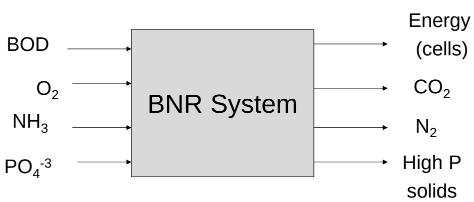
Microbiological Summary



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Physical Nitrogen Removal - Ammonia Stripping

- Ammonia nitrogen in the gaseous ammonia (NH_3) form has a natural tendency to leave the wastewater and go into the atmosphere
- The bulk of “ammonia” in wastewater comes in the form of ammonium (NH_4+), which needs to be converted to ammonia by raising the pH

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Physical Nitrogen Removal - Ammonia Stripping

- At normal temps and a pH of 7, ammonium ion (NH_4^+) dominates
- By feeding lime to increase pH to 10.8-11.5, ammonium (NH_4^+) converts to dissolved ammonia gas (NH_3).
  - At 25º and pH 11, the percentage of ammonia is about 98%
- Wastewater pumped to top of packed bed media (wood or plastic).
- Water droplets fall on media, releasing ammonia gas as large amounts of air move through tower.
  - Calcium carbonate scale can plug media void spaces & build up inside channels, pipes and pumps. Clean with hot water or muriatic acid.

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Physical Nitrogen Removal - Ammonia Stripping

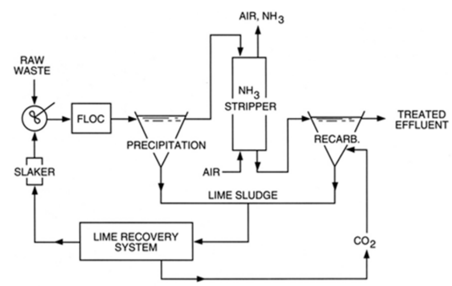

Diagram excerpted from Chapter 6: Nitrogen Removal. In *Advance Waste Treatment*.

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Chemical Nitrogen Removal - Breakpoint Chlorination

- Ammonia nitrogen can be oxidized to nitrogen gas (N_2) through the use of chlorine
- Enough chlorine is added until the ammonia nitrogen has been oxidized to nitrogen gas
- Unfortunately, this takes a large amount of chlorine to remove ammonia
  - For every 1 mg/L of ammonia nitrogen, 10 mg/L of chlorine is needed
- Therefore, this is normally used to remove small amounts of ammonia still left in the wastewater

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Chemical Nitrogen Removal - Breakpoint Chlorination

- Zone 1- formation of chloro-organic & chloramine compounds
- Zone 2-destruction of chloro-organic & chloramine compounds
- Zone 3-formation of free chlorine residual

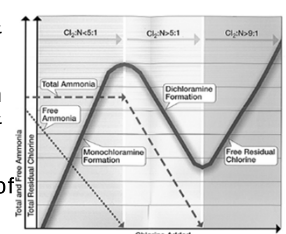

Diagram excerpted from Chapter 6: Nitrogen Removal. In *Advance Waste Treatment*.

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Chemical Nitrogen Removal – Ion Exchange

- The ion exchange process is used to remove undesirable ions from water and wastewater.
- The nitrogen removal process involves passing ammonia-laden wastewater downward through a series of columns packed with natural or synthetic ion exchange resins

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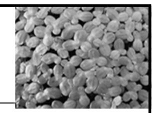
Lemna Duckweed System



- Use of aquatic duckweed plants for wastewater treatment
- Used effectively as a polishing pond after a conventional wastewater treatment pond
- The duckweed cover the polishing pond's surface, preventing sunlight to get to the algae and the algae die off
- Duckweed are capable of removing phosphorus and nitrogen from the water

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Enhanced Biological (Nutrient) Control

- The key to successful process control of enhanced biological systems is for liquid-solids separation
- Operators are not only able to control nutrient removal, but also
  - Sludge settleability
  - Filamentous organisms growth
  - Effluent BOD
  - Effluent suspended solids

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Oxidation Reduction Potential

- Allows evaluation of biological conditions with or without DO available
- Simple and cheap
  - Portable pH meter
  - ORP probe
  - Immerse probe in tank and read
- Responds to chemical ion concentrations

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ORP Control *(Goronzy, 1992)*

Process	Range, mV	e^- Acceptor
cBOD oxidation	+50 to +200	O_2
Poly-P production	+40 to +250	O_2
Nitrification	+150 to +350	O_2
Denitrification	-50 to +50	NO_3^-
Poly-P breakdown	-40 to -175	NO_3^-, $SO_4^=$
Sulfide formation	-50 to -250	$SO_4^=$
Acid formation	-40 to –200	Organics
Methane formation	-200 to -350	Organics

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Operations

- Many operators have a tendency to overreact to situations
  - When making a process change, remember that all processes reflect changing influences of process recycle flows as well as immediate changes associated with influent conditions or chemical reactions
  - After making a change, you should wait at least 2-3 times the overall MCRT before deciding if the change was beneficial

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Biological Nutrient Removal
Review Questions

1. Phosphorous is removed from wastewater treatment plant effluent so that it will not combine with nitrogen and kill algae in receiving waters.
   a. True
   b. False

2. The main reason lime is preferred over alum for the precipitation of phosphorous is the lower cost of lime.
   a. True
   b. False

3. Chemicals used to remove phosphorous from wastewater include all but:
   a. Aluminum sulfate
   b. Calcium hydroxide
   c. Chlorine
   d. Lime
   e. None of the above

4. Lime feeding equipment should be routinely checked:
   a. Every hour
   b. Several times during each shift
   c. Once each shift
   d. Three times a week
   e. Once a week

5. In the lime precipitation process for phosphorous removal, the pH of the combined wastewater and lime slurry should be _______ or above.
   a. 5
   b. 7
   c. 8
   d. 9
   e. 11

6. Important variables the operator must control in the luxury uptake process include all but:
   a. Detention time in the anaerobic tank
   b. Dissolved oxygen level in the stripping tank
   c. Predominance of anaerobic microorganisms in the activated sludge
   d. Primary effluent supply to the aeration tank
   e. Stripping tank sludge recycle rate

7. The key to operating selectors and biological nutrient removal systems is:
    a. Mixing
    b. Nitrogen
    c. Oxygen
    d. Phosphorous

8. Generally speaking, phosphorous levels in wastewater have dropped due to:
    a. Better phosphorous removal processes
    b. Changes in drinking water consumption
    c. Increased phosphorous uptake by plants and aquatic life
    d. Phosphate detergent bans

9. After making a change in the operation of a biological treatment process, how long does it take to properly evaluate whether the change was beneficial?
    a. One MCRT interval
    b. Two to four days
    c. Two to three times the MCRT
    d. Until jar tests have been completed

10. Nitrification is the process by which bacteria reduce nitrate to gaseous nitrogen forms, primarily nitrous oxide and nitrogen gas.
    a. True
    b. False

11. The recommended dissolved oxygen level for nitrification in a suspended growth reactor is 2.0 to 4.0 mg/L.
    a. True
    b. False

12. An anoxic reactor is one which is lacking in dissolved molecular oxygen but may contain chemically bound oxygen.
    a. True
    b. False

13. If cold temperatures are limiting the efficiency of a nitrification process, the operator should increase the organic loading on the unit or decrease the number of microorganisms.
    a. True
    b. False

14. For nitrogen to be biologically removed from an effluent, the process must consist of both nitrification and denitrification.
    a. True
    b. False

15. pH levels may increase during nitrification because nitrification destroys alkalinity.
    a. True
    b. False

16. Nitrification is inhibited at low wastewater temperatures.
    a. True
    b. False

17. Some of the harmful effects of discharging treatment plant effluent containing nitrogen include all but:
    a. Ammonia toxicity to fish in receiving waters
    b. Increased dissolved oxygen depletion in receiving waters
    c. Potential health hazards to newborn infants
    d. Reduction in nutrients available to algae
    e. Reduction of chlorine disinfection efficiency

18. Which of the following activated sludge process modes is best suited for nitrification in a suspended growth reactor?
    a. Complete mix
    b. Contact stabilization
    c. Convention or plug flow
    d. Modified aeration
    e. Step-feed aeration

19. Which of the following can't be used as a food source in an attached growth (fixed film) reactor?
    a. High carbon food
    b. Methane gas
    c. Methanol
    d. Primary effluent
    e. Secondary effluent

20. An anaerobic or anoxic process will show an alkalinity loss whereas a nitrifying process will show an alkalinity gain.
    a. True
    b. False

21. Bulking activated sludge can be caused by all but:
    a. Elevated levels of sulfide
    b. High pH
    c. Low BOD loading rates
    d. Nutrient deficiencies
    e. Septic wastewaters

22. The required basic features of anoxic zones is:
    a. Ability to completely drain basin for inspection and maintenance
    b. Provisions for the buildup of an adequate sludge blanket
    c. Sufficient mixing of contents to maintain the microbial solids in suspension without transferring oxygen to the biomass
    d. Recycling facilities to automatically control the MCRT
    e. All of the above

23. Disadvantage(s) of mechanical aeration include:
    a. Creation of excessive turbulence
    b. High heat loss in cold weather
    c. High maintenance requirements
    d. Noisy operation
    e. A and C

24. Acceptable SVI target levels are ideally less than _____ mL/g.
    a. 200
    b. 150
    c. 120
    d. 100

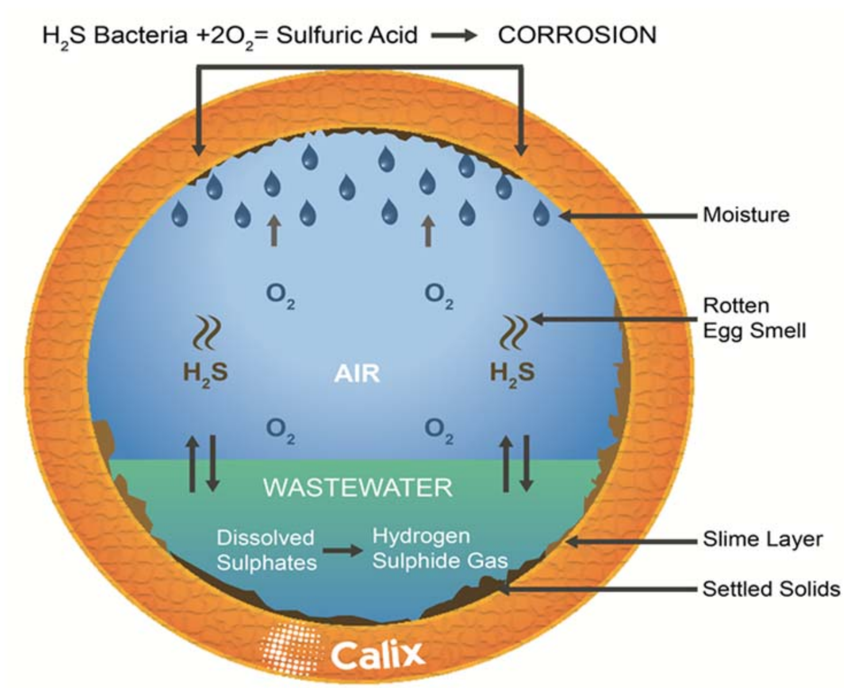
25. The Sludge Volume Index (SVI) is a measure of:
    a. Clarifier removal efficiency
    b. Sludge settleability
    c. Sludge volume in relation to clarifier volume
    d. Sludge wasted in relation to sludge recycled

Answers:

1.	B	8.	D	15.	B	22.	C
2.	A	9.	C	16.	A	23.	B
3.	C	10.	B	17.	D	24.	D
4.	B	11.	A	18.	C	25.	B
5.	E	12.	A	19.	E		
6.	C	13.	B	20.	B		
7.	C	14.	A	21.	B		

Section 3

Odor and Corrosion Control



Odor and Corrosion Control

TENNESSEE DEPARTMENT OF ENVIRONMENT AND CONSERVATION

What is Odor?

- "It smells like money to me!"
  - "Fresh" wastewater does not have an offensive odor
- Chemical/physical interaction with olfactory hairs
- Complex – depends on humidity, temperature, pH
- Subjective – no two people perceive odors alike
- Anaerobic decomposition of organic compounds containing sulfur or nitrogen
- Two major culprits – H_2S and NH_3

Need for Odor Control

- With increased population, collection systems are being stretched farther and farther away from the WWTP
  - Longer collection systems create longer flow times to reach the WWTP
  - Increased travel times can cause the wastewater to become septic and therefore cause odor and corrosion problems
- Also with increase population, the buffer zone initially around a WWTP is being encroached upon with neighborhoods being built around WWTP
- Good housekeeping is an effective means for controlling odors

Characteristic Odors

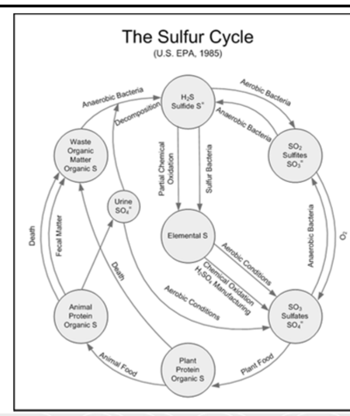
	Formula	Typical Threshold Odor, mg/L	Comments
Ammonia	NH_3	0.037	Sharp, pungent
Cadaverine	$H_2N(CH_2)_5NH_2$	0.24	Putrid, decaying flesh
Dibutylamine	$(C_4H_9)_2NH$	---	Fishy
Hydrogen Sulfide	H_2S	0.00047	Rotten eggs
Indole	C_2H_6NH	---	Fecal
Thiocresol	$CH_3C_6H_4SH$	0.0001	Skunk, rancid

Summary of odors we can detect from various substances and the threshold odor concentration (the level at which our nose first detects an odor)

Odor Measurement

- Difficult to define nature, cause, extent with just the human nose
  - FYI – Taste and odor are closely related
- Threshold Concentration Level
  - Odor is diluted until no longer detectable
  - Odor panel (group of people)
  - Olfactometer (instrument)

Sulfur Cycle



The Main Characters

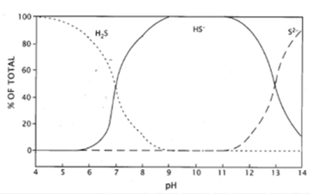
- H_2S and NH_3 are easily identified and give off most offensive odors
- Difficult to measure in liquid phase
  - Volatile, tend to off-gas when disturbed
  - More easily measured in atmosphere
- Many types of test/monitoring devices
  - Color change strip or disc
  - Electronic device (with or w/o high alarm)
  - Data log for record of long term exposure

H_2S – Hydrogen Sulfide

- Colorless, combustible, toxic gas; heavier than air (S.G. = 1.19)
- Characteristic rotten egg odor
  - But at high concentrations it is not noticeable
- Can cause almost instantaneous unconsciousness, permanent brain damage (at concentrations commonly found in unvented lift stations), or even death
- Anaerobic bacteria reduce SO_4^{-2} to HS^-
  - HS^- goes into equilibrium with air layer
  - In water, HS^- no problem
  - In air, HS^- becomes H_2S

H_2S – Hydrogen Sulfide

- Hydrogen sulfide causes most problems at a pH < 5
  - At a pH below 5, all sulfide is present in the gaseous H_2S for and most of it can be released from wastewater and may cause odors, corrosion, explosive conditions and respiratory problems.



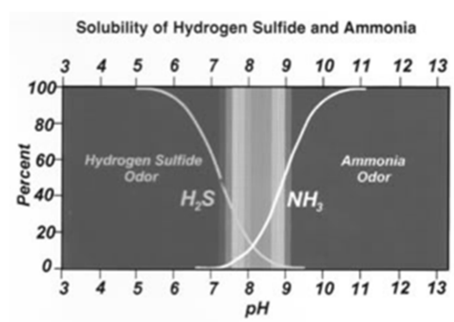
Sulfate to Sulfide Conversion

- DO
- ORP
- BOD
- Detention time
- Temperature
- Sulfur Concentration

Sulfate to Sulfide Conversion

- DO, ORP, BOD, and Detention Time are all related
  - As DO increases, ORP increases (and vice versa)
  - BOD affects the amount of DO in waste stream
  - Detention time supports the oxidation of BOD
- As temperature increases, reduction rate of SO_4^{-2} to HS^- increases
  - Reaction rate doubles every 10°C (up to 40°C)
  - Areas with higher temps have more problems than areas with lower temps
- Sulfur concentration rarely a limiting factor

pH Chart

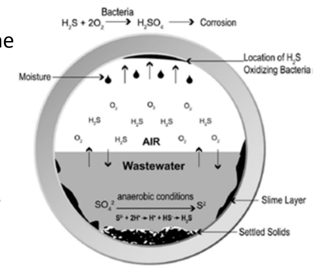


H_2S Toxicity

- Easily detectable at low concentrations
  - Rotten egg odor
- Will fatigue olfactory system even at low concentrations
  - If you smell hydrogen sulfide and then it goes away, move quickly to a well-ventilated area
- Higher concentrations will mask olfactory system entirely
  - Always use a gas meter, the nose is not always reliable
- Length of exposure vs. Concentration
  - Long term exposure to 10 ppm vs. 30 min. at 600 ppm
- Deaths due to H_2S poisoning have been reported

H_2S Corrosion

- H_2S is biologically converted to H_2SO_4 in the presence of water and oxygen
- Corrosion occurs: pipe crown, lift stations, headworks, sludge storage and dewatering, and others



H_2S Corrosion

- H_2SO_4 attacks:
  - Concrete
    - Pipe failure, trench collapse
  - Metal
    - Manhole ladders, support structures
  - Electronics
    - Copper wiring converted to non-conductive copper sulfide

NH_3 - Ammonia

- Toxic, distinct odor
- Very corrosive, especially to copper
- Primarily occurs in lime stabilization process
  - Increase in pH will increase NH_3
- Most common treatment is acid-based scrubbers

Control Strategies

Possible Control Strategies

- Minimize hydraulic detention time in pipes and wet wells
- Maintain DO in the wastewater
- Ensuring sufficient flow velocities to prevent solids deposition in pipelines and channels
- Routinely cleaning structures to remove slime, grease and sludge accumulation
- Treating liquid and solids recycle streams
- Changing or enforcing sewer-use ordinance
- Routinely and frequently disposing of screenings and grit
- Immediately removing floating scum/solids
- Promptly and thoroughly cleaning process units as they are removed from service

Control Strategies

- There are 2 major methods of odor control
  - Chemical addition to the wastewater
  - Mechanical control by odorous air treatment, where odorous vapors can be contained and collected

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Chemical Controls

- Try to keep sulfides in aqueous solution
- Manipulates factors that contribute to H_2S formation:
  - DO
  - BOD
  - ORP
  - pH, etc.

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Chemical Controls

- Chlorination
- Oxygen and aeration
- Ozone
- Chromate
- Metallic ions
- Nitrate compounds
- pH control

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Chlorine – Cl_2

- Often used to destroy hydrogen sulfide at the point of application
- 8 to 10 lbs Cl_2 for 1 lb H_2S
- Dangerous to handle Cl_2; bleach adds to cost
- Strong bactericide
  - Reduces bacteria responsible for sulfide production by inhibiting the growth of biofilm inside sewer lines
  - Could also neutralize bacteria in WWTP

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Chlorine – Cl_2

- Chlorination is one of the oldest and most effective methods used for odor control
- Chlorine is a very reactive chemical and oxidizes many compounds in wastewater

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Chlorine – Cl_2

- Reaction between Cl_2 and H_2S
  - $H_2S + 4Cl_2 + 4H_2O \rightarrow H_2SO_4 + 8HCl$
- Reaction between Cl_2 and NH_3
  - $NH_3 + Cl_2 \rightarrow NH_2Cl + HCl$ (monochloramine)
  - $NH_2Cl + Cl_2 \rightarrow NHCl_2 + HCl$ (dichloramine)
  - $NHCl_2 + Cl_2 \rightarrow NCl_3 + HCl$ (trichloramine)

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Chlorine – Cl_2

- The most important roles that chlorine plays in controlling odors are to
  - Inhibit the growth of slime layers in sewers
  - Destroy bacteria that convert sulfate to sulfide
  - Destroy hydrogen sulfide at the point of application
    - This controls requires less chemical than trying to oxidize the odor once formed
- This means that chlorine should be added in the collection system prior to the plant

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Chlorine – Cl_2

- Doses as high as 12 mg/L Cl_2 for every 1 mg/L H_2S (in solution, not in the atmosphere) may be needed to control the generation of hydrogen sulfide in sewers
- Dangerous to handle Cl_2; bleach adds to cost

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Hydrogen Peroxide – H_2O_2

- Widely used, relatively safe to handle
- Non-toxic by-product (O_2)
  - adds to waste stream DO
- Requires good mixing, long contact time
  - typical to have multiple feed points
  - Can need 15 minutes to 2 hours of contact time
- Less than 5 lb H_2O_2 per 1 lb H_2S
  - Usually a 2:1 to 4:1 of H_2O_2 to S_2- is needed for control

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Hydrogen Peroxide – H_2O_2

- Reacts in 3 possible ways to control odors
  - Oxidant action
    - Converts H_2S to sulfate compounds (SO_4^-)
  - Oxygen producing
    - Keeps system aerobic
  - Bactericidal to the sulfate-reducing bacteria
    - Kills bacteria that produce odors

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Hydrogen Peroxide – H_2O_2

- Benefit: increases DO and slows sulfide formation
- Typical 5 lb O_2 to 1 lb H_2S
- Only suitable for force mains
- Requires storage and handling of liquid O_2

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ORP Adjustment

- All of the oxidizing agents will increase ORP
  - ozone may be exception
- Another method may be to add nitrate upstream
  - Bacteria prefer to take O_2 from nitrate instead of sulfate
  - Reaction also adds DO to system and raises ORP
  - Bioxide® - trade name, in wide use

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Ozone – O_3

- Powerful oxidizing agent that effectively removes odors
- Toxic
- Must be generated on-site ($$$)
- Very short contact time, less than 1 min
- Rarely used
  - Although, Water Authority of Dickson County installed an ozone generator in March 2012 at one of their lift stations.

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Chromate – CrO_4^{2-}

- Effectively inhibit the sulfate reduction to sulfide.
- Cause serious toxic conditions that limit their usefulness.

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Metallic Ions

- Iron or zinc (mainly) has been used to precipitate sulfide compounds.
  - React with sulfides and settle out
  - Sulfur is permanently removed from waste stream
  - Zinc is rarely used anymore due to effluent and sludge limitations
- Has a toxic effect on biological treatment such as sludge digestion and therefore has limitations
- Inexpensive, safe to handle
- Typically fed upstream of problem area
  - Avg. 4 to 5 lbs iron for 1 lb sulfur
- Disadvantages - sludge, low pH
- Added benefit – can also precipitate out phosphorus

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Nitrate Compounds – NO_3^-

- The first chemicals used in the anaerobic breakdown of wastes are nitrate ions
- If enough nitrate ions are present, the sulfate ions will not be broken down
- The cost of this type of treatment to halt hydrogen sulfide production is very high and, at present, is not practical

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Potassium Permanganate – $KMnO_4$

- Very costly
- Rarely used in this application
- Non-corrosive, stable
- Effective for wide range of odor-causing agents
- Precipitates out sulfide compounds

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pH Control – Continuous

- Increasing the pH of the wastewater is an effective odor control method for H_2S
- By increasing the pH above 9, biological slimes and sludge growth are inhibited.
- Any sulfide present will be in the form of HS^- ion or S^- ion rather than as H_2S gas, which is formed and released at low pH values

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pH Control – Shock Treatment

- Short-term, high pH (greater than 12.5) slug dosing with sodium hydroxide is effective in controlling sulfide generation for periods of up to a month or more depending on sewer temperature and sewer conditions

pH Control

- Small pH drop can cause large shift in equilibrium (vapor vs. aqueous)
- Lime and caustic soda most commonly used to keep pH up
- Continuous control disrupts WWTP
- Shock pH treatment used instead
  - pH to 12 for 10 to 20 min or so to destroy biofilm
- Pipe crown corrosion sometimes controlled by spraying with caustic soda

Metal Precipitation

- Most common treatment method
- Iron (or zinc) added to waste stream
  - React with sulfides and settle out
  - Sulfur is permanently removed from waste stream
  - Zinc is rarely used anymore due to effluent and sludge limitations
- Inexpensive, safe to handle
- Disadvantages - sludge, low pH
- Typically fed upstream of problem area
- Avg. 4 to 5 lbs iron for 1 lb sulfur
- Added benefit – can also precipitate out phosphorus

Mechanical Controls

- Attempt to remove or neutralize the ambient vapor H_2S
- Covers, scrubbers, ventilation, and use of non-corrosive liners or coatings

Safety

- Safety items that should be considered when working with or installing chemical odor control systems include:
  - Personal protective equipment
  - Proper lockout/tagout procedures
  - Handling chemicals
  - Secondary containment

Covers

- Installed over problem area and generated gas is vented off and treated
- In anaerobic digesters, H_2S is removed and remainder of gas is used as fuel
- Materials should be corrosion resistant
- Work well for odor control

Scrubbers

- Combined with cover and ventilation
  - Gas is collected and vented out to scrubber
- Packed bed of non-corrosive media
  - Chemical misted down from top
  - Gas pulled up from bottom
- Some are multi-stage: separate sections for oxidation, pH, etc.
- Effective for odor and corrosion control
  - Lift stations, clear wells, and other

Chemical Mist Odor Control System

- Wet scrubber, no media
- Bleach is recirculated
  - $KMnO_4$ and H_2O_2 can also be used
  - NaOH only used when H_2S concentration in gas phase is high
- Softened water is used to minimize scaling

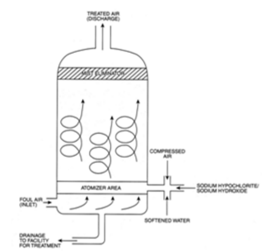
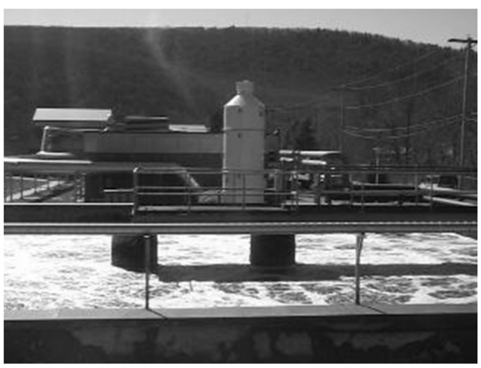
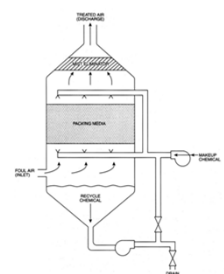


Diagram excerpted from Chapter 1: Odor Control. In *Advance Waste Treatment*.



Packed Tower Scrubber with Countercurrent Air Flow



- Oxidant used:
  - Chlorine
  - Sodium hydroxide
  - Bleach
  - Hydrogen peroxide
    - To remove hydrogen sulfide
  - Sulfuric acid, diluted
    - To remove ammonia

Diagram excerpted from Chapter 1: Odor Control. In *Advance Waste Treatment*.

Packed Tower Scrubber with Cross Air Flow

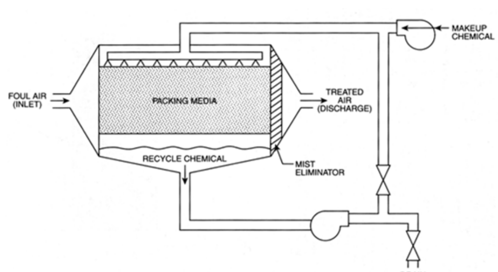
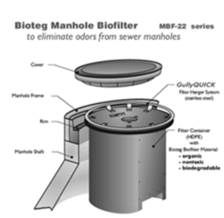


Diagram excerpted from Chapter 1: Odor Control. In *Advance Waste Treatment*.

More Scrubbers?

- Biofilters
  - Media is compost or wood chips
  - H_2S is controlled biologically
- Activated carbon filters
  - Absorb sulfides and other odor-causing compounds
  - Does not have the same capacity for odor removal if regenerated



Electrolytic Chemical Scrubber Using a Brine Solution

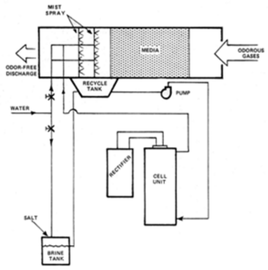


Diagram excerpted from Chapter 1:Odor Control. In *Advance Waste Treatment*.

An Activated Carbon System

Diagram excerpted from Chapter 1: Odor Control. In *Advance Waste Treatment*.

Ventilation

- Wet wells, covered tanks, covered channels
- Introduces oxygen to vapor phase and keeps liquid phase from becoming anaerobic
- Bonus! - provides safe environment for operators and minimizes buildup of flammable or explosive gases

Liners and Coatings

- Very effective at controlling corrosion
- Liners used widely to repair damaged pipes
- Many types:
  - Slip liners
  - Cured-in-place pipe
  - Specialty concrete
  - Epoxies

Electronics Protection

- Degree of protection depends on severity of corrosion potential
- Achieved by airtight enclosures, air conditioned workspaces, corrosion resistant coatings, and/or nitrogen-purged systems

Masking Agents

- Counteractants
  - impose stronger, more pleasant odor over problem
- Neutralizers
  - attempt to combine with odor and reduce its effect

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Masking Agents

- Consider this:
  - Never mask the odor of a toxic substance
  - Not a substitute for good operation or housekeeping
  - Odor problems should be controlled at their source

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Procedures to Solve Odor Problems

- Evaluation of plant performance
- Examination of engineering or design features of plant
- Identification of source or cause of problem
- On-site inspection and investigation of the problem areas

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Odor Control
Review Questions

1. The most common source of sulfide in wastewater is biological activity in the collection sewer or treatment plant
   a. True
   b. False

2. The threshold odor level is the average level at which odors are considered objectionable as measured by an odor panel
   a. True
   b. False

3. Treatment plant operators develop “educated noses” and are usually able to detect odors most other people would not notice.
   a. True
   b. False

4. Adsorption is the taking in or soaking up of one substance into the body of another substance.
   a. True
   b. False

5. At a pH below 5, all sulfide present in wastewater is in the gaseous form.
   a. True
   b. False

6. In a biological odor removal tower, odors will not be removed from the gas stream until a biomass is established on the filter media.
   a. True
   b. False

7. Chemical mist and packed bed odor control units are examples of wet scrubber systems.
   a. True
   b. False

8. Regenerated carbon has the same capacity for odor removal as new carbon.
   a. True
   b. False

9. Besides chlorine, what other chemical(s) are used to control or prevent odors?
   a. Chlorophenol
   b. Dichloramine
   c. Hydrogen peroxide
   d. Sodium hypochlorite
   e. Both C and D

10. Microorganisms that can use either molecular (atmospheric) or combined (bound) oxygen are called:
   a. Anaerobes
   b. Facultative organisms
   c. Obligate aerobes
   d. Strictly aerobic microorganisms
   e. Strictly anaerobic microorganisms

11. Hydrogen sulfide causes the most serious problems at what pH range?
   a. Less than 5
   b. 5 to 7
   c. 7, neutral
   d. 7 to 9
   e. Greater than 9

12. Odors in AIR cannot be treated by:
   a. Absorption
   b. Adsoprtion
   c. pH adjustment
   d. Ozonation
   e. None of the above

13. Conditions that favor hydrogen sulfide production are also associated with other problems such as:
   a. Corrosion of concrete pipelines and manholes
   b. Explosive gas mixtures
   c. Respiratory hazards for operators
   d. All of the above
   e. None of the above

14. Ways that chlorine controls odors include(s):
   a. Destroying bacteria that convert sulfate to sulfide
   b. Destroying hydrogen sulfide at the point of application
   c. Inhibiting the growth of slime layers in sewers
   d. All of the above
   e. None of the above

15. Steps followed (not in order) in procedures used when attempting to solve odor problems include:
    a. Evaluation of plant performance
    b. Examination of engineering or design features of plant
    c. Identification of source or cause of problem
    d. On-site inspection and investigation of the problem areas
    e. All of the above

16. Offensive-smelling inorganic gases found in treatment plants include:
    a. Ammonia
    b. Hydrogen sulfide
    c. Mercaptans
    d. Methane
    e. A and B

17. Safety items that should be considered when working with or installing chemical odor control systems include:
    a. Personal protective equipment
    b. Proper lockout/tagout procedures
    c. Handling of chemicals
    d. Secondary containment
    e. All of the above

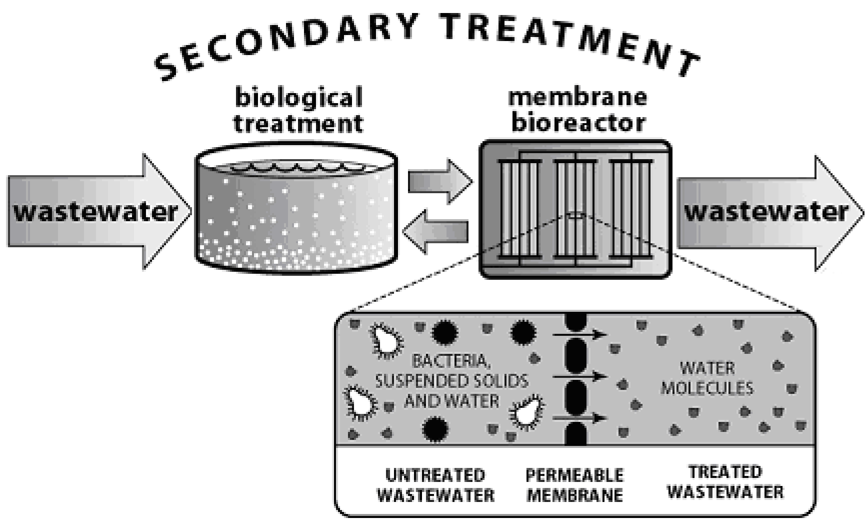
18. Oxidants commonly used in packed bed scrubber systems include all but:
    a. Chlorine
    b. Hydrogen peroxide
    c. Ozone
    d. Sodium hydroxide
    e. Sodium hypochlorite

Answers:

1.	A	6.	A	11.	A	16.	E
2.	B	7.	A	12.	C	17.	E
3.	B	8.	B	13.	D	18.	C
4.	B	9.	E	14.	D		
5.	A	10.	B	15.	E		

Section 4

Secondary Effluent Solids



Solids Removal

Secondary Effluent

TENNESSEE DEPARTMENT OF ENVIRONMENT AND CONSERVATION

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Physical-Chemical Treatment

- Coagulation: clumping together of very fine particles into larger particles (microfloc) caused by the use of chemicals (coagulant) added during rapid mixing
- Flocculation: gathering together of fine particles after coagulation to form larger particles (floc) by gentle mixing
- Liquid/solids separation (gravity, DAF)

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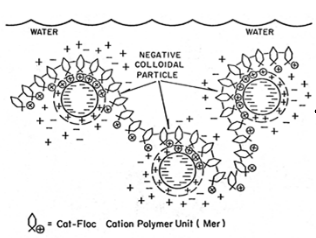
Coagulation/Flocculation Process



- Nonsettleable solids resist settling due to particle size & natural forces between particles
- Suspended, colloidal (fine silt, bacteria, viruses) & dissolved (color, chemicals)

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Coagulation/Flocculation Process

- WW solids tend to have negative charge
  - Including bacteria
- Destabilization adds chemicals to change or neutralize charge of particles

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Coagulation/Flocculation Process

- During the coagulation phase, chemicals are added to the wastewater and rapidly mixed with the water
  - Certain chemical reactions occur quickly resulting in the formation of very small particles, usually called “pinpoint floc”
- Flocculation follows coagulation and consists of gentle mixing of the wastewater
  - The main purpose is to bring together microfloc particles

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Flocculation Process

- The speed of the paddles becomes very important
  - Too rapid a speed may mechanically break up the floc
  - Too slow a speed may not provide enough mixing and may promote dead spots within the tank where mixing does not occur

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Liquid/solids Separation

- Liquid/solids separation step follows flocculation and is almost always conventional sedimentation by gravity settling
  - Although other processes are used occasionally like DAF, gravity filtration and membrane filtration

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Chemical Treatment

- Regardless of the form of chemical treatment process, the most important process controls are:
  - Provide enough mixing energy to completely mix the chemical with the water
  - Control the mixing intensity during flocculation
  - Control the chemical dose

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Chemical Treatment

- Often, filters are installed after chemical treatment to produce a highly polished effluent
- Chemicals can also be used as a "band-aid" effectively during problem situations
  - Reduce sludge bulking
  - Upstream equipment failure
  - Accidental spills entering the plant
  - Seasonal overloads

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Chemical Treatment

- Aluminum (3+) (alum) or iron (3+)(ferric) metal salts are used to coagulate wastewater solids
  - The cationic (positively charged) metals salts adsorb onto negatively charged wastewater solids and neutralize their negative charges

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Chemicals Used to Improve Settling

- Aluminum Sulfate (Dry)
- Aluminum Sulfate (Liquid)
- Ferric Chloride
- Lime
- Polymers

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Aluminum Sulfate (Alum)

- $Al_2(SO_4)_3 \cdot 14\ H_2O$
- Reacts with alkalinity in water to form aluminum hydroxide as the precipitate
- Works best at pH of 5.8 to 8.5 with sufficient alkalinity
- Dry alum: powder, lump form
- Liquid alum: pH < 4; very corrosive
- 1 mg/L alum consumes 0.5 mg/L alkalinity

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Alum

- Alum will support a bacterial growth and cause sludge deposits in feed lines if wastewater is used to transport the alum to the point of application
  - These growths can clog feed lines
  - By keeping a velocity high enough to scour the lines continuously, this problem can be reduced

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Alum

- A 1% solution will have a pH of 3.5
- Overdosing of alum may decrease the pH to a point that will reduce biological activity
- A lower pH may also allow chlorine to further decrease the pH and affect the aquatic life in the receiving streams

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Ferric Chloride ($FeCl_3$)

- Highly corrosive
- Liquid is 35-45% strength; will crystallize at 30°F
- Effective over wider pH range than alum; works better in cold water, forming heavier, denser floc
- Reacts with alkalinity to form iron hydroxide (Fe(OH)3)
- 1 mg/L consumes 0.6 mg/L alkalinity
- Decomposes in presence of light, producing hydrochloric acid

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Lime ($Ca(OH)_2$)

- Calcium hydroxide or quicklime
- Coagulate solids or adjust pH
- Quicklime must be mixed with water (slaked) before used
- Heat generated when water is added
- Inspect mixers and pumps daily for wear
- Irritates skin, eyes, lungs on contact

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Chemical Handling Safety

- Full face respirator
- Acid resistant goggles/ face shield
- Rubber gloves and boots
- Rubber suit/apron
- Emergency eye wash and shower (within 25 ft of storage and feed systems)

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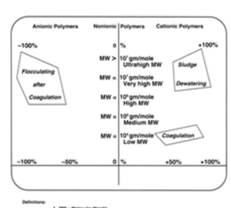
A Polymer Map



Polymer ionic charges “charge density”

- Polymers fed in very small doses
  - < 1%
- Solutions made in water prior to use.
- High to very high MW polymers require several hours to hydrate.

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Polymers

- Advantages
  - Little effect on pH
  - Make work better in cold water with low turbidity
  - Produces less sludge
- Disadvantages
  - Overfeeding can clog filters
  - Must clean up spills immediately- slick & often corrosive (low pH)

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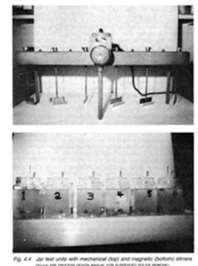
Jar Testing Equipment

- Most valuable tool in operating & controlling chemical treatment process
- Simulates coag./floc. with different chemicals and/or doses
- Full scale plant operation may not match results



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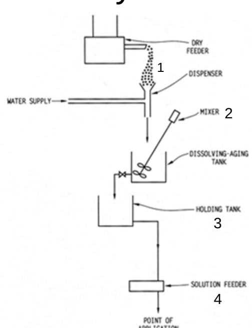
Dry Chemical Feed System

- Accurately controls dosage
- Known amount of chemical and water (1) mixed using high speed mixer (2)
- Solution held in day tank (3)
- Metered output ensures proper dosage into WW (4)
- Safety: dust dangerous if inhaled or on contact with skin/eyes



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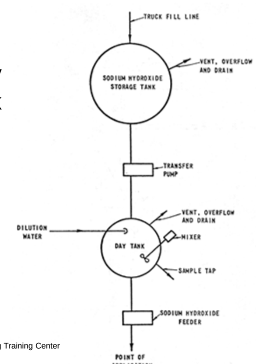
Liquid Chemical Feed System

- May draw directly from storage tank or diluted in smaller tank then fed
- Positive displacement metering pump



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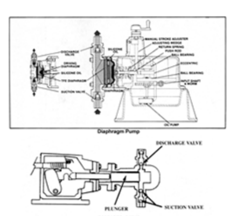
Positive Displacement Pumps

- Top: flexible rubber, plastic or metal diaphragm draws liquid in and out. When raised, suction is exerted. When depressed, liquid is forced through the discharge valve.
- Bottom: easy to adjust piston stroke to regulate chemical feed.



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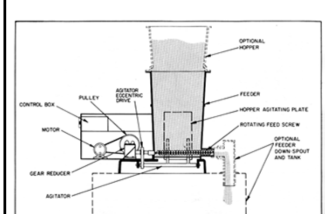
Screw Feeder



- Maintains desired output by varying speed and/or amount of time screw rotates as chemical is discharged
- Must keep screw clean
- Chemical may cake in hopper

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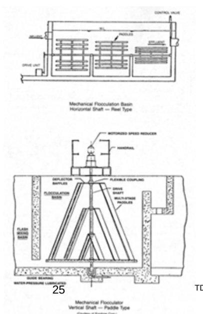
Mechanical Flocculators



- Done in same or separate tank as sedimentation
- Tapered flocculation
- Paddle speed critical
- Top: variation in paddle size to control floc shearing
- Bottom: variable speed drive unit

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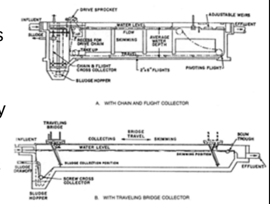
Rectangular Sedimentation Clarifiers

- Rectilinear flow
- Influent enters one end
- Flow hits baffle & moves by gravity to opposite end where effluent overflows outlet weirs
- Settled sludge moved by flights or bridge to hopper
- On return scraper skims scum into trough



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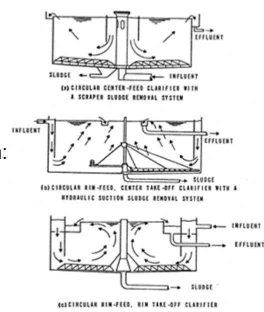
Circular Clarifiers

- Sludge collected at center of conical base
- Scum and oil removed by radial arm at surface
- PM & visual inspection: worn parts, corrosion, proper operation
- Hazards due to slips, trips, drowning, exposure to diseases, electrocution



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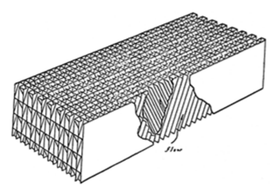
Tube Settler Module



- Shallow depth sedimentation
- Reduces settling time
- Tubes of steel or fiberglass
- Allows basin to settle larger flow
- Requires more frequent sludge removal

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Causes of Short Circuiting

- Water density due to temperature or suspended solids differences
- Strong winds
- High inlet/outlet velocities

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Factors Considered in Clarifier Design

- Weir Overflow Rate, gpd/ft
- Surface Overflow Rate, gpd/ft^2
- Detention Time, hrs
- Solids Loading Rate, lbs/day/ft^2

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Wastewater Filtration

- Microscreens
- Gravity Filtration
- Synthetic Media Filter
- Continuous Backwash, Upflow & Deep-Bed Granular Media Filtration
- Surface Filtration
- Cross Flow Membrane Filtration

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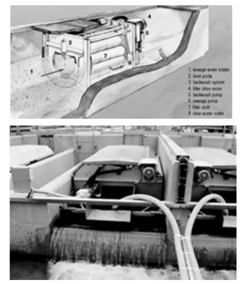
Microscreens



- Straining occurs over submerged section of microfabric
- 20-25 μm PE, PPE, stainless steel wire, copper or Teflon screen
- Filters out very small SS, decreases turbidity & improves effectiveness of disinfection
- Blinding or clogging due to iron or magnesium: clean with hot water or steam

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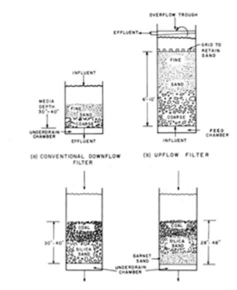
Gravity Filter Configurations

- Deep bed filtration
- One or more materials and/or grades of material
- Most are rapid sand filter with gravity flow from top down
- Most operate on batch basis
- Underdrain collects filtered WW



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Gravity Filter Configurations

- Backwashing indicated by headloss
  - Backwashing a sand filter, treated water is used in order to avoid contamination of the filter bed
  - Incomplete cleaning leads to formation of mudballs
  - After a proper washing, the head loss should be less than 0.5 foot at start-up
- For depth filtration the multimedia filter, the finer, denser media (sand) is placed on the bottom with the course, lighter media (anthracite) on the top.
  - The coarse media removes larger solids that would quickly clog the finer media
  - The fine media will surface strain solids that penetrate the full depth of the coarse media bed

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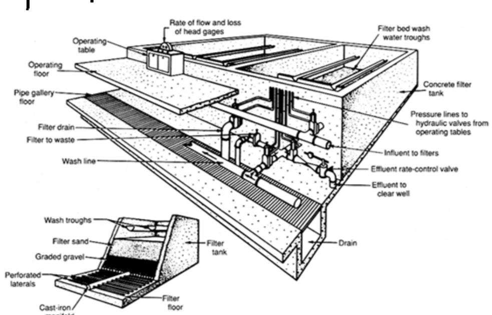
Rapid Sand Filter



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Filter Operating Strategy

- Calcium scaling can occur within the filter and on the surface of the sand media granules when calcium ions and sulfate or carbonate ions are present in the filter influent flow.
  - Usually this happens when lime or sulfuric acid are used for pH control.
  - Prevention or controlling of scaling can be accomplished in several ways:
    - Use caustic in place of lime, or hydrochloric acid in place of sulfuric acid in neutralization
    - Use scale retardant/dispersant available from water treatment chemical suppliers
    - Keep sand bed moving whenever the influent flow is off by introducing clean water, or wash the sand with clean water for four hours before securing the filter.

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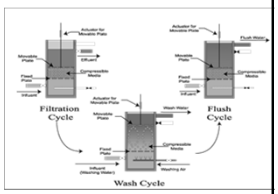
Synthetic Medium Filter

- Schreiber Fuzzy Filter: wastewater flows upward through polyvalinadene media between a lower fixed plate & upper movable plate.
- To clean, upper plate is raised mechanically. Flow to filter continues as air is introduced to scour/wash media periodically (external blower). Freed solids continuously exit filter during washing.



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Synthetic Medium Filter

Clayton County, GA NE STP uses five 7' X 7' filters handling up to 15 MGD at 30 gpm/sq ft.

- Closed, self contained unit
- Small footprint
- No odors or flies
- Filter media is compressible, so porosity can be altered
- Media life: > 10 yrs
- No media loss

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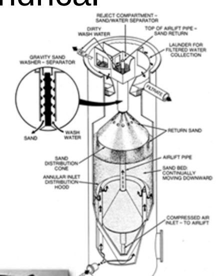
Bottom Feed Cylindrical Filter

- Continuous backwash, upflow, deep bed silica sand media filter
- Do not have to be taken out of service for backwashing
- Fewer and/or smaller filters due to continuous operation



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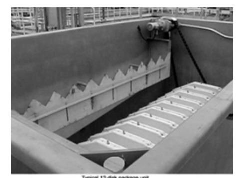
Surface Filtration: Disk Filters

- Cloth membrane as filter media removes fine particles
- Each disk has 6 pie-shaped sections mounted vertically to hollow tube that collects filtered effluent
- Low head-gravity feed
- Filter is static during filtering
- Backwashes automatically base on water level differential
- Disks rotate only during cleaning
- Maintains continuous filtration during backwash



Typical 12-disk package unit.

Filtration is accomplished in a quiescent environment.

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Membrane Filtration

- Membrane filtration processes are classified on the basis of the size of the particle they separate from the wastestream
  - Microfiltration (MF)
  - Ultrafiltration (UF)
  - Nanofiltration (NF)
  - Reverse Osmosis (RO)
- The separation technique involves a thin, semipermeable membrane that acts as a selective barrier that separates the particles on the basis of molecular size

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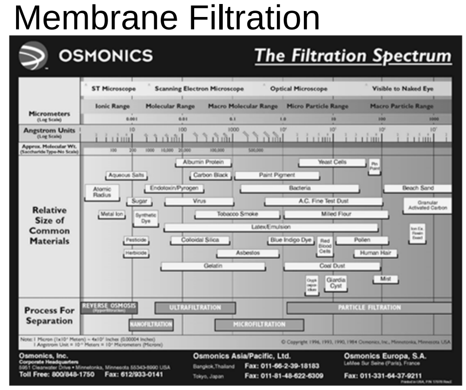
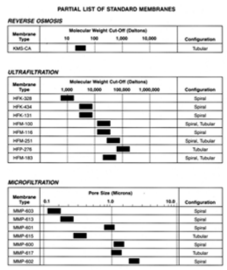
Membrane Filtration



Cross Flow Membrane Filtration

- WW pumped at high velocity along surface
- Driving force is pressure differential between WW side and effluent side
- Table: particle size & mw retention capacities for KOCH membranes



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Cross Flow Membrane Filtration

- Microfiltration membranes
  - Have pores ranging from 0.1-2.0 microns
  - Less common
- Ultrafiltration membranes
  - Most common
  - Pore sizes range from 0.005-0.1 micron
  - Examples of particles that are retained are:
    - Emulsified oils
    - Metal hydroxides
    - Proteins
    - Starches
    - Suspended solids
  - Examples of molecules that pass through the pores
    - Water
    - Alcohols
    - Salts
    - Sugars

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Cross Flow Membrane Filtration

- Nanofiltration
  - Have pores between UF and RO
  - Effective at removing salts
- Reverse Osmosis
  - The tightest membrane process that allows only water to pass through the membrane
  - Retains salts and higher molecular weight components
  - Used for tertiary treatment producing water with low BOD/COD and of near-potable water quality

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Membrane Configuration

- Membranes are housed in various types of modular units
- The basic types of membrane configurations are:
  - Tubular
  - Hollow fiber
  - Spiral
  - Plate and frame
  - Ceramic Tube or Monolith

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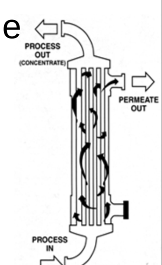
Hollow Fiber Cartridge

- Semi-permeable polymer membrane
- Water (permeate) passes through, but solids are rejected
- Membrane fouling due to oils and greases
- Chemically cleaned in place using water, caustics, surfactants, & acids prescribed by manufacturer (2-3 times/week)
- 5-40 psi
- 3-10 yr membrane life



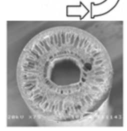


Figure 2 -Hollow fiber membrane, transversal cross-section (75x).

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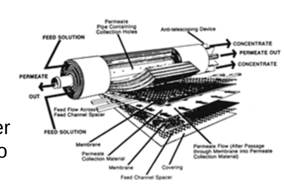
Spiral Wound Module

- Pack large surface area into compact design.
- Membrane cast on non-woven polyester flat sheets & put into spiral modules.
- Operate at 50-150 psi.



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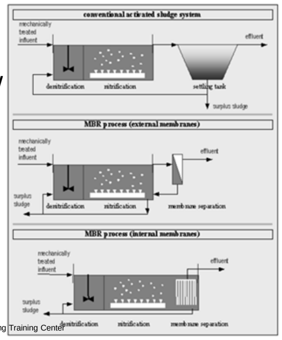
Membrane Bioreactors

- Membrane immersed in WW
- Flat plate microfiltration
- Eliminates need for secondary clarification and filtration
- MLSS: 15,000-30,000 mg/L



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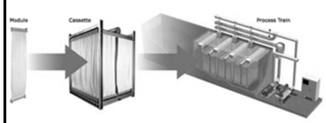
Membrane Bioreactors



- Sludge age > 40 days
- Cleaned 2-3 times/year in place
- >99.9% removal bacteria & viruses

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Solids Removal from Secondary Effluents
Review Questions

1. Coagulation is a process of gentle mixing to ensure contact between the coagulant chemicals and the suspended particles.
   a. True
   b. False

2. Dry alum is corrosive unless it absorbs moisture.
   a. True
   b. False

3. The settling rate of particles is faster at a warmer temperature than it is at a lower temperature.
   a. True
   b. False

4. The conventional single-media filter bed commonly used in potable water systems is generally unsatisfactory in removing solids found in wastewater because of plugging.
   a. True
   b. False

5. In a dual-media filter, the finer, denser sand is placed over the coarse media, anthracite.
   a. True
   b. False

6. Downflow filters are designed to remove suspended solids by either the surface-straining method or the depth filtration method.
   a. True
   b. False

7. The cause of mudball formation in a filter is inadequate oil and grease removal by earlier processes.
   a. True
   b. False

8. Growth of algae and slime in gravity filters can be controlled with occasional applications of chlorine ahead of the filter.
   a. True
   b. False

9. The rate of flow through a granular media filter is expressed as the surface loading rate.
   a. True
   b. False

10. The performance of treatment chemicals during a jar test does not depend on:
   a. Chemical concentration
   b. Mixing intensity
   c. Method of application
   d. Time of day sample is collected
   e. Time of reaction

11. The most critical water quality indicator influencing the performance of polymers is:
   a. Ammonia
   b. Conductivity
   c. Hardness
   d. pH
   e. Phosphate

12. What could be the possible causes of the floc being too small in a chemical coagulation and flocculation system?
   a. Change in pH
   b. Chemical feed pump adjusted too low
   c. Improper chemical dosage
   d. Paddle speed in flocculators too fast
   e. All the above

13. Which of the following tests should not be run daily for process control when chemicals are used to reduce effluent suspended solids?
   a. Chemical dosage
   b. Chemical viscosity
   c. Influent and effluent suspended solids
   d. pH
   e. All the above

14. A jar test cannot be used to determine:
   a. The most economical dosages
   b. The pH of the sample
   c. The plant response to wastewater changes by using lab equipment
   d. What the clarity will probably be in the plant effluent
   e. None of the above

15. Short-circuiting in a clarifier may be caused or made worse by:
    a. Differences in the density of suspended solids in the influent
    b. High inlet and outlet velocities
    c. Strong winds blowing across the surface of the tank
    d. Temperature differences within the tank
    e. All of the above

16. What is the one invariable requirement in all jar test procedures?
    a. Chemicals of the highest possible purity should be used
    b. Jar test apparatus must have at least 6 jars
    c. pH of the samples must be within the range of 6.5 to 8.5
    d. Test conditions should match actual plant conditions

17. Clarifier efficiency is determined using:
    a. Effluent grab samples
    b. Influent and effluent 24-hour composite samples
    c. Nephelometric measuring devices
    d. 24-hour sludge accumulation (volume) measurements
    e. None of the above

Answers:

1.	B	6.	A	11.	D	16.	D
2.	B	7.	B	12.	E	17.	B
3.	A	8.	A	13.	B		
4.	A	9.	A	14.	B		
5.	B	10.	D	15.	E		

Section 5

BOD_5 /$cBOD_5$

BIOCHEMICAL OXYGEN DEMAND

Advanced Wastewater Treatment

TENNESSEE DEPARTMENT OF ENVIRONMENT AND CONSERVATION

Biochemical Oxygen Demand

- This test measures waste loadings to treatment plants and evaluates the BOD-removal efficiency of treatment systems.
- The test measures the molecular oxygen utilized during a specified incubation period for the biochemical degredation of organic material (carbonaceous demand) and the oxygen used to oxidize inorganic material such as sulfides and ferrous iron.
  - It also may be used to measure the amount of oxygen used to oxidize reduced forms of nitrogen (nitrogenous demand) unless their oxidation is prevented by an inhibitor.

(Bacteria) + Food + Oxygen (O_2) → Carbon Dioxide (CO_2)

Food: Measured Indirectly; Oxygen: Measured Directly

Biochemical Oxygen Demand

- The method consists of:
  - Filling typically a 300-mL bottle with sample and dilution water until overflowing
  - Measuring initial DO
  - Capping and incubating at 20 ± 1°C for 5 days ± 6 hours in the dark to prevent photosynthesis that can produce DO
  - Measuring final DO
  - Oxygen depletion is calculated as Biochemical Oxygen Demand

Sampling and Storage

- Grab samples – if analysis is begun within 2 hours of collection, cold storage is unnecessary
  - If analysis is not started within 2 hours of sample collection, keep sample at or below 6°C (40 CFR 136) from the time of collection.
    - *Standard Methods* states 4°C, but since 40 CFR 136 states 6°C, go with the Federal Rule of 6°C
  - Begin analysis within 6 hours of collection.
- Composite samples – keep samples at or below 6°C during compositing.
  - Limit compositing period to 24 hrs

Sample Preparation and Pretreatment

- Check pH, if it is not between 6.0-8.0, adjust sample temp to 20 ± 3°C, then adjust pH to 7.0-7.2 using sulfuric acid or sodium hydroxide
  - Always seed samples that have had their pH adjusted
- If possible, avoid samples containing residual chlorine by sampling ahead of chlorination process
  - If sampling after disinfection, samples MUST be seeded
- Samples supersaturated with DO – samples containing DO concentrations above saturation at 20°C
  - To prevent loss of oxygen during incubation on such samples, reduce DO to saturation by bringing sample to about 20 ± 3°C in partially filled bottle while agitating by vigorous shaking or by aerating with clean, filtered compressed air
    - No need to shake samples that are no supersaturated.
    - Recommend documenting initial DO and put on bench sheet that sample was supersaturated with DO

Preparation of Seed Suspension

- It is necessary to have present in each BOD bottle a population of microorganisms capable of oxidizing the biodegradable organic matter in the sample.
  - Domestic wastewater, unchlorinated or otherwise undisinfected effluents from biological wastewater treatment plants, and surface waters receiving wastewater discharges usually contain satisfactory microbial populations.
  - The preferred seed is obtained from a biological treatment system processing the waste.
  - In this case, use supernatant from settled domestic wastewater, effluent from primary clarifiers, diluted mixed liquor from an aeration basin, undisinfected effluent, or receiving water from below the point of discharge.
    - When effluent or mixed liquor from biological treatment process is used as a seed source, inhibition of nitrification is recommended.

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Preparation of Dilution Water

- Check to ensure that the DO is at least 7.5 mg/L before using water for BOD tests.
- Add phosphate buffer, magnesium sulfate, calcium chloride and ferric chloride solution to source water.
  - Commercially available already mixed.
  - Mix thoroughly and bring temperature to 20 ± 3°C.
- Prepare dilution water immediately before use unless dilution water blanks show that the water is acceptable after longer storage times
  - If the dilution water blanks show a DO depletion greater than 0.20 mg/L, obtain a satisfactory water by improving purification or use water from another source.
- Water needs to be free of heavy metals, for example copper
  - If you purchase your water for dilution water, you should get a certificate of analysis to show it is tested for and free of metals

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Dilution Water Criteria

- Preferably run two blanks, beginning and ending of sample set
- Dilution water blanks must meet quality control limits, <0.2 mg/L DO (preferably <0.1 mg/L)
  - Otherwise discard and prepare fresh solution
- No seed or nitrification inhibitor is added for dilution water blank
- Run one nitrification inhibitor (NI) blank per quarter or with a new lot of NI, whichever is more frequent
- Total of two blanks
  - One dilution water blank at beginning
  - One dilution water blank at end

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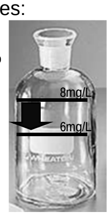
Preparation of Dilutions

- Make at least 3 dilutions of prepared sample estimated to produce a residual DO of at least 1.0 mg/L and a DO uptake of at least 2.0 mg/L after a 5-day incubation.
- Recommended sample volumes:
  - Industrial wastes = 0.1 - 1.0 %
  - Raw\settled sewage = 1.0 - 5.0 %
  - Oxidized effluent = 5.0 - 25 %
  - Polluted river water = 25 - 100 %



First Dilution
2mg/L O_2 demand

Last Dilution
1mg/L O_2 remaining

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Preparation of Dilutions

- Samples should be homogeneous
  - Mix sample while removing aliquot
- Use wide bore pipette
- Pipette as fast as possible to prevent loss of solids
- Pipette each sample dilution separately
- When pouring sample or dilution water into bottles, allow the water to flow down the sides of the bottle to prevent air bubbles from becoming trapped in the bottle

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Dilutions Prepared Directly in BOD Bottles

- Fill each BOD bottle approximately $^2/_3$ full with dilution water.
- Add appropriate amounts of seed suspension and nitrification inhibitor to the individual bottles.
  - When a bottle contains more than 67% (201 mL) of sample after dilution, nutrients may be limited in the diluted sample and subsequently reduce biological activity.
  - In such samples, add the nutrient, mineral and buffer solutions directly to diluted sample at a rate of 1 mL/L or use commercially prepared solutions designed to dose the appropriate bottle size.

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Addition of Seed Suspension

- If seeding is used, add seed suspensions to the dilution vessels or to individual BOD bottles before final dilution
  - Generally below samples will provide a suitable amount of microorganisms
    - 1-3 mL of settled raw wastewater or primary effluent
    - 1-2 mL of at 1:10 dilution of MLSS
  - Do not filter seed suspension before use
  - Always record the exact volume of seed suspension before use
  - The DO uptake attributable to the seed added to each bottle generally should be between 0.6-1.0 mg/L, but the amount of seed should be adjusted from this range to that required to provide GGA results of 198 ± 30.5 mg/L BOD

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Addition of Nitrification Inhibitor

- Seed all samples to which nitrification inhibitor has been added.
- The amount of seed should be consistent with that required to achieve GGA test results in the range of 198 ± 30.5 mg/L
- If using 2-chloro-6-(trichloromethyl)pyridene (TCMP) – do not add TCMP to BOD bottles before they are at least $^2/_3$ filled with diluted sample

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Addition of Nitrification Inhibitor

- Nitrification inhibitor
  - Prevents *Nitrosomonas* from oxidizing ammonia to nitrite, preventing nitrogenous oxygen demand in the sample (CBOD measurement).
- Nitrification:
  - *Nitrosomonas* + NH_3 + O_2 → NO_2^-
  - *Nitrobacter* + NO_2^- + O_2 → NO_3^-
    - Nitrogenous demand observed if these microbiologically mediated reactions occur.

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Sealing of Bottles

- Complete filling of each bottle by adding enough dilution water that insertion of the stopper leaves no bubbles in the bottle.
- Mix the sample by turning the bottle manually several times unless a DO probe having a stirrer is used immediately to measure initial DO concentration.
- As a precaution against drawing air into the dilution bottle during incubation, use a water seal.
  - By adding water to the flared mouth of special BOD bottles
- Place a paper or plastic cup or foil cap over flared mouth of bottle to reduce evaporation of the water seal during incubation.

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Calibration

- Winkler titration - best; most accurate
  - Relies on chemistry
- Probe: Air-saturated water
  - Reagent water at 20°C shaken/aerated to saturate
  - Maximum DO at 20°C ~ 9.00 mg/L
  - Meter result shouldn't vary greatly from the saturation point
  - Correct for pressure and/or altitude differences

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Calibration

- Probe: Water-saturated air (most common)
  - Air-calibration chamber → calibrate at sample temperature.
  - Minimizes errors caused by temperature differences.
  - Keep interior of the chamber just moist -- not filled with water.
  - Typical for probes
  - Probe is stored in a constant humidity environment
  - Container should be sealed somehow (to maintain constant humidity)

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Determination of Initial & Final DO

- Determine the initial DO on all sample dilutions, dilution water blanks and where appropriate, seed controls.
  - Replace any displaced contents with sufficient diluted sample or dilution water to fill the bottle, stopper all bottles tightly, and water seal before beginning incubation.
  - After preparing dilution, measure initial DO within 30 minutes.
- Determine the final DO after 5 days ± 6 hours of incubation in all sample dilutions and in all blanks and checks

Sample Incubation

- Incubate at 20°C ± 1°C the stoppered and sealed BOD bottles containing desired dilutions, seed controls, dilution water blanks and GGA checks.
- Exclude light to avoid growth of algae in the bottles during incubation

Quality Control Checks

- Minimum residual DO and minimum DO depletion:
  - Only bottles, including seed controls, giving a minimum DO depletion of 2.0 mg/L and a residual of 1.0 mg/L after 5 d of incubation are considered to produce valid data
    - Because at least 2.0 mg oxygen uptake/L is required to give a meaningful measure of oxygen uptake and at least 1.0 mg/L must remain throughout the test to ensure that insufficient DO does not affect the rate of oxidation of waste constituents.
    - Exceptions occur for reporting purposes only when the depletions for tests using undiluted samples in all bottles fall below 2.0 mg/L and when the residual in all dilutions is less than 1.0 mg/L
  - When using membrane electrodes for measuring DO, make frequent calibration checks to ensure accurate DO readings.

Quality Control Checks

- Glucose-glutamic acid check
  - The GGA check is the primary basis for establishing accuracy and precision of the BOD test and is the principal measure of seed quality and set-up procedure.
  - Add nitrification inhibitor if seed is obtained from a source that is nitrifying.
  - The resulting average BOD must fall in the range of 198 ± 30.5 mg/L
  - Consistently high values can indicate the use of too much seed suspension, contaminated dilution water or the occurrence of nitrification
  - Consistently low values can indicate poor seed quality or quantity or the presence of a toxic material.
    - If low values persist, prepare a new mixture of GGA and check the sources of dilution water and source of seed.

Quality Control Checks

- Dilution water quality check
  - With each batch of samples incubate one or more bottles of dilution water that contains nutrient, mineral and buffer solutions but no seed or nitrification inhibitor.
  - This dilution water blank serves as a check on quality of unseeded dilution water and cleanliness of incubation bottles.
  - Determine initial and final DO
  - The uptake in 5 days must not be more than 0.20 mg/L and preferably not more than 0.10 mg/L
    - If the water blank exceeds 0.20 mg/L, discard all data for tests using this dilution water or clearly identify such samples in data records.

Quality Control Checks

- Seed control
  - Determine the BOD of the seed suspension as for any other sample
  - This is the seed control
  - Ideally, make 3 dilutions of seed such that the smallest quantity gives at least 2.0 mg/L DO depletion and the largest quantity results in at least 1.0 mg/L DO residual after 5 days of incubation.
  - Determine the DO uptake per milliliter of seed added to each bottle using either the slope method or the ratio method.
    - For the ratio method, divide the DO depletion by the volume of the seed in milliliters for each seed control bottle having a 2.0 mg/L depletion and greater than 1.0 mg/L minimum residual DO and average the results.
    - Seed dilutions showing widely varying depletions per milliliter of seed (± 30%) suggest the presence of toxic substances or large particulates in the seed suspension.
      - In this case, check or change the seed source.

Calculations

$$BOD_5, mg/L = \frac{D_1 - D_2}{P}$$

$$BOD_5, mg/L = \frac{(D_1 - D_2) - (B_1 - B_2)f}{P}$$

Where:
- D_1 = Initial Dissolved Oxygen Concentration in Sample, mg/L
- D_2 = Final Dissolved Oxygen Concentration in Sample, mg/L
- B_1 = Initial Dissolved Oxygen Concentration in Seed Control, mg/L
- B_2 = Final Dissolved Oxygen Concentration in Seed Control, mg/L
- P = Sample Concentration, % (expressed as a decimal)
- $f = \frac{\text{Seed in Sample, \%}}{\text{Seed in Seed Control, \%}}$

Calculations

- Plug data into equation:

$$P = 2/300 = 0.00667$$

$$BOD_5\text{, mg/L} = \frac{(7.3 - 5.2)}{0.00667}$$

$$BOD_5\text{, mg/L} = 315\text{ mg/L}$$

Calculations

- If DO depletion is less than 2.0 mg/L and sample concentration is 100% (no dilution except for seed, nutrient, mineral and buffer solutions), actual seed-corrected, DO depletion may be reported as the BOD even if it is less than 2.0 mg/L
- When all dilutions result in a residual DO<1.0 mg/L, select the bottle having the lowest DO concentration (greatest dilution) and report
  - BOD, mg/L > $\frac{(D_1 - D_2) - (B_1 - B_2)f}{P}$

Reporting

- Average the test results for all qualified bottles within each dilution series
  - Report the results as BOD_5, if nitrification is not inhibited.
  - Report results as $CBOD_5$ if nitrification is inhibited.
- Samples showing large differences between the computed BOD for different dilutions, for example, greater than 30% may indicate the presence of a toxic substance or analytical problems.

Reporting

- Identify results in the test reports when any of the following quality control parameters is not met
  - Dilution water blank exceeds 0.20 mg/L
  - GGA check falls outside acceptable limits
  - Test replicates show more than 30% difference between high and low values
  - Seed control samples do not meet the above criteria in all dilutions
  - Minimum DO is less than 1.0 mg/L

Common Sources of Error

- Not adjusting pH to within 6.5 – 7.5
  - Adjustment not required if effluent is between 6.0-8.5
  - If pH is adjusted, samples must be seeded
- Improper calibration of DO meter
- Incubation temperatures not constant
- Initial DOs above saturation
- Depletion criteria not met
  - Not depleting 2.0 mg/L
  - Final DO <1.0 mg/L

Common Sources of Error

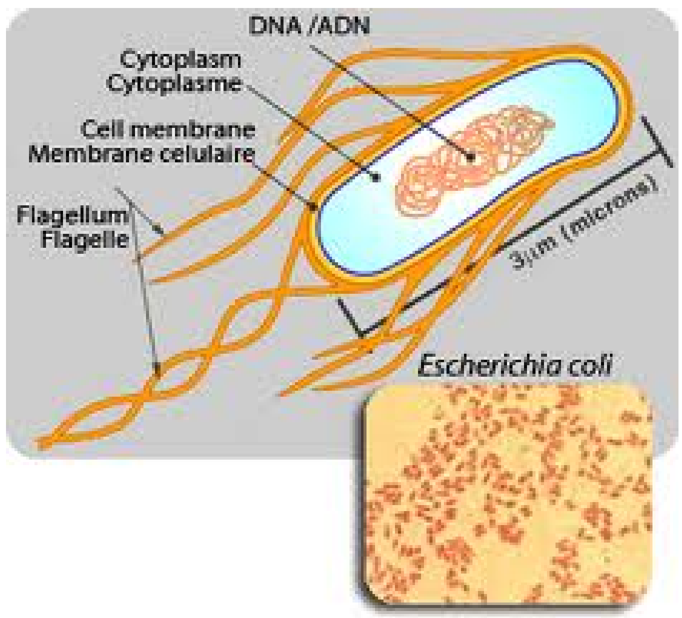
- Subtracting blanks
- Not seeding when required
- Seed strength not constant
- Not analyzing GGA samples
- Not evaluating for toxicity
- Improper calculations
- Water quality issues

BOD Sample Analysis Report

Sample	Bottle Number	Sample mL's	Percent Dilution	Seed mL's Added	Initial DO	Analyst	Final DO	Analyst	DO Depletion	Seed Control Factor	Results Read	BOD5, mg/L	Report BOD
		A	P = A/300		D1		D2		D1 - D2		Date		
Dilution Blank													
Seed Control											Take DO depletion for each seed control bottle and divide it by the volume of seed used to get your mg/L DO depletion per mL of seed.		
									Average				
GGA													
Raw													
Final													

Section 6

E. coli Testing



Bacteriological Analysis

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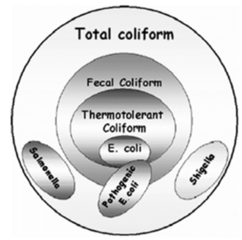
1

Coliform Bacteria

- MPN of coliform bacteria are estimated to indicate the presence of bacteria originating from the intestines of warm-blooded animals
- Coliform bacteria are generally considered harmless
  - But their presence may indicate the presence of pathogenic organisms



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2

Coliform Bacteria

- Comprises all the aerobic and facultative anaerobic gram negative, nonspore-forming, rod-shaped bacteria that ferment lactose within 48 hours ~ 35°C
- Coliform bacteria can be split into fecal and non-fecal groups
- The fecal group can grow at higher temperatures (45°C) than the non-fecal coliforms

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3

Sampling

- Clean, sterilized borosilicate glass or plastic bottles or sterile plastic bags.
- Leave ample air space for mixing.
- Collect samples representative of wastewater tested.
- Use aseptic techniques; avoid sample contamination.
- Test samples as soon as possible.

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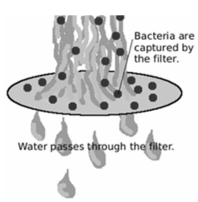
4

Approved Methods



- Coliform (fecal)
  - Number per 100 mL
    - Membrane filtration
- E. coli
  - Number per 100 mL
    - Multiple tub/multiple well (Colilert®)
    - Membrane filtration
      - m-ColiBlue24®
      - Modified mTEC agar

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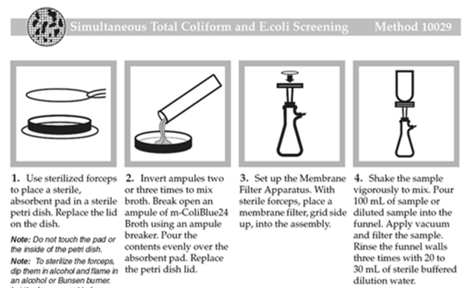
5

Membrane Filtration



M-ColiBlue24® Membrane Filtration Method, Hach Company, www.Hach.com

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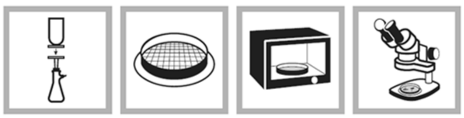
6

Membrane Filtration

Bacteria, Coliform



5. Turn off the vacuum and lift off the funnel top. Using sterile forceps, transfer the filter to the previously prepared petri dish.

6. With a slight rolling motion, place the filter, grid side up, on the absorbent pad. Check for trapped air under the filter and make sure the filter touches the entire pad. Replace the petri dish lid.

7. Invert the petri dish and incubate at 35 ±0.5 °C for 24 hours.

8. Remove the petri dish from the incubator and examine the filters for colony growth. Colonies are typically readily visible; however, a stereoscopic microscope or other 10–15X magnifier may be useful. Red and blue colonies indicate total coliforms and blue colonies specifically indicate *E. coli*.

M-ColiBlue24® Membrane Filtration Method, Hach Company, www.Hach.com

TDEC - Fleming Training Center 7

Membrane Filtration Equipment

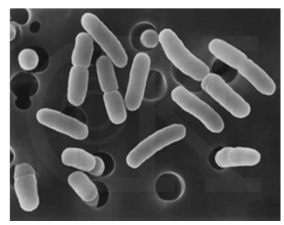
- Water bath or air incubator operating at appropriate temperature
- Vacuum pump
- UV sterilizer or boiling water bath
- 10-15 X dissecting microscope; should have fluorescent illuminator
- Alcohol burner

TDEC - Fleming Training Center 8

Membrane Filtration Supplies and Glassware

- Sterile graduated cylinder
- Sterile pipets
- Sterile MF filtration flask
- Sterile dilution water
- Sterile sample vessels
- Samples containing chlorine must be treated with 3% sodium thiosulfate solution
- mFC Broth

TDEC - Fleming Training Center 9



Fecal Coliform

TDEC - Fleming Training Center 10

Fecal Coliform

- A 100 mL volume of sample is filtered through a 47-mm membrane filter using standard techniques.
- Filter is transferred to a 50-mm petri plate containing an absorbent pad saturated with mFC Broth.
- Invert filter and incubate at 44.5±0.2°C for 24 hrs.
- Count blue colonies.
- Interferences
  - None, but excess particulates may cause colonies to grow together on a crowded filter or slow the sample filtration process.

TDEC - Fleming Training Center 11

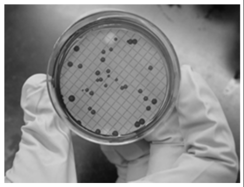
Fecal Coliform

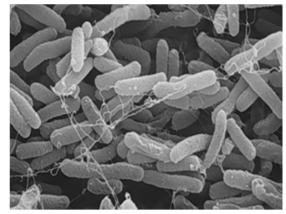
- Maximum hold time is 8 hrs at < 10°C
- Ideal sample volume yields 20-60 colonies
- Samples <20 mL, add 10 mL sterile dilution water to filter funnel before applying vacuum.
- Sanitize funnel between samples.
- Visually determine colony counts on membrane filters.
- Verify using 10-15 X binocular wide-field microscope.

TDEC - Fleming Training Center 12

Fecal Data Interpretation

- Incubation time is 24 ± 2 hrs.
- Fecal coliform density reported as number of colonies per 100 mL of sample.
  - Fecal coliforms appear blue.
  - Colonies = colony forming unit = cfu
- NPDES permit limit: monthly average of 200 cfu/100 mL; daily maximum of 1000 cfu/100 mL.





Escherichia coli (E.coli)

Colilert

Techniques for Measuring

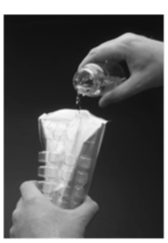
- Most Probable Number (MPN)
  - Idexx QuantiTray
- Membrane Filter
  - mColiBlue24
  - mTEC Agar

Colilert® & Colilert-18®

MPN Method

- Add substrate to a 100 mL sample
- If making dilutions, use sterile DI water, not sterile buffered water.

Colilert® & Colilert-18®



- Shake sample vigorously. Wait for bubbles to dissipate.
- Pour into QuantiTray.

Colilert® & Colilert-18®

- Seal sample in Quanti-Tray
- Incubate at 35±0.5°C for 18 hrs (Colilert-18) OR 24 hrs (Colilert)

Colilert® & Colilert-18®

- Examine tray for appropriate color change
- Yellow is an indicator of total coliforms

Left: The 97 well QuantiTray 2000 will count up to 2419 cfu without dilution.
Right: The 51 well QuantiTray will count up to 200 cfu without dilution.

TDEC - Fleming Training Center

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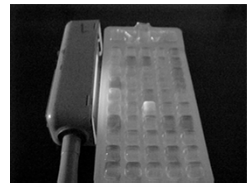
Colilert® & Colilert-18®

- Examine positive total coliform for fluorescence using a UV light in a dark environment
- Fluorescence is a positive indicator for E. coli
- Calculate MPN value according to the table provided with the QuantiTray



TDEC - Fleming Training Center

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IDEXX Quanti-Tray®/2000 MPN Table *(per 100ml)*

Small Wells Positive

# Large Wells Positive	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0	<1	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.1	15.1	16.1	17.1	18.1	19.1	20.2	21.2	22.2	23.3	24.3
1	1.0	2.0	3.0	4.0	5.0	6.0	7.1	8.1	9.1	10.1	11.1	12.1	13.2	14.2	15.2	16.2	17.3	18.3	19.3	20.4	21.4	22.4	23.5	24.5	25.6
2	2.0	3.0	4.1	5.1	6.1	7.1	8.1	9.2	10.2	11.2	12.2	13.3	14.3	15.4	16.4	17.4	18.5	19.5	20.6	21.6	22.7	23.7	24.8	25.8	26.9
3	3.1	4.1	5.1	6.1	7.2	8.2	9.2	10.3	11.3	12.4	13.4	14.5	15.5	16.5	17.6	18.6	19.7	20.8	21.8	22.9	23.9	25.0	26.1	27.1	28.2
4	4.1	5.2	6.2	7.2	8.3	9.3	10.4	11.4	12.5	13.5	14.6	15.6	16.7	17.8	18.8	19.9	21.0	22.0	23.1	24.2	25.3	26.3	27.4	28.5	29.6
5	5.2	6.3	7.3	8.4	9.4	10.5	11.5	12.6	13.7	14.7	15.8	16.9	17.9	19.0	20.1	21.2	22.2	23.3	24.4	25.5	26.6	27.7	28.8	29.9	31.0
6	6.3	7.4	8.4	9.5	10.6	11.6	12.7	13.8	14.9	16.0	17.0	18.1	19.2	20.3	21.4	22.5	23.6	24.7	25.8	26.9	28.0	29.1	30.2	31.3	32.4
7	7.5	8.5	9.6	10.7	11.8	12.8	13.9	15.0	16.1	17.2	18.3	19.4	20.5	21.6	22.7	23.8	24.9	26.0	27.1	28.3	29.4	30.5	31.6	32.8	33.9
8	8.6	9.7	10.8	11.9	13.0	14.1	15.2	16.3	17.4	18.5	19.6	20.7	21.8	22.9	24.1	25.2	26.3	27.4	28.6	29.7	30.8	32.0	33.1	34.3	35.4
9	9.8	10.9	12.0	13.1	14.2	15.3	16.4	17.6	18.7	19.8	20.9	22.0	23.2	24.3	25.4	26.6	27.7	28.9	30.0	31.2	32.3	33.5	34.6	35.8	37.0
10	11.0	12.1	13.2	14.4	15.5	16.6	17.7	18.9	20.0	21.1	22.3	23.4	24.6	25.7	26.9	28.0	29.2	30.3	31.5	32.7	33.8	35.0	36.2	37.4	38.6
11	12.2	13.4	14.5	15.6	16.8	17.9	19.1	20.2	21.4	22.5	23.7	24.8	26.0	27.2	28.3	29.5	30.7	31.9	33.0	34.2	35.4	36.6	37.8	39.0	40.2
12	13.5	14.6	15.8	16.9	18.1	19.3	20.4	21.6	22.8	23.9	25.1	26.3	27.5	28.6	29.8	31.0	32.2	33.4	34.6	35.8	37.0	38.2	39.5	40.7	41.9
13	14.8	16.0	17.1	18.3	19.5	20.6	21.8	23.0	24.2	25.4	26.6	27.8	29.0	30.2	31.4	32.6	33.8	35.0	36.2	37.5	38.7	39.9	41.2	42.4	43.6
14	16.1	17.3	18.5	19.7	20.9	22.1	23.3	24.5	25.7	26.9	28.1	29.3	30.5	31.7	33.0	34.2	35.4	36.7	37.9	39.1	40.4	41.6	42.9	44.2	45.4
15	17.5	18.7	19.9	21.1	22.3	23.5	24.7	25.9	27.2	28.4	29.6	30.9	32.1	33.3	34.6	35.8	37.1	38.4	39.6	40.9	42.2	43.4	44.7	46.0	47.3
16	18.9	20.1	21.3	22.6	23.8	25.0	26.2	27.5	28.7	30.0	31.2	32.5	33.7	35.0	36.3	37.5	38.8	40.1	41.4	42.7	44.0	45.3	46.6	47.9	49.2
17	20.3	21.6	22.8	24.1	25.3	26.6	27.8	29.1	30.3	31.6	32.9	34.1	35.4	36.7	38.0	39.3	40.6	41.9	43.2	44.5	45.9	47.2	48.5	49.8	51.2
18	21.8	23.1	24.3	25.6	26.9	28.1	29.4	30.7	32.0	33.3	34.6	35.9	37.2	38.5	39.8	41.1	42.4	43.8	45.1	46.5	47.8	49.2	50.5	51.9	53.2
19	23.3	24.6	25.9	27.2	28.5	29.8	31.1	32.4	33.7	35.0	36.3	37.6	39.0	40.3	41.6	43.0	44.3	45.7	47.1	48.4	49.8	51.2	52.6	54.0	55.4
20	24.9	26.2	27.5	28.8	30.1	31.5	32.8	34.1	35.4	36.8	38.1	39.5	40.8	42.2	43.6	44.9	46.3	47.7	49.1	50.5	51.9	53.3	54.7	56.1	57.6
21	26.5	27.9	29.2	30.5	31.8	33.2	34.5	35.9	37.3	38.6	40.0	41.4	42.8	44.1	45.5	46.9	48.4	49.8	51.2	52.6	54.1	55.5	56.9	58.4	59.9
22	28.2	29.5	30.9	32.3	33.6	35.0	36.4	37.7	39.1	40.5	41.9	43.3	44.8	46.2	47.6	49.0	50.5	51.9	53.4	54.8	56.3	57.8	59.3	60.8	62.3
23	29.9	31.3	32.7	34.1	35.5	36.8	38.3	39.7	41.1	42.5	43.9	45.4	46.8	48.3	49.7	51.2	52.7	54.2	55.6	57.1	58.6	60.2	61.7	63.2	64.7
24	31.7	33.1	34.5	35.9	37.3	38.8	40.2	41.7	43.1	44.6	46.0	47.5	49.0	50.5	52.0	53.5	55.0	56.5	58.0	59.5	61.1	62.6	64.2	65.8	67.3
25	33.6	35.0	36.4	37.9	39.3	40.8	42.2	43.7	45.2	46.7	48.2	49.7	51.2	52.7	54.3	55.8	57.3	58.9	60.5	62.0	63.6	65.2	66.8	68.4	70.0
26	35.5	36.9	38.4	39.9	41.4	42.8	44.3	45.9	47.4	48.9	50.4	52.0	53.5	55.1	56.7	58.2	59.8	61.4	63.0	64.7	66.3	67.9	69.6	71.2	72.9
27	37.4	38.9	40.4	42.0	43.5	45.0	46.5	48.1	49.6	51.2	52.8	54.4	56.0	57.6	59.2	60.8	62.4	64.1	65.7	67.4	69.1	70.8	72.5	74.2	75.9
28	39.5	41.0	42.6	44.1	45.7	47.3	48.8	50.4	52.0	53.6	55.2	56.9	58.5	60.2	61.8	63.5	65.2	66.9	68.6	70.3	72.0	73.7	75.5	77.3	79.0
29	41.7	43.2	44.8	46.4	48.0	49.6	51.2	52.8	54.5	56.1	57.8	59.5	61.2	62.9	64.6	66.3	68.0	69.8	71.5	73.3	75.1	76.9	78.7	80.5	82.4
30	43.9	45.5	47.1	48.7	50.4	52.0	53.7	55.4	57.1	58.8	60.5	62.2	64.0	65.7	67.5	69.3	71.0	72.9	74.7	76.5	78.3	80.2	82.1	84.0	85.9
31	46.2	47.9	49.5	51.2	52.9	54.6	56.3	58.1	59.8	61.6	63.3	65.1	66.9	68.7	70.5	72.4	74.2	76.1	78.0	79.9	81.8	83.7	85.7	87.6	89.6
32	48.7	50.4	52.1	53.8	55.6	57.3	59.1	60.9	62.7	64.5	66.3	68.2	70.0	71.9	73.8	75.7	77.6	79.5	81.5	83.5	85.4	87.5	89.5	91.5	93.6
33	51.2	53.0	54.8	56.5	58.3	60.2	62.0	63.8	65.7	67.6	69.5	71.4	73.3	75.2	77.2	79.2	81.2	83.2	85.2	87.3	89.3	91.4	93.6	95.7	97.8
34	53.9	55.7	57.6	59.4	61.3	63.1	65.0	67.0	68.9	70.8	72.8	74.8	76.8	78.8	80.8	82.9	85.0	87.1	89.2	91.4	93.5	95.7	97.9	100.2	102.4
35	56.8	58.6	60.5	62.4	64.4	66.3	68.3	70.3	72.3	74.3	76.3	78.4	80.5	82.6	84.7	86.9	89.1	91.3	93.5	95.7	98.0	100.3	102.6	105.0	107.3
36	59.8	61.7	63.7	65.7	67.7	69.7	71.7	73.8	75.9	78.0	80.1	82.3	84.5	86.7	88.9	91.2	93.5	95.8	98.1	100.5	102.9	105.3	107.7	110.2	112.7
37	62.9	65.0	67.0	69.1	71.2	73.3	75.4	77.6	79.8	82.0	84.2	86.5	88.8	91.1	93.4	95.8	98.2	100.6	103.1	105.6	108.1	110.7	113.3	115.9	118.6
38	66.3	68.4	70.6	72.7	74.9	77.1	79.4	81.6	83.9	86.2	88.6	91.0	93.4	95.8	98.3	100.8	103.4	105.9	108.6	111.2	113.9	116.6	119.4	122.2	125.0
39	70.0	72.2	74.4	76.7	78.9	81.3	83.6	86.0	88.4	90.9	93.4	95.9	98.4	101.0	103.6	106.3	109.0	111.8	114.6	117.4	120.3	123.2	126.1	129.2	132.2
40	73.8	76.2	78.5	80.9	83.3	85.7	88.2	90.8	93.3	95.9	98.5	101.2	103.9	106.7	109.5	112.4	115.3	118.2	121.2	124.3	127.4	130.5	133.7	137.0	140.3
41	78.0	80.5	83.0	85.5	88.0	90.6	93.3	95.9	98.7	101.4	104.3	107.1	110.0	113.0	116.0	119.1	122.2	125.4	128.7	132.0	135.4	138.8	142.3	145.9	149.5
42	82.6	85.2	87.8	90.5	93.2	96.0	98.8	101.7	104.6	107.6	110.6	113.7	116.9	120.1	123.4	126.7	130.1	133.6	137.2	140.8	144.5	148.3	152.2	156.1	160.2
43	87.6	90.4	93.2	96.0	99.0	101.9	105.0	108.1	111.2	114.5	117.8	121.1	124.6	128.1	131.7	135.4	139.1	143.0	147.0	151.0	155.2	159.4	163.8	168.2	172.8
44	93.1	96.1	99.1	102.2	105.4	108.6	111.9	115.3	118.7	122.3	125.9	129.6	133.4	137.4	141.4	145.5	149.7	154.1	158.5	163.1	167.9	172.7	177.7	182.9	188.2
45	99.3	102.5	105.8	109.2	112.6	116.2	119.8	123.6	127.4	131.4	135.4	139.6	143.9	148.3	152.9	157.6	162.4	167.4	172.6	178.0	183.5	189.2	195.1	201.2	207.5
46	106.3	109.8	113.4	117.2	121.0	125.0	129.1	133.3	137.6	142.1	146.7	151.5	156.5	161.6	167.0	172.5	178.2	184.2	190.4	196.8	203.5	210.5	217.8	225.4	233.3
47	114.3	118.3	122.4	126.6	130.9	135.4	140.1	145.0	150.0	155.3	160.7	166.4	172.3	178.5	185.0	191.8	198.9	206.4	214.2	222.4	231.0	240.0	249.5	259.5	270.0
48	123.9	128.4	133.1	137.9	143.0	148.3	153.9	159.7	165.8	172.2	178.9	186.0	193.5	201.4	209.8	218.7	228.2	238.2	248.9	260.3	272.3	285.1	298.7	313.0	328.2
49	135.5	140.8	146.4	152.3	158.5	165.0	172.0	179.3	187.2	195.6	204.6	214.3	224.7	235.9	248.1	261.3	275.5	290.9	307.6	325.5	344.8	365.4	387.3	410.6	435.2

09-63236-01

IDEXX Quanti-Tray®/2000 MPN Table *(per 100ml)*

Small Wells Positive

# Large Wells Positive	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
0	25.3	26.4	27.4	28.4	29.5	30.5	31.5	32.6	33.6	34.7	35.7	36.8	37.8	38.9	40.0	41.0	42.1	43.1	44.2	45.3	46.3	47.4	48.5	49.5
1	26.6	27.7	28.7	29.8	30.8	31.9	32.9	34.0	35.0	36.1	37.2	38.2	39.3	40.4	41.4	42.5	43.6	44.7	45.7	46.8	47.9	49.0	50.1	51.2
2	27.9	29.0	30.0	31.1	32.2	33.2	34.3	35.4	36.5	37.5	38.6	39.7	40.8	41.9	43.0	44.0	45.1	46.2	47.3	48.4	49.5	50.6	51.7	52.8
3	29.3	30.4	31.4	32.5	33.6	34.7	35.8	36.8	37.9	39.0	40.1	41.2	42.3	43.4	44.5	45.6	46.7	47.8	48.9	50.0	51.2	52.3	53.4	54.5
4	30.7	31.8	32.8	33.9	35.0	36.1	37.2	38.3	39.4	40.5	41.6	42.8	43.9	45.0	46.1	47.2	48.3	49.5	50.6	51.7	52.9	54.0	55.1	56.3
5	32.1	33.2	34.3	35.4	36.5	37.6	38.7	39.9	41.0	42.1	43.2	44.4	45.5	46.6	47.7	48.9	50.0	51.2	52.3	53.5	54.6	55.8	56.9	58.1
6	33.5	34.7	35.8	36.9	38.0	39.2	40.3	41.4	42.6	43.7	44.8	46.0	47.1	48.3	49.4	50.6	51.7	52.9	54.1	55.2	56.4	57.6	58.7	59.9
7	35.0	36.2	37.3	38.4	39.6	40.7	41.9	43.0	44.2	45.3	46.5	47.7	48.8	50.0	51.2	52.3	53.5	54.7	55.9	57.1	58.3	59.4	60.6	61.8
8	36.6	37.7	38.9	40.0	41.2	42.3	43.5	44.7	45.9	47.0	48.2	49.4	50.6	51.8	53.0	54.1	55.3	56.5	57.7	59.0	60.2	61.4	62.6	63.8
9	38.1	39.3	40.5	41.6	42.8	44.0	45.2	46.4	47.6	48.8	50.0	51.2	52.4	53.6	54.8	56.0	57.2	58.4	59.7	60.9	62.1	63.4	64.6	65.8
10	39.7	40.9	42.1	43.3	44.5	45.7	46.9	48.1	49.3	50.6	51.8	53.0	54.2	55.5	56.7	57.9	59.2	60.4	61.7	62.9	64.2	65.4	66.7	67.9
11	41.4	42.6	43.8	45.0	46.3	47.5	48.7	49.9	51.2	52.4	53.7	54.9	56.1	57.4	58.6	59.9	61.2	62.4	63.7	65.0	66.3	67.5	68.8	70.1
12	43.1	44.3	45.6	46.8	48.1	49.3	50.6	51.8	53.1	54.3	55.6	56.8	58.1	59.4	60.7	62.0	63.2	64.5	65.8	67.1	68.4	69.7	71.0	72.4
13	44.9	46.1	47.4	48.6	49.9	51.2	52.5	53.7	55.0	56.3	57.6	58.9	60.2	61.5	62.8	64.1	65.4	66.7	68.0	69.3	70.7	72.0	73.3	74.7
14	46.7	48.0	49.3	50.5	51.8	53.1	54.4	55.7	57.0	58.3	59.6	60.9	62.3	63.6	64.9	66.3	67.6	68.9	70.3	71.6	73.0	74.4	75.7	77.1
15	48.6	49.9	51.2	52.5	53.8	55.1	56.4	57.8	59.1	60.4	61.8	63.1	64.5	65.8	67.2	68.5	69.9	71.3	72.6	74.0	75.4	76.8	78.2	79.6
16	50.5	51.8	53.2	54.5	55.8	57.2	58.5	59.9	61.2	62.6	64.0	65.3	66.7	68.1	69.5	70.9	72.3	73.7	75.1	76.5	77.9	79.3	80.8	82.2
17	52.5	53.9	55.2	56.6	58.0	59.3	60.7	62.1	63.5	64.9	66.3	67.7	69.1	70.5	71.9	73.3	74.8	76.2	77.6	79.1	80.5	82.0	83.5	84.9
18	54.6	56.0	57.4	58.8	60.2	61.6	63.0	64.4	65.8	67.2	68.6	70.1	71.5	73.0	74.4	75.9	77.3	78.8	80.3	81.8	83.3	84.8	86.3	87.8
19	56.8	58.2	59.6	61.0	62.4	63.9	65.3	66.8	68.2	69.7	71.1	72.6	74.1	75.5	77.0	78.5	80.0	81.5	83.1	84.6	86.1	87.6	89.2	90.7
20	59.0	60.4	61.9	63.3	64.8	66.3	67.7	69.2	70.7	72.2	73.7	75.2	76.7	78.2	79.8	81.3	82.8	84.4	85.9	87.5	89.1	90.7	92.2	93.8
21	61.3	62.8	64.3	65.8	67.3	68.8	70.3	71.8	73.3	74.9	76.4	77.9	79.5	81.1	82.6	84.2	85.8	87.4	89.0	90.6	92.2	93.8	95.4	97.1
22	63.8	65.3	66.8	68.3	69.8	71.4	72.9	74.5	76.1	77.6	79.2	80.8	82.4	84.0	85.6	87.2	88.9	90.5	92.1	93.8	95.5	97.1	98.8	100.5
23	66.3	67.8	69.4	71.0	72.5	74.1	75.7	77.3	78.9	80.5	82.2	83.8	85.4	87.1	88.7	90.4	92.1	93.8	95.5	97.2	98.9	100.6	102.4	104.1
24	68.9	70.5	72.1	73.7	75.3	77.0	78.6	80.3	81.9	83.6	85.2	86.9	88.6	90.3	92.0	93.8	95.5	97.2	99.0	100.7	102.5	104.3	106.1	107.9
25	71.7	73.3	75.0	76.6	78.3	80.0	81.7	83.3	85.1	86.8	88.5	90.2	92.0	93.7	95.5	97.3	99.1	100.9	102.7	104.5	106.3	108.2	110.0	111.9
26	74.6	76.3	78.0	79.7	81.4	83.1	84.8	86.6	88.4	90.1	91.9	93.7	95.5	97.3	99.2	101.0	102.9	104.7	106.6	108.5	110.4	112.3	114.2	116.2
27	77.6	79.4	81.1	82.9	84.6	86.4	88.2	90.0	91.9	93.7	95.5	97.4	99.3	101.2	103.1	105.0	106.9	108.8	110.8	112.7	114.7	116.7	118.7	120.7
28	80.8	82.6	84.4	86.3	88.1	89.9	91.8	93.7	95.6	97.5	99.4	101.3	103.3	105.2	107.2	109.2	111.2	113.2	115.2	117.3	119.3	121.4	123.5	125.6
29	84.2	86.1	87.9	89.8	91.7	93.7	95.6	97.5	99.5	101.5	103.5	105.5	107.5	109.5	111.6	113.7	115.7	117.8	120.0	122.1	124.2	126.4	128.6	130.8
30	87.8	89.7	91.7	93.6	95.6	97.6	99.6	101.6	103.7	105.7	107.8	109.9	112.0	114.2	116.3	118.5	120.6	122.8	125.1	127.3	129.5	131.8	134.1	136.4
31	91.6	93.6	95.6	97.7	99.7	101.8	103.9	106.0	108.2	110.3	112.5	114.7	116.9	119.1	121.4	123.6	125.9	128.2	130.5	132.9	135.3	137.7	140.1	142.5
32	95.7	97.8	99.9	102.0	104.2	106.3	108.5	110.7	113.0	115.2	117.5	119.8	122.1	124.5	126.8	129.2	131.6	134.0	136.5	139.0	141.5	144.0	146.6	149.1
33	100.0	102.2	104.4	106.6	108.9	111.2	113.5	115.8	118.2	120.5	122.9	125.4	127.8	130.3	132.8	135.3	137.8	140.4	143.0	145.6	148.3	150.9	153.7	156.4
34	104.7	107.0	109.3	111.7	114.0	116.4	118.9	121.3	123.8	126.3	128.8	131.4	134.0	136.6	139.2	141.9	144.6	147.4	150.1	152.9	155.7	158.6	161.5	164.4
35	109.7	112.2	114.6	117.1	119.6	122.2	124.7	127.3	129.9	132.6	135.3	138.0	140.8	143.6	146.4	149.2	152.1	155.0	158.0	161.0	164.0	167.1	170.2	173.3
36	115.2	117.8	120.4	123.0	125.7	128.4	131.1	133.9	136.7	139.5	142.4	145.3	148.3	151.3	154.3	157.3	160.5	163.6	166.8	170.0	173.3	176.6	179.9	183.3
37	121.3	124.0	126.8	129.6	132.4	135.3	138.2	141.2	144.2	147.3	150.3	153.5	156.7	159.9	163.1	166.5	169.8	173.2	176.7	180.2	183.7	187.3	191.0	194.7
38	127.9	130.8	133.8	136.8	139.9	143.0	146.2	149.4	152.6	155.9	159.2	162.6	166.1	169.6	173.2	176.8	180.4	184.2	188.0	191.8	195.7	199.7	203.7	207.7
39	135.3	138.5	141.7	145.0	148.3	151.7	155.1	158.6	162.1	165.7	169.4	173.1	176.9	180.7	184.7	188.7	192.7	196.8	201.0	205.3	209.6	214.0	218.5	223.0
40	143.7	147.1	150.6	154.2	157.8	161.5	165.3	169.1	173.0	177.0	181.1	185.2	189.4	193.7	198.1	202.5	207.1	211.7	216.4	221.1	226.0	231.0	236.0	241.1
41	153.2	157.0	160.9	164.8	168.9	173.0	177.2	181.5	185.8	190.3	194.8	199.5	204.2	209.1	214.0	219.1	224.2	229.4	234.8	240.2	245.8	251.5	257.2	263.1
42	164.3	168.6	172.9	177.3	181.9	186.5	191.3	196.1	201.1	206.2	211.4	216.7	222.2	227.7	233.4	239.2	245.2	251.3	257.5	263.8	270.3	276.9	283.6	290.5
43	177.5	182.3	187.3	192.4	197.6	202.9	208.4	214.0	219.8	225.8	231.8	238.1	244.5	251.0	257.7	264.6	271.7	278.9	286.3	293.8	301.5	309.4	317.4	325.7
44	193.6	199.3	205.1	211.0	217.2	223.5	230.0	236.7	243.6	250.8	258.1	265.6	273.3	281.2	289.4	297.8	306.3	315.1	324.1	333.3	342.8	352.4	362.3	372.4
45	214.1	220.9	227.9	235.2	242.7	250.4	258.4	266.7	275.3	284.1	293.3	302.6	312.3	322.3	332.5	343.0	353.8	364.9	376.2	387.9	399.8	412.0	424.5	437.4
46	241.5	250.0	258.9	268.2	277.8	287.8	298.1	308.8	319.9	331.4	343.3	355.5	368.1	381.1	394.5	408.3	422.5	437.1	452.0	467.4	483.3	499.6	516.3	533.5
47	280.9	292.4	304.4	316.9	330.0	343.6	357.8	372.5	387.7	403.4	419.8	436.6	454.1	472.1	490.7	509.9	529.8	550.4	571.7	593.8	616.7	640.5	665.3	691.0
48	344.1	360.9	378.4	396.8	416.0	436.0	456.9	478.6	501.2	524.7	549.3	574.8	601.5	629.4	658.6	689.3	721.5	755.6	791.5	829.7	870.4	913.9	960.6	1011.2
49	461.1	488.4	517.2	547.5	579.4	613.1	648.8	686.7	727.0	770.1	816.4	866.4	920.8	980.4	1046.2	1119.9	1203.3	1299.7	1413.6	1553.1	1732.9	1986.3	2419.6	>2419.6

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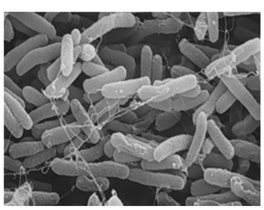

Escherichia coli (E.coli)

Modified mTEC Agar with
Membrane Filtration

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EPA Method 1603

- Membrane Filter – modified mTEC agar
- Filter sample dilutions through a 47mm diameter sterile, white, grid marked filter (0.45µm pore size)
- Place sample in a petri dish with modified mTEC agar
- Invert dish and incubate for 35± 0.5°C for 2 hours
  - Resuscitates injured or stressed bacteria
- Then incubate at 44.5± 0.2°C for 22 hours
- After incubation, remove the plate from the water bath or dry air incubator

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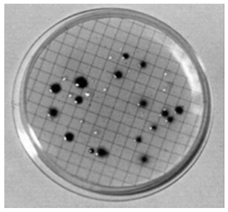
EPA Method 1603

- Count and record the number of red or magenta colonies (verify with stereoscopic microscope)
- See the USEPA microbiology methods manual, Part II, Section C, 3.5, for general counting rules



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EPA Method 1603

- QC Tests:
  - Initial precision and recovery
  - Ongoing precision and recovery
  - Matrix spike
  - Negative control
  - Positive control
  - Filter sterility check
  - Method blank
  - Filtration blank
  - Media sterility check

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EPA Method 1603

- Initial precision and recovery
  - Should be performed by each lab before the method is used for monitoring field samples
- Ongoing precision and recovery
  - Run after every 20 field and matrix spike samples or one per week that samples are analyzed
- Matrix spike
  - Run 1 per 20 samples
- Negative control
  - Should be analyzed whenever a new batch of media or reagents is used
- Positive control
  - Should be analyzed whenever a new batch of media or reagents is used

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EPA Method 1603

- Filter sterility check
  - Place at least one membrane filter per lot of filters on a tryptic soy agar (TSA) plate and incubate for 24 ± 2 hours at 35ºC ± 0.5 ºC .
  - Absence of growth indicates sterility of the filter.
  - Run daily.
- Method blank
  - Filter a 50-mL volume of sterile buffered dilution water and place on a modified mTEC agar plate and incubate.
  - Absence of growth indicates freedom of contamination from the target organism.
  - Run daily.

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EPA Method 1603

- Filtration blank
  - Filter a 50-mL volume of sterile buffered dilution water and place on a TSA plate and incubate at just at 35ºC ± 0.5 ºC for 24 ± 2 hours .
  - Absence of growth indicates sterility of the buffer and filtration assembly.
  - Run daily.
- Media sterility check
  - The lab should test media sterility by incubating one unit (tube or plate) from each batch of medium (TSA, modified mTEC and verification media) as appropriate and observing for growth.
  - Absence of growth indicates media sterility.
  - Run daily.

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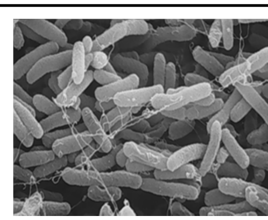

Escherichia coli (E.coli)

m-ColiBlue24® with
Membrane Filtration

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E. coli m-ColiBlue24®

- Maximum hold time is 8 hrs at < 10°C
- Ideal sample volume yields 20-80 colonies
- Run a minimum of 3 dilutions
- Samples <20 mL, add 10 mL sterile dilution water to filter funnel before applying vacuum.
- Sanitize funnel between samples.
- Visually determine colony counts on membrane filters.
- Verify using 10-15 X binocular wide-field microscope.

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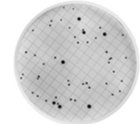
E. coli m-ColiBlue24®



- Incubation at 35 ± 0.5°C for 24 ± 2 hrs.
- *E. coli* density reported as number of colonies per 100 mL of sample.
- *E. coli* appear blue
- NPDES permit limit: monthly average of 126 cfu/100 mL
  - If your monthly geometric mean is less than 126, this means your disinfection is adequate.
- Samples and equipment known or suspected to have viable E. coli attached or contained must be sterilized prior to disposal.

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Expected Reactions of Various Microorganisms

- Total coliforms will produce a red colony
  - Enterobacter species
    - *E. cloacae*
    - *E. aerogenes*
  - Klebsiella species
    - *K. pneumoniae*
  - Citrobacter species
    - *C. freundii*
- *Escherichia coli* will produce a blue colony
  - *E. coli* O157:H7 will not produce a blue colony, but will grow as a red colony

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Expected Reactions of Various Microorganisms

- Known negative reaction (no growth) after 24-25 hours
  - *Pseudomonas aeruginosa*
    - *Variable reaction may be positive for total coliform when incubated longer than 25 hours*
  - *Proteus vulgaris*
  - *Aeromonas hydrophila*
- Some strains of the following microorganisms are known to produce a false-positive total coliform reaction (a red colony, but not a true total coliform)
  - *Serratia species*
  - *Hafnia alvei*
  - *Vibrio fluvialis*
  - *Aeromonas species*
  - *Proteus vulgaris*
  - *Providencia stuartii*
  - *Yersinia enterocolitica*
  - *Leclercia adecarboxylata*
  - *Ewingella americana*
  - *Staphylococcus species*
  - *Proteus mirabilis*

M-ColiBlue24® Trouble-Shooting Guide, Hach Company, www.Hach.com

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E. coli Information

- For Colilert ®: IDEXX Laboratories, www.idexx.com
- For mTEC Agar and mColiBlue-24® media: Hach Company, www.Hach.com
- EPA Method 1603: E.coli In Water By Membrane Filtration Using Modified-Thermotolerant Escherichia coli Agar (Modified mTEC), September 2002, EPA-821-R-02-023

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All Bacteriological Checks

- Temperatures are documented twice daily, at least 4 hours apart
- Thermometers are certified at least annually against NIST thermometers
- Reagents for storage requirements and expiration dates
- E. coli colonies identified correctly
- Calculations are correct
- Holding Times are met
  - Sample collection
  - Analysis start
  - End times

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Geometric Mean

- You have run your E. coli samples for the month and need to figure your geometric mean.
- Your results are as follows:
  - 60 cfu
  - 100 cfu
  - 0 cfu
  - 0 cfu

$$\text{Geometric Mean} = (X_1)(X_2)(X_3)...(X_n)^{1/n}$$

$$\text{Geometric Mean} = \sqrt[n]{(X_1)(X_2)(X_3)...(X_n)}$$

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Geometric Mean

- Geometric Mean – $(X_1)(X_2)(X_3)...(X_n)^{1/n}$
- Step 1: 1/n → 1 divided the number of test results. For our example above, there are four test results.
  - 1 ÷ 4 = 0.25 (write this number down, you will use it in Step 3)
- Step 2: Multiply all of the test results together and punch the = button on the calculator. **Remember to count 0 as a 1**.
  - 60 x 100 x 1 x 1 = 6000 (Do Not clear out your calculator)
- Step 3: Punch the y^x button and then type in the number from Step 1, then punch =.
  - 6000 y^x 0.25 = 8.8011

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Geometric Mean

- Geometric Mean – $(X_1)(X_2)(X_3)...(X_n)^{1/n}$
- Step 1: 1/n → 1 divided the number of test results. For our example above, there are four test results.
  - 1 ÷ 4 = 0.25 (write this number down, you will use it in Step 3)
- Step 2: Multiply all of the test results together and punch the = button on the calculator. **Remember to count 0 as a 1**.
  - 60 x 100 x 1 x 1 = 6000 (Do Not clear out your calculator)
- Step 3: Punch the ^ button, then type in the number from Step 1, & then punch =.
  - 6000 y^x 0.25 = 8.8011

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Geometric Mean

- Now, try one on your own:
- 20, 20, 210, 350
- Geometric Mean = 73.6

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Geometric Mean

- ¼ = 0.25
- (20)(20)(210)(350) = 29,400,000
- $(29,400,000)^{0.25}$ = 73.6

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HACH® WATER ANALYSIS HANDBOOK

Bacteria, Coliform

Methods 8074, 8367*, and 10029**

Membrane Filtration Method

m-Endo, m-FC, m-FC/RA, m-TEC, modified m-TEC, M-EI, m-ColiBlue24®, and Pseudomonas Broth

Scope and Application: potable water, nonpotable water, recreation water, and wastewater

* USEPA accepted
** USEPA approved

Introduction

The Membrane Filtration (MF) method is a fast, simple way to estimate bacterial populations in water. The MF method is especially useful when evaluating large sample volumes or performing many coliform tests daily.

Method

In the initial step, an appropriate sample volume passes through a membrane filter with a pore size small enough (0.45 micron) to retain the bacteria present. The filter is placed on an absorbent pad (in a petri dish) saturated with a culture medium that is selective for coliform growth. The petri dish containing the filter and pad is incubated, upside down, for 24 hours at the appropriate temperature. After incubation, the colonies that have grown are identified and counted using a low-power microscope.

Convenient Packaging

Hach PourRite™ Ampules contain prepared selective media. This eliminates the measuring, mixing, and autoclaving needed when preparing dehydrated media. The ampules are designed with a large, unrestrictive opening that allows media to pour out easily. Simply break off the top of the ampule and pour the medium onto an absorbent pad in a petri dish.

Each ampule contains enough medium for one test. Medium packaged in PourRite Ampules has a shelf-life of one year. Ampules are shipped with a Certificate of Analysis and have an expiration date printed on the label.

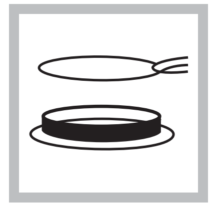
Tips and Techniques

- When the sample is less than 20 mL (diluted or undiluted), add 10 mL of sterile dilution water to the filter funnel before applying the vacuum. This aids in distributing the bacteria evenly across the entire filter surface.
- The volume of sample to be filtered will vary with the sample type. Select a maximum sample size to give 20 to 200 colony-forming units (CFU) per filter. The ideal sample volume of nonpotable water or wastewater for coliform testing yields 20–80 coliform colonies per filter. Generally, for finished, potable water, the volume to be filtered will be 100 mL.

Using m-ColiBlue24 Broth PourRite Ampules

The m-ColiBlue24 Broth can be used to analyze drinking water, bottled water, beverages; surface, well, and groundwater, waste water, recreational waters, and process water for ultrapure, chemical processing and pharmaceutical applications.

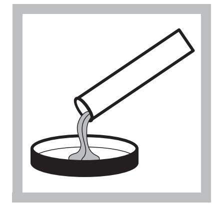
Simultaneous Total Coliform and E.coli Screening — Method 10029



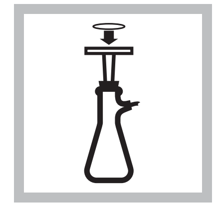
1. Use sterilized forceps to place a sterile, absorbent pad in a sterile petri dish. Replace the lid on the dish.

Note: *Do not touch the pad or the inside of the petri dish.*

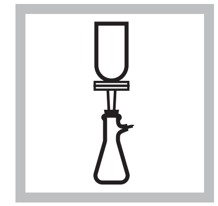
Note: *To sterilize the forceps, dip them in alcohol and flame in an alcohol or Bunsen burner. Let the forceps cool before use.*



2. Invert ampules two or three times to mix broth. Break open an ampule of m-ColiBlue24 Broth using an ampule breaker. Pour the contents evenly over the absorbent pad. Replace the petri dish lid.

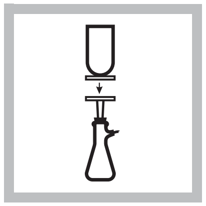


3. Set up the Membrane Filter Apparatus. With sterile forceps, place a membrane filter, grid side up, into the assembly.

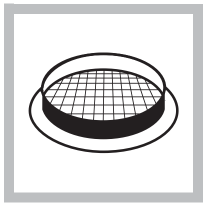


4. Shake the sample vigorously to mix. Pour 100 mL of sample or diluted sample into the funnel. Apply vacuum and filter the sample. Rinse the funnel walls three times with 20 to 30 mL of sterile buffered dilution water.

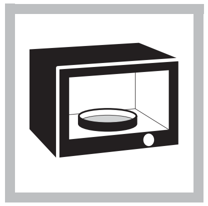
Bacteria, Coliform



5. Turn off the vacuum and lift off the funnel top. Using sterile forceps, transfer the filter to the previously prepared petri dish.



6. With a slight rolling motion, place the filter, grid side up, on the absorbent pad. Check for trapped air under the filter and make sure the filter touches the entire pad. Replace the petri dish lid.



7. Invert the petri dish and incubate at 35 ±0.5 °C for 24 hours.

8. Remove the petri dish from the incubator and examine the filters for colony growth. Colonies are typically readily visible; however, a stereoscopic microscope or other 10–15X magnifier may be useful. Red and blue colonies indicate total coliforms and blue colonies specifically indicate *E. coli*.

Note: *Sometimes only the center of a colony will be colored. Therefore, a colony with any amount of red color should be counted as red and a colony with any amount of blue should be counted as a blue colony. Red colonies may vary in color intensity. Blue colonies may appear blue to purple. Count all the red and blue colonies as total coliforms. Count all the blue to purple colonies as* E. coli.

Optional Testing of Red Colonies

The m-ColiBlue24 Broth is formulated so that coliforms other than *E. coli* grow as red colonies. The percentage of red colonies that are false positives (non-coliforms) is comparable to the percentage of sheen colonies grown on m-Endo Broth that are false positives (non-coliforms); therefore, confirmation is not required.

A few varieties of the non-coliform bacteria *Pseudomonas, Vibrio,* and *Aeromonas* spp. may grow on m-ColiBlue24 Broth and form red colonies. Such bacteria can be readily distinguished from total coliforms by the oxidase test. *Pseudomonas, Vibrio*, and *Aeromonas* spp. are oxidase-positive. Total coliforms and *Escherichia coli* are oxidase-negative. If your sample contains high levels of interfering bacteria, you can perform an oxidase test to confirm which red colonies are total coliforms.

Wastewater Microbiological Tests

Sample	Test Method	Reporting	Number
100 mL Effluent	Colilert with QuantiTray	E. coli/100 mL	
100 mL Dilution Water	mFC Broth	Fecal Coliforms/100 mL	
25 mL Effluent	mFC Broth	Fecal Coliforms/100 mL	
100 mL Effluent	mFC Broth	Fecal Coliforms/100 mL	
50 mL Effluent	mColiBlue24	E. coli/100 mL	
100 mL Effluent	mColiBlue24	E. coli/100 mL	
QC Sample	mColiBlue24	E. coli/100 mL	

Section 7

Fats, Oils and Grease

Fats, Oil and Grease Control

Fleming Training Center

TDEC
TENNESSEE DEPARTMENT OF ENVIRONMENT AND CONSERVATION

TDEC - Fleming Training Center

Introduction

- Review information presented in Tennessee Oil and Grease Control Document, June 2002, TDEC.
- Editors: Jennifer Peters Dodd and Roger D. Lemasters, TDEC.
- Purpose: Tool for municipalities to create regulations and enforcement plans dealing with oil and grease on a local level.

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Background

- Oil and grease in sewers causing problems for many TN cities.
- Contributing factors:
  - increase in restaurants
  - aging collection system
  - decrease in disposal options

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Background

- Federal pretreatment regulations (40 CFR 403.5(b)(6)) specifically prohibit petroleum oil, non-biodegradable cutting oil, or products of mineral origin in amounts that will cause interference or pass through.
- Few cities have regulations that specify limits and enforcement of oil and grease discharges from restaurants.

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Background

- Minimizing oil and grease discharges to collection system will reduce sewer blockages and sewage backup into service laterals.
- Guidance document focuses on edible oil and grease from restaurants and other food processors (prisons, churches, schools, etc.)

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Contents

- Introduction
- Fats, Oil, and Grease Limits
- Preventing Grease from Entering the Sewer Collection System
- Grease Separation Devices
- Disposal Options
- Education
- Appendices

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Characteristics of Oil & Grease

- Found in wastewater as an emulsion or free-floating agglomerates.
- WEF's Pretreatment of Industrial Wastes, Manual of Practice FD-3 defines grease as: "fats, oils, waxes, and soaps according to their effect on wastewater collection and treatment systems and their physical (semisolid) forms".
- FOG: general term for fats, oil, and grease.

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Characteristics of Oil &Grease

- Due to its structure, grease collects on cool internal surfaces of sewers
  - blockages
  - grease logs
- Grease also accumulates due to cooling and dilution of surfactants, that allows grease to separate and collect on pipes and wet wells
  - fouling of controls
  - prevent proper operation of pumps

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Characteristics of Oil &Grease

- Grease blockages may lead to sewage backup at service laterals or manholes.
- Sewer agency is responsible for any damage that occurs.
- If the damage results in a violation of a permit issued by TDEC-DWR, enforcement action against the sewer agency is possible.

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Fats, Oil and Grease Limits

- When setting FOG limits, cities must consider:
  - protection of CS and WWTP
  - practicality of monitoring and enforcement
  - cost and manpower needed for enforcement

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Numerical Limits

- Most commonly used limit is 100 mg/L.
- Some cities specify different FOG limits for FOG from different sources.
- Limits may vary due to:
  - number of wet wells
  - sewer type, slope, and flow
  - sewer O & M
  - history of grease related clogs

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Numerical Limits

- EPA suggested influent to biological treatment contain less than 50 mg/L of FOG and that dilution in CS would reduce any 100 mg/L discharges to acceptable levels for the WWTP.
- Use of numerical limits allow uniform regulation of local restaurants.
- FOG analysis is somewhat costly and some restaurants resist paying for sampling.

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Numerical Limits

- Instead, may use temperature limit for grease trap effluent.
- Grease traps are not effective if temperature is too high (85°F).
- Numerical temperature limits can aid in applying and enforcing limits.
- Can easily be monitored.
- Cannot guarantee grease trap is properly maintained and operated.

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Best Management Practices (BMP)

- Effective tool in controlling FOG without requiring extensive monitoring
  - dry wiping pots, pans, and dishware
  - discontinue use of garbage grinders
  - routine cleaning of grease traps
  - retain copies of grease trap hauler manifests
  - place oil recycle container in convenient location

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Numerical Limits vs. BMP

- Cities may consider surcharging restaurants for high-strength BOD and suspended solids.
- Whether numerical limits or BMPs are used, authority for the FOG program is based on the local sewer use ordinance.
- Should not conflict with local building codes, plumbing codes, and health department regulations.

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Sampling

- Collect as grab samples
- Specially cleaned 1 L wide-mouth glass container
- Preserve with HCl or H_2SO_4 to pH < 2
- Refrigerate at 6°C or less up to 28 days
- Sample at peak flows to determine adequacy of equipment
- For surcharge purposes, sample at average flow

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Sampling

- Frequency depends on the need for data
- Perform surcharge monitoring monthly
- When scheduling compliance monitoring consider:
  - staff availability
  - cost of sampling
  - compliance history of the facility
- May be scheduled or unannounced

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Analysis

- New EPA-approved FOG method is Method 1664
- Uses hexane instead of freon
- More labor intensive than Method 413.1
- Average price for analysis is similar

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Preventing Grease From Entering Sewers

- The most economical and prudent method is proper pretreatment of waste streams to reduce or eliminate grease.
- Since waste streams vary, consider several options.

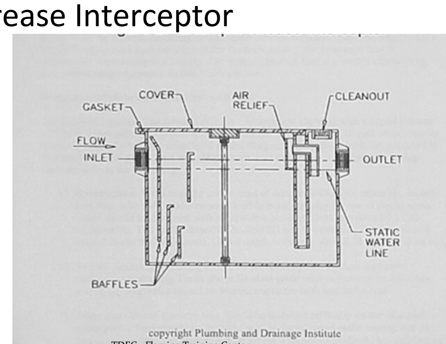
Zero Discharge of FOG

- Scrape food into solid waste container
- Scrape cookware before washing
- No garbage grinders
- Train restaurant managers and employees in disposal of cooking oil in recycling containers

Grease Removal Devices

- Must remove emulsified and free-floating FOG
- Three types:
  - passive under-sink devices
  - large outside passive devices
  - mechanical devices

Grease Interceptor



Preventing Grease from Entering Sewers

- Remember, multiple sources of FOG in restaurant kitchens
- Commercial/residential sources of FOG:
  - food manufacturers and processors
  - food providers
  - normal cooking and cleaning in homes

Use of Additives by Facilities

- Should be regulated by the Control Authority.
- Solvents, caustics, and acids dissolve FOG, but can harm WWTP and its workers.
- Enzymes and detergents dissolve FOG, but this reaction is often reversible. This benefits the restaurant, but causes accumulation in downstream areas.
- Bacteria consume grease-must use proper microorganisms; often more effective in CS.

Grease Separation Devices

- Grease trap or interceptor consists of enclosed chamber, designed to separate and retain oil and grease from wastewater.
- Fats and greases have lower specific gravity than water and rise to surface.
- Wastewater passes through to sewer.
- Periodic cleaning needed to remove accumulated grease and settled solids, restoring separation volume.

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Criteria to Ensure Separation

- Time: retention time to allow emulsified grease and oil to separate and float.
- Temperature: adequate volume to allow wastewater to cool, allowing FOG to separate.
- Turbulence: during high discharge rates, ensure solids and grease are not kept in suspension.

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Passive Separation Devices

- Small Point-of-Use Interceptors:
  - installed near wastewater source
  - fabricated steel
  - sized by storage capacity and flow

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Passive Separation Devices

- Precast In-Ground Traps:
  - concrete with min. 2 compartments
  - manhole for cleaning/inspection
  - min. 2 hrs detention time at design flow, modified by a loading factor
  - inspect and clean regularly
  - sampling ports in inlet and outlet piping

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Automatic Separation Devices

- Trap and remove free-floating grease and oils (and sometimes accumulated solids)
- Stainless steel enclosure, internal baffles, removable solids separator screen, grease level sensing probe, electric heater element, and skimmer or dipper.

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Automatic Separation Devices

- Heat accumulated grease to 115-130°F so it melts and can be dipped or skimmed off to a separate storage container.
- Typically not located after dishwashers since detention times are inadequate to break hot, detergent-laden grease and water emulsions.

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Disposal Options: Pumping

- Ultimate disposal of FOG is important part of a FOG control program.
- Traps should generally be pumped when grease and solids combined measure 30% of the depth of the tank.
- TDEC recommends pumping the entire contents of the trap, followed by cleaning with a scraper. Tees, baffles and bottom are then inspected.

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Disposal Options: Recycling

- Encourage facility managers stress waste cooking oil be placed only in recycle container
- Uses: dust suppressant, manufacturing lubricant, and binder for pesticides and fertilizers to help them stick to plants when sprayed on fields.

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Disposal Options: Land Application

- To landfill, must pass paint filter test.
- Most grease trap waste contains free water, so must therefore be dewatered:
  - add absorbent (sawdust, straw, etc.)
  - mechanical drying or drying bed
  - mechanical dewatering (JEA uses gravity draining and vacuum filtration with polymer)

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Education

- To ensure your FOG control program is successful, you must educate:
  - public officials
  - restaurants and other facilities
  - recyclers
  - public (civic and environmental groups, scouts, local media, etc.)

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Information Sources

- Oregon Association of Clean Water Agencies' FOG BMP Manual
  - www.oracwa.org/pages/intro.htm
- North Carolina Pollution Prevention
  - www.p2pays.org/food/index.htm
- Town of Cary, NC
  - http://townofcary.org/grease/

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EXAMPLE FOG ORDINANCE

ORDINANCE NO. _______

AN ORDINANCE TO REGULATE ANIMAL AND VEGETABLE FATS, OILS AND GREASE AS WELL AS SOIL/SAND AND LINT TRAPS AND INTERCEPTORS.

BE IT ENACTED BY THE ________________________________ OF THE CITY OF ________________________________, TENNESSEE, THAT: [Or whatever introductory provision, if any, is required by the city's charter.]

Section 1. Purpose. The purpose of this ordinance is to control discharges into the public sewerage collection system and treatment plant that interfere with the operations or the system, cause blockage and plugging of pipelines, interfere with normal operation of pumps and their controls and contribute waste of a strength or form that is beyond the treatment capability of the treatment plant.

Section 2. Fat, Oil, and Grease (FOG),waste food, and sand interceptors. FOG, waste food and sand interceptors shall be installed when, in the opinion of the Superintendent, they are necessary for the proper handling of liquid wastes containing Fats, Oils, and Grease, ground food waste, sand, soil, and solids, or other harmful ingredients in excessive amounts which impact the wastewater collection system. Such interceptors shall not be required for single family residences, but may be required on multiple family residences. All interceptors shall be of a type and capacity approved by the Superintendent, and shall be located as to be readily and easily accessible for cleaning and inspection.

Section 3. Definitions. In the interpretation and application of this chapter the following words and phrases shall have the indicated meanings:

(1) "Interceptor." A devise designed and installed to separate and retain for removal, by automatic or manual means, deleterious, hazardous or undesirable matter from normal wastes, while permitting normal sewage or waste to discharge into the drainage system by gravity.

(2) "Grease Trap." An interceptor whose rated flow exceeds 50 g.p.m. and is located outside the building.

(3) "Grease Interceptor." An interceptor whose rated flow is 50 g.p.m. or less and is typically located inside the building.

Section 4. Fat, Oil, Grease, and Food Waste. (1) New construction and renovation. Upon construction or renovation, all restaurants, cafeterias, hotels, motels, hospitals, nursing homes, schools, grocery stores, prisons, jails, churches, camps, caterers, manufacturing plants and any other sewer users who discharge applicable waste shall submit a FOG and food waste control plan that will effectively control the discharge of FOG and food waste.

(2) Existing structures. All existing restaurants, cafeterias, hotels, motels, hospitals, nursing homes, schools, grocery stores,

prisons, jails, churches, camps, caterers, manufacturing plants and any other sewer users who discharge applicable waste shall be required to submit a plan for control of FOG and food waste, if and when the Superintendent determines that FOG and food waste are causing excessive loading, plugging, damage or operational problems to structures or equipment in the public sewer system.

(3) Implementation of plan. After approval of the FOG Plan by the Superintendent the sewer user must: implement the plan within a reasonable amount of time; service and maintain the equipment in order to prevent adverse impact upon the sewer collection system and treatment facility. If in the opinion of the Superintendent the user continues to impact the collection system and treatment plant, additional pretreatment measures may be required.

Section 5. Sand, soil, and oil interceptors. All car washes, truck washes, garages, service stations and other sources of sand, soil, and oil shall install effective sand, soil, and oil interceptors. These interceptors will be sized to effectively remove sand, soil, and oil at the expected flow rates. These interceptors will be cleaned on a regular basis to prevent impact upon the wastewater collection and treatment system. Owners whose interceptors are deemed to be ineffective by the Superintendent may be asked to change the cleaning frequency or to increase the size of the interceptors. Owners or operators of washing facilities will prevent the inflow of rainwater into the sanitary sewers.

Section 6. Laundries. Commercial laundries shall be equipped with an interceptor with a wire basket or similar device, removable for cleaning, that prevents passage into the sewer system of solids ½ inch or larger in size such as ,strings, rags, buttons, or other solids detrimental to the system.

Section 7. Control equipment. The equipment or facilities installed to control FOG, food waste, sand and soil, must be designed in accordance with Southern Plumbing Code and Tennessee Department of Environment and Conservation engineering standards or applicable city guidelines. Underground equipment shall be tightly sealed to prevent inflow of rainwater and easily accessible to allow regular maintenance. Control equipment shall be maintained by the owner or operator of the facility so as to prevent a stoppage of the public sewer, and the accumulation of FOG in the lines, pump stations and treatment plant. If the City is required to clean out the public sewer lines as a result of a stoppage resulting from poorly maintained control equipment, or lack there of, the owner or operator shall be required to refund the labor, equipment, materials and overhead costs to the City. Nothing in this section shall be construed to prohibit or restrict any other remedy the City has under this ordinance, or state or federal law.

The City retains the right to inspect and approve installation of the control equipment.

Section 8. Solvents Prohibited. The use of degreasing or line cleaning products containing petroleum based solvents is prohibited.

Section 9. Enforcement and penalties. Any person who violates this ordinance shall be guilty of a civil violation punishable under and according to the general penalty provision of the City's municipal code of ordinances. Each day's violation of this ordinance shall be considered a separate offense.

Section 10. Alteration of Control Methods. The city through the Superintendent reserves the right to request additional control measures if measures taken are shown to be insufficient to protect sewer collection system and treatment plant from interference due to the discharge of fats, oils, and grease, sand/soil, or lint.

Section 11. Each section, subsection, paragraph sentence, and clause of this ordinance, is declared to be separable and severable.

Section 12. [Ordinance publication requirements or other formalities, upon which the legality of the ordinance depends, may be stated here.]

Passed first reading: ________________________________

Passed second reading: ______________________________

____

(Mayor)

____

(Recorder)

Town of Cary
Sewer Use Ordinance – Fats, Oils, and Grease Control

Adopted by Town Council: December 10, 1998
Modified by Town Council: August 10, 2006

Sec. 36-183. Fat, oil, and grease control

(a) *Scope and purpose.* The objective of this section is to aid in preventing the introduction and accumulation of fats, oils, and greases into the municipal wastewater system which will or tend to cause or contribute to sanitary sewer blockages and obstructions. Food Service Establishments and other industrial or commercial establishments generating wastewater containing fats, oils or greases are subject to this section. This section regulates such users by requiring that grease interceptors and other approved strategies be installed, implemented, and maintained in accordance with the provisions hereof.

(b) *Definitions.* The definitions contained in Section 36-172 and the following terms, when used in this section, shall apply.

Action Level means the concentration based numeric value that the Grease interceptor effluent, at the device's outlet tee and prior to mixing with any other waste water from the contributing establishment's property, are expected to achieve on a consistent or stipulated basis.

Common interceptor means one or more interceptors receiving FOG laden wastewater from more than on establishment. Common interceptors may be located at shopping centers, malls, entertainment complexes, sporting arenas, hotels, multi-tenant "flex" spaces, mixed use spaces, and other sites where multiple establishments are connected to a single grease interceptor. The owner of the property on which the common grease interceptor is located shall be primarily responsible for the maintenance, upkeep, and repair of the common interceptor.

Fats, oils, and greases means organic polar compounds derived from animal and/or plant sources that contain multiple carbon chain triglyceride molecules. These substances are detectable and measurable using analytical test procedures established in 40 CFR 136, as may be amended from time to time. All are sometimes referred to herein as "grease" or "greases~~.~~" or "FOG".

Food Service Establishments or "FSE" means those establishments primarily engaged in activities of preparing, serving, or otherwise making available for consumption foodstuffs and that use one or more of the following preparation activities: Cooking by frying (all methods), baking (all methods), grilling, sautéing, rotisserie cooking, broiling (all methods), boiling blanching, roasting, toasting, or poaching, and infrared heating, searing, barbecuing, and any other food preparation or serving activity that produces a consumable food product in or on a receptacle requiring washing to be reused.

FOG enforcement response plan means the document and written plan and procedures by which the director implements an enforcement strategy applicable to the FOG control and management program established herein. The plan applies to FOG program violations and matters of program noncompliance. Stipulated penalties for specific and programmatic infractions are addressed in the plan and set forth in the Town's annual budget ordinance. The director shall make site and case specific determinations of program non-conformance in accordance with this Division 2.

Grease trap or interceptor means a device for separating waterborne greases and grease complexes from wastewater and retaining such greases and grease complexes prior to the wastewater exiting the trap and entering the sanitary sewer collection and treatment system. Grease traps also serve to collect solids that settle, generated by and from activities that subject Users to this section, prior to the water exiting the trap and entering the sanitary sewer collection and treatment system. Grease traps and interceptors are sometimes referred to herein as "grease interceptors."

Minimum design capability means the design features of a grease interceptor and its ability or volume required to effectively intercept and retain greases and settled solids from grease-laden wastewaters discharged to the public sanitary sewer.

Noncooking establishments means those establishments primarily engaged in the preparation of precooked foodstuffs that do not include any form of cooking: but that may produce a consumable food product in or on a receptacle requiring washing to be reused.

Town of Cary
Sewer Use Ordinance – Fats, Oils, and Grease Control

On-site grease interceptor treatment (sometimes "Onsite Treatment") means mechanisms or procedures utilized by a User to treat grease interceptor contents on the User's site, followed by the reintroduction of such treated wastewater back into the interceptor. On-site grease interceptor treatment may only be accomplished by a User if the User or the User's contract service provider is permitted by the NC Division of Waste Management as a septage management firm or service provider.

Program Acknowledgement Certificate means program confirmation documentation issued by the Director. The User is required to keep Program Acknowledgement Certificate on premises and produce it upon request of Town of Cary.

Service provider means any third party not in the employment of the User that performs maintenance, repair, and other services on a User's grease interceptor at the User's directive.

User is as defined in Section 36-172 for the purpose of this Section. Users include property owners who provide common interceptors for one or more independent establishments, including tenants.

(c) *Grease interceptor installation, maintenance, recordkeeping, and grease removal.*

(1) Grease interceptors shall be installed and maintained at the User's expense, when a User operators a food service establishment. Grease interceptors may be required in noncooking or cold dairy and frozen foodstuffs establishments and other industrial or commercial establishments when the establishment generates wastewater containing fat or grease and the director determines an interceptor is necessary to prevent contribution or accumulation of grease to the sanitary sewer collection and treatment system. Upon notification by the Director or designee that the User is subject to the terms of an enforcement action, as stipulated in the FOG Enforcement Response Plan, said user shall not allow wastewater discharge concentration from subject grease interceptor to exceed an establishment action level of 200 milligrams per liter, expressed as Hexane Extractable Material. All grease interceptors shall be of a type, design, and capacity approved by the director and shall be readily and easily accessible for maintenance and repair, including cleaning and for town inspection. All grease interceptors shall be serviced and emptied of accumulated waste content as required in order to maintain minimum design capability or effective volume of the grease interceptor, but not less often than every sixty (60) days or as permitted in a valid program modification. Users who are required to pass wastewater through a grease interceptor shall:

a. Provide for a minimum hydraulic retention time of 24 minutes at actual peak flow between the influent and effluent baffles, with twenty-five percent (25%) of the total volume of the grease interceptor being allowed for any food-derived solids to settle or accumulate and floatable grease-derived materials to rise and accumulate, identified hereafter as a solids blanket and grease cap respectively."

b. Remove any accumulated grease cap and solids blanket as required, but at intervals of not longer than sixty (60) days at the user's expense, or in accordance with a valid program modification or other director's requirements. Grease interceptors shall be kept free of inorganic solid materials, such as grit, rocks, gravel, sand, eating utensils, cigarettes, shells, towels, rags, etc., which could settle into this solids blanket and thereby reduce the effective volume of the grease interceptor.

c. If the User performs on-site grease interceptor treatment pursuant to a modification granted under 36-183(g)(5) below, User shall

1. Prior to commencement of Onsite Treatment obtain written approval by and from the Director of all processes utilized in said Onsite Treatment.

2. If any pumped wastes or other materials removed from the grease interceptor are treated in any fashion on-site and reintroduced back into the grease interceptor as an activity of and after such on-site treatment, the user shall meet the criteria contained in (c)(1)(c)(3) below.

3. Attain and adhere to the criteria listed below:

a. After 30 minutes of settling time, not more than 3.0 ml/L of settlable solids, as measured in a 1 liter Imhoff cone shall be allowed, and;
b. Within and not more than 24 hours after onsite grease interceptor servicing, not more than 2” (inches) of settlable solids and/or grease shall be allowed to have accumulated therein as a result of said operations.
c. Service vehicles and equipment used in onsite Grease interceptor servicing shall be registered with the Public Works and Utilities Department, and as required by the North Carolina Division of Waste Management.
d. When servicing Grease interceptors service vehicles and equipment shall have onboard, at all times, a certificate of approval for the operations and methods used, issued by the Director.
e. Any tanks, tankage, or vessel(s) associated with a modification shall be empty upon arrival at the initial FSE user site for which this modification is intended to be applied.

d. Operate and maintain the grease interceptor to achieve and consistently maintain any applicable grease action level . "Consistent" shall mean any wastewater sample taken from such grease interceptor must meet the terms of numerical limit attainment described in subsection (c)(1). If a User documents that conditions exist (“space constraints”) on their establishment site that limit the ability to locate a grease interceptor on the exterior of the establishment, the User may request an interior location for the interceptor. Such request shall contain the following information:

1. Location of town sewer main and easement in relation to available exterior space outside building.

2. Existing plumbing layout at or in a site.

3. A Statement of Understanding, signed by the User or authorized agent, acknowledging and accepting conditions Director may place on permitting an identified interior location. Conditions may include requirements to use alternative mechanisms, devices, procedures, or operations relative to an interior location.

4. Such other information as may be required by the Director.

e. The use of biological or other additives as a grease degradation or conditioning agent is permissible only upon prior written approval of the director. Any User using biological or other additives shall maintain the trap or interceptor in such a manner that attainment of any grease wastewater, action level, solids blanket or grease cap criteria, goal or directive, as measured from the grease interceptor outlet or interior, is consistently achieved.

f. The use of automatic grease removal systems is permissible only upon prior written approval of the director, the lead plumbing inspector of the town, and the Wake County Department of Environmental Services or the US Department of Agriculture. Any user using a grease interceptor located on the interior of the site shall be subject to any operational requirements set forth by the North Carolina Division of Waste Management. Any User using this equipment shall operate the system in such a manner that attainment of the grease wastewater discharge limit, as measured from the unit's outlet, is consistently achieved as required by the Director.

g. The director may make determinations of grease interceptor adequacy need, design, appropriateness, application, location, modification(s), and conditional usage based on review of all relevant information regarding grease interceptor performance, facility site and building plan review by all regulatory reviewing agencies and may require repairs to, or modification or replacement of grease interceptors.

(2) The user shall maintain a written record of grease interceptor maintenance for three years. All such records will be available for inspection by the town at all times. These records shall include:

a. FSE name and physical location
b. Date of grease interceptor service
c. Time of grease interceptor service
d. Name of grease interceptor service company
e. Name and signature of grease interceptor service company agent performing said service
f. Established service frequency and type of service: full pumpout, partial pumpout, on-site treatment (type of nature of operations)
g. Number and size of each grease interceptor serviced at FSE location
h. Approximated amount, per best professional judgement of contract service provider, of grease and solids removed from each grease interceptor
i. Total volume of waste removed from each grease interceptor
j. Destination of removed wastes, food solids, and wastewater disposal
k. Signature and date of FSE personnel confirming service completion
l. Such other information as required by Director

(3) No nongrease-laden sources are allowed to be connected to sewer lines intended for grease interceptor service.

(4) Access manholes shall have an installed diameter of 24 inches, a maximum weight of 50 pounds, and shall be provided over each chamber, interior baffle wall, and each sanitary tee. The access penetrations, commonly referred to as “risers” into the grease interceptor shall also be, at a minimum, 24 inches in diameter. The access manholes shall extend at least to finished grade and be designed and maintained to prevent water inflow or infiltration. The manholes shall also have readily removable covers to facilitate inspection, grease removal, and wastewater sampling activities.

(5) A User may request a modification to the following requirements of this ordinance. Such request for a modification shall be in writing and shall provide the information set forth below.

(a) *The user’s grease interceptor pumping frequency.* The Director may modify the 60 day grease interceptor pump out frequency when the User provides data, and performance criteria relative to the overall effectiveness of a proposed alternate and such can be substantiated by the Director. Proposed alternatives may include: grease interceptor pumping or maintenance matters, bioremediation as a complement to Grease interceptor maintenance, Grease interceptor selection and sizing criteria, onsite grease interceptor maintenance, and specialized ware washing procedures

(b) *Grease interceptor maintenance and service procedures*. The Director may modify the method(s) or procedure(s) utilized service a grease interceptor when the User provides data, and performance criteria relatie to the overall effectiveness of a proposed alternate method or procedure and such can be substantiated by the Director. If a modification to maintenance and service procedures is permitted it shall be a conditional discharged permit approval.

(c) Any modification must be approved by the Director in written form before implementation by the User or the user’s designated service provider. The User shall pay modification fees as set forth in the Budget Ordinance Fee Schedule.

Sec. 36-184. Severability.

If any provision, paragraph, word, section or article of this division is invalidated by any court of competent jurisdiction, the remaining provisions, paragraphs, words, sections, and chapters shall not be affected and shall continue in full force and effect.

Sec. 36-185. Conflict.

All other ordinances and parts of other ordinances inconsistent or conflicting with any part of this division are hereby repealed to the extent of such inconsistency or conflict.

Hamilton County Water & Wastewater Treatment Authority

FOOD SERVICE ESTABLISHMENT GREASE CONTROL INSPECTION FORM

Inspection Date: ____________________

Facility Name: ____________________

Facility Representative: Mr./Ms. ____________________ **Title:** ____________________

Phone: ____________________ **Owner/Regional Manager Name:** ____________________

Facility Address: ____________________ Mail Address; ____________________

____________________ (if different) ____________________

Sewer Map ID: ____________________ **Sewer Plat ID:** ____________________ **GPS ID:** ____________________

1. Grease Interceptor? ___Yes ___ No
(For #1, if "NO" then go to #14)

2. Interceptor Size (gallons) ___500 ___750 ___1000 ___1500 ___2000 ___3000 ___Two interceptors in series Other____________________

3. Manhole Access to interceptor: __1 __2 __3 __4

4. Estimated Grease Layer Depth: ____________________

5. Effluent T visible? ___Yes ___No
(inspector can see the T)

6. Effluent T attached &in good condition: ___Yes ___No ___Unknown

7. Grease Interceptor Hauler Used: ____________________

8. Bacteria / Enzymens used: ___Yes ___No

9. Product Name: ____________________

10. Frequency Interceptor Cleaned? ____________________

11. Complete Contents Pumped? ___Yes ___No

12. Records of Maintenance/Cleaning Available? ___Yes ___No

13. Last date cleaned: ____________________

Grease Trap

14. Grease Trap? ___Yes ___No
(For #14, if "NO" then go to #20)

15. Location: ___Under sink trap ___Floor trap ___Outside "floor" trap

16. Grease Trap flow-through rating / grease capacity Estimate: ___5 gpm/10 lb ___10 gpm/ 20 lb ___15 gpm/ 30 lb ___20 gpm/40 lb ___35 gpm/70 lb ___50 gpm/100 lb ___ Other: ____________________

17. Frequency Trap is cleaned: ____________________

18. Maintenance/Cleaning Records: ___Yes ___ No

19. Grease Trap comments/location disposed of waste: ____________________

BMPs & outside conditons, other than grease interceptor or trap

20. Best Management Practices Implemented ___Yes ___No

21. Grease Recycle Bin ___Yes ___No

22. Cleanout Covers missing or damaged? ___Yes ___No (# Cleanout covers missing: _____ damaged: _____)
(Facility needs to repair missing or damaged cleanout covers immediatley)

23. FOG impact at dumpster or around recycle bin? ___Yes ___No (if Yes, give explanation below)

24. DOWNSTREAM MANHOLE: ___ Evidence of Grease in Manhole (___slight ___moderate ___heavy)

Comments: ____________________

25. SAMPLE POINT Access? ___Yes ___No Effluent Temp:____________________ Effluent pH:____________________

26. Sample point ID: ___ Interceptor Effluent T ___Downstream MH ___Cleanout ___Sample drop box

27. Picture ID: __________ // ______ **of Interceptor ___ of downstream MH ___other:** ____________________

Visual inspection results, comments: ____________________

____

____

Inspector Name: ____________________ Signature: ____________________

Facility Representative Signature: ____________________

Inspection form copy provided to facility? ___Yes

Section 8

Biosolids

Sludge Thickening, Digestion, and Dewatering

- or -

Now What Do We Do With It?

TDEC
TENNESSEE DEPARTMENT OF ENVIRONMENT AND CONSERVATION

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Sludge Types and Characteristics

- Primary sludge is defined as all suspended solids that are removed from the wastestream and that are not a by-product of biological removal of organic matter.
- Secondary sludge is from new bacterial cells that are produced as the bacteria feed on and degrade organic matter
  - Usually these bacterial cells are removed in the secondary clarifier to maintain the proper balance between food and microorganisms (F/M)

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Sludge Types and Characteristics

Primary Sludge

- Coarse and fibrous
- Higher density than water
- 40-80% volatile (organic) solids
- 20-60% nonvolatile (inorganic) solids

Secondary Sludge

- More flocculant, less fibrous
- Specific gravity close to water
- 75-80% volatile (organic) matter
- 20-25% nonvolatile (inorganic) matter

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Primary Sludge Production

- The quantity of primary sludge generated depends on:
  - Influent wastewater flow
  - Concentration of influent settleable suspended solids
  - Efficiency of the primary sedimentation basin

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Secondary Sludge Production

- The quantity of secondary sludge generated depends on:
  - Influent flow to the biological or secondary system
  - Influent organic load to the biological system
  - Efficiency of the biological system in removing organic matter
  - Growth rate of the bacteria in the system, which is highly dependent on:
    - Temperature
    - Nutrient balances
    - Amount of oxygen supplied to the system
    - Ratio between the amount of food supplied (BOD)
    - Mass quantity of biological cells developed within the system
    - Detention time
    - and other factors

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Secondary Sludge Production

- General rule of thumb that operators may use to estimate secondary sludge production is that for every pound of organic matter (soluble 5-day BOD) used by the bacterial cells, approximately 0.30 – 0.70 pounds of new bacterial cells are produced and have to be taken out of the system

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Sludge Thickening, Digestion, and Dewatering

- Thickening
  - Gravity
  - Floatation
  - Gravity belt
- Stabilization
  - Anaerobic digestion
  - Aerobic digestion
- Dewatering
  - Centrifuge
  - Plate and frame
  - Belt filter press
  - Vacuum filter
  - Drying beds

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Sludge Thickening

Main component of sludge is water

~90% or more before treatment

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Thickening

- Settled solids removed from the bottom of the primary clarifier (primary sludge) and settled biological solids removed from the bottom of secondary clarifiers (secondary sludge) contain large volumes of water
  - Primary sludge ≈ 95-97% water
    - For every pound of primary solids, there are 20-30 pounds of water
  - For every pound of secondary solids, approximately 50-150 pounds of water are incorporated in the sludge mass

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Thickening

- The advantages normally associated with sludge thickening include:
  - Improved digester performance due to a smaller volume of sludge
  - Construction cost savings for new digestion facilities due to smaller sludge volumes treated
  - A reduction in digester heating requirements because less water has to be heated

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Gravity Thickening

- Most effective on primary sludge
- Detention time is around 24 hours
- Thickening tank looks like a primary circular clarifier
- Monitored for blanket depth and sludge concentration
- Affected by temperature of sludge
  - Increased temperature will increase biological activity and gas production
- Separates solids into three zones
  - Clear supernatant
  - Sedimentation zone
  - Thickening zone

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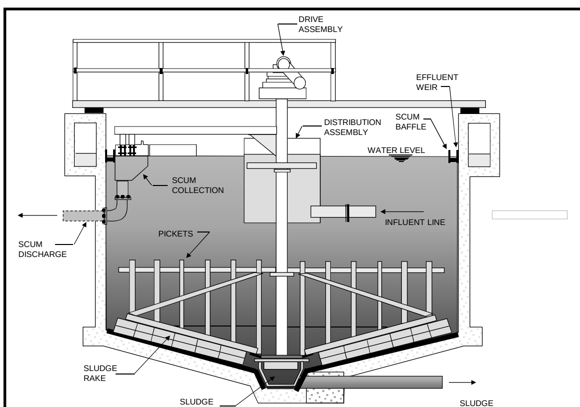

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GRAVITY THICKENER

Gravity Thickening

- Dilute sludge is fed into center well
- Sludge rake provides for movement of the settled (thickening) sludge.
  - As the rake slowly rotates, the settled solids are moved to the center of the tank where they are deposited in a sludge hopper.
- The vertical steel members (pickets) that are usually mounted on the sludge rake assembly provide for gentle stirring or flocculation of the settled sludge as the rake rotates
  - This gentle stirring action serves 2 purposes
  - Trapped gasses in the sludge are released to prevent rising of the solids
  - Also, stirring prevents accumulation of a large volume of solids (scum) floating on the thickener surface
- Supernatant is returned to primary clarifier or plant headworks
- Thickened sludge is pumped to digester or dewatered

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Factors Affecting Gravity Thickeners

- Type of sludge
- Age of the feed sludge
- Sludge temperature
- Sludge blanket depth
- Solids and hydraulic detention times
- Solids and hydraulic loadings

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Factors Affecting Gravity Thickeners

- Secondary sludges are not as well suited for gravity thickening as primary sludge
- Secondary sludges contain large quantities of bound water that makes the sludge less dense than primary sludge solids
  - Biological solids are composed of approximately 85-90% water by weight within the cell mass
  - The water contained within the cell wall is referred to as "bound water"
  - The fact that biological solids contain large volumes of cell water and are often smaller or finer than primary sludge solids makes them harder to separate by gravity concentration

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Factors Affecting Gravity Thickeners

- If sufficient oxygen is not available in the aeration basin or nutrient imbalances are present, filamentous organisms may grow in the aeration basin
- The predominance of these organisms will decrease the settleability of activated sludge and it will not settle as readily in the secondary clarifiers or compact to its highest degree in gravity thickeners
- Greater compaction can be achieved by the addition of chemicals

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Factors Affecting Gravity Thickeners

- As the temperature of the sludge (primary or secondary) increases, the rate of biological activity is increased and the sludge tends to gasify and rise at a faster rate
- During summertime (warm weather) operation, the settled sludge has to be removed at a faster rate from the thickener than during wintertime operations.

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Gravity Thickening

- Normal operating procedures:
  - Monitoring of the influent, effluent and concentrated sludge streams should be done at least once per shift and should include collection of samples for later laboratory analysis
  - Water at the surface should be relatively clear and free from solids and gas bubbles
  - The sludge blanket is usually kept around 5-8 feet
  - The speed of the sludge collectors should be fast enough to allow the settled solids to move toward the sludge collection sump
- On occasion, sludge in primary sedimentation tanks and gravity thickeners can become very thick and resistant to pumping.
  - If this happens, a hole (coning) can develop in the blanket and liquid from above the blanket can be pulled through the pump

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Flotation Thickener

- Treats waste activated sludge
  - Often with added polymers
- Dissolved-air flotation (DAF)
- Small amount of recycled water is aerated under pressure
- Air bubbles attach to the solids and carry them to the surface
- The "Float Cake" is skimmed off the surface
- Cake is 2 – 4% solids without polymer fed, or 3 – 5% solids with polymer fed
- Primary sludges are not easier to treat than biological sludges in a DAF

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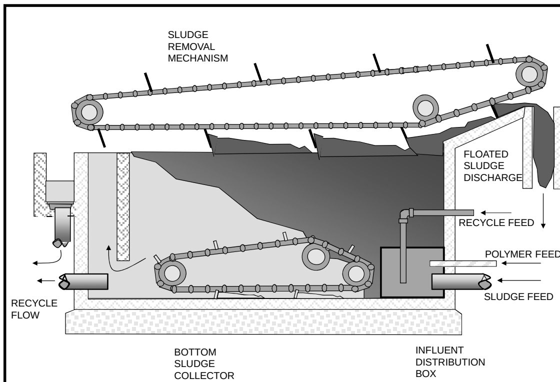

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Flotation Thickener

- The objective of flotation thickening is to separate solids from the liquid phase in an upward direction by attaching air bubbles to particles of suspended solids
  - Dispersed air flotation where bubbles are generated by mixers or diffused aerators
  - Biological flotation where gases formed by biological activity are used to float solids
  - Dissolved air (vacuum) flotation where water is aerated at atmospheric pressure and released under a vacuum
  - Dissolved air (pressure) flotation where air is put into solution under pressure and released at atmospheric pressure
- Flotation by dissolved air (pressure) is the most commonly used procedure for wastewater sludges

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Factors Affecting DAF

- Primary sludges are generally heavier than excess biological sludges and are not as easy to treat by flotation concentration
- Gritty or heavy primary sludge particles will settle and be deposited on the floor of the flotation unit and provisions should be made to remove these settled solids
- Sludge age usually does not affect flotation performance as drastically as it affects gravity concentrators.
  - A relatively old sludge has a natural tendency to float due to gasification and this natural buoyancy will have little or no negative effect on the operation of flotation thickeners

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Troubleshooting DAF

Operational Problem	Possible Cause	Check or Monitor	Possible Solution
1. Solids carry over with effluent but good float (thickened sludge) concentration	1. Float blanket too thick	1a.Flight Speed	1a. Increase flight speed
		1b. Solids loading	1b. Lower flow rate to unit; if possible
2. Good Effluent quality but float thin (dilute	2. Float blanket too thin	2a. Flight speed	2a. Decrease flight speed
		2b. Solids loading	2b. Increase flow rate; if possible
3. Poor effluent quality and thin (dilute) float	3a. Air to Solids Raito (A/S) is low	3a(1) Air rate (2) Compressor	3a(1) Increase air input (2) Repair or turn on compressor
	3b. Pressure too low or too high	3b. Pressure gauge	3b. Open or close valve
	3c. Recycle pump inoperative	3c. Pressure gauge and pump	3 c. Turn on recycle pump.
	3d. Rearation pump inoperative	3d. Pump pressure	3d. Turn on rearation pump
	3e. Chemical addition inadequate	3e. Chemical system	3e. Increase chemical dosage
	3f. Loading excessive	3f. Loading rates	3f. Lower flow rate

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Gravity Belt Thickener

- Very effective sludge thickening alternative for secondary sludges
- Sludge to be thickened is preconditioned (usually with a polymer) then applied to the gravity belt thickener where free water drains through small openings in the belt and is collected in a trough below the belt.

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Gravity Belt Thickener

- Belts are available in a variety of materials (nylon, polypropylene) each with various porosities
  - As the porosity increases, the resistance to flow decreases and larger volumes of water are able to be drained
  - If the porosity is too large, sludge solids may pass through the belt and result in poor filtrate quality
  - If the porosity is too low, the belt may bind or plug, which will produce frequent washouts
    - Washout occurs when a large quantity of free water is unable to be released in the drainage zone and it travels to the discharge end where it is carried out with the thickened sludge.
- With proper operating conditions, secondary sludges can be thickened from concentrations of 0.3-0.6% suspended solids to concentrations of 4-6% suspended solids

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Gravity Belt Thickener

- The belt speed can be varied from approximately 2-10 ft/min
- The speed at which the belt should be operated depends on the sludge flow rate to the belt and the concentration of the influent sludge
- As the belt speed is increased, the rate of belt area contacting the influent sludge also increases and allows for greater volumes of water to drain, belt washout will cause a reduction in the thickened sludge concentration.
  - As the concentration of influent sludge increases, less water is associated with the sludge mass and reduced belt speed can be used.
  - The ideal operating belt speed is the slowest the operator can maintain without washing out the belt.

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Gravity Belt Thickener - Troubleshooting

- The most frequent problem encountered with gravity belt thickeners is washing out
  - Usually this problem is indicated by large volumes of water carrying over with the thickened sludge
  - When this happens check
    - The polymer dosage
    - Hydraulic loading
    - Solids loading
    - Belt speed
    - Belt washing equipment

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Gravity Belt Thickener - Troubleshooting

- If the polymer dose is too low, the solids will not flocculate and free water will not be released from the sludge mass
- If the polymer dose is adequate, evidenced by large floc particles and free water, increase the belt speed so as to provide more belt surface area for drainage
- If the belt is already at its maximum setting, check the flow rate to the belt and reduce it if the rate is higher than normal
- If the polymer dose, belt speed and hydraulic loading are set properly but washing out is still occurring, the problem may be related to binding of the belt
  - Check the appearance of the belt as it leaves the washing chamber
  - If the belt appears to be dirtier than normal, increase the wash water rate, turn off the polymer and feed pumps and allow the belt to be washed until it is clean
  - Belt binding often develops because of polymer overdosing

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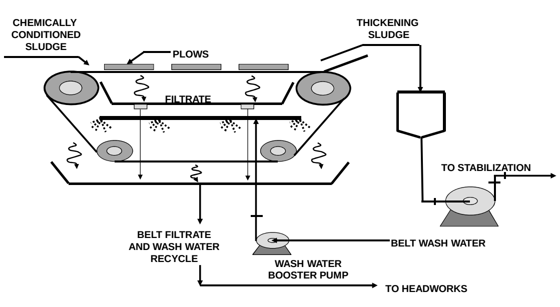

Gravity Belt Filter Thickener

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Biosolids Stabilization (Digestion)

Reduce volume
Stabilize organic matter
Eliminate pathogenic organisms

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Stabilization

- Converts the volatile (organic) or odor-causing portion of the sludge solids to
  - Non-odorous end products
  - Prevents the breeding of insects upon disposal
  - Reduces the number of pathogenic (disease-carrying) bacteria content
  - Improves the sludge dewaterability
  - Can be done:
    - Anaerobically
    - Aerobically
    - Chemically

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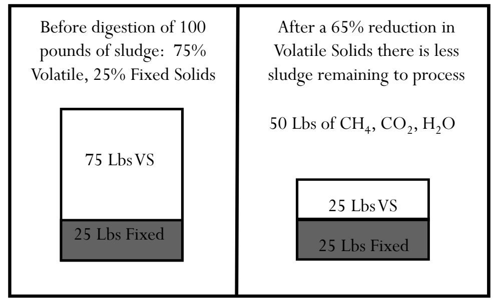
General Overview



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Biosolids Stabilization

Anaerobic Digestion

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Anaerobic Digestion

- The most widely used method of sludge stabilization is anaerobic digestion in which decomposition of organic matter is performed by microorganisms in the absence of oxygen
- Anaerobic digestion is complex biochemical process in which several groups of anaerobic and facultative (survive with or without oxygen) organisms break down organic matter.
  - In the first phase, facultative, acid-forming organisms convert complex organic matter to volatile (organic) acids
  - In the second phase, anaerobic methane-forming organisms convert the acids to odorless end products of methane gas and carbon dioxide

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Anaerobic Digestion

- Anaerobic digesters are usually heated to maintain temperatures of 94-97° F (34-36 ° C).
- If the temperature falls below this range or if the digestion time falls below 15 days, the digester may become upset and require close monitoring and attention

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Anaerobic Digestion

- 2-phase process:
  - Acid formers - Facultative bacteria convert organic matter to volatile acids, CO_2, and H_2S
    - SAPROPHYTIC ORGANISMS
  - Methane producers - Anaerobic bacteria convert acids to CH_4 and CO_2
    - The methane producers are not as abundant in raw wastewater as are the acid formers.
    - The methane producers desire a pH range of 6.6 to 7.6 and will reproduce only in that range.
- 28-40% carbon dioxide, 60-72% methane
  - Minimum methane for reuse is 62%
- Sludge retention time is 30-60 days

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Psychrophilic Bacteria

- The lowest range (in an unheated digester) utilizes Psychrophilic (cold temperature loving) bacteria.
  - The psychrophilic upper range is around 68°F (20°C).
  - Digestion in this range requires from 50 to 180 days, depending upon the degree of treatment or solids reduction required.

Mesophilic Bacteria

- Organisms in the middle temperature range are called the Mesophilic (medium temperature loving) bacteria
  - Thrive between about 68°F (20°C) and 113°F (45°C).
  - The optimum temperature range is 85°F (30°C) to 100°F (38°C), with temperatures being maintained at about 95°F (35°C) in most anaerobic digesters.
  - Digestion at 95°F may take from 5 to 50 days or more (normally around 25 to 30 days), depending upon the required degree of volatile solids reduction and adequacy of mixing.

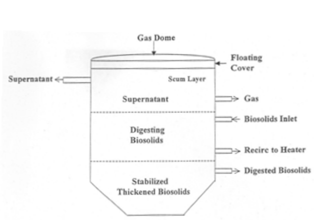
Thermophilic Bacteria

- Organisms in the third temperature range are called Thermophilic (hot temperature loving) bacteria and they thrive above 113 °F (45°C).
- The optimum temperature range is considered 120 °F (49°C).
- The time required for digestion in this range falls between 5 and 12 days, depending upon operational conditions and degree of volatile solids reduction.
  - However, the problems of maintaining temperature, sensitivity of the organisms to temperature change, and some reported problems of poor solids - liquid separation are reasons why only a few plants have actually been operated in the thermophilic range.

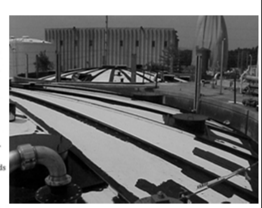
Changing Temperatures

- You can't change temperature and expect a quick change in bacteria population and therefore a shorter digestion time
- An excellent rule for digestion is never change the temperature more than one degree a day to allow the bacterial culture to become acclimated (adjust to the temperature changes).

Anaerobic Digestion



Cross-section of a floating-cover anaerobic digester.



Anaerobic Digestion – Normal Ranges

Parameter	Normal Ranges
Sludge retention time	30 – 60 days (Heated)
Operating Temperature	90 – 95 °F (Heated)
Volatile Solids Loading	0.04 – 0.1 lb VM/day/ft^3
% Methane in gas	60 – 72%
% Carbon Dioxide in gas	28 – 40%
pH	6.8 – 7.2
Volatile acids: alkalinity ratio	≤0.1
Volatile solids reduction	40 – 60%

* For every 1 lb. of VM destroyed, 12-18 ft^3 of gas is produced.

Anaerobic Digestion

- Volatile Acids to Alkalinity Ratio

$$\text{Ratio} = \frac{\text{volatile acids concentration, mg/L}}{\text{alkalinity concentration, mg/L}}$$

  - VA/Alk relationship is the key to successful digester operation
  - Must monitor alkalinity
  - Can be used to control operation of anaerobic digester
  - Very sensitive indicator of process condition
  - One of the first indicators that the digester is going sour

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Acid-Alkalinity Relationship

Optimum	VA/ALK = .05 - 0.1
Stress	VA/ALK = 0.3 - 0.4
Deep Trouble	VA/ALK = 0.5 - 0.7
Failure	VA/ALK = 0.8 and above

- Each treatment plant will have its own characteristic ratio for proper sludge digestion (generally less than 0.1)
  - High buffer capacity exists when VA are low and the Alkalinity is high (120 mg/L VA/2400 mg/L Alk)
  - When the VA/Alk ratio is 0.8 or higher, the pH of the digester will begin to drop.

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Acid-Alkalinity Relationship

- When the VA/Alk ratio starts to increase
  - Extend the mixing time of the digester contents
  - Control the heat more evenly
  - Decrease the raw sludge feed rates
  - Decrease the digested sludge withdrawal rates from digesters
- Pumping a thicker sludge to the digester can help prevent a loss of alkalinity

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Anaerobic Digestion

- Mixing
  - Puts microorganisms in contact with food
  - Controls pH, distributes buffering alkalinity
  - Distributes heat throughout the tank
  - Mixing combined with heating speeds up the digestion rate

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Anaerobic Digestion

- Mechanical mixing is most common method
  - Shaft-driven propeller extended down into sludge
  - Susceptible to wear
  - Cleaning and replacement necessary
- Other methods
  - Propeller with draft tube
  - Bubble-gun type

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Anaerobic Digestion

Anaerobic Digestion – Sludge Parameters	
< 4% Solids	Loss of alkalinity Decreased Sludge retention time Increased heating requirements Decreased volatile acid/alkalinity ratio
4 – 8% Solids	Normal Operation
> 8% Solids	Poor mixing Organic overloading Decreased volatile acid/alkalinity ratio

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Anaerobic Digestion

- A digester can be compared with your own body.
  - Both require food; but if fed too much will become upset.
  - Excess acid will upset both.
- Sour digester?
  - Lime
    - Lime is added at a 1:1 ratio, 1 lb of lime for every 1 lb or volatile acid
  - Soda ash
  - Transfer alkalinity from secondary digester to primary

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Anaerobic Digestion

- Foaming
  - Problems: odors, excess pressure on cover, plugs gas piping system
  - Cause: Gas production at startup with insufficient solids separation
  - Prevention: Adequate mixing before foaming starts

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Neutralizing a Sour Digester

- The recovery of a sour digester can be accelerated by neutralizing the acids with a caustic material such as anhydrous ammonia, soda ash, or lime, by transferring alkalinity in the form of digested sludge from the secondary digester.
- Such neutralization reduces the volatile acid/alkalinity to a level suitable from growth of the methane fermenters and provides buffering material which will help maintain the required volatile acid/alkalinity relationship and pH.
- If digestion capacity and available recovery time are great enough, it is probably preferable to simply reduce loading while heating and mixing so that natural recovery occurs.

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Neutralizing a Sour Digester

- When neutralizing a digester, the prescribed dose must be carefully calculated.
  - Too little will be ineffective, and too much is both toxic and wasteful. In considering dosage with lime, the small plant without laboratory facilities could use a rough guide a dosage of about **one pound of lime added for every 1000 gallons of sludge** to be treated.
  - You must realize that neutralizing a sour digester will only bring the PH to a suitable level, it will not cure the cause of the upset.
- Stuck Digester - A stuck digester does not decompose organic matter properly.
  - The digester is characterized by low gas production, high VA/alk relationship, and poor liquid-solids separation.
  - A digester in a stuck condition is sometimes called a "sour" or "upset" digester.

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Gas Production

- When methane fermentation starts and the methane content reaches around 60%, the gas will be capable of burning.
- Methane production eventually should predominate, generating a gas with 65-70% methane and 30-35% carbon dioxide by volume.
- Digester gas will burn when it contains 56% methane, but is not usable as a fuel until the methane content approaches 62%.
- When the gas produced is burnable, it may be used to heat the digester as well as for powering engines and for providing building heating.

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Biosolids Stabilization

Aerobic Digestion

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Factors Affecting Aerobic Digestion

- Sludge type
- Digestion time
- Digestion temperature
- Volatile solids loading
- Quantity of air supplied
- Dissolved oxygen (DO) concentrations within the digester
  - This is the most important water quality test for an aerobic digester

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Aerobic Digestion

- Extended aeration of wastewater
  - Wastes stabilized by long-term aeration of about 10-20 days
  - Check pH weekly and adjust if less than 6.5
  - Lower equipment costs than anaerobic (but higher energy costs)
  - Less noxious odors at DO ≥ 1 mg/L
  - Better on secondary sludge than primary sludge
  - Sludge has higher water content
  - By products: residual solids, CO_2, H_2O, SO_4^-, NO_3^-

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Aerobic Digestion

- Widest application is with secondary sludges
  - Which are made primarily of biological cells that are produced in activated sludge or trickling filter processes as a by-product of degrading organic matter
  - In the absence of an external food source (no new food being introduced), these microorganisms enter the endogenous or death phase of their life cycle.
  - When no new food is available, the biomass begins to self-metabolize (consume its own cellular material), which results in a conversion of biomass to end products of carbon dioxide and water; and a net decrease in the sludge mass

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Aerobic Digestion

- When primary sludge is fed into an aerobic digester, food becomes available to the microorganisms
  - In the presence of an external food source (the primary sludge), the biomass will convert the food to end products of carbon dioxide and water; and will function in the growth phase, the biomass will reproduce, resulting in a net increase in the sludge mass
  - Aerobic digestion times are long enough to allow the food to be depleted and the biomass to eventually enter the endogenous or death phase
  - The main drawback to aerobically digested primary sludge is that more air has to be supplied to maintain a desirable DO level because the bacteria are more active when food is available

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Biosolids Stabilization

Chemical Stabilization

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Chemical Stabilization

- Sludges that are not biologically digested or thermally stabilized can be made stable by the addition of large doses of lime or chlorine to destroy pathogenic and nonpathogenic organisms.
- Chemical addition to sludge to prepare it for ultimate disposal is not a common practice
- Chemical addition is usually considered to be a temporary stabilization process and finds application at overloaded plants or at plants experiencing stabilization facility upsets
- The main drawback to chemical stabilization is the cost associated with the large quantities of chemical required.

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Lime Stabilization

- Lime stabilization is accomplished by adding sufficient quantities of lime to the sludge to raise the pH to 11.5 -12.0
- Estimated dosages to achieve a pH of 11.5-12.0 are generally 200-220 pounds of lime per ton for primary sludge solids
- The addition of lime adds to the overall quantity of solids that must be ultimately disposed
- The high pH of the stabilized solids may also reduce the range of beneficial reuse opportunities

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Lime Stabilization

- Lim arrives from the supplier in powder form and can't be added directly to the sludge
- The powdered lime must be made into a slurry with the addition of water prior to blending with the sludge
- The process of lime stabilization produces an unfavorable environment and destroys pathogenic and nonpathogenic bacteria
  - Studies have shown that >99% of the fecal coliforms and fecal streptococci can be destroyed
- If the pH is not adjusted to the 11.5-12.0 range, the goals of stabilization will not be achieved.

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Chlorine Stabilization

- Chlorine stabilization is accomplished by adding sufficient quantities of gaseous chlorine to the sludge to kill pathogenic and nonpathogenic organisms.
- Estimated dosages to achieve disinfection are generally 100-300 lbs chlorine/ton of sludge solids
- Waste activated sludge (WAS) requires higher doses than primary sludge
- The addition of the large quantities of chlorine required for stabilization will result in an acidic (pH less than 3.5) sludge and neutralization with lime or caustic may be required prior to dewatering due to the corrosive condition of the mixture.

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Sludge Dewatering

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Sludge Dewatering

- Dewatering reduces sludge moisture and volume to allow for more economical disposal
- Types:
  - Centrifuge
  - Plate and Frame Press
  - Belt Press
  - Vacuum Filter
  - Drying Beds
  - Composting

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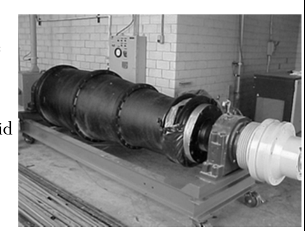
Centrifuge

- Used to thicken or dewater secondary sludges
- Sludge fed at constant rate into rotating horizontal bowl
- Solids separated from liquid and compacted by centrifugal force (1000 – 2000 rpm)



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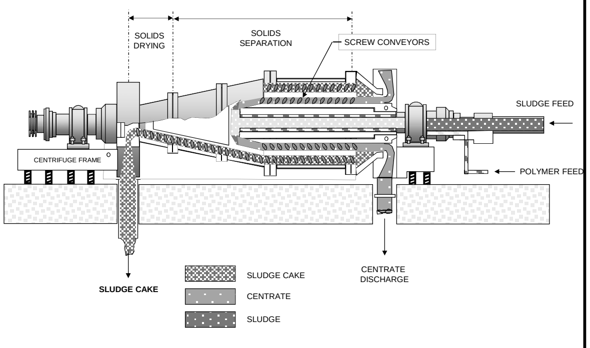

SCROLL CENTRIFUGE

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Plate-and-Frame

- Solids are pumped in batches into spaces between plates
- 200 – 250 psi pressure applied to squeeze out water
- At end of cycle (1.5 – 4 hours), plates are separated and solid drops out onto conveyor
- Pressure filtration that forces liquid through the filter media

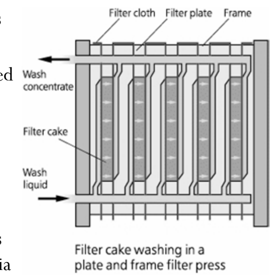

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Plate-and-Frame

JVAP (US Filter) – Chattanooga
- Modified plate and frame that is vacuum assisted
- Steam heated at 163.4ºF for 30 min
- Entire process takes about 4 hours

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Belt Filter Press

- Low power use
- Reliable
- Continuous operation
- Two long belts that travel over a series of rollers
- Sludge applied to free water zone (much water will drain off here)
- Solids then squeezed between a series of rollers (and more water is removed)
- Remaining solids are scraped from the belt
- Belts are washed and the process repeats

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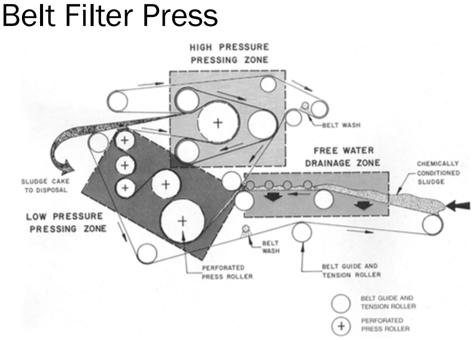
Belt Filter Press



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Vacuum Filter

- Sludge pumped into a tank around a partially submerged rotating drum
- Drum rotates, vacuum collects solids on surface
- Vacuum removes excess water
- Vacuum is then released and solids are removed

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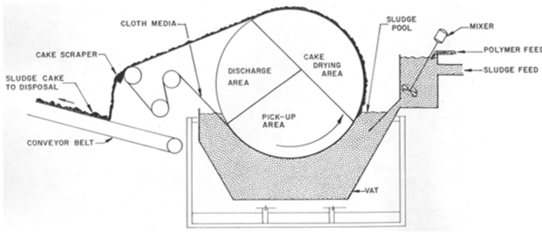
Vacuum Filter



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Drying Bed

- Simplest of all methods
- Sludge deposited in layer on sand bed or other surface with drain
- Dewatering occurs by drainage and evaporation
- Time required is affected by climate, depth of solids, and type of solids
- Sometimes drying beds are covered while others have vacuum assisted drainage

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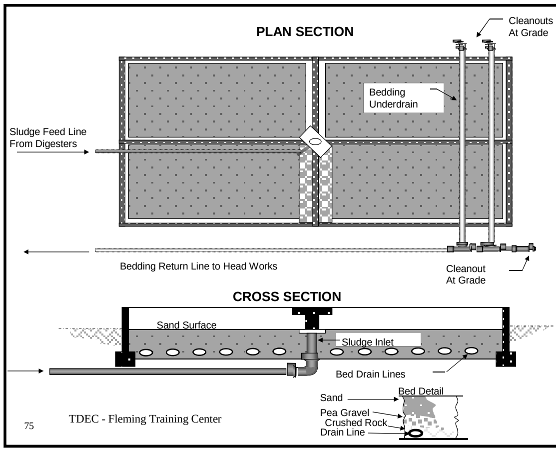

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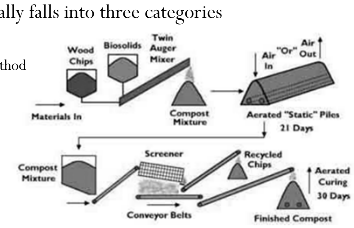
Composting

- Composting results in the decomposition of organic matter by the action of Thermophilic facultative aerobic microorganisms to sanitary, nuisance-free, humus-like material
- Composting generally falls into three categories
  - Windrow
    - Most common method
  - Static pile
  - Mechanical



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Composting – Windrow Operation

- Dewater sludge to the highest degree economically practical.
- Blend dewatered sludge with recycled compost or bulking agents to produce a homogenous (evenly blended) mixture with a moisture content of 45-65%.
- Form the windrow piles and turn (aerate) once or twice daily for the first 4-5 days after windrow formation.
- Turn the piles approximately once every two days to once a week to maintain the desired temp. (130-140ºF or 55-60ºC) until the process is complete.
  - The temperature of the piles should be routinely monitored during this period.
- Load the compost onto trucks for disposal or recycle purposes.

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Composting – Windrow Operation

- If stacks are turned too often, excessive heat will be released and the temperature may drop to a point where it is unfavorable for the thermophilic composting bacteria.
- When pathogen destruction is a goal, temperature measurements must be taken and recorded.
- A well-operated windrow compost facility can dry sludge from an initial moisture content of approximately 60% to a moisture content of 30% in about 15-20 days to a final moisture of 20% in approximately 20-30 days.
- The most common problems that arise are anaerobic conditions and reductions in compost temperatures.

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Composting – Safety

- Large numbers of spores are released into the atmosphere during certain composting operations (compost screening, dumping and mixing of compost, and wood chip dumping).
- To reduce the exposure to airborne pathogens:
  - Enclose the cabs of heavy equipment
  - Ventilate all enclosed areas properly
  - Provide dust masks to employees working in dusty areas.

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503 Regs

- The 40 CFR part 503 Sludge Regulations was published in the Federal Register on February 19, 1993,and became effective on March 22, 1993.
- This regulation requires the generator of sludge to treat the sludge to a certain degree before land applying of the sludge.
- The 503 regulation requires the sludge to be monitored for
  - certain pollutants (metals)
  - disease causing organisms called pathogens
  - and Vector Attraction Reduction, which is the reduction of Volatile organic solids to the degree where vectors (flies, mosquitoes, and other disease -carrying organisms) are not attracted to the sludge or biosolids once it is placed on the land.

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503 Regs

- Now that the 503 regulation is in effect, digesters will have to be efficiently operated to meet the parameters of the regulation.
- If the Sludge is prepared for land application or surface disposal, it must comply with applicable pathogen reduction requirements.
- The part 503 regulation allows nine pathogen reduction alternatives, which are divided into two distinct classes :
  - Class A
  - Class B

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503 Regs

- Class A alternatives produce a sludge that is virtually pathogen free.
- Class B alternatives significantly reduce the pathogen level in sludge.
- Both Class A and B alternatives specify maximum levels of fecal coliform allowed in the sludge.
- Monitoring frequency for the pollutants, pathogen reduction and vector reduction requirements are based on amount of (dry weight tons) disposal per year.
- Records of the results will be kept at the sludge wastewater plant.

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503 Regs

- If your wastewater plant has a design influent flow rate equal to or greater than 1 million gallons per day, or serves a population of 10,000 or more, or Class I Sludge management facilities (State of Tennessee Industrial Pretreatment Program) you must report annually to the permitting authority.
- Annual reports cover information and data collected during the calendar year (January 1 to December 31) and are due February 19, every year and submitted to the permitting authority, which is the EPA Regional 6 in Kansas Office for Tennessee.

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Metals Limits

- The sludge (Biosolids) applied to land must meet the ceiling concentrations for table section 503.13 pollutants at a minimum.
- The Table 3 section 503.13 pollutant concentration limits are the best limits to meet because they are considered exceptional quality required no loading rate limits to the land being applied to.

TABLE 3 OF § 503.13.—POLLUTANT CONCENTRATIONS

Pollutant	Monthly average concentration (milligrams per kilogram)[1]
Arsenic	41
Cadmium	39
Copper	1500
Lead	300
Mercury	17
Nickel	420
Selenium	100
Zinc	2800

[1] Dry weight basis.

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Pathogen Requirements

- Either Class A or Class B pathogen requirements and site restrictions must be met before the biosolids (sludge) can be land applied; the two classes differ depending on the level of pathogen reduction that has been obtained.
  - Aerobic digesters with adequate detention times (40-60 days), maintaining correct dissolved oxygen levels and feeding the digesters correctly will usually be able to have to the sludge tested for class B pathogens and meet it with satisfactory results (**less than 2 million colony** - forming units per gram of total solids - dry weight).

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Pathogen Requirements

- There are a total of 3 options to meet the Class B Reduction:
  - Fecal Coliform Count
  - Processes to Significantly Reduce Pathogens
  - Processes to Significantly Reduce Pathogens Equivalent

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Vector Attraction Reduction

- Vector attraction reduction is to reduce the attraction of vectors (flies, mosquitoes, and other potential disease - carrying organisms) to the biosolids or sludge.
- 1 of 10 options specified in part 503 to achieve vector attraction reduction must be met when biosolids are applied to land.

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Requirements in one of the following options must be met for vector attraction reduction

- Reduce the mass of volatile solids by a minimum of 38%
- Demonstrate vector attraction reduction with additional anaerobic digestion in a bench-scale unit
- Meet a specific oxygen uptake rate for aerobically treated biosolids
- Use aerobic processes at greater than 40°C (avg. temp 45°C) for 14 days or longer (during biosolids composting)
- Add alkaline materials to raise the pH under specified conditions

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Requirements in one of the following options must be met for vector attraction reduction

- Reduce the moisture content of biosolids that do not contain unstabilized solids from other than primary treatment to at least 75% solids
- Reduce the moisture content of biosolids with unstabilized solids to at least 90%
- Inject biosolids beneath the soil surface within a specified time, depending on the level of pathogen treatment
- Incorporate biosolids applied to or placed on the land surface within specified time periods after application to or placement on the land surface

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Sludge Digestion Math

Volatile Solids to the Digester, lbs/day

1. If 8,250 lbs/day of solids with a volatile solids content of 68% are sent to the digester, how many lbs/day volatile solids are sent to the digester?

2. A total of 3600 gpd of sludge is pumped to a digester. If the sludge has 5.7% solids content with 71% volatile solids, how many lbs/day volatile solids are pumped to the digester.

Digester Loading Rate, lbs VS added / day / ft^3

3. What is the digester loading if a digester, 45 ft. diameter with a liquid level of 20 ft., receives 82,500 lbs/day of sludge with 5.8% solids and 69% volatile solids?

4. A digester, 40 ft. in diameter with a liquid level of 18 ft. receives 26,400 gpd of sludge with 5.7% solids and 71% volatile solids. What is the digester loading in lbs VS added/day/ft^3?

Volatile Acids / Alkalinity Ratio

5. The volatile acids concentration of the sludge in an anaerobic digester is 170 mg/L. If the measured alkalinity is 2150 mg/L, what is the VA/Alkalinity ratio?

6. What is the VA/Alkalinity ratio if the volatile acids concentration of the sludge in an anaerobic digester is 215 mg/L and the measured alkalinity is 1957 mg/L?

Percent Volatile Solids Reduction

7. The raw sludge to a digester has a volatile solids content of 69%. The digested sludge volatile solids content is 53%. What is the percent volatile solids reduction?

8. The raw sludge to a digester has a volatile solids content of 72%. The digested sludge volatile solids content is 51%. What is the percent volatile solids reduction?

Volatile Solids Destroyed, lbs VS / day / ft^3

9. A flow of 3750 gpd sludge is pumped to a 35,000 ft^3 digester. The solids concentration of the sludge is 6.3% with a volatile solids content of 68%. If the volatile solids reduction during digestion is 54%, how many lbs/day volatile solids are destroyed per ft^3 of digester capacity?

10. A flow of 2165 gpd sludge is pumped to a 22,500 ft^3 digester. The solids concentration of the sludge is 4.5% with a volatile solids content of 72%. If the volatile solids reduction during digestion is 45%, how many lbs/day volatile solids are destroyed per ft^3 of digester capacity?

Digester Gas Production, ft^3 Gas Produced / lb. VS destroyed

11. The anaerobic digester at a treatment plant receives a total of 10,500 gpd of raw sludge. This sludge has a solids content of 5.3% of which 64% is volatile. If the digester yields a volatile solids reduction of 61%, and the average digester gas production is 22,300 ft^3, what is the daily gas production in ft^3/lb VS destroyed daily?

12. The anaerobic digester at a treatment plant receives a total of 11,400 gpd of raw sludge. This sludge has a solids content of 5.4% of which 62% is volatile. If the digester yields a volatile solids reduction of 58%, and the average digester gas production is 25,850 ft^3, what is the daily gas production in ft^3/lb VS destroyed daily?

Digestion Time, days

13. An aerobic digester 40 ft. in diameter has a side water depth of 12 ft. The sludge flow to the digester is 8200 gpd. Calculate the hydraulic detention time in days.

14. A 50 ft. aerobic digester has a side water depth of 10 ft. The sludge flow to the digester is 9500 gpd. Calculate the detention time in days.

Oxygen Uptake Rate, mg/L/hr

15. Dissolved air concentrations are taken on an air-saturated sample of digested aerobic sludge at one-minute intervals. Given the following results, calculate the oxygen uptake, mg/L/hr.

Elapsed Time, Min	DO, mg/L
0	7.9
1	6.8
2	6.1
3	5.3
4	4.6
5	3.9

16. Dissolved air concentrations are taken on an air-saturated sample of digested aerobic sludge at one-minute intervals. Given the following results, calculate the oxygen uptake, mg/L/hr.

Elapsed Time, Min	DO, mg/L
0	6.9
1	5.8
2	5.0
3	4.3
4	3.7
5	2.9

Answers

1. 5610 VS lbs/day
2. 1215 lbs/day
3. 0.10 lbs VS added/day/ft^3
4. 0.39 lbs VS added/day/ft^3
5. 0.08
6. 0.11
7. 49%
8. 59.5%
9. 0.021 lbs VS/day/ft^3
10. 0.012 lbs VS/day/ft^3
11. 12.3 ft^3/lb VS destroyed
12. 14.0 ft^3/lb VS destroyed
13. 13.7 days
14. 15.5 days
15. 44 mg/L/hr
16. 42 mg/L/hr

Sludge Digestion Math

Volatile Solids to the Digester, lbs/day

1. If 8,250 lbs/day of solids with a volatile solids content of 68% are sent to the digester, how many lbs/day volatile solids are sent to the digester?

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V.S. = (Total Solids, lbs/d)(% VS)
= (8250 lbs/d)(0.68)
= 5610 VS lbs/d

2. A total of 3600 gpd of sludge is pumped to a digester. If the sludge has 5.7% solids content with 71% volatile solids, how many lbs/day volatile solids are pumped to the digester.

V.S. lbs/d = (3600 gpd)(8.34)(0.057)(0.71) (solids, lbs)
= 1215 lbs/d

Digester Loading Rate, lbs VS added / day / ft^3

* ~ 0.15 - 0.35 in a heated, mixed, high rate digester

3. What is the digester loading if a digester, 45 ft. diameter with a liquid level of 20 ft., receives 82,500 lbs/day of sludge with 5.8% solids and 69% volatile solids?

$$\text{Digester Loading} = \frac{(\text{sludge, lbs/d})(\%\text{ Solids})(\%\text{ VS})}{(0.785)(D, ft)^2(d, ft)}$$

$$= \frac{(82{,}500 \text{ lbs/d})(0.058)(0.69)}{(0.785)(45 ft)^2(20 ft)}$$

$$= \frac{3301.65}{31792.5} = 0.10 \text{ lbs VS added/day/ft}^3$$

4. A digester, 40 ft. in diameter with a liquid level of 18 ft. receives 26,400 gpd of sludge with 5.7% solids and 71% volatile solids. What is the digester loading in lbs VS added/day/ft^3?

$$\text{Digester Loading} = \frac{(26{,}400 \text{ gpd})(8.34)(0.057)(0.71)}{(0.785)(40 ft)^2(18 ft)}$$

$$= \frac{8910.52}{22608} = 0.39 \text{ lbs VS added/day/ft}^3$$

Volatile Acids / Alkalinity Ratio

- VA/Alk ratio is an indicator of the progress of digestion and the balance between the 2 stage process of anaerobic digestion
- Normally <0.1

5. The volatile acids concentration of the sludge in an anaerobic digester is 170 mg/L. If the measured alkalinity is 2150 mg/L, what is the VA/Alkalinity ratio?

$$\text{VA/Alk ratio} = \frac{\text{Volatile Acids, mg/L}}{\text{Alkalinity mg/L}}$$

$$= \frac{170 \text{ mg/L}}{2150 \text{ mg/L}} = \boxed{0.08}$$

- Increase indicates possible excess feeding of raw sludge to the digester or removal of too much digested sludge

6. What is the VA/Alkalinity ratio if the volatile acids concentration of the sludge in an anaerobic digester is 215 mg/L and the measured alkalinity is 1957 mg/L?

$$\text{VA/Alk ratio} = \frac{215 \text{ mg/L}}{1957 \text{ mg/L}} = \boxed{0.11}$$

Percent Volatile Solids Reduction

- One of the best indicators of the effectiveness of the digestion process

7. The raw sludge to a digester has a volatile solids content of 69%. The digested sludge volatile solids content is 53%. What is the percent volatile solids reduction?

$$\text{\% VS Reduction} = \frac{(\text{In} - \text{Out})}{(\text{In} - (\text{In})(\text{Out}))} \times 100$$

$$= \frac{0.69 - 0.53}{0.69 - (0.69)(0.53)} \times 100$$

$$= \frac{0.16}{0.69 - 0.3657} \times 100$$

$$\rightarrow \frac{0.16}{0.3243} \times 100 = \boxed{49\%}$$

8. The raw sludge to a digester has a volatile solids content of 72%. The digested sludge volatile solids content is 51%. What is the percent volatile solids reduction?

$$\text{\% VS Reduction} = \frac{0.72 - 0.51}{0.72 - (0.72)(0.51)} \times 100$$

$$= \frac{0.21}{0.72 - 0.3672} \times 100$$

$$= \frac{0.21}{0.3528} \times 100 \rightarrow \boxed{59.5\%}$$

Volatile Solids Destroyed, lbs VS / day / ft^3

9. A flow of 3750 gpd sludge is pumped to a 35,000 ft^3 digester. The solids concentration of the sludge is 6.3% with a volatile solids content of 68%. If the volatile solids reduction during digestion is 54%, how many lbs/day volatile solids are destroyed per ft^3 of digester capacity?

$$\text{VS destroyed, lbs VS/day/ft}^3 = \frac{(\text{Sludge, gpd})(8.34)(\%\text{ Solids})(\%\text{ VS})(\%\text{ VS reduc.})}{(0.785)(D, ft)^2(d, ft)}$$

$$= \frac{(3750\text{ gpd})(8.34)(0.063)(0.68)(0.54)}{35{,}000\text{ ft}^3}$$

$$= \boxed{0.021\text{ lbs VS/day/ft}^3}$$

10. A flow of 2165 gpd sludge is pumped to a 22,500 ft^3 digester. The solids concentration of the sludge is 4.5% with a volatile solids content of 72%. If the volatile solids reduction during digestion is 45%, how many lbs/day volatile solids are destroyed per ft^3 of digester capacity?

$$\text{VS destroyed, lbs VS/day/ft}^3 = \frac{(2165\text{ gpd})(8.34)(0.045)(0.72)(0.45)}{22{,}500\text{ ft}^3}$$

$$= \boxed{0.012\text{ lbs VS/day/ft}^3}$$

$\text{VS, lbs} = (10{,}500\text{ gpd})(8.34)(.053)(.64) = 2970.3744\text{ lbs/d VS}$

Digester Gas Production, ft^3 Gas Produced / lb. VS destroyed

11. The anaerobic digester at a treatment plant receives a total of 10,500 gpd of raw sludge. This sludge has a solids content of 5.3% of which 64% is volatile. If the digester yields a volatile solids reduction of 61%, and the average digester gas production is 22,300 ft^3, what is the daily gas production in ft^3/lb VS destroyed daily?

$$\text{Digestor Gas Production, ft}^3\text{/lbs VS destroyed} = \frac{\text{gas produced, ft}^3\text{/d}}{(\text{VS to digester, lbs/d})(\%\text{ VS Reduc.})}$$

$$= \frac{22{,}300\text{ ft}^3}{(2970.3744\text{ lbs/d})(0.61)} = \boxed{12.3}$$

12. The anaerobic digester at a treatment plant receives a total of 11,400 gpd of raw sludge. This sludge has a solids content of 5.4% of which 62% is volatile. If the digester yields a volatile solids reduction of 58%, and the average digester gas production is 25,850 ft^3, what is the daily gas production in ft^3/lb VS destroyed daily?

$$\text{Digestor Gas Production, ft}^3\text{/lbs VS destroyed} = \frac{25{,}850\text{ ft}^3}{(11{,}400\text{ gpd})(8.34)(0.054)(0.62)(0.58)}$$

$$= \boxed{14.0}$$

- Indicator of the progress of digestion
- Normal range is 12-18 ft^3 gas/lb VS destroyed
- lower indicates slowing of digestion & sludge removal may be overdone
- sharp increase indicates presence of high organic content of sludge

Digestion Time, days • Flow through time in digester

13. An aerobic digester 40 ft. in diameter has a side water depth of 12 ft. The sludge flow to the digester is 8200 gpd. Calculate the hydraulic detention time in days.

$$\text{Digestion Time, days} = \frac{(0.785)(D, ft)^2(d, ft)(7.48)}{\text{Sludge Flow Rate, gpd}}$$

$$= \frac{(0.785)(40 ft)^2(12 ft)(7.48)}{8200 \text{ gpd}}$$

$$= 13.7 \text{ days}$$

14. A 50 ft. aerobic digester has a side water depth of 10 ft. The sludge flow to the digester is 9500 gpd. Calculate the detention time in days.

$$\text{Digestion Time, days} = \frac{(0.785)(50 ft)^2(10 ft)(7.48)}{9500 \text{ gpd}}$$

$$= 15.5 \text{ days}$$

(OUR)

Oxygen Uptake Rate, mg/L/hr • Indicates biomass activity
• an increase means increase microorganism activity
• a decrease occurs when bugs are less active

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15. Dissolved air concentrations are taken on an air-saturated sample of digested aerobic sludge at one-minute intervals. Given the following results, calculate the oxygen uptake, mg/L/hr.

Elapsed Time, Min	DO, mg/L
0	7.9
1	6.8
2	6.1
3	5.3
4	4.6
5	3.9

• DO on digested sample is measured at 1min. intervals for 5min total
• DO @ 2 & 5 min are used to calculate

$$\text{OUR, mg/L/hr} = \frac{\text{start DO} - \text{end DO}}{\text{elapsed time}} \times 60$$

$$= \frac{6.1 - 3.9}{3 \text{ min}} \times 60$$

$$= 44 \text{ mg/L/hr}$$

16. Dissolved air concentrations are taken on an air-saturated sample of digested aerobic sludge at one-minute intervals. Given the following results, calculate the oxygen uptake, mg/L/hr.

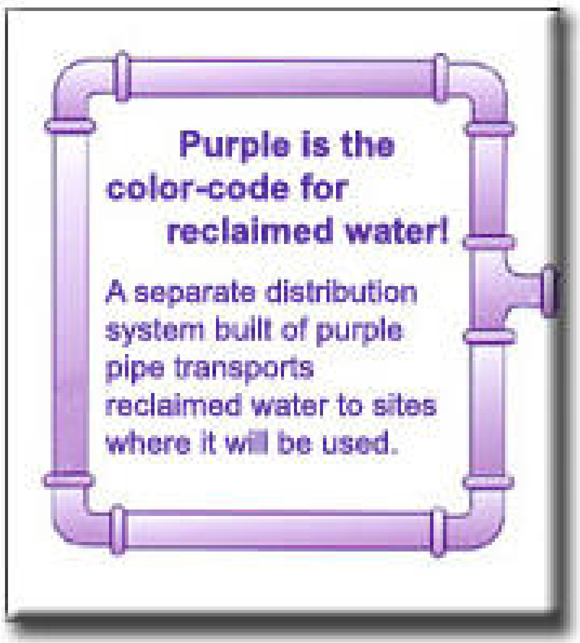
Elapsed Time, Min	DO, mg/L
0	6.9
1	5.8
2	5.0
3	4.3
4	3.7
5	2.9

$$\text{OUR mg/L} = \frac{5.0 - 2.9}{3 \text{ min}} \times 60$$

$$= 42 \text{ mg/L/hr}$$

Section 9

Reclamation and Reuse



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WASTEWATER RECLAMATION AND REUSE

Advanced Wastewater Treatment

Wastewater Reclamation and Reuse

- Recycled
  - Water or wastewater is used within a facility before it is discharged to a treatment system
- Reclamation
  - Operation or process of changing the condition or characteristics of water so that improved uses can be achieved.
- Reuse
  - Water is discharged and then withdrawn by another user

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Wastewater Reclamation and Reuse

- Water agencies forced to seek new water sources
  - Population growth
  - Contamination of surface or groundwater
  - Droughts
  - Uneven water distribution
- Water reuse common in many areas
  - In US, especially in arid and semi-arid areas
  - Mostly restricted to non-potable reuse, like irrigation
- Other alternatives
  - Water conservation
  - More efficient use
  - Development of new water resource and management

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Water Reuse: Historical Perspective

1912	San Francisco, CA	First small urban reuse begins with the irrigation of Golden Gate Park
1942	Baltimore, MD (Bethlehem Steel)	Metals cooling and steel processing
1960	Colorado Springs, CO	Landscape irrigation of golf courses, cemeteries and freeways
1984	Tokyo, Japan	Water recycling for toilet flushing in 19 high-rise buildings in congested metropolitan area
1987	Monterey, CA	Agricultural irrigation for food crops eaten uncooked (celery, broccoli, lettuce, cauliflower, etc.)

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Wastewater Reuse Categories

- Agricultural irrigation
- Landscape irrigation
- Industrial recycling and reuse
- Groundwater recharge
- Recreational and environmental uses
- Non-potable urban uses
- Potable reuse

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Agricultural Irrigation

- Largest use in US
- Uses:
  - Crop irrigation
  - Commercial nurseries
- Issues/Constraints:
  - Surface and groundwater contamination if not managed properly
  - Marketability of crops and public assistance

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Landscape Irrigation

7

- Uses:
  - Parks
  - School yards
  - Golf courses
  - Greenbelts
  - Cemeteries
  - Freeway medians
  - Residential
- Issues/Constraints:
  - Effect of water quality, particularly salts, on soils and crops
  - Public health concerns related to pathogens
  - Use area control including buffer zone may result in higher costs

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Industrial Recycling and Reuse

8

- Uses:
  - Cooling water
  - Process water
  - Boiler feed
  - Heavy construction
- Issues/Constraints:
  - Constituents in reclaimed water related to scaling, corrosion, biological growth and fouling
  - Possible aerosol transmission or pathogens in cooling water
  - Cross-connection of potable and reclaimed water lines

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Groundwater Recharge

9

- Uses:
  - Groundwater replenishment
    - Spreading basins
  - Saltwater intrusion control
    - Direct injection
  - Subsidence control
- Issues/Constraints:
  - Possible contamination of groundwater aquifer used as potable water source
  - Organic chemicals in reclaimed water and their toxicological effects
  - Total dissolved solids, nitrates and pathogens

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Recreational and Environmental Uses

10

- Uses:
  - Development of lakes and ponds
  - Marsh enhancement
  - Stream flow augmentation
  - Fisheries
  - Snowmaking
- Issues/Constraints:
  - Health concerns about pathogens
  - Eutrophication due to nitrogen and phosphorus in receiving water
  - Toxicity to aquatic life

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Non-potable Urban Uses

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- Minimal use in US
- Uses:
  - Fire protection
  - Air conditioning
  - Toilet flushing
  - Flushing of sanitary sewers
- Issues/Constraints:
  - Health concern over possible aerosol transmission of pathogens
  - Effects of water quality on scaling, corrosion, biological growth and fouling
  - Cross-connection of potable and reclaimed water lines

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Potable Reuse

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- Minimal use in US
- Uses:
  - Blending in water supply reservoirs
  - Pipe-to-pipe water supply
- Issues/Constraints:
  - Constituents in reclaimed water (especially trace organic chemicals and their toxicological effects)
  - Aesthetics and public acceptance
  - Health concerns about pathogen transmission

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Effluent Disposal

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- Dilution
  - Lakes
  - Rivers
  - Streams
- Wastewater Reclamation
  - Land application
  - Underground disposal

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Disposal by Dilution

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- Treatment required prior to discharge:
  - Stabilize waste
  - Protect public health
  - Meet discharge requirements
- Site specific
- Most common method of effluent disposal
- How does one evaluate the effect of a WWTP's effluent upon the receiving stream?
  - Sample water in stream above and below the plant's outfall location
  - Perform a DO profile of the stream

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Disposal by Dilution

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- Diffusers
- Cascading outfalls
  - Increase D.O.
  - Remove chlorine
  - Remove sulfur dioxide
- Surface discharge

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Land Treatment Systems

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- When high-quality effluent or even zero-discharge is required, land treatment offers a means of reclamation or ultimate disposal

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Land Treatment Systems

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- Simulate natural pathways of treatment
- Use soil, plants, and bacteria to treat and reclaim wastewater
- Treatment is provided by natural processes as effluent moves through soil and plants
- Some of wastewater is lost by evaporation and transpiration
- Remainder returns to hydrologic cycle through surface runoff or percolation to groundwater

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Hydrologic Cycle

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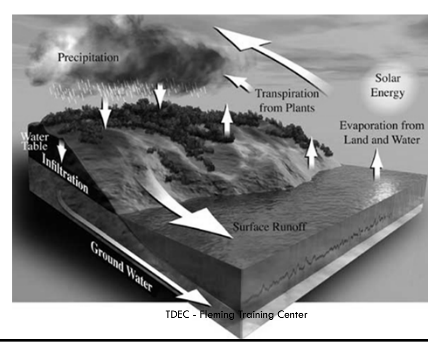

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Land Application System

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- Treatment prior to application
- Transmission to the land treatment site
- Storage
- Distribution over the site
- Runoff recovery system
- Crop systems

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Land Application System

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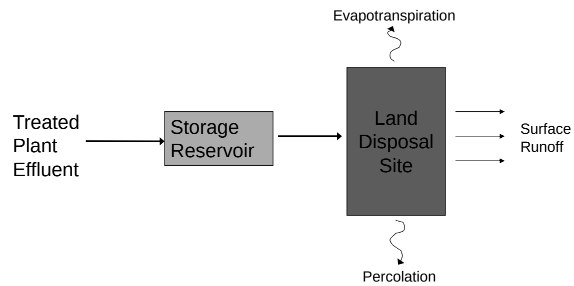

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Site Considerations

21

- Control of ponding problems
  - Percolation
  - Crop selection
  - Drainage tiles
- Install PVC laterals below ground
- Potential odor release with spray systems
- Routine inspection of equipment
- Plan "B" in case system fails

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Wastewater Reclamation: Land Application

22

- Irrigation most common:
  - Ridge and furrow
  - Sprinklers
  - Surface/drip systems
- Overland flow

Wastewater Treatment Plant & Poplar Tree Reuse System; Woodburn, Oregon

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Irrigation

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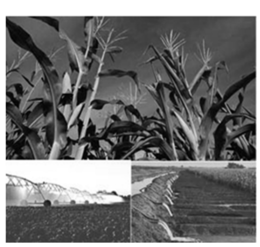
- Method depends on crop grown
  - Silage / hay
  - Parks / golf courses
  - Horticulture / timber / turf grass
- Water & nutrients enhance plant growth for beneficial use.
- Water removed by:
  - Surface evaporation & plant transpiration
  - Deep percolation to subsoil



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Irrigation

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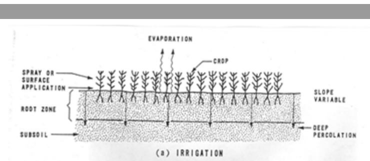

- Irrigation application of wastewater over relatively flat area, usually by spray (sprinklers) or surface spreading
- Water and nutrients are absorbed by plants and soil
- In soil, organic matter is oxidized by bacteria

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Irrigation

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- Most common land treatment in US
- Spray: fixed or moving
- Surface spreading: controlled flooding or ridge & furrow
- Climate affects efficiency
  - If ground freezes, subsurface seepage is greatly reduced.
  - Therefore storage of treated wastewater may be necessary
- Ex: lawns, parks, golf courses, pastures, forests, fodder crops (corn, alfalfa), fiber crops, cemeteries

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Irrigation - Spray Systems

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- Fixed
  - Buried or on surface
  - Cultivated crops or woodlands
- Moving - center pivot
- Minimum slope 2 – 3%
  - Promotes lateral drainage and reduces ponding
- Maximum slope in TN:
  - Row crops 8%
  - Forage crops 15%
  - Forests 30 %

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Irrigation - Spray Systems

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Center pivot, moving spray irrigation

Fixed spray irrigation on risers

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Irrigation – Ridge & Furrow

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- Wastewater flows through furrows between rows of crop
- Wastewater slowly percolates into soil
- Wastewater receives partial treatment before it is absorbed by plants

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Irrigation – Ridge & Furrow

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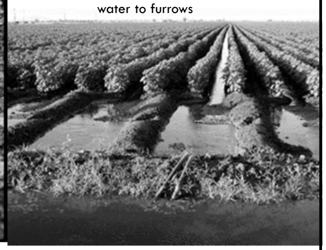
Gated pipe applying flow to furrows

Irrigation ditch in foreground supplying water to furrows



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Irrigation – Removal Efficiencies

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Parameter	% Removal
BOD	98
COD	80
Suspended Solids	98
Nitrogen	85
Phosphorus	95
Metals	95
Microorganisms	98

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Irrigation – Removal Efficiencies

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- Under normal circumstances:
  - Water and nitrogen are absorbed by crops
  - Phosphorus and metals are adsorbed by soil particles
  - Bacteria is removed by filtration
  - Viruses are removed by adsorption
- Nitrogen cycle
  - Secondary effluent contains ammonia, nitrate and organic nitrogen
  - Ammonia and organic nitrogen are retained in soil by adsorption and ion exchange, then oxidized to nitrate
  - Major removal mechanisms are ammonia volatilization, crop uptake and denitrification

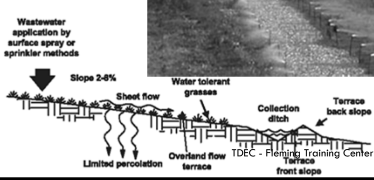
Overland Flow

32

- Spray or surface application
  - 6-12 hours/day
  - 5-7 days/week
- 2-4% slope
- Slow surface flow treats wastewater
- Water removed by evaporation & percolation
- Runoff collection

Overland Flow

33



Overland Flow

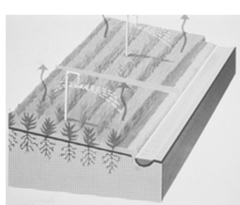
34

- Wastewater is applied intermittently at top of terrace
- Runoff collected at bottom (for further treatment)
- Treatment occurs through direct contact with soil

Overland Flow

35

- Low pressure sprays
  - <20 psi
  - Low energy costs
  - Good wastewater distribution
  - Nozzles subject to plugging
- Surface distribution
  - Generate minimal aerosols
  - Higher energy costs
  - Hard to maintain uniform distribution



Distribution Methods

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	Methods	Advantages	Limitations
Surface Methods	General	Low energy costs Minimize aerosols and wind drift Small Buffer zones	Difficult to achieve uniform distribution Moderate erosion potential
Surface Methods	Gated Pipe	Same as General, plus: Easy to clean Easiest to balance hydraulically	Same as General, plus: Potential for freezing and settling
Surface Methods	Slotted or Perforated Pipe	Same as General	Same as Gated Pipe, plus: Small openings clog Most difficult to balance hydraulically
Surface Methods	Bubbling Orifices	Same as General, plus: Not subject to freezing/settling Only the orifice must be leveled	Same as General, plus: Difficult to clean when clogged
Low-pressure Sprays		Better distribution than surface methods Less aerosols than sprinkler Low energy costs	Nozzles subject to clogging More aerosols and wind drift than surface methods
Sprinklers		Most uniform distribution	High energy costs Aerosol and wind drift potential Large buffer zones

Suitable Grasses

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	Common Name	Perennial or Annual	Rooting Characteristics	Method of Establishment	Growing Height (cm)
Cool Season Grass	Reed canary	Perennial	sod	seed	120-210
	Tall fescue	Perennial	bunch	seed	90-120
	Rye grass	Annual	sod	seed	60-90
	Redtop	Perennial	sod	seed	60-90
	KY bluegrass	Perennial	sod	seed	30-75
	Orchard grass	Perennial	bunch	seed	15-60
Warm Season	Common Bermuda	Perennial	sod	seed	30-45
	Coastal Bermuda	Perennial	sod	sprig	30-60
	Dallis grass	Perennial	bunch	seed	60-120
	Bahia	Perennial	sod	seed	60-120

Suitable Grasses

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- Well established plant cover is essential for efficient performance of overland flow
- Primary purpose of plants is to facilitate treatment of wastewater
- Planting a mixture of different grasses usually gives best results
- Ryegrass used as a nurse crop; grows quickly until other grasses are established

Suitable Grasses

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- Cool Season Grass – plant from Spring through early Summer or early Fall to late Fall
- Warm Season Grass – generally should be planted from late Spring through early Fall
- Planting time affected by expected rainfall, location, climate, grass variety, etc
- Amount of seed required to establish cover depends on:
  - Expected germination
  - Type of grass
  - Water availability
  - Time available for crop development

Overland Flow – Removal Efficiencies

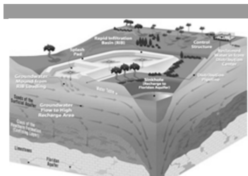
40

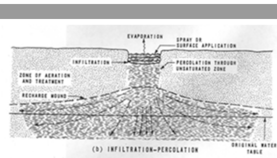
Parameter	% Removal
BOD	92
Suspended Solids	92
Nitrogen	70-90
Phosphorus	40-80
Metals	50

- Treatment by oxidation and filtration
  - SS removed by filtration through vegetative cover
  - BOD oxidized by microorganisms in soil and on vegetative debris
  - Nitrogen removal by denitrification and plant uptake

Rapid Infiltration

41





- Primary objective is to recharge the groundwater
- Wastewater is applied to spreading basins or seepage basins and allowed to percolate through the soil
- No plants are used or desired

Rapid Infiltration

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- Top– Picture of a seepage basin in Nevada
- Bottom - Large volumes of reclaimed water, which have undergone advanced secondary treatment, are reused through land-based applications in a 40-square-mile area near Orlando, Florida.

Rapid Infiltration

43

- Effluent is discharged into a basin with a porous liner
- No plants needed or desired
- Primary objective is groundwater recharge
- Not approved in Tennessee
  - Due to Karst topography – cracks in limestone provide direct route of infiltration to groundwater and therefore no treatment achieved and groundwater may become contaminated

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Land Treatment Limitations

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- Sealing soil surface due to high SS in final effluent
  - More common in clay soils
  - Three possible solutions:
    - Remove SS from the effluent
    - Disk or plow field to break mats of solids
    - Apply water intermittently and allow surface mat to dry and crack
- Build up salts in soil
  - Salts are toxic to plants
  - Leach out the salts by applying fresh water (not effluent)
  - Rip up the soil 4 – 5 ft deep to encourage percolation

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Land Treatment Limitations

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- The severity of both soil sealing due to suspended solids and salinity problems due to dissolved solids depends on the type of soil in the disposal area.
- These problems are more difficult to correct in clay soils than in sandy soils.
- Excessive nitrate ions can reach groundwater if irrigation or rapid infiltration are overloaded or not properly operated.
  - Rapid infiltration systems have no crops to remove nitrogen so they must be operated in wet/dry cycles in order to first nitrify the ammonium (dry) and then denitrify the nitrate (wet) to form nitrogen gas (N_2), which is released to the atmosphere.

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Land Treatment Limitations

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- Excessive nitrate ions reach groundwater
  - Rain can soak soil so that no treatment is achieved
  - Do not apply nitrate in excess of crop's nitrogen uptake ability
  - Excessive nitrate in groundwater can lead to methylmoglobenemia (blue baby syndrome)
    - Too much nitrate consumed by child leads to nitrate in stomach and intestines where nitrogen is absorbed into bloodstream and it bonds to red blood cells preventing them from carrying oxygen.
    - Baby becomes oxygen deprived, turns blue and suffocates

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Monitoring Requirements

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Area	Test	Frequency
Effluent and groundwater or seepage	BOD	Two times per week
	Fecal coliform	Weekly
	Total coliform	Weekly
	Flow	Continuous
	Nitrogen	Weekly
	Phosphorus	Weekly
	Suspended solids	Two times per week
	pH	Daily
	Total dissolved solids (TDS)	Monthly
	Boron	Monthly
	Chloride	Monthly
Vegetation	- - - variable depending on crop - - -	
Soils	Conductivity	Two times per month
	pH	Two times per month
	Cation Exchange Capacity (CEC)	Two times per month

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