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PLANT OPTIMIZATION

MCET
ENVIRONMENTAL, HEALTH, AND SAFETY TRAINING

Presented by
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College of Southern Maryland
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Process Training Sessions

Before class starts, please:
- **Check in**

During class, please:
- **Asks questions**
- Feel free to get up and leave the classroom at any time (i.e., rest rooms, phone calls, etc.)

After class, please:
- **Fill out Class Evaluation**
- **Answer Questions on Post Quiz**

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Housekeeping

- 1–day class
- Start class – 8:00 am
- 10-minute Breaks – every hour
- Lunch ~ 11:30 am – 12:30 pm
- End class ~ 3:30 to 4:00 pm

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Instructor Expectations

- Begin and end class on time
- Be interactive – participate at your own comfort level
- Share experiences and needs
- Less lecture, more discussions
- Keep it simple
- ***Make this an enjoyable and informative experience!***

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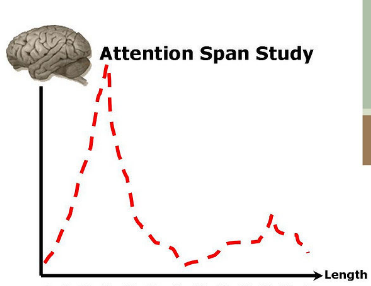
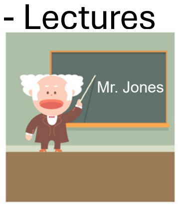
Student Attention Span - Lectures





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How this Class is Structured

- This 1-day class will be more class discussion, less lecture
- The workshop will be structured around three teaching components:
  1) Establishing rapport (Trainer as facilitator)
  2) Stimulating student interest (Trainer as motivator)
  3) Structuring classroom experiences (Trainer as designer)

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Discussions

- Student involvement in class discussions is encouraged:

1) To keep students attentive

2) To help students retain information

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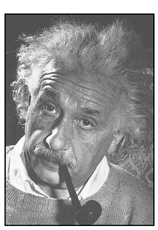
The Guiding Expectation

"Things should be made as simple as possible -- but no simpler."



Albert Einstein

www.physik.uni-frankfurt.de/~jr/physpiceinstein.html

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Ground Rules

- Discussion is encouraged; share experiences
- Use terms we all can understand
- Everyone is different, so please show respect for others in the room
- Express opinions - of things, not people
- Maintain confidences

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Ice Breaker

- Before we start, let's introduce ourselves.
  1) Name,
  2) What do you do, and
  3) What are your learning needs for facility optimization?

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Class Outline

- Introduction
  1) Overview
  2) Optimization
  3) Continuous Improvement
- Water Treatment Facilities
  1) Turbidity Removal
  2) Disinfection with Chlorine (and UV optional)
- Wastewater Treatment Facilities
  1) BOD and TSS Removal
  2) Nutrient Removal, phosphorus & nitrogen
  3) Disinfection, w/chlorine or UV
  4) Sludge Handling and Disposal

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Introduction

Overview

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Process Optimization

- Optimization of water and wastewater treatment processes:
  1. Ensures regulatory compliance
  2. Protects the environment
  3. Reduces the occurrence of O&M problems
  4. Can result in cost avoidances (i.e., save money)

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Process Optimization

- Water and wastewater treatment processes involve:

1. Water or wastewater loadings
2. Mechanical & electrical equipment
3. Biological processes (Wastewater)
4. Chemical addition
5. Human elements (i.e., staffing & management)
6. All components must align correctly for a treatment system to be efficient, effective and reliable

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Cost vs Quality

- Water and wastewater treatment facilities face a trade-off between:
  1. Operational **cost**
  2. Effluent **quality**
- Achieving the right balance is essential

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Optimization - Two Views

- Optimize to meet the Permit
- Optimize to reduce costs

- **Need to meet the Permit first**

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The Permit

- Issued by the State to match Federal mandates
- For Wastewater plants, based on the needs of the receiving stream
- For Water plants, set by drinking water standards
- Must be met or there are consequences
- The permit drives plant costs

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Process Optimization

- Misalignment of any treatment component(s) can result in process:
  1. Inefficiency (expense increases)
  2. Ineffectiveness (not getting results)
- In the worst cases, processes can fail completely:
  1. Discharge permit non-compliance
  2. Non-compliance with safe drinking water standards

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Introduction

Definitions and Acronyms

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Optimization

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Optimization

1) Refers to making something as fully perfect and functional as possible
2) Aims to make something as good as it can be
3) Relates to achieving optimal functionality, focusing on enhancing performance, efficiency, and effectiveness

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Process Goals

Water

- Meet Safe Drinking Water Standards
- Optimize well water treatment and disinfect
- Optimize surface water treatment for removal of turbidity and pathogens through:
  1. Coagulation
  2. Flocculation
  3. Sedimentation
  4. Filtration
  5. Disinfection

Wastewater

- Meet Clean Water discharge standards to satisfy water quality needs of receiving waters
- Optimize BOD5, TSS, nutrients (TP & TN), and pathogens removal through:
  1. Primary Treatment
  2. Biological Treatment
  3. Nutrient removal treatment
  4. Filtration
  5. Disinfection
  6. Sludge handling and disposal

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Optimization

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Plant and Operator Assessment

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Process Parameters

- The wastewater-generating process
- Chemicals used in the process
- The raw water source
- Chemical and physical water and wastewater characteristics
- Flows and loadings of all pertinent inputs
- Peak loads and potential upset conditions
- Variability, both normal and unusual events
- Desired water or effluent quality

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Treatment Processes

- Process type (e.g. physical/chemical, biological, mechanical, electrochemical, membrane, etc.)
- Equipment design and capacity
- Equipment condition
- Operating and maintenance procedures
- Appropriateness of the process and equipment

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Process Controls

- Monitoring the right parameters at the right location
- Using the right test to measure parameters
- Collecting test samples properly and at the right locations
- Collecting and evaluating lab data effectively
- Logging physical and visual observations and using them to evaluate process health
- Logging data for future historical evaluations
- Using appropriate controls for the desired process adjustments
- Using the right type of instrumentation at the right location in the process
- Making the correct adjustments based on good data

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Chemical Usage

- Proper chemicals are used only as needed
- Proper chemical dosage is based on use tests (e.g. jar tests, titrations)
- Use conditions are appropriate (e.g. pH, alkalinity, temperature)
- Chemicals are prepared correctly (e.g. flocculant polymers)
- Chemicals are mixed and dispersed effectively

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Operator Knowledge

- Chemistry basics
- Treatment plant process fundamentals
- Treatment process parameters and control methods
- Target ranges for control parameters and how to adjust them
- The effect of variability on treatment processes
- Lab tests and physical/visual monitoring
- On-line controls
- Responding to upset conditions

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Effectiveness and Efficiency

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Optimizing WTPs and WWTPs

- To ensure efficient and effective treatment, process control in facilities involves a combination of:
  1. Advanced technology
  2. Intelligent control
  3. Multi-objective optimization
- Optimization takes time; may take years

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Optimization (Ideal)

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Continuous Improvement

- Continuous improvement is defined as a systematic and ongoing effort to enhance performance, services, and processes over time
- Primary goal is to incrementally make small, positive changes that collectively lead to significant improvements in efficiency, quality, and overall performance

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Continuous Improvement

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Effectiveness vs Efficiency

1. Effectiveness is:
   a) Getting better results
   b) Doing things that yield positive results
   c) About doing or using the right things
2. Efficiency is:
   a) The ability to reduce expenses
   b) Completing a task cheaper or faster
   c) About doing things the right way

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Effectiveness vs Efficiency

1. Ideally, organizations find ways to be effective *and* efficient

2. But it is possible to be effective, but *not* efficient, or vice versa, or neither

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Efficacy

- The capacity for producing a desired result or effect
- Doing something right

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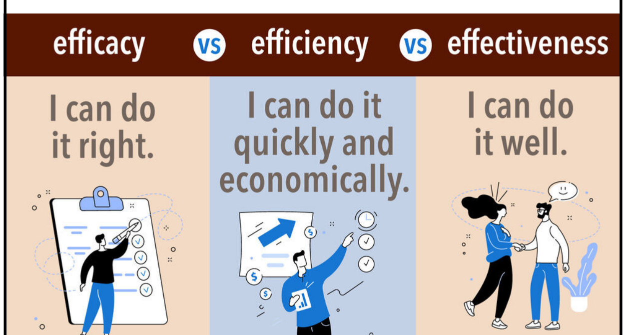
Efficacy vs Efficiency vs Effectiveness



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Quality, Speed, Costs

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Quality, Speed, and Costs

- Government agencies are **interested in quality, speed and costs**
- Contractors are **interested in costs, speed and quality**
- The sequence of these items is in accordance with the relative importance to each party

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Good, Fast, or Cheap: **Pick Two**

- Buyers want products of the highest quality, produced at the fastest speed, and priced at the lowest costs
- Sellers assert that only two of those objectives can be achieved at the same time:
  1. This notion has been expressed as:
     (a) Quality. Speed, Price - Choose two.
     (b) Good, Fast, Cheap - Pick two.

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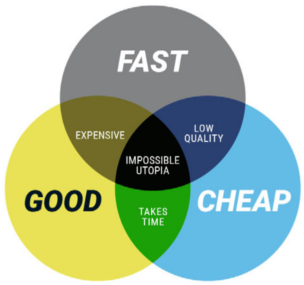
Good, Fast, or Cheap: **Pick Two**



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Regulatory Framework

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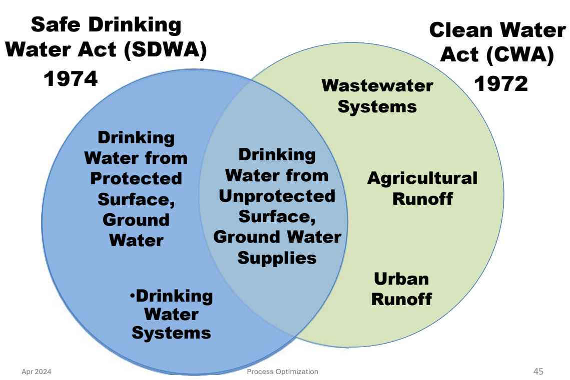
Legislative Mandates



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EPA Goals

- EPA, established in 1970, sets goals for:
  - **A. <u>Water Treatment facilities (1974)</u>**
    1. Public health
    2. Provide drinking water that meets Safe Drinking Water standards that contributes to the health, nutrition, and overall well-being of water customers
  - **B. <u>Wastewater Treatment facilities</u> (1972)**
    1. Environmental health
    2. Treat wastewater to meet water quality standards before releasing it back into natural water bodies

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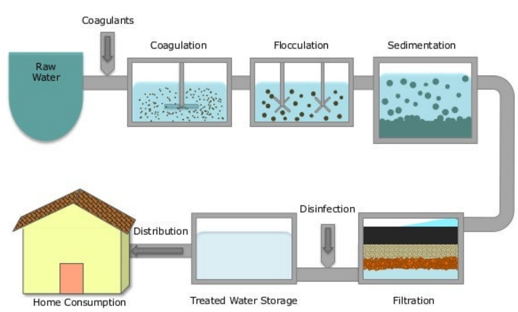
Surface Water Treatment Plant



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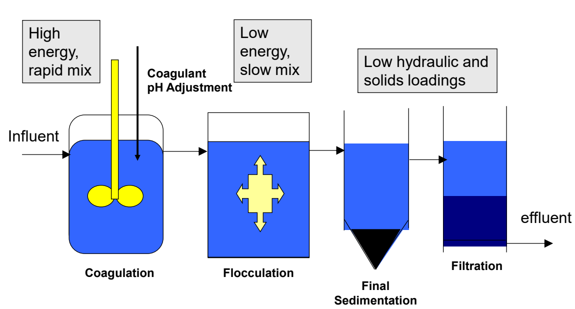
Water Treatment Plant Stages



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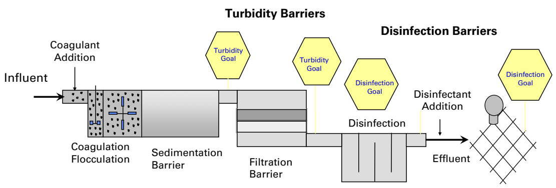
Multiple Barriers

- Water treatment strategies focus on multiple barrier approaches to assure safe water for **consumption**
  - Turbidity removal (Sedimentation + filtration) beyond permit levels
  - Disinfection (Effluent + distribution)



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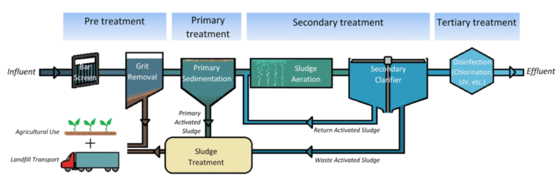
Wastewater Treatment Plant



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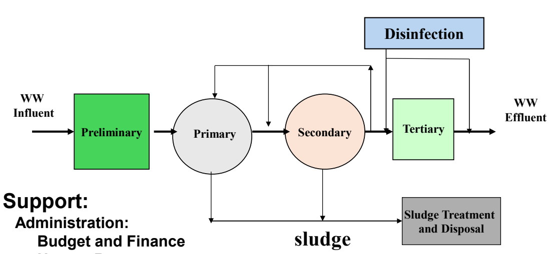
Conventional WWTP Process Diagram



Support:
- **Administration:**
  - **Budget and Finance**
  - **Human Resources**
  - **Planning**
  - **Procurement**
  - **Customer Service**
  - **Engineering and Construction**
- **Maintenance**
- **Laboratory**

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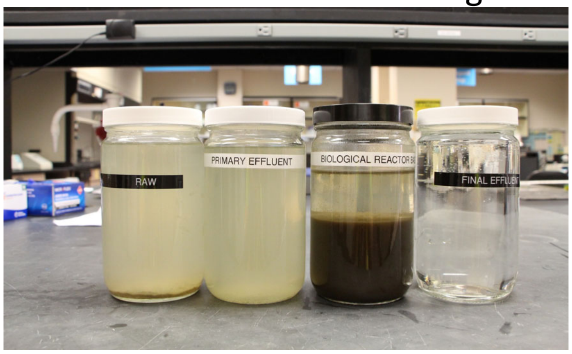
Wastewater Treatment Stages



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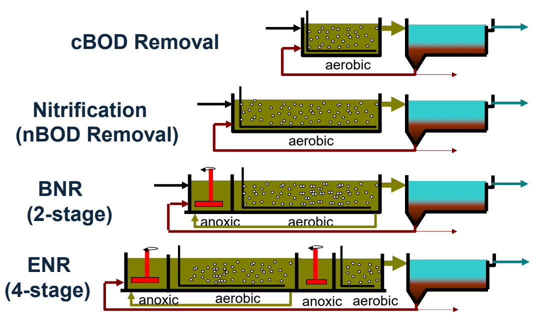
Evolution of Activated Sludge



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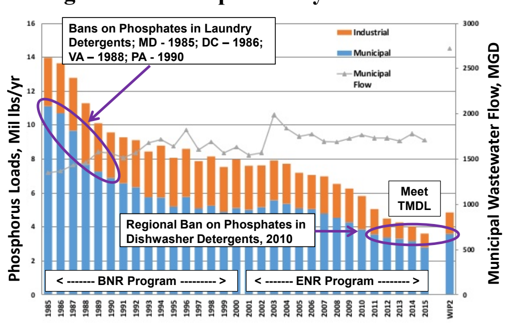
TP Loadings to the Chesapeake Bay - Wastewater



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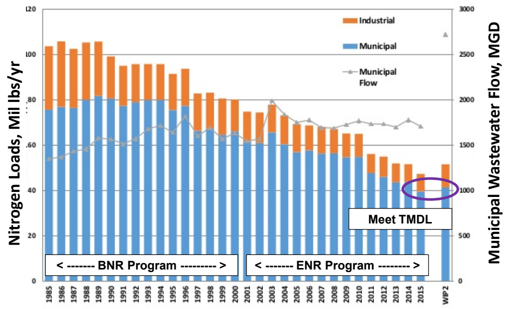
TN Loadings to the Chesapeake Bay - Wastewater



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Water Treatment Facilities

Objectives

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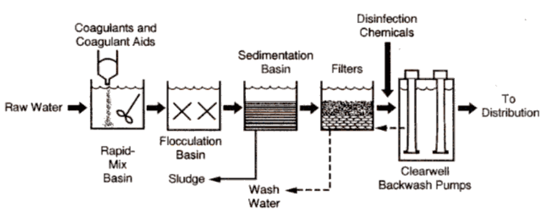
Conventional Treatment



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Water Treatment Objectives

- To discuss the fundamentals of coagulation, clarification, and filtration
- To discuss the inter-relationships between these processes for meeting new regulations and treatment goals
- Selection of proper clarification and coagulant type

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Water Treatment Facilities

Turbidity Removal

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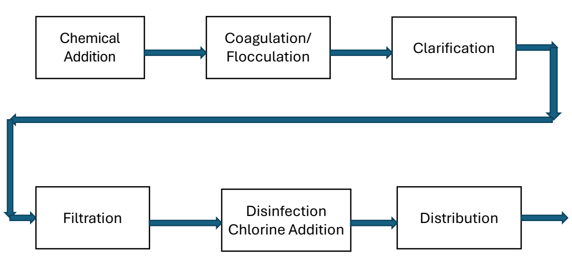
Water Treatment



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Common Contaminants of Concern

- Particles - Turbidity
- Pathogens:
  - Cryptosporidium
  - Giardia
  - Bacteria and viruses
- Organic matter:
  - Total or dissolved organic carbon (TOC or DOC)
  - Color
  - Precursor to disinfection byproducts (DBPs), if using chemicals for disinfection

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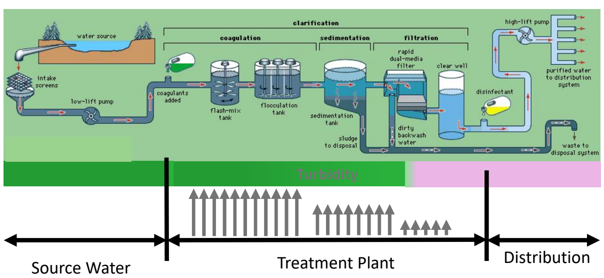
Surface Water Treatment Plant and Distribution System



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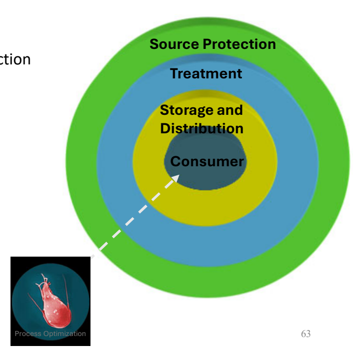
Multiple Barriers In Water Supply Protection

- Sources
  1. Watershed management programs
  2. Intake and wellhead protection
- Treatment
  1. Coagulation, flocculation, sedimentation
  2. Filtration
  3. Disinfection
- Storage
  1. Disinfectant contact time
  2. Screens
- Distribution
  1. Pressure
  2. Disinfection



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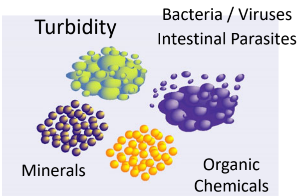
Solids Removal

Filtration is the **last** physical barrier preventing solids into the plant discharge. Any malfunction in the treatment process could result in unsafe water for reuse and water quality problems.



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Turbidity

- Turbid or cloudy water is caused by suspended particles scattering or absorbing light
- Turbidity is an indirect measurement of the amount of suspended matter in the water
- However, since solids of different sizes, shapes, and surfaces reflect light differently, turbidity and suspended solids do not correlate well

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Turbidity

- Turbidity is normally gauged with an instrument that measures the amount of light scattered at an angle of 90° from a source beam
- The units of turbidity are usually in Nephelometric Turbidity Units (NTU).

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Bench-top Turbidimeter

- Measurement of "cloudiness" in the water
- Expressed in NTU (Nephelometric Turbidity Units)
- Basis for regulatory compliance and process control
- Turbidimeters must be calibrated to maintain accuracy

Bench-top Turbidimeter & Primary Standards

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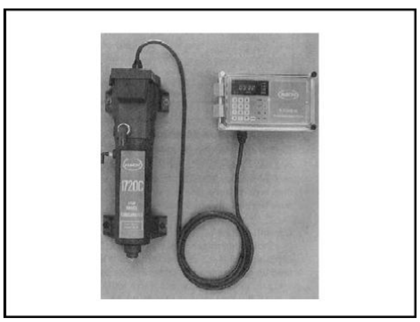
ON-LINE TURBIDIMETERS



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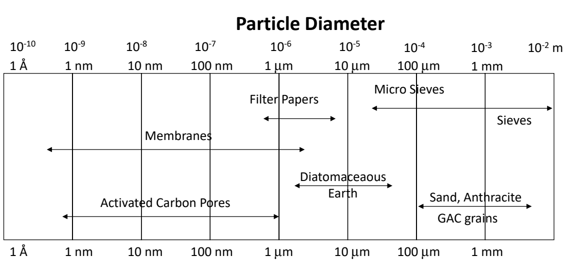
Size Spectrum of Granular Filter Media



(After Stumm, ES&T, Vol. 11, p. 1066, 1977)

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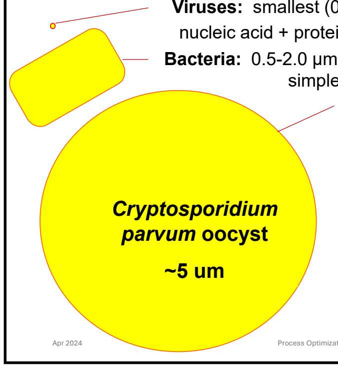
Classes of Microorganisms: The Microbial World



Viruses: smallest (0.02-0.3 µm diameter); simplest: nucleic acid + protein coat (+ lipoprotein envelope)

Bacteria: 0.5-2.0 µm diameter; prokaryotes; cellular; simple internal org.; binary fission.

Protozoa: most >2 µm - 2 mm; eucaryotic; uni-cellular; non-photosynthetic; flexible cell membrane.; wide sizes and shapes; hardy cysts and oocysts; flagellates amoebae, ciliates, sporozoans (*Cryptosporidium* sp.) and microsporidia.

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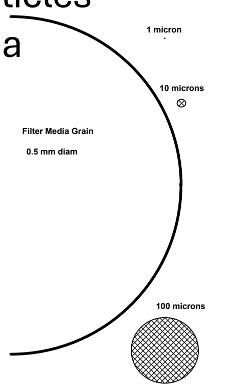
Relative Size of Particles and Filter Media

Soil	1-100 µm
Cryptosporidium oocysts	5 µm
Bacteria	0.3 – 3 µm
Viruses	0.005 – 0.1 µm
Floc particles	100 - 2000 µm
Visible particle w/ 20:20 vision	37 µm

Filter media pores range from 50 to 400 µm depending on media size



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Particles

- Turbidity is a regulated parameter
- Surrogate for Giardia and Cryptosporidium
- Interfere with disinfection
- Affects coagulant dose (for some waters)
- Impact on water treatment costs:
  - Coagulant demand
  - Filter run length
  - Residuals handling and disposal

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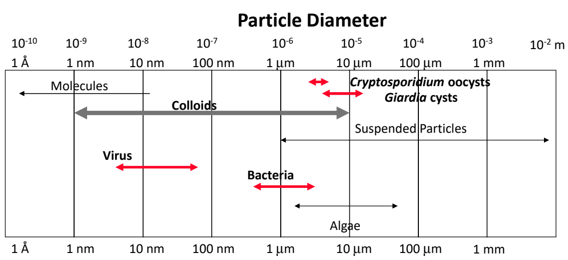
Colloids

- Small particles
  1. No definite size range
  2. Generally 1 nm - 10 µm
  3. Can be smaller or larger
- In water they are also called "aqua sols"
- Particles can be either organic or inorganic

Particle Size



(After Stumm, ES&T, Vol. 11, p. 1066, 1977)

Types of particles

- Inorganic
  1. Clays
  2. Metal oxides and hydroxides
     A. $Al(OH)_3$ floc in coagulation
     B. $Fe(OH)_3$ floc from oxidation of FeII & coagulation
     C. MnO_2 from oxidation of MnII
     D. SiO_2 (silica)
  3. Carbonates
     A. $CaCO_3$ and $CaMgCO_3$

Types of particles

- Organic particles:
  1. Microoganisms
     - A. Virus
     - B. Bacteria
     - C. Algae
     - D. Protozoa (*Giardia* & *Cryptosporidium*)
  2. Organic debris
  3. Humic substances

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Particle Charge

- In natural aquatic systems, most particles have a negative charge
- Since water has no electrical charge, the charge on the particles must be balanced by an equivalent number of counter charges (ions) in the water
- Results in “stabilized” particles that repel each other
- Particles tend not to release water

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Particles in raw water resist settling due to…………

1) Particle Size

- Suspended Solids
  - non-settleable solids
  - settleable solids
- Colloidal Solids
- Dissolved Solids

2) Natural Forces

- Zeta Potential
- Van der Waals Force

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Water Treatment

Coagulation

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ROLE OF COAGULATION

- WATER TREATMENT PLANTS - do not work without good coagulation!!!
  1. Coagulation affects:
     A. Flocculation, Sedimentation, Flotation, and Filtration Performance
     B. Affects bubble attachment to flocs and removal by DAFs
     C. Affects Granular Media Filtration Performance
- TREATMENT GOALS
  1. Turbidity: ≤ 0.1 NTU
  2. NOM/TOC: ≤ 2.0 mg/L

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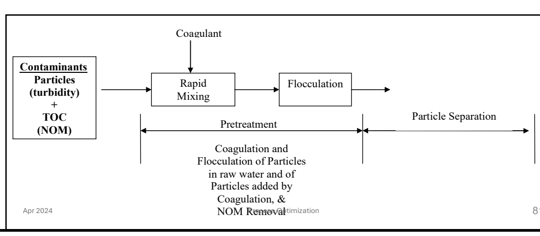
COAGULATION AND FLOCCULATION PROCESSES

•COAGULATION – chemical step involving addition of coagulants. Chemical reactions occur with these particles and chemical reactions involving phase changes may also occur with water (OH-) and Natural Organic Material (NOM) or Total Organic Carbon (TOC) .

•FLOCCULATION – physical step in which the sizes of particles are increased by collisions and attachment of smaller particles leading to larger floc particles.



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Objectives of Coagulation

- To destabilize particles
- To convert “dissolved” substances to particulate substances

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Coagulation – Process Description

- Adding and rapid mixing of chemical coagulants into the raw water.
- The process of adding a chemical or combination of chemicals to neutralize the electrostatic charges on suspended particles in raw water so that they will attract to form larger particles.

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Settling Rate for Small Particles

TABLE 4-1 Natural settling rates for small particles

Particle Diameter, *mm*	Representative Particle	Time Required to Settle in 1-ft (0.3-m) Depth
		Settleable
10	Gravel	0.3 seconds
1	Coarse sand	3 seconds
0.1	Fine sand	38 seconds
0.01	Silt	33 minutes
		Considered Nonsettleable
0.001	Bacteria	55 hours
0.0001	Color	230 days
0.00001	Colloidal particles	6.3 years
0.000001	Colloidal particles	63-year minimum

Source: Water Quality and Treatment. *3rd ed. 1971.*

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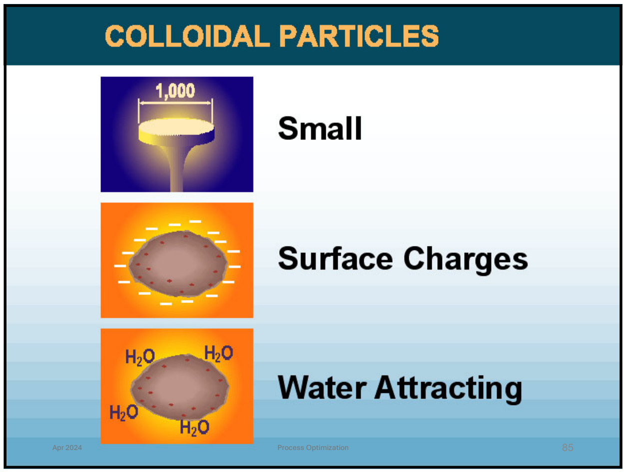
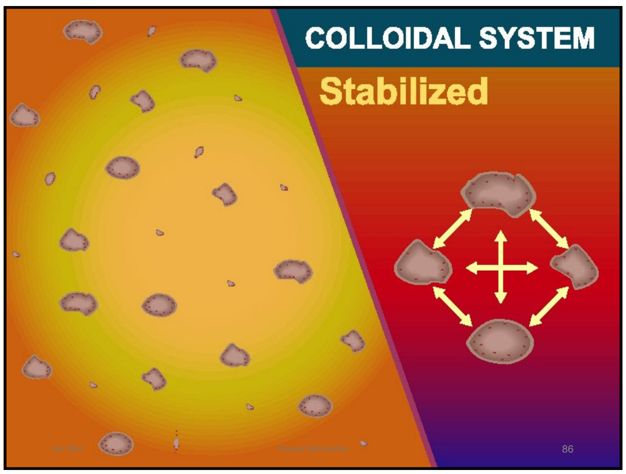
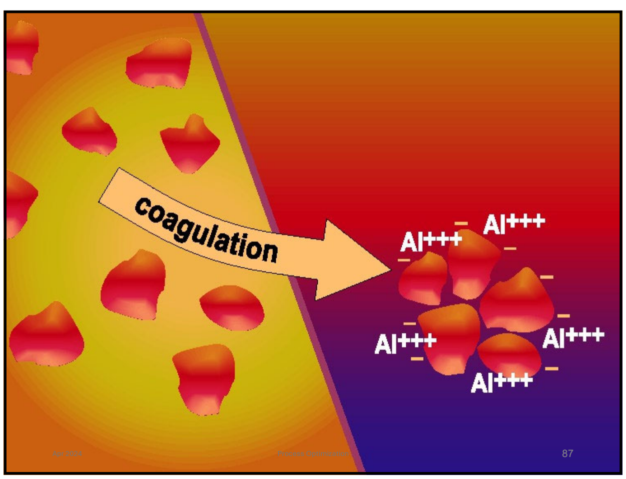

COLLOIDAL PARTICLES
1,000
Small
Surface Charges
Water Attracting

85


COLLOIDAL SYSTEM
Stabilized
86

86


coagulation
Al+++
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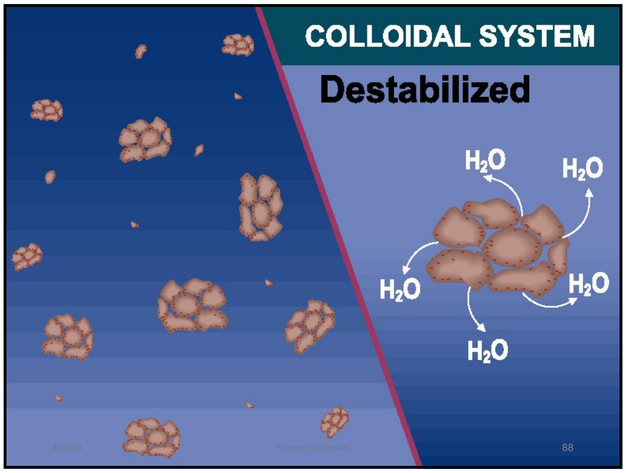

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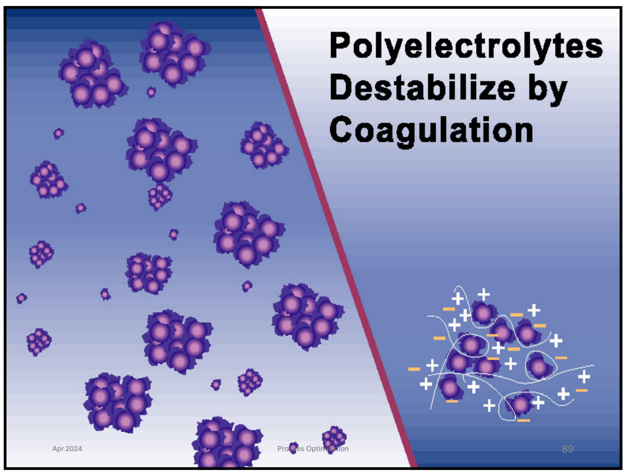

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Primary Coagulants

TABLE 4-2 Common coagulation chemicals

Common Name	Chemical Formula	Comments
Aluminum sulfate	$Al_2(SO_4)_3 \cdot 14(H_2O)$	Most common coagulant in the United States; often used with cationic polymers
Ferric chloride	$FeCl_3$	May be more effective than alum in some applications
Ferric sulfate	$Fe_2(SO_4)_3$	Often used with lime softening
Ferrous sulfate	$Fe_2(SO_4)_3 \cdot 7H_2O$	Less pH dependent than alum
Aluminum polymers	—	Include polyaluminum chloride and polyaluminum sulfates
Cationic polymers	—	Synthetic polyelectrolytes; large molecules
Sodium aluminate	$Na_2Al_2O_4$	Used with alum to improve coagulation
Sodium silicate	$Na_2O \cdot (SiO_2)_x$	x can range from 0.5 to 4.0; ingredient of activated silica coagulant aids

Source: Adapted from *Water Treatment Plant Design.* 1990.

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Effects of Water Temperature on Coagulation

- Warm Water = Improved Coagulation
- Cold Water = Reduced Coagulation

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Effects of pH & Alkalinity on Coagulation

Aluminum and Ferric based coagulants.....

- react better in waters within a certain pH range and alkalinity range.
  - Alum: 5.5 – 7.5
  - Ferric: 5.0 – 8.5
- require adequate alkalinity for optimum coagulation
  - Alum: 1 mg/L converts 0.5 mg/L of $CaCO_3$
  - Ferric: 1 mg/L converts 0.75 mg/L of $CaCO_3$
- are very acidic and will reduce pH / alkalinity

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Effects of Turbidity on Coagulation

- Low turbidity
  - Sometimes difficult to form a proper floc
  - More coagulant may be needed
  - Coagulant aid / weighting agent may need to be applied
- Fluctuating turbidity
  - coagulant dose must be adjusted

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Low turbidity waters

- May need more alum than high turbidity waters -- not enough particles to collide (chemistry may be right, but physics is wrong)
- Cationic polymers not effective for low turbidity waters in conventional treatment
- Low alum doses and cationic polymers may be effective in direct filtration and for non-conventional clarification including:
  - DAF, sludge blanket, adsorption, ballasted flocculation clarifiers

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Effects of Color on Coagulation

- Color causing organics compounds react with coagulants.
- Pre-treatment with oxidants or adsorbants may be necessary

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Coagulation – Chemical Feed Systems

- Liquid Chemical Feeder
  - diaphragm pumps
  - perastaltic (hose) pumps
- Dry Chemical Feeders
  - volumetric feeders
  - gravimetric feeders

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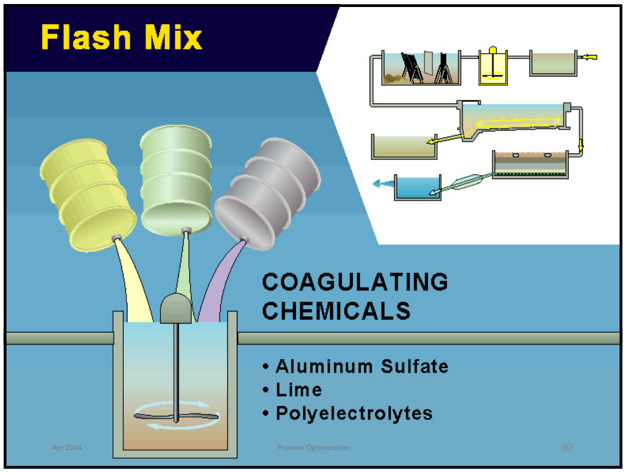

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Coagulation – Rapid Mix

The process of providing rapid agitation to distribute the coagulant and other chemicals evenly throughout the water

Types of Rapid Mix Devices:

- **Mechanical Mixers**
- **Static Mixers**
- **Pumps and Conduits**
- **Baffled Chambers**

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Blending & Motion

Blending Applications in Water and Wastewater Treatment Plants

- Polymer Mixers
- Chemical Batch Mixers
- Rapid Mixers
- Neutralization Mixers

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Operation / Process Control Monitoring

- **Operational control tests and equipment**
  - ➢ Jar Tests
  - ➢ pH and Alkalinity Tests
  - ➢ Turbidity Tests
  - ➢ Visual Inspections
  - ➢ Filterability Tests
  - ➢ Zeta Potential Tests
  - ➢ Streaming Current Monitors
  - ➢ Particle Counters

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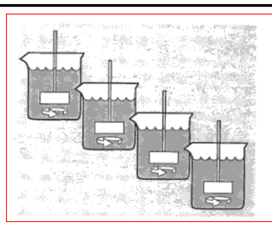
Jar Test



- Simulates C / F / S processes
- Used to evaluate…..
  - ➢ coagulant chemicals type, combination, order of application and optimum dose
  - ➢ flash mix intensity and detention time
  - ➢ flocculator speed and detention time
  - ➢ Settling velocity (for sedimentation basin)

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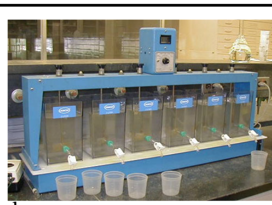
Jar Test



- Should be conducted….
  - ➢ using raw water as sample
  - ➢ whenever there are changes in raw water quality (turbidity, color, pH, alkalinity, temperature)
  - ➢ at least once per day
- Modified version of of jar test should be conducted in-plant to verify results

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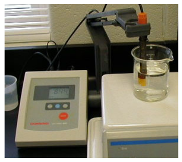
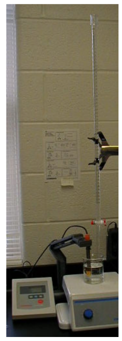
pH and Alkalinity Tests



- Should be conducted on raw water and in conjunction with jar test
- Indicates if pH / alkalinity needs to be adjusted for improved coagulation
- Requires pH meter, burette, and H_2SO_4



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Process Control – Establishing the Coagulant Dose

1. Conduct laboratory jar test
   - Determine optimum dose of coagulant chemical(s)
2. Determine and set chemical feed rate
3. Verify coagulant dose
   - Mini jar test from samples taken at…
     - ➢ flocculation basin influent and effluent
   - Turbidity – Settled Water
     - ➢ from mini jar test and sedimentation basin effluent
4. Fine tune coagulant dose

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Establishing the Coagulant Dose

- Once you have determined the optimum dose by conducting the jar test……
- Convert dose (mg/L) to a feed rate (lb/day)
  - ➢ Formula: lb/day = (Dose mg/L)(Flow MGD)(8.34)
- Verify/fine tune dose

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Common Cross-Connections Owned or Controlled by the Water System

- Chemical Feed Systems:
  - Submerged inlets or water piped directly to chemical feed tanks
  - No anti-siphon valves on chemical feeders
  - Hose bibs with no vacuum breaker
  - Split chemical feeds to raw and finished water

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Operation and Maintenance of Chemical Feed Systems

- Preventive maintenance
- Back-up units
- Condition of housing for equipment
- Chemical storage
- Hazard Communication
- Chemical containment
- Safety
- Calibration of chemical feed systems

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Water Treatment

Flocculation

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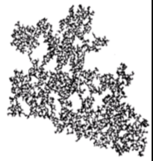
Formation And Settling of Floc Particles

- Flocculation Process is Used in Most Water Treatment Plants
  - Floc formation increases particle size
  - The structure of floc particles includes spaces with water between the original or primary particles causing a decrease in density



- Flocculation Forms Particles
  - With some characteristic diameter (d_f) larger than the primary particles (d_p).
  - With density of floc particles (ρ_f) less than the primary particles (ρ_p)

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Formation And Settling of Floc Particles

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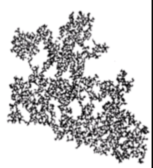

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  - With some characteristic diameter (d_f) larger than the primary particles (d_p).
  - With density of floc particles (ρ_f) less than the primary particles (ρ_p)

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Flocculation – Process Description

- Gentle stirring of the water (after coagulation has been accomplished) to bring suspended particles together so that they will form larger, more settleable clumps called floc.
- Detention time typically 10 – 30 minutes
- Flow through velocity typically 0.5 – 1.5 ft/sec

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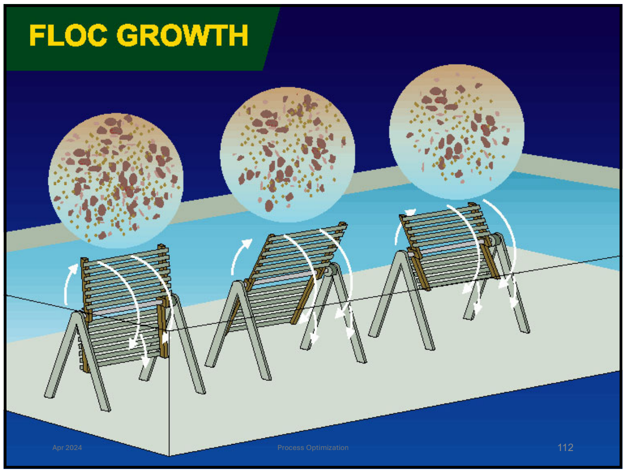

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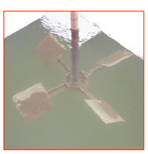
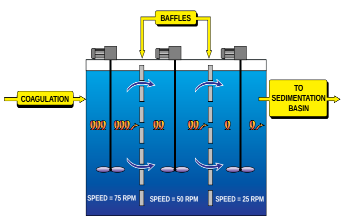
Factors Affecting Flocculation

- Coagulation Efficiency
- Detention Time
- Flocculator Speed





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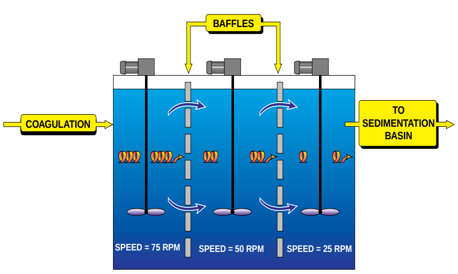
Flocculation Equipment



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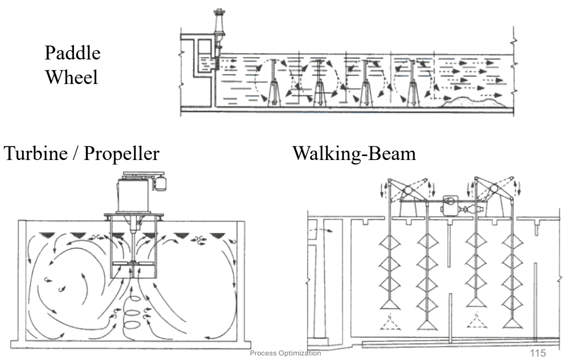
Mechanical Flocculators



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Flocculation – Operational Considerations

- Floc building in size / density through the process
  - Paddle speed adjusted to prevent shearing or settling of the floc
  - All paddles intact and all flocculators operating
  - Look for indicators of short circuiting
  - Speed adjusted as temperature (water density) changes
  - Adequate number of units in service

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Water Treatment

Sedimentation

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Factors Affecting Settling Rate

- Temperature (4º C)
- TDS
- Particle density
- Flow-thru velocity
- Solids charge
- pH

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Re-Suspending Settled Solids

- Stilling Well too Close to Bottom
- Sludge Blanket too Deep
- High Flow Turbulence
- Side-Wall Short Circuiting

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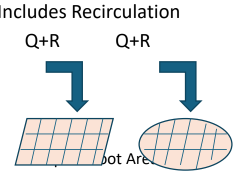
Flow Loadings

Hydraulic Loading Rate (HLR)

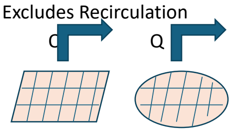
- Includes Recirculation



- HLR = Q+R, gpd / Area, sq ft

Surface Overflow Rate (SOFR)

- Excludes Recirculation



Square foot Area

- SOFR = Q, gpd / Area, sq ft

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Detention Time

- DT = Volume / Flow Rate = V /Q
- Volume = $\frac{\pi D^2}{4}$ x Depth
- Flow = Q = gallons per Hour = gph
  1. Gpd / 7.48 gal per Ft^3 = Ft^3 / Hr
- DT = Ft^3 / Ft^3 / Hr = Hours
- 2 – 3 Hours Design – Septicity, Denite

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Sedimentation/Clarification Tanks

- Conventional Basins
  1. Rectangular Clarifiers
  2. Circular Clarifiers
- Dissolved Air Flotation
- Inclined Plate Settlers (Lamella™)
- Floc Blanket - Super Pulsator®
- Solids Recirculation - Accelator®
- Absorption Clarifier - Trident®
- Ballasted Clarifier - Actiflo ™

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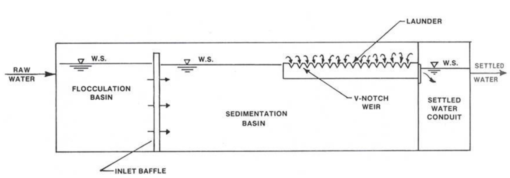
Conventional Basin Designs - Rectangular



- Flow Distribution

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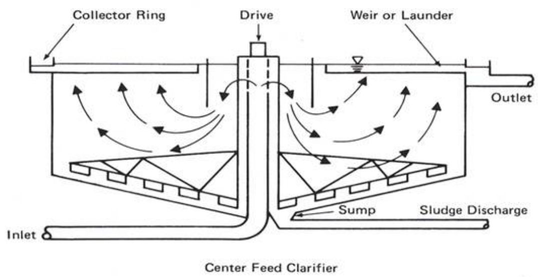
Circular Sedimentation Schematic



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Design Criteria

Surface Loading	0.2 – 0.5 gpm/sf
Water Depth	9 – 15 feet
Detention Time	1.5 – 3 hours
Width:Length	1:5
Weir Loading	< 15 gpm/sf

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Sedimentation / Clarification – Process Description

- Reducing the velocity of water in basins so that suspended material (floc) can settle out by gravity.
  - Detention time typically 1.5 – 3.0 hours
  - Flow through velocity typically 2 – 4 ft/min
  - Surface loading rate 500 – 1,200 GPD/ft^2
- Sludge, the residue of solids and water, accumulates at the bottom of the basin and must then be pumped out of the basin for disposal.

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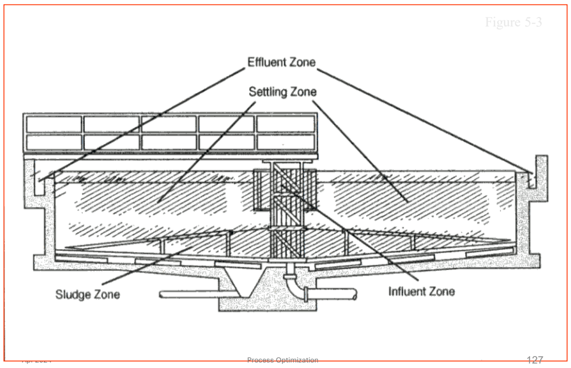
Zones in a Sedimentation Basin



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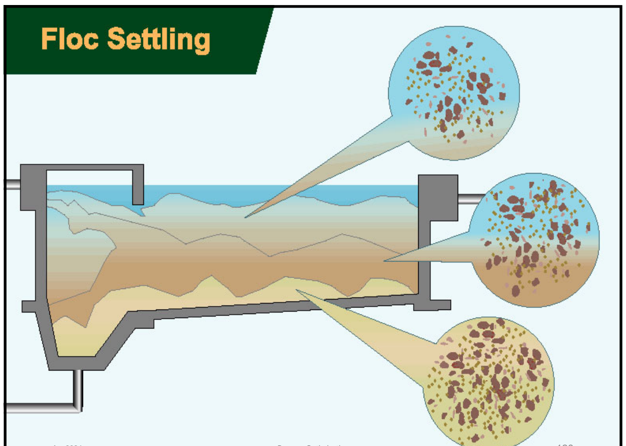
Floc Settling



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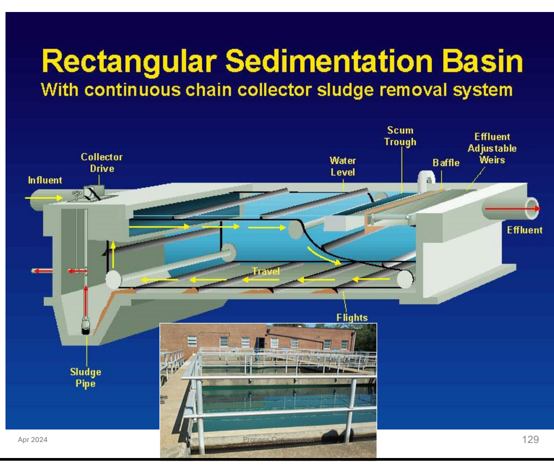

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Solids Collection

- Rectangular Flights
  1. Endless chains
  2. Travel in Direction of Flow for Grease
  3. Travel Against Flow for Settled Solids
- Sludge Hopper > Pump or Gravity
  1. Scum Pit > Pump or Ejector

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Circular Sedimentation Basin

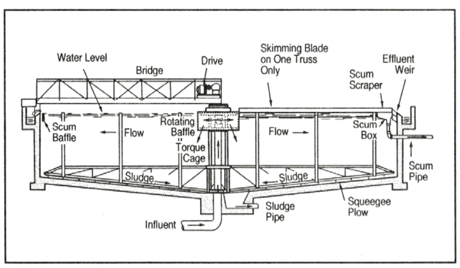

FIGURE 5-5 A typical circular sedimentation basin

Courtesy of FMC Corporation, MHS Division

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Circular Collectors

- Rotate Clockwise
  1. Surface Skimmers for Grease
  2. Bottom Flights for Settled Solids
- Solids Removal
  1. Pump
  2. Gravity
  3. Draft Tubes

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Pros and Cons – Conventional Sedimentation Basins

Pros

- More tolerance to shock loads ("Bullet – Proof" process)
- Easy to operate and forgiving
- Low head loss and operating costs
- Non-proprietary vendor sourcing

Cons

- Requires large area low loading rate 0.3 gpm/ft^2
- Requires 30 to 40 minutes floc HDT
- Subject to density flow created in the basin.
- Needs to be covered in northern climate (freezing)
- Scrapers can jam and break (need good torque clutches)
- Not so good on algae or light floc
- Expensive to construct

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Performance Goals - Sedimentation

- Turbidity ≤ 2 NTU 95% time when source turbidity > 10 NTU
- Turbidity ≤ 1 NTU 95% time when source turbidity ≤ 10 NTU
- Factors affecting sedimentation
  - Efficiency of C/F Processes
  - Detention Time
  - Surface Loading Rate
  - Weir Overflow
  - Temperature
  - Density Currents
  - Wind
  - Sludge Build-up

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Water Treatment

Filtration

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Filtration

- Process Description
  - Removal of suspended matter by passing the water through a granular porous medium such as sand, anthracite coal, or a membrane.
- Overall Goals:
  - Surface Water Treatment Rule (SWTR)
    - Surface sources must receive filtration and disinfection
    - Finished water turbidity standard of 0.5 NTU
  - Interim Enhanced Surface Water Treatment Rule (IESWTR)
    - Finished water turbidity standard of 0.3 NTU
    - Benchmarking / profiling for Cryptosporidium removal

TYPES OF FILTRATION

- Granular Media Filtration
  1. Most common type
  2. Depth Filtration
     A. Water moves through the pores between filter grains
     B. Particles are smaller than pores and are deposited by colliding with the grain surface and attaching or sticking
     C. Filters and Rate: Slow Sand, Rapid Rate, High Rate
- Membrane Filtration
  1. Particles larger than pores (removal by sieving)
  2. Microfiltration and ultrafiltration
  3. Nanofiltration and Reverse Osmosis

Filtration Process Variables

- Filter media
  1. Grain size
  2. Shape
  3. Density
  4. Composition
  5. Porosity
- Filtration Rate
- Allowable Head Loss
- Liquid Characteristics (e.g., temperature)

Filtration Process Variables (cont)

- Influent Characteristics
- Suspended solids concentration
- Particle size
- Particle charge

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Filtration mechanisms

Soil	1-100 µm
Cryptosporidium oocysts	5 µm
Bacteria	0.3 – 3 µm
Viruses	0.005 – 0.1 µm
Floc particles	100 - 2000 µm
Visible particle w/ 20:20 vision	37 µm

Filter media pores range from 50 to 400 µm depending on media size

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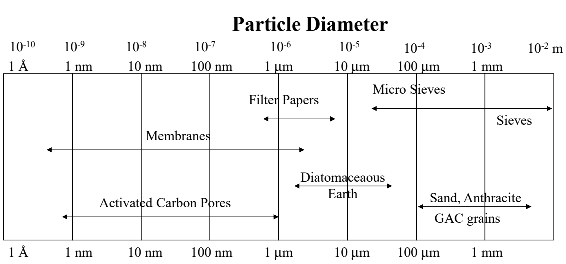
Size Spectrum of Granular Filter Media and Pores



(After Stumm, ES&T, Vol. 11, p. 1066, 1977)

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Filtration
Particle Removal Mechanisms

- Straining
- Sedimentation
- Compaction (inertial)
- Interception
- Adsorption (chemical)
- Adsorption (physical)
- Adhesion
- Coagulation / flocculation
- Biological growth

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Filter Composition

- Sand & anthracite
- Sand & activated carbon
- Sand & resin
- Resin & anthracite
- Anthracite, sand and garnet
- Activated carbon, anthracite and sand
- Activated carbon, sand and garnet
- Resin beads (± charge, neutral)

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Filter Removals

- Bi-Modal distribution of particle sizes
- Sand is more important when floc is weak
- The more layers of different porosity, the longer the run time
- Diatomaceous filter not suitable for activated sludge (erratic operation

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Gravity Filter Components

- Influent Trough (Backwash Return)
- Media
- Underdrain
- Scouring System
- Backwash System (Pumps)
- Effluent Rate-Control Valve

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Water Filtration

Media

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Filter Media

- Broadly speaking, filter media should possess the following qualities:
  1. Coarse enough to retain large quantities of floc
  2. Sufficiently fine particles to prevent passage of suspended solids
  3. Deep enough to allow relatively long filter runs
  4. Graded to permit backwash cleaning
  5. However, fine sand retains floc and tends to shorten filter runs; the opposite is true for course sand

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Filter Media

- Effective size and uniformity coefficient are defined as follows:
  1. Effective size is the 10-percentile diameter; that is 10% by weight of the filter media is less than this diameter (D_{10})
  2. Uniformity coefficient is the ratio of the 60-percentile size to the 10-percentile size (D_{60}/D_{10})
  3. Conventional sand media has an effective size of 0.45 – 0.55 mm and a uniformity coefficient less than 1.65

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Typical Filter Media Characteristics

Material	Size Range (mm)	Uniformity Coefficient	Specific Gravity	Hardness (MOH scale)
Anthracite Coal	0.8 – 1.2	< 1.85	1.5 – 3.0	3.0
Silica Sand	0.3 – 0.6	< 1.5	> 2.5	7.0
Garnet Sand	0.2 – 0.4	< 1.5	3.8 – 4.3	7.5 – 8.0
Silica Gravel	1.0 - 50	N/A	> 2.5	7.0
GAC	0.8 – 1.2	< 2.0	1.5 – 3.0	N/A

Note: The Mohs scale is an ordinal scale with a relative scale of hardness 1 to 10

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Filter Media

- A sand filter bed with a relatively uniform grain size can provide effective filtration
- Dual media filter beds usually use anthracite and sand
- Multimedia filter beds generally use anthracite, sand, and garnet
- Advantages of dual and multimedia filters are:
  1. Higher filtration rates
  2. Ability to filter a water with higher turbidity
  3. Possibly longer filtration runs

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Filter Media Thickness

- Dual Media
  1. Anthracite: 18 inches (8 – 24)
  2. Sand 12 inches (10 – 24)
  3. Filtration Rate: 6 gpm / ft^2 (2 – 10)
- Multimedia
  1. Anthracite: 15 inches (8 – 20)
  2. Sand 12 inches (8 – 16)
  3. Garnet 3 inches (2 – 4)
  4. Filtration Rate: 6 gpm /ft^2 (2 – 12)

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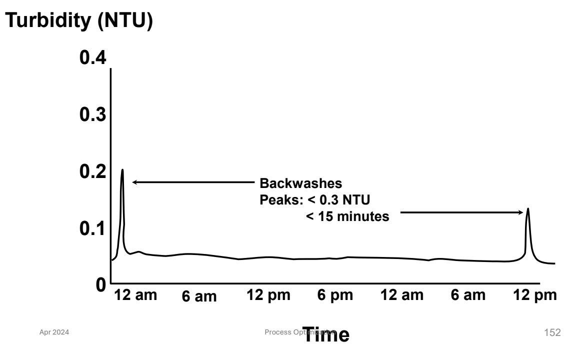
Filter Profile – Good Performance



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Approaches to Filtration

- Filtration by Granular Media
  - Conventional Treatment
  - Direct Filtration
  - Slow Sand Filtration
- Diatomaceous Earth Filtration
- Bag and Cartridge Filtration
- Membrane Filtration
- Reverse Osmosis (RO)

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Granular Media – Filtration Theory

- Mechanisms of particulate removal
  - Transport mechanisms (major)
    - A. Sedimentation, impaction, interception, diffusion, and hydrodynamic forces
  - Adsorption (major)
  - Absorption (minor)
  - Straining (minor)

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The Filtration Process

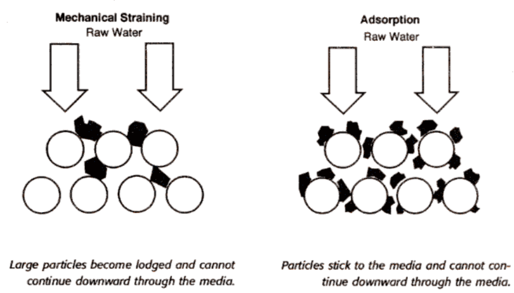

Figure 6-1

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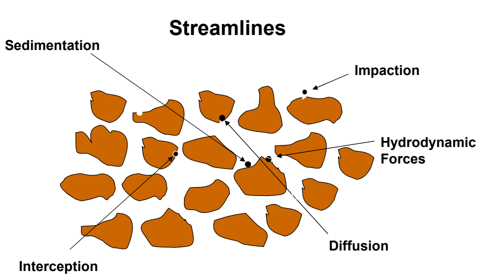
Filtration Attachment Mechanisms



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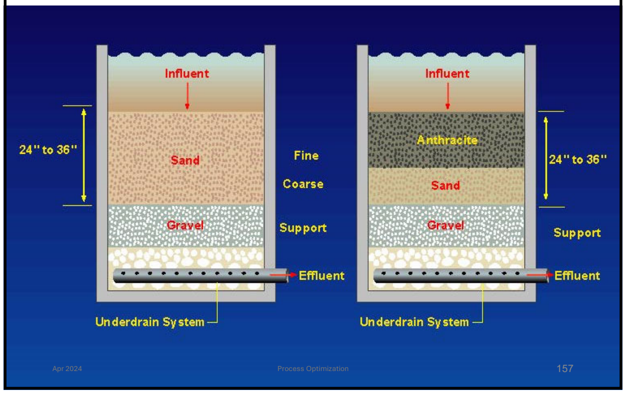
Single and Dual Media Filters



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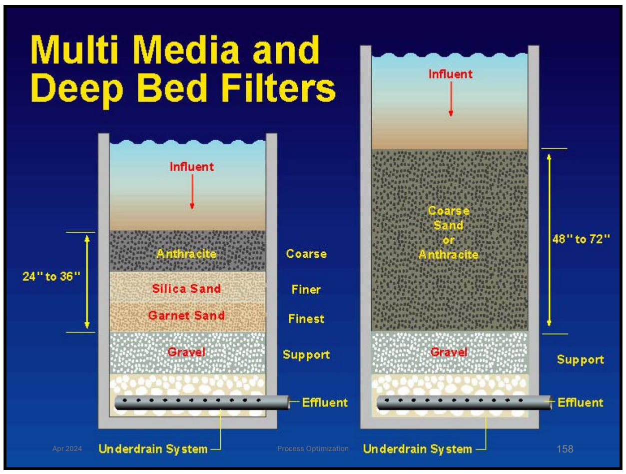

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Comparison of Gravity Filter Characteristics

Characteristic	Slow Sand Filters	Conventional Rapid Sand Filters	High-Rate Filters
Filtration Rate:	0.05 gpm/ft^2	2 gpm/ft^2	3-8 gpm/ft^2
Media:	Sand	Sand	Sand and Coal or Sand, Coal, & Garnet
Media Distribution:	Un-stratified	Stratified	Stratified
Filter Runs:	20-60 days	12-36 hours	12-36 hours
Loss of Head:	0.2 feet initial to 4 feet final	1 foot initial to 8 or 9 feet final	1 foot initial to 8 or 9 feet final
Amount of Backwash Water Used:	No Backwash	2-4% of water filtered	6% of water filtered

Table 6-1

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Comparison of Gravity Filter Characteristics

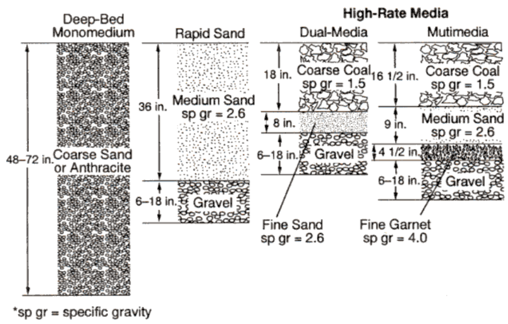

Figure 6-8

160

Filter Operation

- Goal is to optimize filtration process (i.e., low turbidity
- Operator should routinely evaluate filter performance
  - Filtered water turbidity/turbidity breakthrough
  - Length of filter run/head loss
  - Ratio of the volume of backwash water used to the volume of filtered water

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Typical Filter Run

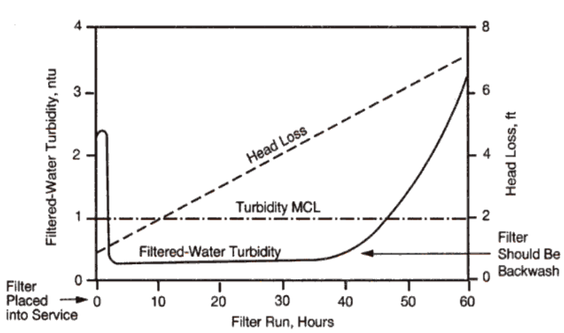

Figure 6-27

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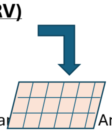
Filtration and Backwash Rates

Filtration Rate (FR) and Unit Filter Run Volume (UFRV)

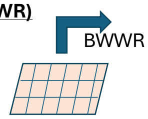
Q



Squar Area

- FR = Q, gpm / Area, sq ft
- UFRV = Total gallons / Area, sq ft

Backwash Water Rate (BWWR)



Square foot Filter Area

- BWWR = BWWQ, gpm / Area, sq ft

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What is Filter Backwash Water?

- Resulting water pushed back through the filter in the cleaning process
- Filter backwashing is an integral part of treatment plant operation

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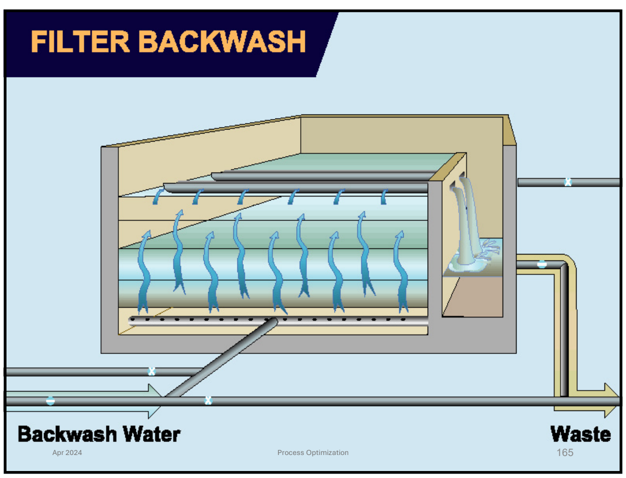

165

Filter Backwash Operation

- Backwash
  - Fluidizes (expands) bed by reversing flow
  - Removes entrapped solids
- Backwash rates
  - Range from 10-35 GPM/ft^2 for adequate cleaning
  - Some standards require a minimum of 15 GPM/ft^2 or 50 percent bed expansion

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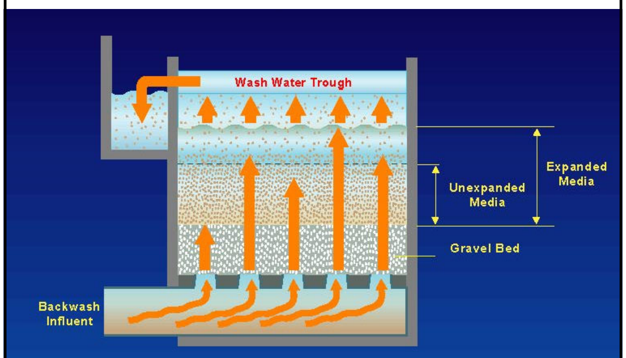
Filter Bed Expansion



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Filter Backwash Evaluation

- Watch the backwash
  - Boils (uneven flow distribution)
  - Media carryover
  - Clarity of wash water (turbidity)
- Observe filter media following backwash
  - Cracks and evenness

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Water Filtration

Operational Issues

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Visual Inspection of Filter

- Drain filter to examine
- Media surface should be smooth
- **Look for cracks, ridges, depressions and holes**
- Media in wash water troughs??
- Document everything observed

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Visual Inspection of Filter

Inspecting Media

Freeboard Measurement

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Filter Operating Problems

- Generally, there are three types of filter performance problems:
  1. Poor chemical pretreatment of feed waters to the filter
     A. Coagulation
  2. Rapid changes in flow to the filter
     A. Flow surges that cause turbidity breakthrough
  3. Ineffective backwashing of filters
     A. Mudball formations, filter bed shrinkage, media displacement or loss, and air binding

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Filter Operating Problems

- Poor chemical pretreatment ahead of filter
  1. Coagulation/flocculation/sedimentation must be monitored and optimized continuously
  2. Adjustments in coagulant added must be made frequently to prevent the filter from becoming clogged with suspended solids or coagulant
  3. Turbidity breakthrough in the filter effluent may indicate:
     A. More coagulant is needed, or
     B. Better coagulant mixing is required

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Filter Operating Problems

- Rapid changes in flow to the filter
  1. Effluent turbidity may be affected by surges in flow
  2. If flow increases are necessary, increase flow gradually
  3. Care must be taken to avoid overloading one filter when backwashing another
  4. When starting-up a filter:
     A. Backwash before putting them in operation

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Filter Operating Problems

- Ineffective/improper backwashing
  1. Mud ball formation
  2. Filter media cracking and separation from filter walls (could result from mud ball formations) causing short circuiting of flow through the media
  3. Supporting gravel disruption caused by backwash valve opening too quickly or uneven distribution of backwash water due to plugged under drain
     A. “Boiling” occurs
     B. Media will wash out into under drain

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Filter Operating Problems

- Ineffective/improper backwashing
  1. Air binding; not common; pressure in the filter becomes negative during operation
     A. Air dissolved in the water comes out of solution and becomes trapped in the filter
     B. Creates high head conditions and short filter runs
     C. Generally occurs when:
        i. Water level is less than 5 feet above filter bed
        ii. Water is cold and super-saturated with air
     D. Operate filters greater than 5 feet above filter bed or backwash more frequently

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Filter Operating Problems

- Media loss during backwash
  1. Especially when filter surface wash is used
  2. Expand filter bed 15 - 30%
     A. Bed Expansion, % = Inches of Rise/Total Media Depth
  3. Option, turn off surface wash approximately two minutes before the end of the backwash
  4. Another option, raise filter troughs to prevent excessive media loss

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Media Appearance after Backwash

- Filter media:
  1. Will appear to move laterally during backwash
  2. Will show no boils at the surface
  3. Will be level and smooth with no cracks or mudballs on surface

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Results of Improper Backwashing

- Turbidity Breakthrough
- Short filter runs
- Air binding
- Mudball formation
- Filter bed shrinkage
- Gravel displacement
- Damage to underdrains
- Media loss

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Gravity Filter Backwashing

- Bed Expansion
- Scouring
- No "Boiling" or "Dead" Zones
- Avoid Air Charging and Water Hammer

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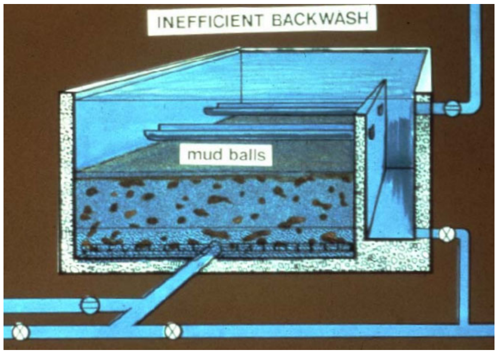
Results of Ineffective Backwashing



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Filter Profiling

- The intent of filter profiling is to allow system operators to **interpret** filter profiles, **investigate** the cause of the elevated turbidity, and take actions to **correct** problems
- If a system does not take **preventative** actions, continued turbidity breakthrough could trigger more problems

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Water Treatment Facilities

Disinfection

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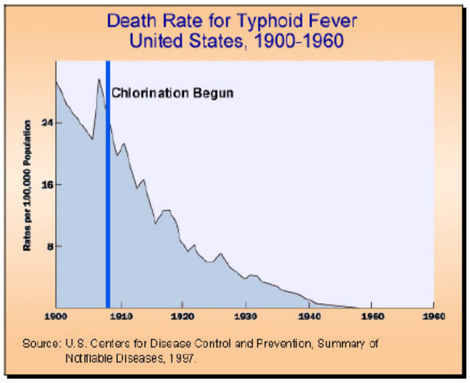

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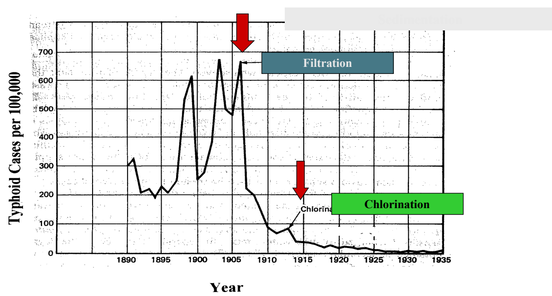
Typhoid Cases 1890-1935 Philadelphia



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Types of Pathogens

- Viruses (e.g., Norwalk virus, rotaviruses)
- Bacteria (e.g., *Shigella, E.coli*)
- Parasites, protozoa and cysts (e.g., *Giardia lamblia, Cryptosporidium*)

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Bacteria

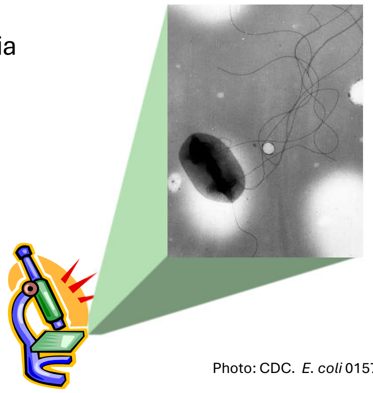

Photo: CDC. *E. coli* 0157:H7

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Viruses

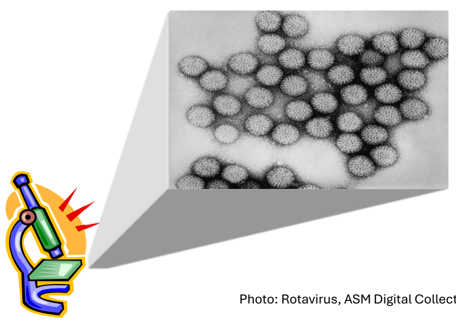

Photo: Rotavirus, ASM Digital Collection

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Protozoa

Giardia

Cryptosporidium

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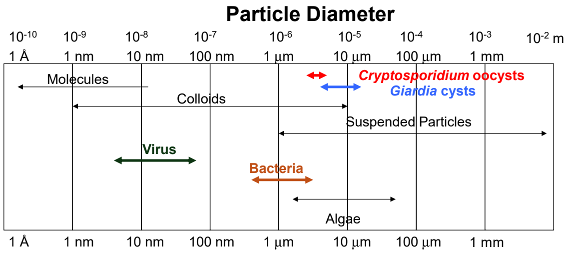
Particle Size



(After Stumm, ES&T, Vol. 11, p. 1066, 1977)

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Wastewater Treatment Facilities

BOD and TSS Removal

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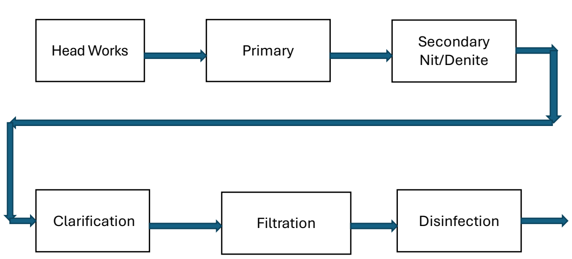
Wastewater Treatment



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Wastewater Characteristics

- Q – Flow, GPD, gallons/day (or gpm, MGD, gallons/hour)
- BOD – Biochemical Oxygen Demand, mg/l
  1. cBOD – Carbonaceous BOD
  2. nBOD – Nitrogenous BOD
- COD – Chemical Oxygen Demand, mg/l
- DO – Dissolved Oxygen
- Suspended Solids, mg/l:
  1. TSS – Total Suspended Solids
  2. VSS – Volatile Suspended Solids

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Optimizing WWTPs - Strategies

- Implementing advanced treatment technologies
- Optimizing treatment processes
- Improving energy efficiency
- Reducing resource consumption
- Ensuring maintenance and upkeep
- Development of an optimization of facilities
- Determination of objectives and inventory
- Preparation of substance balances
- Sketches for optimization
- Energy cost savings through optimal aeration system
- Adequacy of temperature for optimization of wastewater cleaning

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Biological Treatment

- AS – Activated Sludge
  1. MLSS – Mixed Liquor Suspended Solids
  2. MLVSS – Mixed Liquor Volatile Suspended Solids
  3. WAS – Waste Activated Sludge
  4. RAS – Recycled Activated Sludge
- AS Process Control:
  1. DT – Detention Time , Tank volume/flow rate, V/Q, hours
  2. MCRT/SRT – Mean Cell/Solids Retention Time, days
  3. F:M – Food-to-Mass ratio, BOD/MLVSS
  4. SV – Sludge Volume after 30 minutes
  5. SVI – Sludge Volume Index, SV x 10,000/MLSS

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Biological Treatment

- BNR/ENR – Biological/Enhanced Nutrient Removal
  1. Anaerobic – Soluble BOD uptake and Phosphorus Release
  2. Anoxic – Denitrification
  3. Aerobic - Nitrification
  4. IR or NR– Internal Recycle /Nitrate Recycle

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Microorganisms

- **Aerobic** (Oxic) - Organisms requiring, or not destroyed, by the presence of free oxygen
- **Anoxic**: Organisms requiring , or not destroyed, by the absence of free oxygen; nitrates (NO_3) are present.
- **Anaerobic** - Organisms requiring, or not destroyed, by the absence of free oxygen and NO_3
- **Facultative** - Organisms able to function both in the presence or absence of free oxygen
- **Heterotrophic** - Organisms that use organic materials as their source of cell carbon
- **Autotrophic** - Organisms able to use carbon dioxide and other inorganic matter as their source of carbon
- **Filamentous** – Bulking organisms that grow in thread or filamentous form

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Activated Sludge Aeration*

- Converts BOD to CO2 and water
- Requires minimum of 2-3 hours detention time
- With longer aeration times (6 hours) can nitrify
- Requires good aeration control/DO control in various locations
- Can operate in different modes – plug flow, step feed, etc.
- Must observe biology to avoid problems (microscope)

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Optimize Aeration*

- Periodic examination of diffuser fouling
- Automatic DO control
- Match aeration to flows and loadings (day/night)
- Coarse vs. fine bubble diffusers
- Optimize grid pattern for diffusers
- Provide turndown on blowers (inlet vanes/vari-speed)
- If filamentous growth, add chlorine for a fixed time

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Coarse Bubble

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Fine Bubble

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Activated Sludge Sedimentation

- Takes mixed liquor from aeration and settles it
- Circular or rectangular clarifiers
- Usually a number of units
- Flow distribution among units and within the clarifier important
- Returns sludge to aeration
- Sludge wasting important to controlling biology
- Sludge blankets controlled to avoid decomposition

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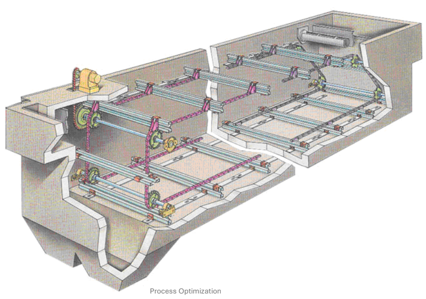
Rectangular Secondary Clarifier



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Optimize Sedimentation

- Use dye tests to evaluate flow distribution
- Monitor and control sludge blankets – various methods
- Take o/s annually to examine submerged equipment
- For bulking sludge change biology/DO, or chlorinate return sludge
- SVI (settling) tests
- Add polymer or ferric chloride to improve settling

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Final Filtration

- Needed if > secondary treatment is required. Removes TSS, Phosphorus in wastewater
- Removes solids in water treatment
- Use single or dual media filters (sand/anthracite)
- Or moving bed, etc.
- Various means of control
- Chlorinate influent or backwash water
- Approx 10% of processed water used for backwash
- Backwash sometimes accompanied with air
- Media fouling requires attention

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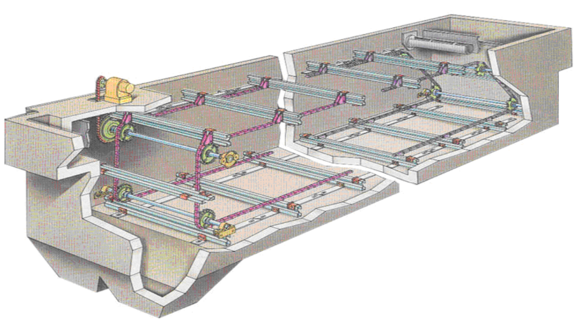

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Optimizing Filtration*

- Optimize amount of backwash water. Backwash only when necessary
- Schedule backwashing to low energy cost times of day (i.e., evenings). Backwashing is the largest energy user in filtration
- Some plants chlorinate filter influent for both disinfection and for control of media fouling
- Equalize flow among available filters
- Examine under-drains annually for media loss, etc.
- Maintain all automatic valves – many associated with backwash
- Examine media for chemical buildup (mudballs)
- Automate backwash sequence (a batch process) to minimize damage to filters

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Disinfection

- Either chlorination/dechlorination or UV (most used)
- Monitor effectiveness with fecal coliform test done daily
- Usually controlled to a chlorine residual within the plant for at least 30 minutes (Permit requirement)
- Reaction time slow
- UV controlled to an exposure level for a fixed time
- All residual chlorine must be removed before discharge – done with sodium bisulfite or SO2

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Optimizing Disinfection

- Flow pace chemicals
- On-line analyzers for residual – for both hypochlorite and bisulfite feeds
- Do not store hypochlorite too long in warm weather – it loses strength
- Add chlorine ahead of filtration

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Solids Processing

- Thickening - Gravity or Dissolved Air Flotation
- Blending (optional)
- Dewatering and lime addition
- Digestion (optional)
- Final dewatering
- Class A or B
- Hauling to land application sites/landfill
- Incineration
- Drying

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Dewatering *

- Increases solids from 5% to 20 -30%
- Used in both water and wastewater treatment
- Conditioning with chemicals always required
- Necessary for trucking to land application sites, for incineration, for composting, and for landfilling
- Methods used are
  1. Belt Filter Press
  2. Centrifuge
  3. Filter Press
  4. Lagoons and Drying Beds

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Centrifuge

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Optimizing Dewatering

- All methods are dependent on proper conditioning
- Inorganic chemicals add weight to final product
- Organic chemicals (polymers) add no weight
- Chemical selection is done by lab tests, and confirmed in full scale
- Mixing of conditioning chemical very important to make the floc, but not breaking it down
- All dewatering does better if screenings and grit are removed

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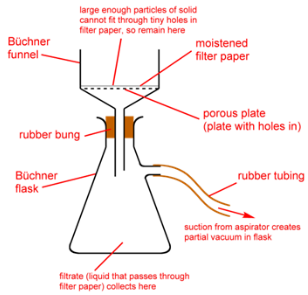
Buchner Funnel



214

Jar testing

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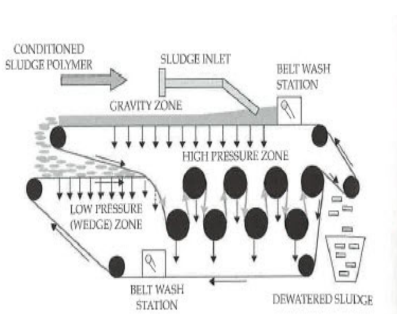
Belt Press



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Optimizing a Belt Filter Press

- Polymer can be neither under nor over-conditioned
- Use lab test to check drainage with different polymer feed rates
- Monitor belt condition – clean when plugged
- Find the best belt tension number
- Feed solids need to be low enough for good polymer incorporation

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Optimizing a Centrifuge

- Maintaining a constant ratio of primary to secondary sludge is critical to stable operation
- Auto controls on centrifuge usually control torque
- Polymer addition point can be varied and there is an optimum location that can change
- High cake solids usually means dirty centrate – find the balance
- Monitor cake solids and centrate and adjust polymer rate
- Monitor SVI – lower is better
- Identify under -performing units

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Optimizing Drying Beds

- Need a lot of land area, with properly designed underdrain system
- Can add polymer to improve drainage
- Cover if affected by too much rain

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Hauling to Land App Sites

- Usually pay by the wet ton hauled and applied
- Can minimize tonnage by getting a drier cake, using less inorganic chemicals
  1. If lime stabilizing undigested solids need to meet pH of 12 without going too far over

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Reducing Costs

- Determine current costs and compare to standards/norms
- Compare to like facilities
- Look at how you do things and compare with others - You might find a better way

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Reducing Costs

- Before you start this effort, be clear on the plant's overriding performance goals, e.g.
  1. Permit – Zero violations
  2. Safety – Zer0 lost time accidents
  3. Budget targets - % reduction each year
  4. Minimize downtime of equipment

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Example Plant Budget

- Labor (direct salaries) $577,000
- Overtime 60,000
- Benefits (35%) 202,000
- Training (~3.5% of direct salaries) 20,000
- Operating Supplies (mostly chemicals) 300,000
- Maintenance Supplies 50,000
- Lab supplies + Contract analysis 10,500
- Power 180,000
- BioSolids hauling & land app 170,000
- Miscellaneous 8,000

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Budget Summary

- Total $1,757,500
- At 2.5 MGD average flow
  1. $1,757,500 / 2.5 x 365 = $1925/MG
  2. Staff = 10 members
  3. AWT plant - Permit limits include N and P + low levels of BOD and TSS

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Analysis*

- Labor 47%
- Oper supplies 19%
- Power 11%
- Biosolids 11%
- All other 12%

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Labor

- Does every set of tasks fit into a 40 hour work week?
- Can people be trained to multi-task?
- Can lab staff , or maintenance staff fill in for operations?
- Employee availability = 85% (show calculation)
- Eliminate unnecessary tasks – perform task analysis
  1. Define process standards
  2. Look at each area and define a standard of care
  3. Define needed tasks, time needed and who assigned

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Calculation

- Determine % availability of a staff person
  1. Assume 2080 hours per year (40 hours/week & 52 weeks/year)
  2. Vacation time – 20 days/year
  3. Sick leave – 5 days/year
  4. Holidays – 9 days/year
  5. Total = 34 days/year = 34 X 8 = 272
  6. 272/2080 = 13.1% or 86.9% available

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Management

- Old model – a person in charge of each section, e.g. operations, maintenance, lab, etc.
- New model – one person manages several functions; relies on technical experts in each area
- Can you consolidate O&M, E&I, Lab & Process Engineering
- Working managers?

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Operations Staffing

- Can some operations tasks be automated?
  1. Tradeoff with instrumentation staff
  2. Investment in Process Control Systems
- Sampling – auto samplers
- Maintenance responsibilities – PM or CM
- Ownership
- Day vs. night staffing
- Standardize operations between shifts
- Shift handoffs

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Maintenance Staffing

- Attempt to make majority of work planned
  1. Maintenance Management System - CMMS - records
  2. Predictive maintenance
  3. Preventive maintenance – define work hours
  4. Corrective maintenance
  5. Capital Improvement
     A. Concept of ROI

Qualified staff for automation and PCS maintenance

Consider contracting out specialty work, e.g. HVAC, cranes, centrifuge rebuilds

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Maintenance (cont)

- Parts
  1. Available and in a box handed to mechanic
  2. What you keep on your shelf vs. vendor's shelf
  3. Critical spare parts
     A. For equipment with little installed redundancy
     B. For equipment with long lead times

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Addressing Overtime*

- Planned vs. unplanned OT
- Can multi skills offset some OT?
- How do you prioritize work and staffing?
- Minimum staffing on shifts
- Can others fill in?

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Operating Chemicals (WWT)

- Next largest expenses may include:
  1. Polymers for settling, or for thickening/dewatering
  2. Methanol for denitrification
  3. Sodium hypochlorite for disinfection and odor control; also biology control in secondary
  4. Sodium bisulfite for dechlorination
  5. Ferric chloride or alum for phosphorus removal
  6. Lime/magnesium hydroxide/ caustic for pH adjustment

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Operating Chemicals (Water)

- Al or Fe salts for coagulation
- Lime or caustic for pH control
- Sodium hypochlorite for safety in the delivery system; bisulfite for dechlor
- Some chemicals to add fluoride to the water
- Some chemicals for taste and odor

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Two Approaches

- Pay less for each chemical – via good purchasing techniques
- Use less to do each job – under operation's control

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Pay Less

- Price often depends on quantity purchased
- Try to work with other agencies to do a group bid
- Getting competition is key to good pricing – search out suppliers
- Benchmark to learn what others are paying for that chemical
- Use chemical marketing firms to track pricing
- Use BLS PPI for some common chemicals

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Feeding Chemicals

- Dry Product
  1. Gravimetric
  2. Volumetric
- Liquids
  1. Pumping a liquid or slurry, w/wo carrier water
- Gas
  1. Must be dissolved in water

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Dry Feeders*

- Usually, a silo or day tank to a volumetric feeder
  1. Day tank can be on a scale
  2. Can use a calibrated screw to feed. Requires periodic calibration
  3. Other feeders – Belt, Revolving plate, Rotary, Shaker
  4. Inspect to avoid buildup from moisture

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Feed Controls - Solids

- Target a #/dry ton in solids streams
- Difficult to have an on-line analyzer that works
- Can run % solids or TSS in field
  1. Need visual or grab sample of dewatered cake or centrate – to vary polymer dose

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Feeding Liquids

- Positive displacement pumps
  1. Gear pumps
  2. Hose pumps (2000 hours life)
  3. Diaphragm pump
  4. Rotary lobe pump
  5. Progressive Cavity pump

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Pump Selection*

- Gear pumps – becoming more popular
- Hose pumps – Hose has a life span
  1. No air binding
- Diaphragm pumps
  1. Vari speed and vari stroke
  2. Can air bind

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Pump Selection (cont)*

- Rotary lobe pump – handles product without damaging, e.g. polymer
- Progressive cavity pump – Good general, all-purpose pump
- Drum pump – for small feed systems

- Pumps cannot be over or under sized
- Use graduated cylinder for calibrating pumps
- Carrier water advantages/disadvantages

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Carrier Water

- Works to help disperse the chemical in the total flow, esp. if little mixing at point of application
- Some chemicals react with carrier water
  1. Ferric chloride forms ferric hydroxide

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Flushing Water

- All chemical piping should have a flushing connection
  1. Never leave chemical sitting in a pipe. It attacks the piping/glue at fittings - hypo
  2. Can have an auto solenoid to flush when feed stopped
  3. Protect from leaving it on

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Feed Controls – Liquid

- Can be constant flow, but not optimum
- Best if flow-paced with main flow – metered flow rate determines pump speed or stroke
- Difficult to measure flow rates of chemical, often use a correlated speed
- Target a mg/l dosage into liquid flow
- Can use feedback from an on-line analyzer, e.g. NO_3 analyzer to set methanol flow

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Feeding Gas

- Examples – Chlorine, Sulfur dioxide, Oxygen, Ozone
- Need an evaporator for Cl_2 and SO_2
- Water solution

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Addition Points

- Get good mixing
- Reaction times
- Add at a point of natural turbulence or install a mixer
  1. Chemical Injection Units
  2. Ejectors
  3. Static Mixers
  4. Flocculation Tanks (mostly for solids streams)

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Addition Points (cont)

- Difficult to get good mixing in raw sewage
- Most mechanical mixers require clean water
- CIUs are high speed machines that work well for Hypo, ferric chloride, and caustic
- Ejectors also work with these chemicals

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Use Less*

- Collect data on usage
- Trend the data
- Compare with theoretical values
- Compare with literature
- Benchmark
- Look at addition point – good mixing?
- Flow pacing
- Online analyzers
- Jar testing to confirm dosages required
- Calibrate feed equipment

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Example Chemical Dosages

- Ferric Chloride (P removal) – 5 mg/l of Fe and another 2.5 at second point
- Sodium Hypochlorite for Disinfection – 4 mg/l
- Sodium Bisulfite – 2.5 mg/l
- Methanol – 3 lbs/lb of NO_3-N
- Caustic – 0.81 lbs/lb of alkalinity
- Lime for solids stabilization – 15 to 20% of dry solids

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Example Chemical dosages

- Polymer – in wastewater to aid settling- 0.2 mg/l
- Polymer for Thickening – 5 lbs/dry ton solids
- Polymer for Dewatering – 10 to 15 lbs/ton solids

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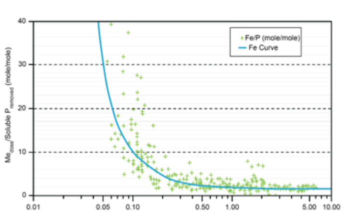
Phosphorous Removal



Ratio of iron (Fe^{+3}) dose to phosphorus removed as a function of residual soluble orthophosphate concentration

Data from the Blue Plains Advanced Wastewater Treatment Plant, Washington, D.C. and Luedecke, C.; Hermanowicz, S.; Jenkins, D. (1987). Precipitation of Ferric Phosphate in Activated Sludge: A Chemical Model and Its Verification. Water Sci. Technol., 21, 325–338.

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Calculation (1)

- Given: Average flow = .075 MGD
- Fe dosage of 7.5 mg/l
- Calculate gpm of Ferric chloride feed

- 0.75 MGD X 8.34 #/MG/mg/l X 7.5 mg/l of Fe = 46.9 # Fe/day
- 46.9 #/day X (162.35/55.85) =
  136.4 # $FeCl_3$/day

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Calculation (2)

- Given $FeCl_3$ as delivered is 34% solution; density of 11.67 # solution/gallon.
- 136.4 # $FeCl_3$/day /0.34 # $FeCl_3$/# solution = 401.2 # solution/day
- 401.2/ 11.67 #/gal = 34.4 gal/day of $FeCl_3$ solution
- 34.4/1440 min/day = 0.24 gal/min $FeCl_3$ solution

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Optimizing Chemical Feed

- Trend data – know where you are
  1. Measure flow or lbs of solids processed and lbs of chemical used per what is measured – Daily/Weekly/Monthly
  2. Plot data
  3. Look for ways to reduce consumption
  4. Chemicals can be a large portion of total budget

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Optimizing Chemical Feed

- Use flow pacing, on-line analyzers
- Give operators the data
- Set performance targets
- Calibrate pumps and dry feeders monthly/quarterly
  1. Hose pumps and diaphragms wear
  2. Volumetric screws get plugged

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Resources

- Chlorine Institute – www.cl2.org
  1. Chlorine, hypo, caustic, hydrochloric acid
- Methanol Institute – www.methanol.org
- National Lime Association – www.lime.org

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Optimizing Polymer

- QA on deliveries – compare with original tested
- Jar tests for settling optimization
- Jar tests/Buchner funnel for solids
- Maybe add with Fe or Al
- Rise test in DAF
- Performance testing in field – Microwave or Sartorius

- A benefit of increased primary sludge is improvement in dewatering (using less chemical there)

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Polymer Calculation

- Setting: Should Operations pay additional polymer costs to get higher cake solids in the dewatered cake?
- Assumptions: Polymer added at 10 lbs/dry ton to produce a 26% solids. If add 11 lbs/dry ton, can get 27% solids. Polymer cost is $1.75/pound.
- Hauling costs are $40.00/wet ton biosolids
- Average sludge production is 15 dry tons/day

- 15/0.26 = 57.7 wet tons/day ; 15/0.27 = 55.6 wet tons/day

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Continued

- Cost/day to haul biosolids
  1. At 26% solids 57.7 wet tons X $40.00 = $2308/day
  2. At 27% solids 55.6 wet tons X $40.00 = $2224/day
  3. Difference is $84/day

  Cost/day for extra polymer
  10lbs/dry ton X 15 dry tons/day = $150/day
  11 lbs/dry ton X 15 dry tons/day = $165/day
  Difference is $15/day
  Conclusion : **Add the extra polymer**

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Methanol

- Formula
- Try to use the carbon in wastewater first
- Flow pace addition
- Measure ammonia and add required amount
- Trim by measuring nitrate
- Insure good mixing
- Avoid overdosing as it drops DO and increases BOD
- Also vaporizes and may exceed air pollution limits

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Sodium Hypochlorite *

- Disinfection and incoming odor control
- Run tests to see what chlorine residual meets fecal standard
- Flow pace or use a chlorine residual analyzer and trim feed
- Try to get double duty, e.g. disinfect and minimize growth on filter media

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Sodium Bisulfite

- Dechlorination
- Instantaneous reaction
- Flow pace and trim with an on-line analyzer for chlorine residual

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Ferric chloride or Alum

- Formula – Fe + PO4 = FePO4
- Jar tests to optimize
- Check for competing reactions, e.g. sulfides
- Can use ferrous to react with H2S
- Review mixing at addition point

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pH Adjustment*

- Can use lime, magnesium hydroxide, or caustic
- Good mixing
- On-line analyzer for pH

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pH Adjustment*

- Wastewater usually enters plant at a pH near 6.5, but can vary depending on industrial component
- Usually regulated to discharge at 6.0 to 9.0
- Some processes cause a drop in pH
  1. Chemical (ferric chloride) for P removal
  2. Nitrification

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pH Adjustment (cont)

- Lime (quicklime) is the least costly, but comes with handling problems
  1. Must be slaked
  2. Lime must be kept away from moisture
  3. Some large facilities have been shut down due to handling difficulties
     A. Absorbs moisture in storage
     B. White-outs
     C. Scaling in lines after slaking

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Raising Alkalinity (pH)

Chemical		$Ca(OH)_2$	$Mg(OH)_2$	NaOH
#chem/#alk		0.82	0.595	0.81
$/# chem.		$0.1445	$0.25	0.30
$/# alk added		0.1185	0.149	0.243
Cost/day (1,000#/day of alk)		$118.5	$149	$243

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Reducing Costs

- Biosolids Reuse/Disposal

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Biosolids

- Evaluate contracts for final reuse or disposal
- Do you have competition when it is bid?
- Benchmark with other plants
- Can you team up with another plant under one contract?
- Can you manage the hauling/land application with your staff and vehicles?
- Can you change your in-plant processes to make final disposal less expensive? This could be a long-term project

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Typical Plant Use of Energy

• Pumping	12.0%
• Aeration	55.0%
• Clarifiers	3.0%
• Digestion	11.0%
• Solids Processing	8.0%
• Buildings, HVAC, Lighting	6.0%
• Other	5.0%

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Energy Use

- Typical activated sludge plant = 1200 to 2500 kwh/MG
- With advanced nutrient removal = increase another 30 to 50%

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Optimizing Energy Use

- Two approaches
  1. Use less
  2. Pay less for what you do use

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Energy Audit

- An audit helps you understand:
  1. How much energy your plant uses
  2. Helps you understand why you use it
  3. Most of the time, this knowledge can lead you to defining saving opportunities

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How to Begin to Optimize*

- Perform energy audit
  1. List all motors over x hp (depends on plant size)
  2. Estimate hours/day for each large user
  3. Build a table by asset of kwh/day use
  4. Estimate daily/annual cost of each asset
  5. Calculate kwh/MG and compare to benchmark
- Examine rate structure
  1. Based on usage above, is there a better rate structure
     A. Demand Billing, e.g.

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Inventory of Motors

Motor List by Area of the Plant					
Equipment	Rated hp	No. of units	Hrs/day	Year Installed	Efficiency
Raw Pump	150	5	16	2001	86.5%

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Definitions*

- Watts (W) – Volts X Amps
- Kilowatts (kW) – 1000 watts
- Kilowatt Hours (kWH) – kW x Hours = the amount of power used
- 1.0 Horsepower – 0.746 kilowatts
- Duty cycle – number of hours a motor is running per day or per month
- Load factor – measured (or assumed) percentage of full load amps

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Energy Management Plan

- Gather Data
- Analyze the data
- Develop a plan
- Implement the plan
- Evaluate results

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Steps in conducting a Level 1 Audit

- Review your power bills (one to two years of data)
- Do an inventory of your largest motors
  - A. List horsepower rating, duty cycles, etc. of each

1. With the above information look for opportunities to save
2. Develop a number of Energy Conservation Measures (ECMs)

- The pitfall of a Level 1 audit is that it is not based on real data. It therefore assumes efficiencies that may not be realistic

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Rate Structure

- Each company has a variety of rate structures
- Some for residential; some for commercial; some for industrial
- A plant and pump stations are considered industrial, because they have large motors that create more challenges for the power supplier
- You may have different rate structures for the plant vs. the pump stations, depending on maximum demand
- If you can generate power on-site, that puts you into another rate structure

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Working with your power company

- Become friends with your account manager
- Ask them to help you understand your bill and how you can save
- This is one industry where helping you save money also benefits them. Why???
- Explore different rate structures
- They may even help you with an energy audit

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Dissecting your Power Bill

- Basic charge - $ per month – the cost of having an account
- On peak usage - $ per kwh used during a day from 9 AM to 10 PM (could be tiered)
- Off peak usage - $ per kwh used during a day from 10 PM to 9 AM
- Demand - $ per kw – based on the maximum rate of electrical use in a 15, 30, or 60 minute period during that billing period
- Power factor – the ratio of real power to apparent power . You pay more if < 0.9

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Explanation of bill components

- Basic charge
  1. This is a monthly charge for the rate class that your facility is billed under
  2. Not much that can be negotiated here

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Explanation of bill components

- On peak and off peak
  1. During certain times of the year, the power company bills at different rates for time of day.
  2. On peak is usually higher and covers during the day
  3. There may be one rate for the first 100 kwh and another for the remainder
  4. Off peak can be lower and covers during the night
  5. You can save money if you can move certain operations to the night time when the rate is lower
     i. Does anyone have an example of an operation that can be moved to another time?

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Explanation of bill components

- Demand rate
  1. The power company also considers the total demand at any one time. They need to have the capacity to deliver your maximum demand. So they charge you for having to have capacity available.
  2. Demand is often measured in increments of 15, 30, or 60 minutes.
  3. Demand can be up to half the total bill
  4. However, it can be managed to minimize demand and therefore this component of the bill
     A. Anyone have an example?

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Explanation of bill components

- Power factor (PF)
  1. Can be an extra charge or a credit
  2. An extra charge if PF is less than 0.9
  3. A credit if PF is greater than 0.9
  4. Most motors require more power than what is required to operate them
  5. The ratio of what is used compared to what needs to be supplied is the PF
  6. This can be corrected

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Correcting power factor

1. Installing capacitors (small investment that pays back quickly)
   A. Can purchase for individual motors from electrical suppliers, such as GE, Schneider, Eaton, ABB, and many others
   B. Correcting power factor always saves money
2. Minimizing the operation of idling or lightly-loaded motors
3. Avoid operation of equipment above the rated voltage
4. Replace standard motors with high efficiency as the old ones wear out

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Concept of ECMs *

- Recommend an Energy Conservation Measure
- Calculate cost of making the change, e.g. buy new equipment, build something new, etc.
- Calculate savings in annual budget
- Determine payback – if < 5 years, do it
- Do the highest payback projects first

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Return on Investment*

- If an improvement costs $10,000, is it worth it?
  1. Based on this improvement, the savings are estimated at $500/year in less energy cost.
  2. $10,000/500 = 20 years to get your money back
  3. Would not be justified based on saving energy alone

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Getting Data

- Best to measure while unit working using a watt meter
- Can estimate using nameplate data
  1. {Hp X (0 .746)/motor efficiency (.90)} X annual hours X $/kwhr X load factor (0.65) = Annual costs
  2. Using amps and volts
  3. {(Load amps X volts X 1.732 X power factor)/1000} X annual hours X $/kwhr = Annual costs

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Some energy saving measures

- Screening – very low energy use, haul to landfill
- Influent pumping – maximize wet well level
- Grit – Optimize blower use if aerated; change sheaves to reduce power use; pump only 15 minutes per hour
- Primary – Remove as many solids as possible as it reduces load on aeration; CEPT; sludge and scum pumping largest use in primary; optimize pumping
- Secondary – blower use high – use inlet vanes, vari-speed blowers, fine bubble diffusers; DO control; optimize DO level

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Energy saving measures (2)*

- RAS pumping can be significant since it is 40 to 100% of total forward flow
- WAS pumping only 1 to 3% of influent flow, but may have a high head
- Disinfection – low use, but high use of energy to produce hypo or UV
- Filtration – most energy use in backwashing, esp if air scour; if demand billing, may be able to backwash at off-peak power rates

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Optimizing Pumps

- Pumps wear over time
- To check, take measurements and compare with original pump curve
- Can show which pumps are most worn
- Can develop a rebuild program with priorities
- Can install alternate impellers if flow changes made, vs. throttling
- Do you need a constant flow or variable flow

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Causes of pump inefficiency*

- Wrong type of application
- Oversized
- Poor system design
- Cavitation – can lead to pump failure
- Wear ring clearance excessive
- Internal recirculation
- Poor flow control maybe pumping more than process needs
- Bearings worn
- Mechanical seal leakage – or improper packing adjustment

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Routine pump evaluations

- Find a way to compare flow pumped vs. power consumed
  1. Use drawdown in a tank
  2. Or pump to a tank
  3. Install a temporary meter on discharge line
  4. Measure suction & discharge pressure (use new gages)
  5. Measure power use
     A. If a VFD, measure power into the VFD

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VFD

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Motors*

- Should generally purchase high efficiency motors for equipment with long run hours
- These cost 15 to 60% more than standard motors
- Calculate payback to determine if cost effective
- Example

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Example Calculation on High-Efficiency Motors

- Question: Is it worth the money to purchase a high-efficiency motor?
- Assumptions: 10 hp motor; Normal efficiency = 86.5%; It costs $518.00; High efficiency = 91.2% and costs $781.00. Power costs $0.08/kwhr; Duty cycle 24 hours/day = 8760 hours/year.
- Hi-efficiency costs: (10 hp X 0.746 kw/hp / 0.912) X 8760 hours/year X $0.08/kwhr = $5732.00/year

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Continued*

- Normal efficiency costs: (10 hp X 0.746 kw/hp / 0.865) X 8760 hours/year X $0.08/kwhr = $6044.00
- Difference in annual cost is $6044 - $5732 = $312.00
- Difference in purchase price is $781 - $518 = $263.00
- Payback is 263/312 = 84.3% or about 10 months.
- Any payback less than 3 to 4 years is worth doing.

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Care of motors

- Keep vents clean – avoid overheating
- Keep belt tension optimized
- Do not over lubricate – a motor should last about 11 years or 100,000 hours

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Summary

- There are many things you can do to optimize
- Focus on highest payback projects first
- Make one change at a time on a process
- Document your results - to sell to upper management
- Be patient – It can take years to finish – Or you may never finish…..

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