Basic Concepts of Wastewater Treatment

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Basic Concepts of Wastewater Treatment

Stephen Elder

Agenda

- Introductions / Objectives
- Pollutants Contained in Domestic Wastewater & Their Affect on Public Health & The Environment
- Physical / Chemical / Biological Treatment Overview
- Preliminary & Primary Treatment
- Secondary & Advanced Treatment / Activated Sludge
- Filtration
- Disinfection / Dechlorination
- Effluent Monitoring
- Post Test
- Evaluation & Closing

Questions

Anytime

Purpose of This Training

- Provide an overview of the reasons we treat wastewater.
- Describe the basic processes at wastewater treatment facilities
- Introduce operational considerations for WWTFs

Pollutants Contained in Domestic Wastewater & Their Affect on Public Health & The Environment

Why do we treat wastewater ?

- ✓ Protection of Public Health
  - Removal of Pathogenic Organisms
- ✓ Protection of the Water Environment
  - Removal of Pollutants that will….
    1. Deplete Dissolved Oxygen
    2. Promote Algae Growth
    3. Inhibit Growth of Submerged Aquatic Vegetation

Pollutants That Compromise Public Health

- Pathogenic (Disease Causing) Organisms
  - Bacteria
  - Viruses
  - Intestinal Parasites
- Toxic Substances

How do we determine if pathogens are present?

- Sampling / Analysis for Presence of "Indicator Organisms"
  - Total Coliform
  - Fecal Coliform
  - E.Coli

Pollutants that Affect the Water Environment

- Organic Solids
  - Dissolved
  - Particulate
- Inorganic Solids
- Low Dissolved Oxygen
- High or Low pH
- Nutrients
  - Nitrogen
  - Phosphorus
- Toxic Compounds

Solids

- TSS (Total Suspended Solids)
  - Settlable
  - Colloidal

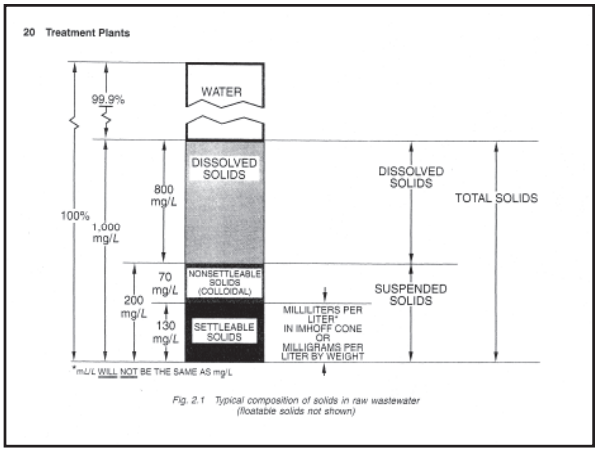


Fig. 2.1 Typical composition of solids in raw wastewater (floatable solids not shown)

Organic Compounds

- BOD (Bio-Chemical Oxygen Demand)
  - Test used to determine the strength of the wastewater. This also provides a gauge of the amount of food available to the microorganisms.
  - Soluble (Dissolved in the wastewater)
  - Particulate (Particles free floating in the wastewater. A portion can be settled out.

pH and DO

- pH

  0 ---------- 7 ---------- 14

  (Acid) (Alkaline)

- Dissolved Oxygen (DO)
  - Importance
  - What affects DO?

Nutrients

- Nitrogen
  - Ammonia (NH_3)
  - Organic Nitrogen
  - Nitrite (NO_2)
  - Nitrate (NO_3)
- Phosphorus
  - Soluble
  - Particulate

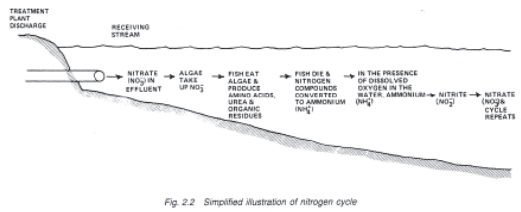


Fig. 2.2 Simplified illustration of nitrogen cycle

Toxic Compounds

- Ammonia
- Chlorine
- Metals
- Other

NPDES Program Organization And Basic Requirements

Clean Water Act

- Federal Law Established in 1972
- Includes the "NPDES" Program
  - National Pollutant Discharge Elimination System
- Responsibility for Enforcement
  - Federal: US Environmental Protection Agency
  - State: Maryland Department of Environment

EPA United States Environmental Protection Agency

MDE

NPDES Program

- The State of Maryland received delegation from EPA in 1974 to operate the NPDES program.
- This includes:
  - Issuing NPDES or "Discharge" Permits
  - Enforcing the provisions of those discharge permits
  - Managing construction grants / loan projects

Responsibilities of NPDES Permit Holders

- Comply with ALL provisions of the permit
- Operate and maintain the collection system and treatment plant
- Meet effluent quality and loading requirements
- Perform "self-monitoring" in accordance with 40 CFR 136
- Report monitoring results and violations to regulatory agencies
- Other

Physical / Chemical / Biological Treatment Overview

Physical Treatment

- Screening
  - Removal of paper, plastics, rags, rocks, etc
  - Process uses “bar screens”
- Sedimentation
  - Removal of settleable solids by gravity
  - Grit tanks
  - Large settling tanks called “clarifiers”

Physical Treatment

- Floatation
  - Skimming of floating material
  - Oil & Grease
  - Also occurs in clarifiers
- Filtration
  - Removal of fine particles
  - Sand filters
  - Membranes

Physical Treatment

- Disinfection by Ultra-Violet Light
  - Inactivates Pathogens

Chemical Treatment

- pH Adjustment
  - UP: Lime, Soda Ash, Caustic Soda
  - DOWN: Acid
- Coagulation / Precipitation
  - Removal of fine solids and/or phosphorus
- Disinfection
  - Inactivates Pathogens
  - Chlorine or Chlorine Based Compound

Chemical Treatment

- Sludge Conditioning / Dewatering
  - Polymer
- Carbon Addition
  - Methanol, Glycerin, etc.
- Odor Control
  - Caustic Scrubbers

Biological Treatment

- Uses specific types of microorganisms to ..
  - Convert Organics to CO_2 and H_2O
    - BOD / TSS Removal
  - Convert Ammonia to Nitrate
    - Nitrification
  - Convert Nitrate to N_2
    - Denitrification
  - Uptake Phosphorus

Biological Treatment

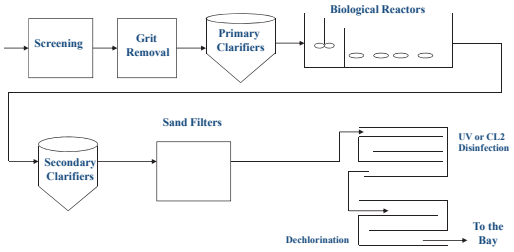
- Types of Biological Treatment
  - Dispersed Growth
    - Lagoons
    - Activated Sludge
  - Attached Growth
    - Trickling Filters
    - Rotating Biological Contactors (RBC's)
  - Combination of Dispersed & Attached Growth
    - Integrated Fixed-Film / Activated Sludge (IFAS)
    - Membrane Bioreactor (MBR)

Biological Treatment

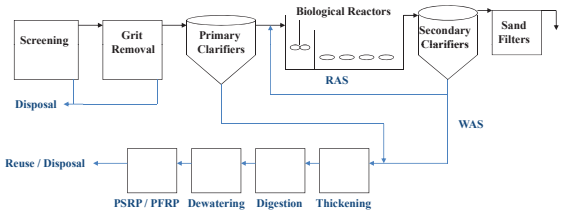
- Duplicates reactions that occur naturally in the water body, except….
  - Controlled Conditions
    - Enclosed tanks
    - Controlled dissolved oxygen levels (air addition)
    - Controlled Food / Microorganism Ratio
  - Reduced degradation of water body

General Treatment Plant Configuration

General Plant Configuration "Liquid" Processes



General Plant Configuration "Solids" Processes



Lagoons

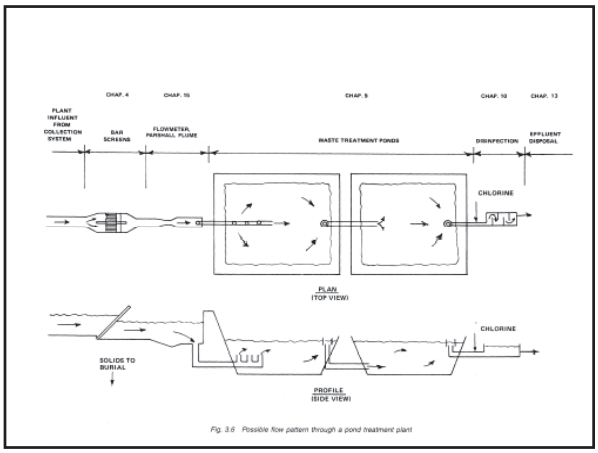
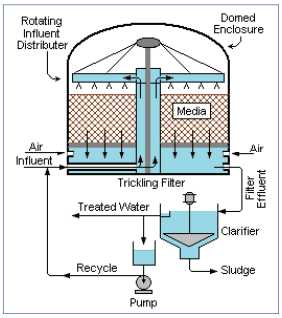
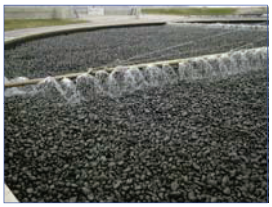
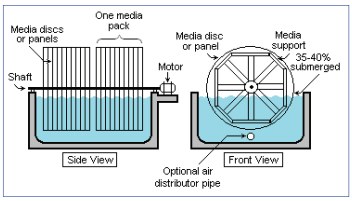


Fig. 3.6 Possible flow pattern through a pond treatment plant

Trickling Filters







Rotating Biological Contactors (RBC)

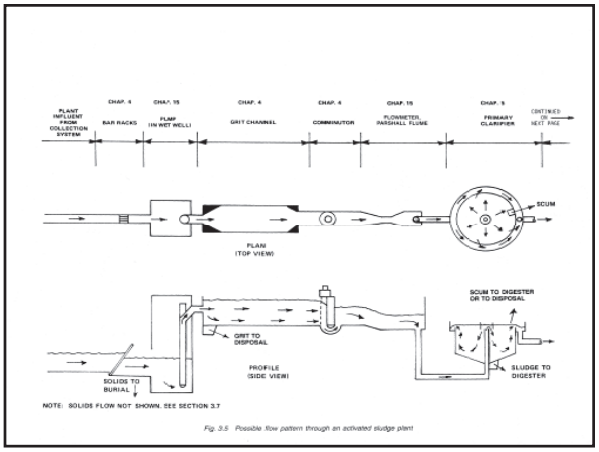


Fig. 3.5 Possible flow pattern through an activated sludge plant

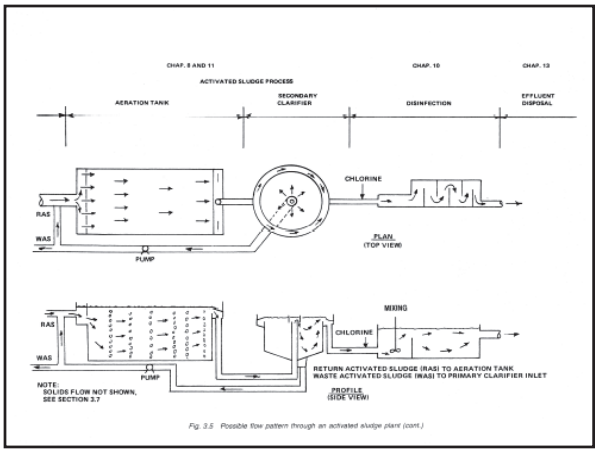
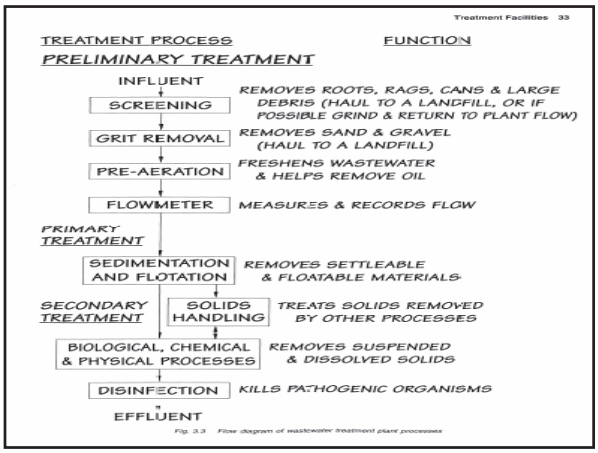
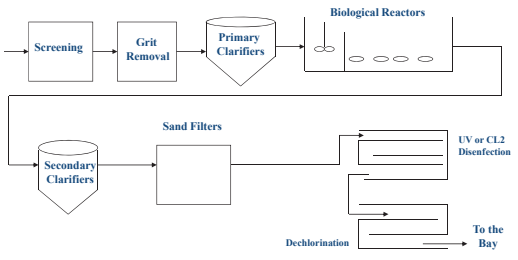


Fig. 3.5 Possible flow pattern through an activated sludge plant (cont.)



Preliminary Treatment

Preliminary Treatment



Preliminary Treatment
Screening & Grit Removal

- Screening
  - Remove Rags and Other Large Debris
  - Odors
  - Hazards - Hydrogen Sulfided and Methane
  - What is the common method of disposal?
- Grit Removal
  - What is grit
  - Why do we remove it?
  - What is the common method of disposal?

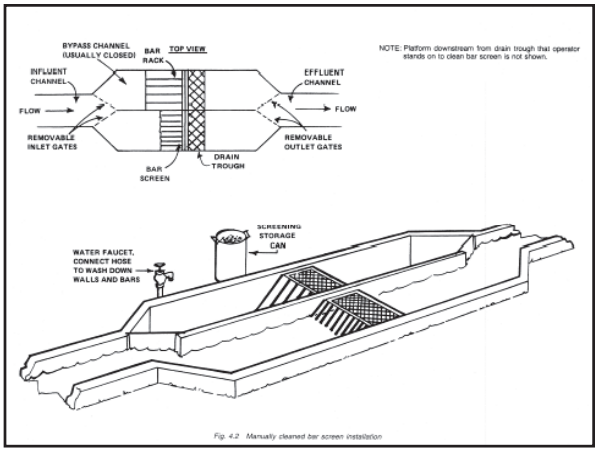


Fig. 4.2 Manually cleaned bar screen installation

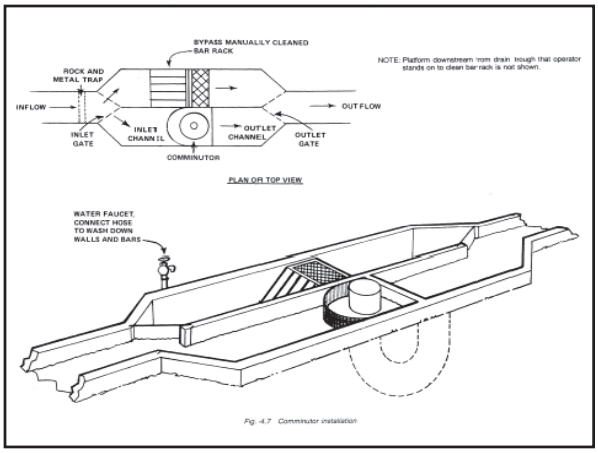


Fig. 4.7 Comminutor installation

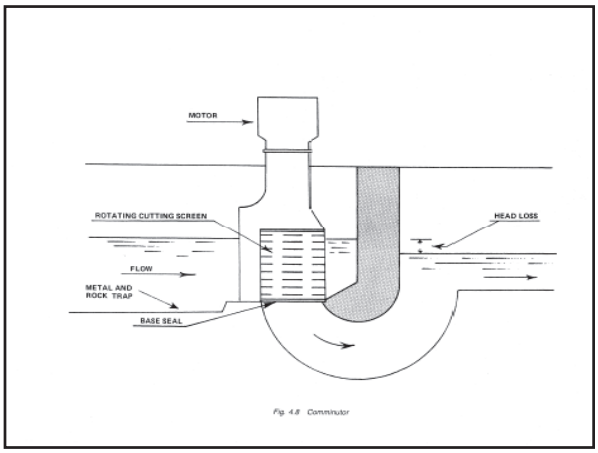


Fig. 4.8 Comminutor

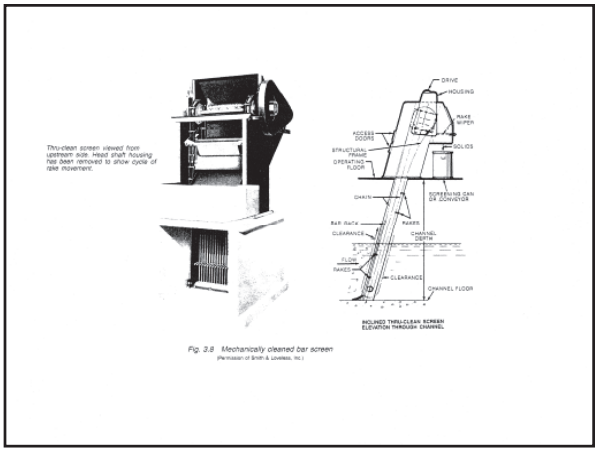


Fig. 3.8 Mechanically cleaned bar screen
(Permission of Smith & Loveless, Inc.)

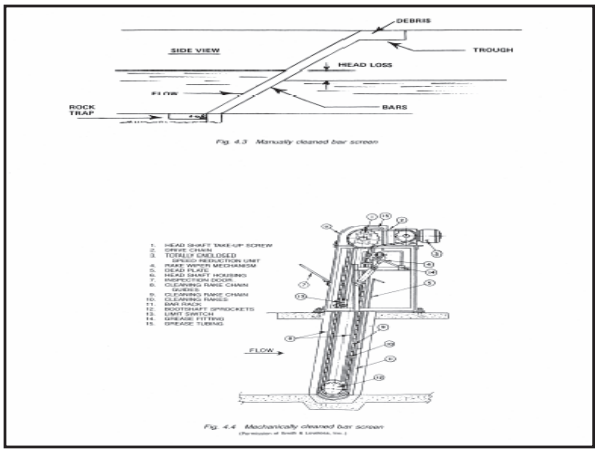


Fig. 4.3 Manually cleaned bar screen

Fig. 4.4 Mechanically cleaned bar screen
(Permission of Smith & Loveless, Inc.)

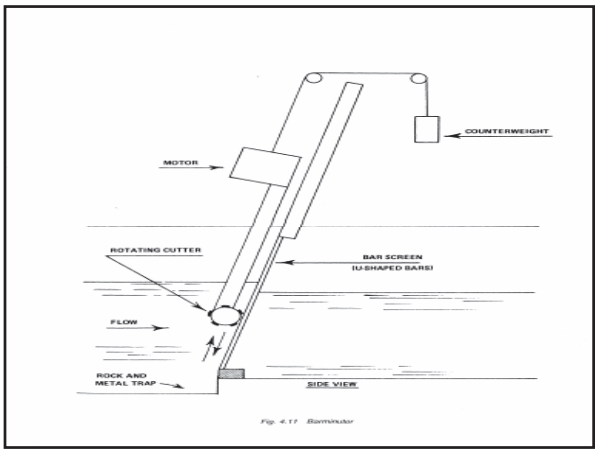


Fig. 4.17 Barminutor

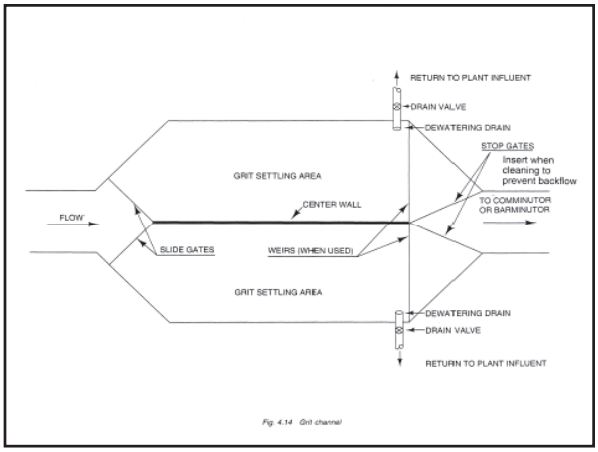


Fig. 4.14 Grit channel

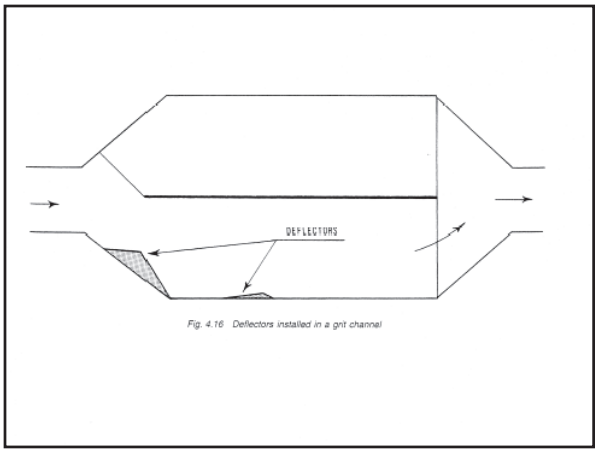


Fig. 4.16 Deflectors installed in a grit channel

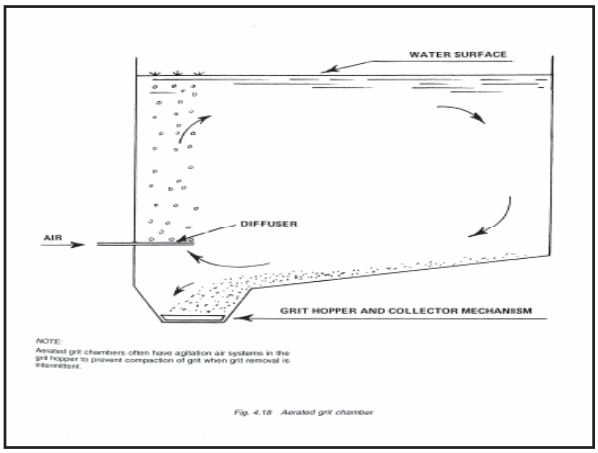


Fig. 4.18 Aerated grit chamber

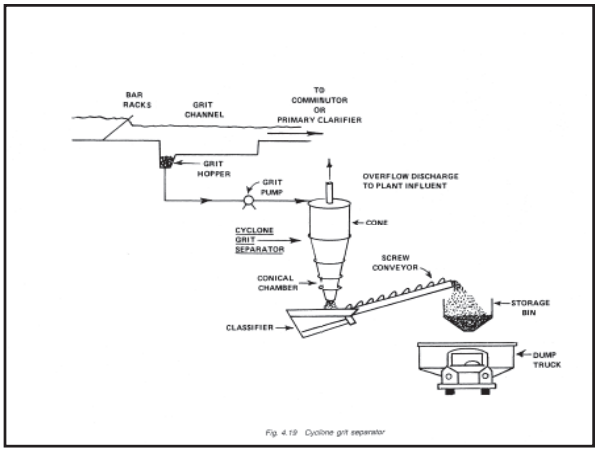


Fig. 4.19 Cyclone grit separator

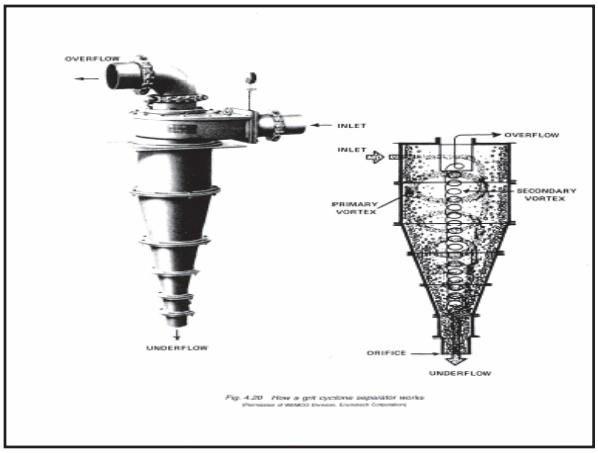


Fig. 4.20 How a grit cyclone separator works

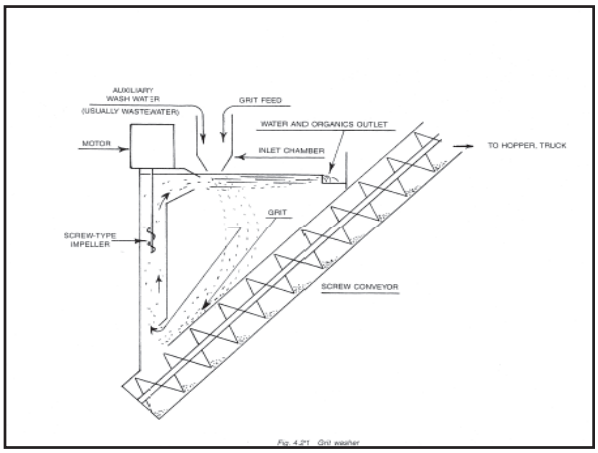
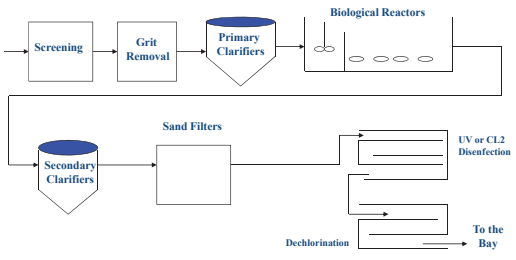


Fig. 4.21 Grit washer

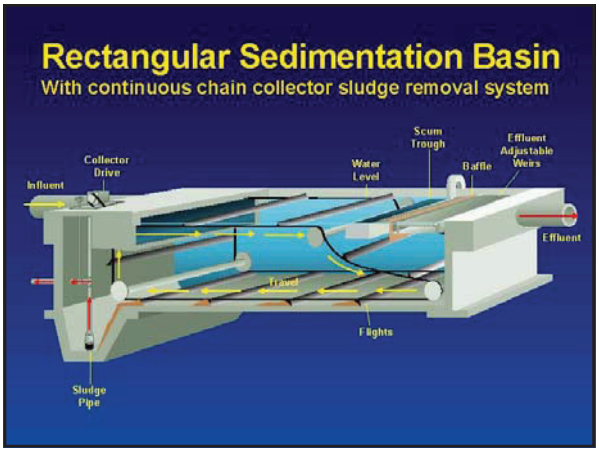
Primary Treatment

Sedimentation / Floatation



Primary Clarifiers

- Remove settleable solids and floatables
- Reduce BOD / TSS
- Factors that affect efficiency
- Bulking & gasification
- Sludge blankets
- Short circuiting



Circular Clarifier

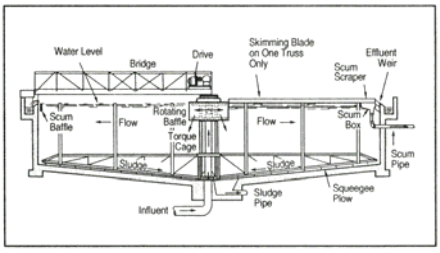


FIGURE 5-5 A typical circular sedimentation basin

Courtesy of FMC Corporation, MHS Division

Circular Sedimentation Basin

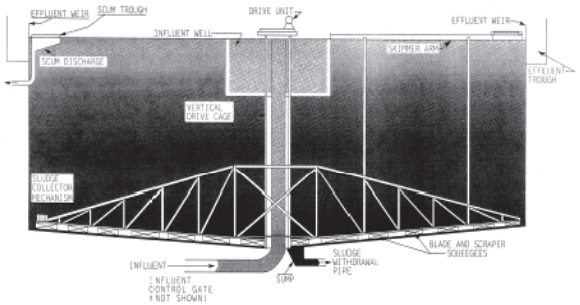
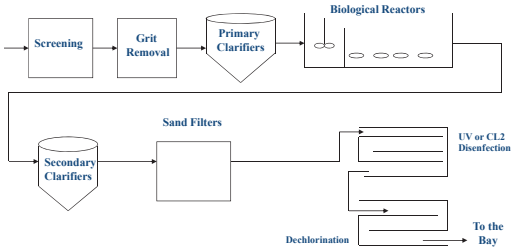


Fig. 5.4 Side-view section of a circular clarifier with blades and scraper squeegees

Secondary & Advanced Treatment – Activated Sludge

Biological Treatment / Activated Sludge



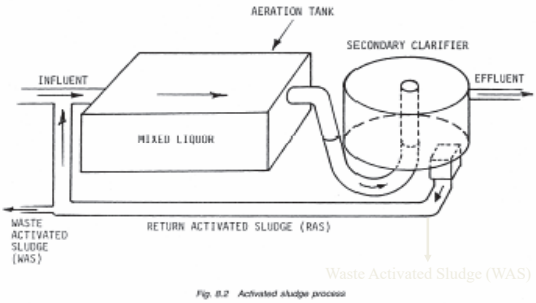


Fig. 8.2 Activated sludge process

RAS / WAS

- Return Activated Sludge (RAS)
  - Biomass recyled from the secondary clarifier to the Biological Reactor
  - Thicker in concentration than MLSS
- Waste Activated Sludge (WAS)
  - Biomass removed from the Biological Reactor
  - Sent to Solids Processing

Mixed Liquor

- Mixed Liquor Suspended Solids (MLSS)
  - Suspended Solids in the Biological Reactor
- Mixed Liquor Volatile Suspended Solids (MLVSS)
  - Volatile (active) Suspended Solids in the Biological Reactor
- Expressed as concentration (mg/L) or quantity (lbs)

F/M & MCRT

- Food to Microorganisms Ratio (F:M)
  - Ratio of BOD (food) to MLSS (microorganisms)
- Mean Cell Residence Time (MCRT)
  - How many days a microorganism is "in the system"

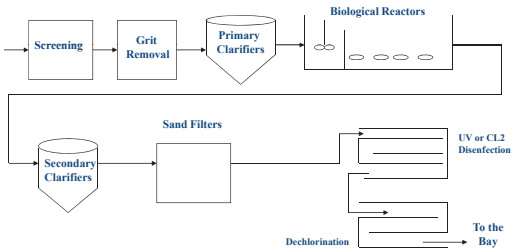
Other Important Data

- Mixed Liquor Dissolved Oxygen (MLDO)
  - Oxygen in Aerobic portion of Biological Reactor
- Depth of Blanket (DOB)
  - Depth of settled sludge in secondary clarifiers
- Mixed Liquor pH and Alkalinity
  - Affects the type & growth rate of microorganisms
  - Alkalinity is the capacity of liquid to neutralize acid
    - Expressed as mg/L $CaCO_3$

Conditions Affected by Dissolved Oxygen

- Aerobic
  - Positive D.O. present
- Anoxic
  - No D.O. present but NO3 present
- Anaerobic
  - No D.O. and No NO3 present

Biological Treatment / Activated Sludge



Biological Reactors

- Remove BOD
- Convert / Remove Nutrients
  - Nitrogen & Phosphorus
- What is activated sludge
  - Bacteria
  - Protozoa
  - Animals

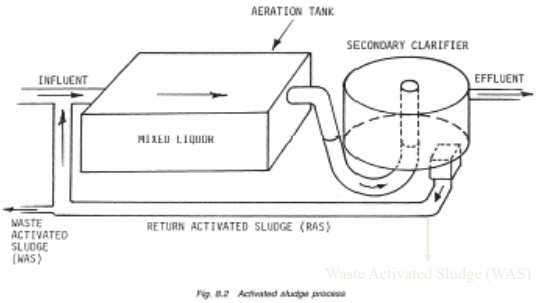


Fig. 8.2 Activated sludge process

Secondary Clarifiers

- Remove settleable and floatable solids
- Return Activated Sludge (RAS) to the Reactors
- Waste Activated Sludge (WAS) to Solids Processing
- Factors that affect efficiency
- Bulking & gasification
- Sludge blankets
- Short circuiting

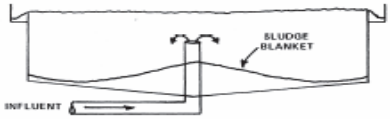


Fig. 5.12 Activated sludge settling near center of clarifier

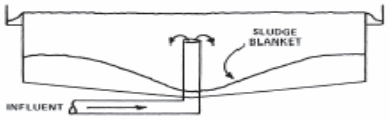
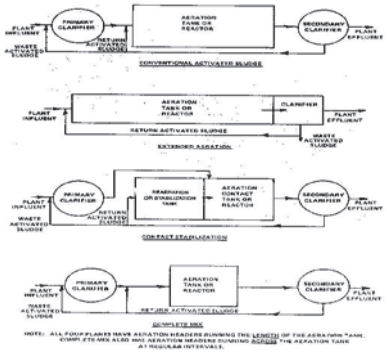


Fig. 5.13 Activated sludge settling near outer edge of clarifier

Activated Sludge - Processes

- Conventional
- Step Feed
- Contact Stabilization
- Extended Aeration
  - Oxidation Ditches, Biolac, Package Plants
- Sequencing Batch Reactor (SBR)
- Membrane Bio-Reactor (MBR)
- Biological Nutrient Removal (BNR) Systems

Activated Sludge System Configurations



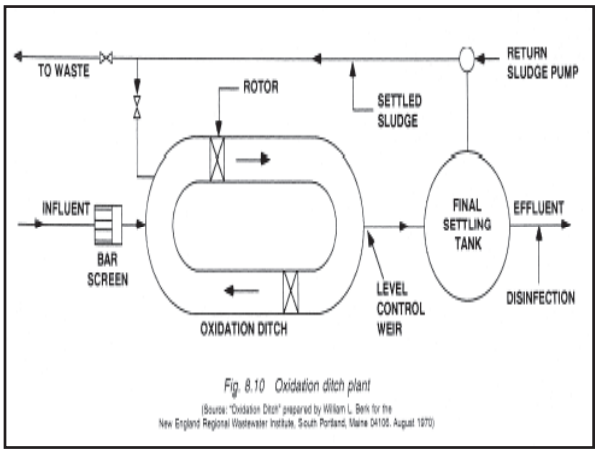


Fig. 8.10 Oxidation ditch plant

(Source: "Oxidation Ditch" prepared by William L. Berk for the New England Regional Wastewater Institute, South Portland, Maine 04106, August 1970)

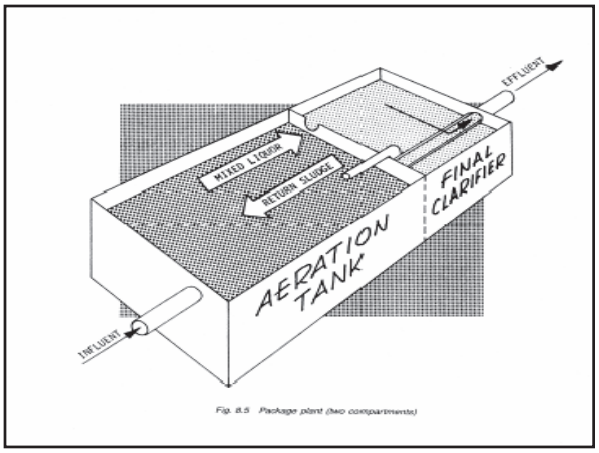


Fig. 8.5 Package plant (two compartments)

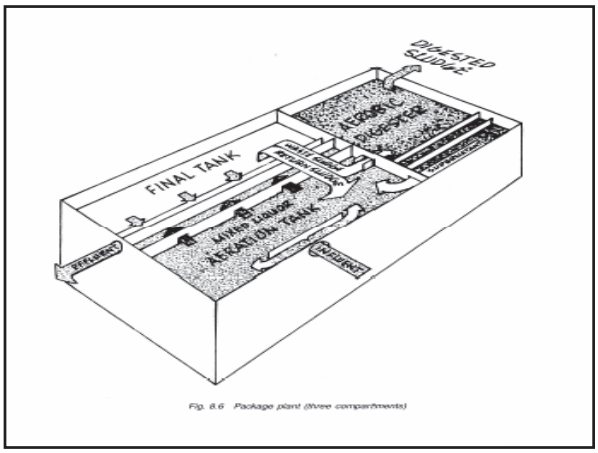
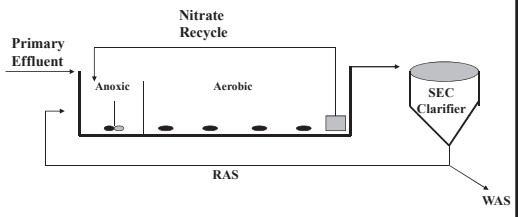
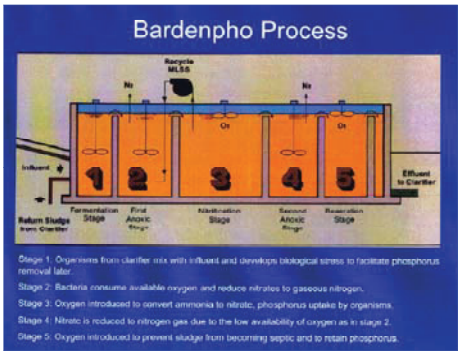


Fig. 8.6 Package plant (three compartments)

Biological Nitrogen Removal (MLE Process)



Biological Nitrogen & Phosphorus Removal



Activated Sludge Process

- How does it work ?

Organisms + Food + DO = More organism

Or

Bio-Mass + BOD + Air = Need to Waste

↗ ↖

Soluble or Particulate

ACTIVATED SLUDGE

- Mechanisms to remove BOD and SS.
- Soluble vs. Particulate BOD.
- BOD removal by ADsorption.
- BOD removal by ABsorption.

Bacteria

- Remove the BOD
- Primary BOD removers
- Need:
  - Food (BOD)
  - Air
  - Nutrients
  - pH
  - Temperature
  - Life span (MCRT)

Protozoa

- Indicators organisms
- Food source - Bacteria and BOD
- Microscopic slide to identify

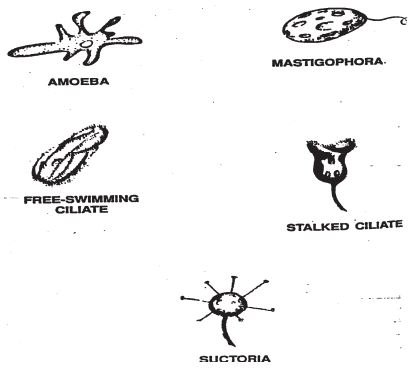
Protozoa

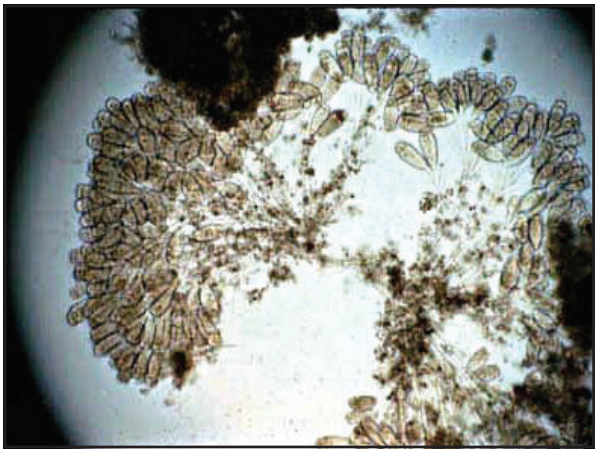
- Amoebas
- Flagellates
- Crawling Ciliates
- Stalk Cilitates

Other Organisms :

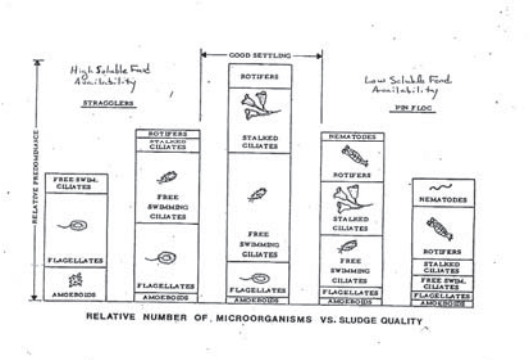
- Rotifers
- Nematodes
- Fungi

Protozoas





Microorganisms Table



BIOMASS – Quality & Quantity

- Impact on effective BOD removal.
- Process control to effect biomass.
- Key process parameter to monitor performance.

» MCRT

What is MCRT?

MCRT (days) =

$$\frac{\text{Biomass in system (lbs)}}{\text{Biomass wasted (lbs per day)}}$$

= average number of days that Microorganisms remain in the system

Nitrogen in Domestic Wastewater
TKN = Org. N + Ammonia

Organic Nitrogen	
Proteins	15 mg/L
Urea	
Ammonia Nitrogen	25 mg/L
Nitrate/Nitrite Nitrogen	0 mg/L

Nitrification

Why Nitrify?

- **Minimize oxygen depletion in receiving waters**
- **Prevent ammonia toxicity in receiving waters**

Nitrogen Removal Basics

What is Nitrification?

Conversion of Ammonia to Nitrate

$NH_3^+ \rightarrow NO_3^-$

TKN = Ammonia + Organic N

Nitrification

Nitrosomonas

$NH_3^+ + O_2 \rightarrow NO_2^- + H_2O + H^+$

Oxygen Required = 3.43 lb / lb N oxidized

Alkalinity Required = 7.14 lb as $CaCO_3$ / lb N oxidized

Nitrobacter

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

Oxygen Required = 1.14 lb / lb N oxidized

For both reactions together:

Total Oxygen Required = 4.57 lb / lb N oxidized

Total Alkalinity Required = 7.14 lb as $CaCO_3$ / lb N oxidized

DENITRIFICATION
TN = TKN + NOx

Why Denitrify?

Minimize nutrient discharge to stream

Save energy

Save alkalinity

DENITRIFICATION

Nitrate — Organic Carbon → Carbon Dioxide + Nitrogen + Water + Hydroxide

$NO_3^- + \text{Organic-C} \rightarrow CO_2 + N_2\uparrow_{\text{Gas}} + H_2O + OH^-$

This is equivalent to 2.86 lbs COD utilized per lb nitrate-N denitrified

Alkalinity produced = 3.57 lbs as $CaCO_3$ per lb nitrate-N denitrified

$NO_3^- + H^+ \rightarrow N_2\uparrow_{\text{Gas}} + H_2O + O_2$

Oxygen equivalents recovered = 2.86 lbs per lb nitrate-N denitrified

Activated Sludge Process Control

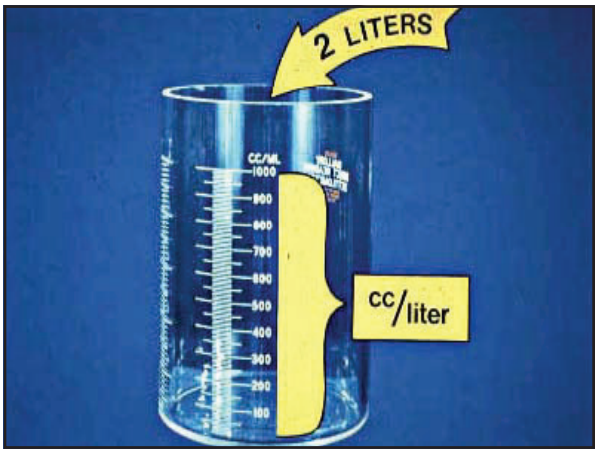
- Concept:
  - To provide the right amount of bio-mass for the BOD in the influent and the water temp.
  - Suspended growth biological process.
  - Maintain proper MCRT for the process being used.
  - To remove as much of the BOD and SS as possible.
  - Input only the amount of DO needed.
  - To produce a good quality / settling bio-mass.

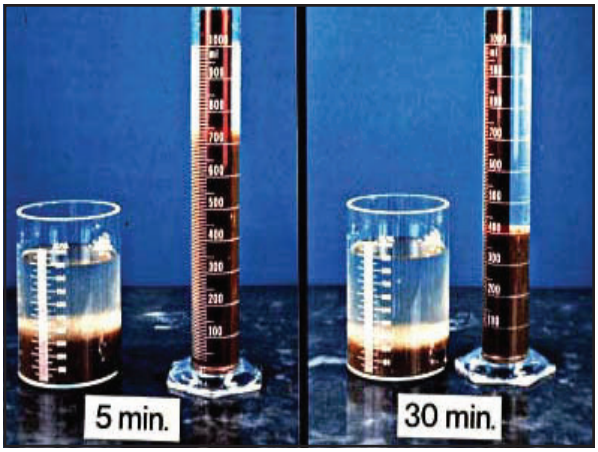
PROCESS CONTROL TESTS

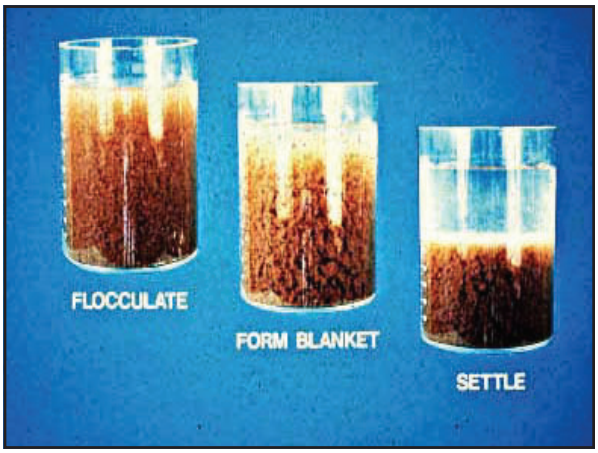
- MLSS
- RASss
- MLDO
- SSV
- Alkalinity
- Centrifuge
- MLVSS
- MLpH
- Microscope
- DOB
- NH3, NO3, OP
- ML Temperature

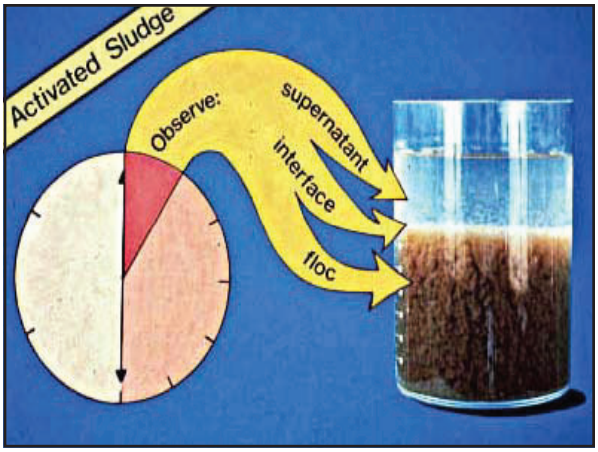
SSV / SVI

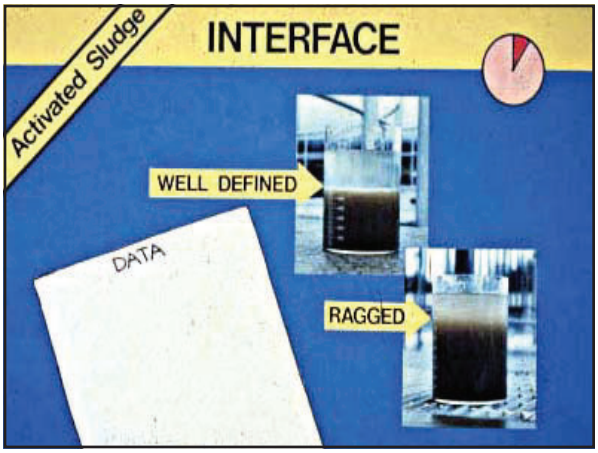
- Settled Sludge Volume (SSV) and
- Sludge Volume Index (SVI)
  - Indicator of the settling in the Secondary Clarifiers
  - SVI Test performed using the MLSS

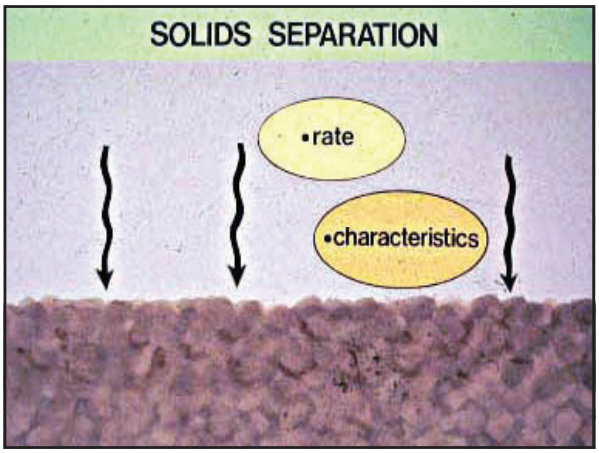


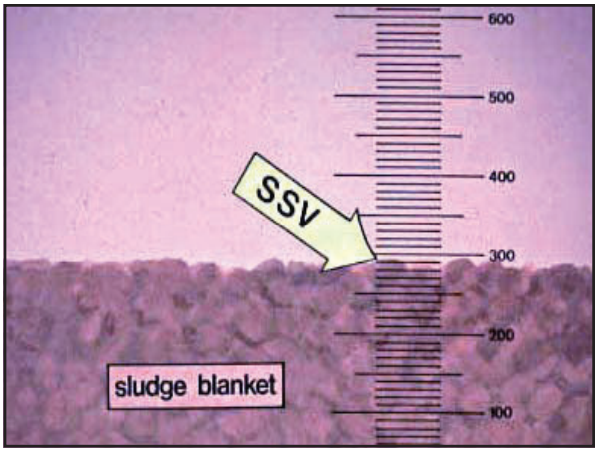


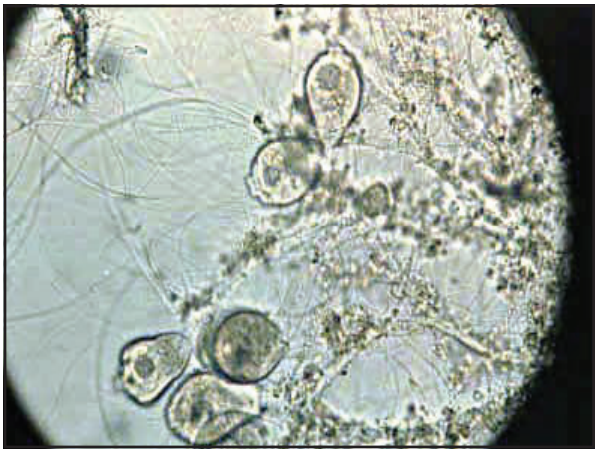












Causes of Excessive Filamentous Bacteria

- Low MLDO
- High MCRT, low F/M
- Septicity
- Nutrient deficiency
- Low MLpH

Control of Filaments

- Incorporate selector zone ahead of biological process
- Reduce MCRT
- Add settling agent (polymer) to clarifier influent
- Controlled chlorination
  - Apply to RAS for bulking
  - Spray on surface for foaming

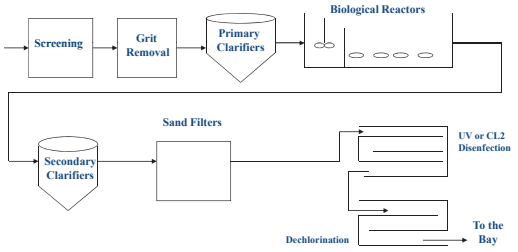
Basic Process Control Options

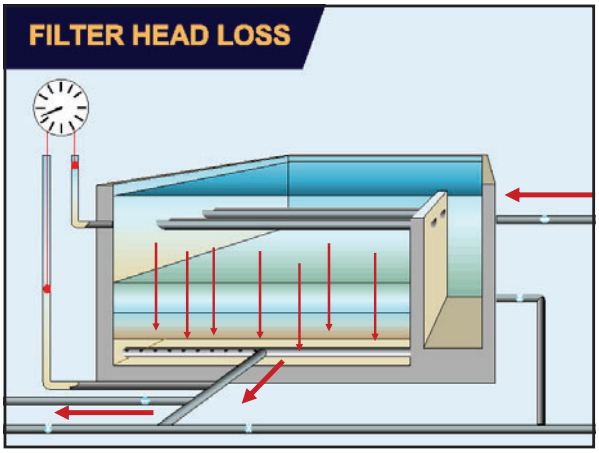
How does each affect performance?

- Regulate MLDO (Mixed Liquor Dissolved Oxygen)
- Regulate pH and Alkalinity
- Regulate RAS flow rate
- Regulate WAS flow rate
- Nutrient Removal
  - Regulate all above, plus..
    - ✓ Nitrate Recycle Rate
    - ✓Supplemental Carbon Addition

Filtration

Filtration





The Filtration Process

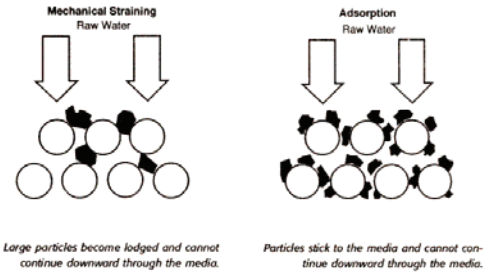
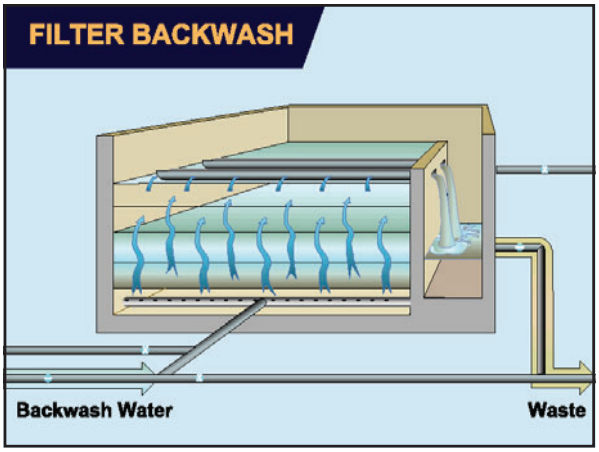
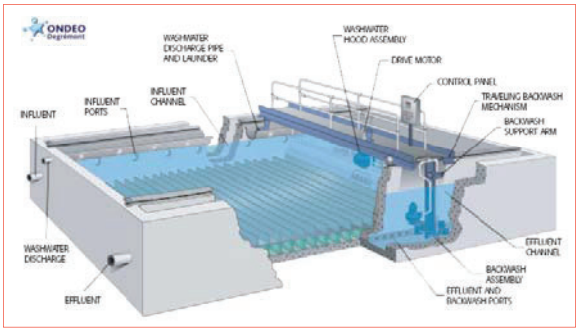


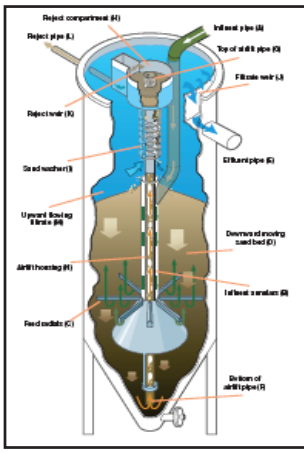
Figure 6-1

FILTER BACKWASH



Automatic (Continuous) Backwash Filter

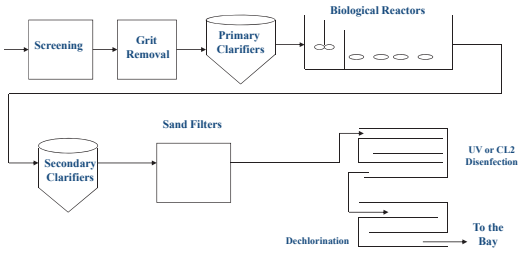




Parkson Dynasand® Filter

Disinfection

Disinfection



Terms to know

- Disinfection
- Pathogens
- Coliform
  - Total Coliform
  - Fecal Coliform
  - E.Coli
- Dechlorination

Disinfection

•Why do we disinfect ?

• How do we disinfect ?

• Factors that effect efficiency

Purpose of Disinfection

- Pathogen Reduction
- Indicators are
  - Fecal Coliform
  - E.Coli

Methods of Disinfection

- Chlorine Gas
- Calcium Hypochlorite
- Sodium Hypochlorite
- Ozone
- Ultraviolet (UV) light

Disinfection By Chlorine Key Concepts

- Dose
- Demand
- Residual
  - Free
  - Combined
  - Total
- Contact Time
- Turbidity
- Temperature
- pH

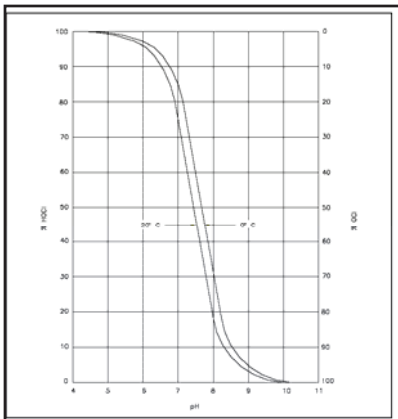
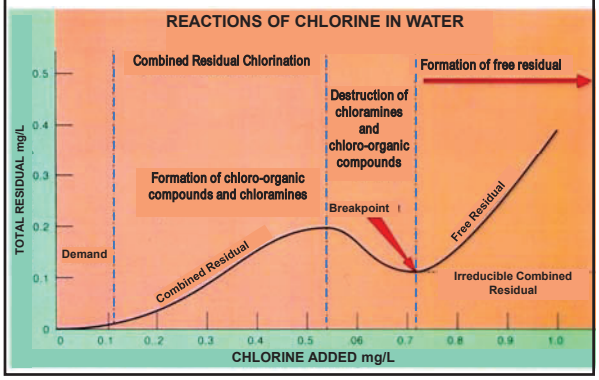


Figure 1 - Distribution of HOCl and OCl- In Water at Various pH Levels

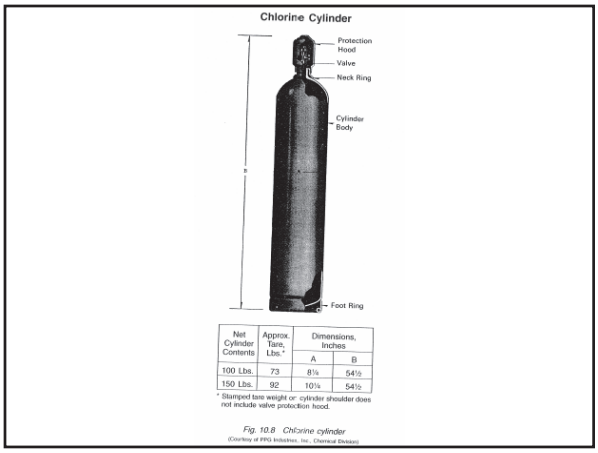
Effects of pH

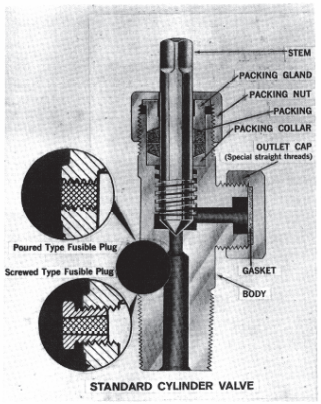
Breakpoint Chlorination Curve



Chlorine Compounds

- Chlorine Gas (100%)
- Calcium Hypochlorite (65-70%)
- Sodium Hypochlorite (5–15%)





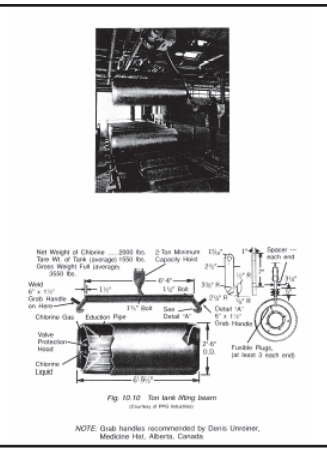
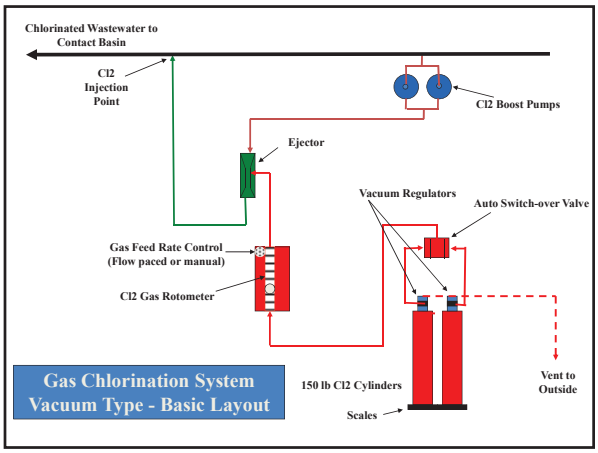


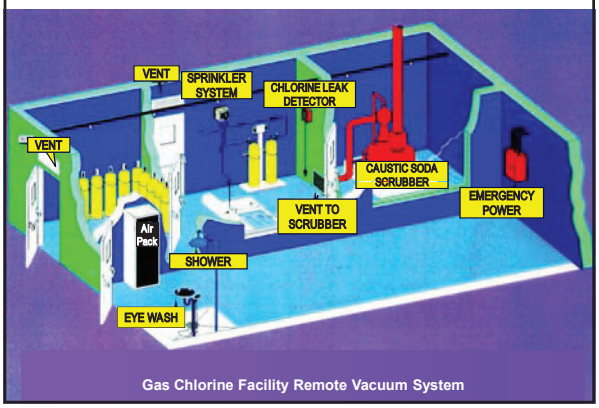
Fig. 10.10 Ton tank lifting beam

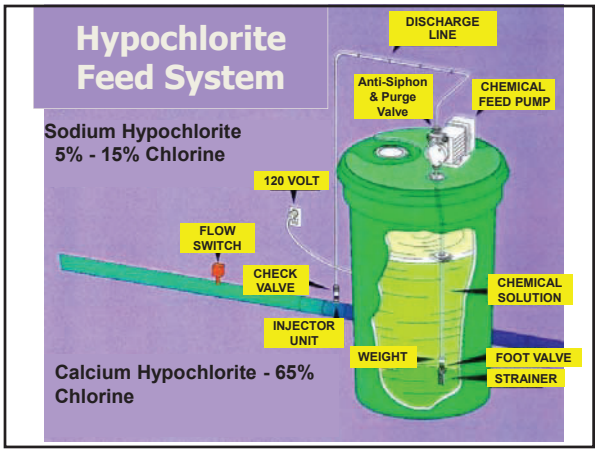
NOTE: Grab handles recommended by Denis Umreiner, Medicine Hat, Alberta, Canada

Duplex Vacuum System

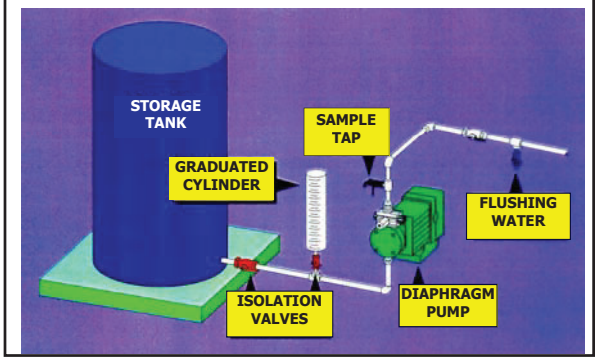


Gas Chlorine Facilities





Hypochlorite Feed System With Calibration Column



Diaphragm-Type Metering Pump

Perastaltic Pump

Calcium Hypochlorite Tablet Feeder

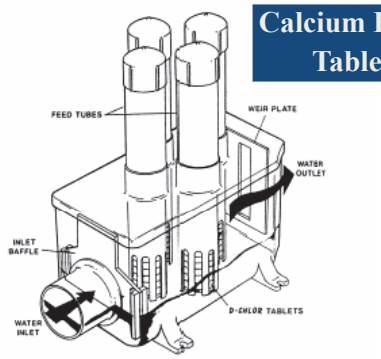


Fig. 10.22 Tablet dechlorination unit
(Permission of ELTECH International Corporation)

Ultra-Violet (UV)

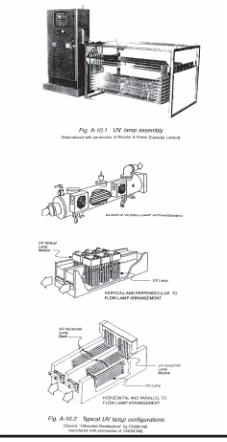


Fig. A-10.2 Typical UV lamp configurations

Ultra-Violet (UV)

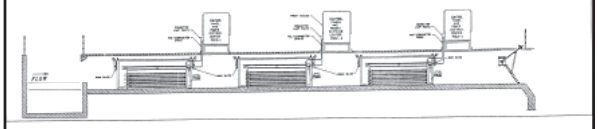


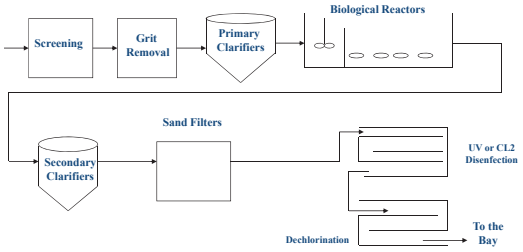
Fig. A-10.3 Horizontal, in-channel UV lamp installation

Ultra-Violet (UV)

Ultra-Violet (UV)

Dechlorination

Dechlorination



De-Chlorination

- Why do we de-chlorinate ?
- Most common method
- Sulfur Dioxide (Sodium Bisulfite)
- How does it work?
- What can affect the reaction?
- Side effects of over feeding

De-Chlorination

- Sulfur Dioxide dissolves rapidly, forming sulfuric acid:

  $SO_2 + H_2O \rightarrow H_2SO_3$

- The sulfite radical formed in this solution reacts with free and combined chlorine:

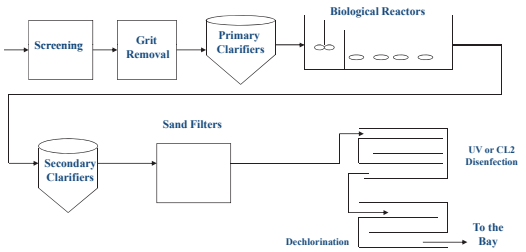
  $H_2SO_3 + HOCl + H_2O \rightarrow H_2SO_4$

  $H_2SO_3 + NH_3Cl + H_2O \rightarrow NH_4HSO_4 + HCl$

- Each reaction is rapid and complete

Effluent Monitoring

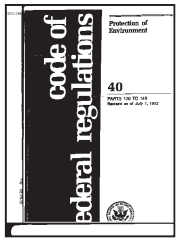
Effluent Discharge



NPDES Required Monitoring

Based on the NPDES Permit

- Flow
- pH / DO / Chlorine Residual
- BOD / TSS
- Fecal Coliform / E.Coli
- Nitrogen
  - Ammonia (NH3) + Organic Nitrogen = TKN
  - Nitrite (NO2) & Nitrate (NO3)
  - Total Nitrogen = TKN + NO2 + NO3
- Phosphorus
  - Total Phosphorus
  - Ortho-Phos
- Metals
- Other



Flow Measuring Devices

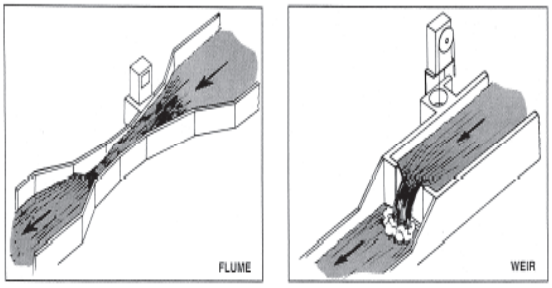


Fig. 3.12 Flow measuring devices

Parshall Flume

Representative Sampling

- **Grab Sample**
  - **an individual sample collected (and analyzed) in less than 15 minutes.**
- **Composite Sample**
  - **a combination of individual samples obtained at hourly or smaller intervals over a time period. Either the volume of each individual sample is proportional to discharge flow rates or the sampling interval (for constant volume samples) is proportional to the flow rates over the time period used to produce the composite.**

Composite Sampler

Questions?