Chapter 24 - Wastewater Treatment

Objectives of WWT

- Reduce organic content (reduction of BOD)
- Removal/reduction of nutrients i.e., N,P
- Removal/inactivation of pathogenic microbes

What is Wastewater?

- Dairy and industrial waste
  - slaughterhouse waste, dairy waste, tannery wastewater, etc.
- Domestic waste:
  - human and animal excreta and waters used for washing, bathing, and cooking.
- 100-500 g wet weight of feces and 1-1.3 L of urine/capita/day
- 15-20 g BOD/day is contributed by each person

Wastewater Contaminants

- Suspended solids
- Priority pollutants: metalloids (As, Se) and metals (Cd, Hg), benzene compounds, and chlorinated compounds
- Microorganisms: pathogenic and nonpathogenic
- Organics: refractory and biodegradable
- Nutrients:
  - Phosphorus
  - Nitrogen (ammonia, nitrites, nitrates)

Objective 1 - Reduce organic content (reduction of BOD)

The amount of organic carbon present determines:

- the amount of O_2 needed for biological treatment
- the size of waste treatment facility needed
- the efficiency of the treatment process

There are three methods to determine carbon present:

- biochemical oxygen demand
- total organic carbon
- chemical oxygen demand

Biochemical Oxygen Demand (BOD)

- Definition: The amount of dissolved oxygen utilized by microbes for the biochemical oxidation of organic (carbonaceous BOD) and inorganic (autotrophic or nitrogenous BOD)
- The BOD test was developed in 1930's. This is a five day test that measures the amount of O_2 consumed in a wastewater sample by a mixed population of heterotrophic bacteria in the dark at $20^{o}C$
- BOD of wastewater is typically 110-440 mg/L and must be reduced to 20 mg/L for discharge

$$\boxed{BOD = \frac{D_i - D_f}{P}}$$

where:

D_i = initial dissolved O_2 concentration

D_f = final or 5-day dissolved O_2 concentration

P = volumetric fraction of wastewater

Example: 5 ml wastewater is added to a 300 ml BOD flask

$P = \frac{5}{300} = 0.0167$ $\quad D_i = 8$ mg/L $\quad D_f = 2$ mg/L

$$BOD = \frac{8 - 2}{0.0167} = 359 \text{ mg/L}$$

Oxidation is usually 60-70% complete after 5 days

Total Organic Carbon (TOC)

- TOC is measured using a TOC analyzer. The sample is combusted and organic carbon quantified using infrared detection.

Chemical Oxygen Demand (COD)

- COD is measured following digestion at high temperature with strong oxidant such as chromic acid, or sulfuric acid/potassium dichromate. The chromate ion reacts with the COD producing a color that is measured.

If COD >> than BOD what does this mean?

Wastewater treatment

- Primary treatment
  - Sedimentation and screening of large debris
- Secondary treatment
  - Biological and chemical treatment
- Tertiary treatment
  - Further chemical treatment

Primary treatment (physical)

- Metal grating
  - Large debris
- Short retention time
  - Settling out of sand and gravel
- Primary settling tank
  - Approximately half suspended solids sediment. The sedimented material is called <u>primary sludge</u>

Secondary Treatment

- Biological treatment
  - activated sludge
  - trickling filter
  - oxidation ponds
- A disinfection step is usually included at the end of the biological treatment
  - chlorination

Objective is to reduce BOD, odors and pathogens

Activated sludge process – most common

- Primary wastewater mixed with bacteria-rich (activated) sludge and air or oxygen is pumped into the mixture
- Promotes bacterial growth and decomposition of organic matter
- Last step is a settling tank where sludge settles out and then the treated wastewater moves on for tertiary treatment
- Some settled sludge is used to inoculate incoming primary effluent
- BOD removal is approximately 85%
- Microbial removal by activated sludge

  80-99% removal of bacteria (sunlight, temperature, antagonistic microorganisms, predation by ciliated protozoans, competition from other bacteria, adsorption to sludge solids)

  90-99% removal of viruses (mostly through solids settling, but also bacterial antiviral products and predation)

Secondary treatment – Trickling filters

- Trickling filters are beds of stones or corrugated plastic. The primary wastewater is sprayed over the filter and microbes decompose organic material aerobically.

- Low pathogen removal
  - Bacteria, 20-90%
  - Viruses, 50-90%
  - Giardia cysts, 70-90%

Stabilization or oxidation ponds

- Oxidation ponds are a few meters deep, and up to a hectare in size. They are low cost with retention times of 1 to 4 weeks.
- Types: Aerobic, Aerated, Anaerobic
- Odor and mosquitoes can be a problem
- Pathogen removal:
  - Bacteria, 90-99%
  - Virus, 90-99%
  - Protozoa, 67-99%
- Mechanisms include the long detention time (natural die-off), high pH (10-10.5) generated by photosynthesis, predation, sunlight, temperature
- Stabilization ponds are the preferred wastewater treatment process in developing countries due to low cost, low maintenance. This is balanced by larger land requirement.

Tertiary treatment

- Tertiary treatment involves a series of additional steps to further reduce organics, turbidity, N, P, metals and pathogens. This is for wastewater that may impact recreational areas, will be used for irrigation, or will be used for drinking water.

- Physicochemical process

    Coagulation

    Filtration

    Activated carbon adsorption of organics

    Disinfection

Coagulation

<u>Flocculation and Sedimentation</u>

- Synthetic organic polymers
- Alum (aluminum sulfate)
- Iron salts (ferric sulfate, ferric chloride)
- Slow mixing
- Reduces microorganisms (transfer to sludge)
  - Bacteria 90 %
  - Virus 60 %
  - Protozoa 90 %

Filtration

- Removal of flocculated matter
  - Organic matter
  - Microorganisms
  - Mineral colloids

Disinfection

- Most common is halogens: chlorine, chloramine, chlorine dioxide, bromine, or iodine
- Ozone is more expensive but does not leave toxic residuals
- Metals: copper and silver have been used for disinfection of swimming pool and hot tub water.
- Ultraviolet is also more expensive and does not leave toxic residuals.

Pathogen Removal During Sewage Treatment

Type of sewage treatment	Removal range for various microbes
Primary	5-40%
Septic tanks	25-75%
Trickling filters	18-99%
Activated sludge	25-99%
Anaerobic digestion	25-92%
Waste stabilization ponds	60-99
Tertiary (flocculation, sand filtration, etc.)	93-99.99%

The other product left after wastewater treatment is sludge

- Sludge is generated during primary and secondary treatment. Processing of sludge has three major goals:
  - Reduce water content
  - Reduce odors
  - Reduce pathogens
- Sludge treatment is the most costly operation of wastewater treatment
  - 7 million tons/day (USA)
- Primary sludge
  - 3 to 8% solids
- Secondary
  - 0.5 to 2% solids

Sludge Treatment Processes

Thickening (water removal)

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Digestion (pathogen inactivation and odor control)

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Conditioning (improved dewatering with alum and high temp, 175-230^{o} C)

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Dewatering (pathogen inactivation and odor control)

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Incineration (volume and weight reduction)

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Final disposal

Discharge of Wastewater and Sludge?

- Sludge
  - landfarming
  - landfill
  - incineration
  - ocean
- Wastewater
  - Bodies of water: oceans, lakes, etc.
  - Land application
  - Constructed wetlands

Wastewater Treatment Alternatives

- Septic tanks
  - raw domestic wastewater
- Constructed wetland systems
  - wastewater effluent
- Composting
  - Municipal solid waste
  - sludge

Septic Tanks

- Underground tanks where solids are separated from incoming wastewater. Some biological digestion of the waste organic matter occurs under anaerobic conditions. Also involves a leachfield.
- Rural areas – septic tanks serve approx. 25% of U.S. pop.

Constructed Wetlands

- Used for further treatment of wastewater effluent, mine drainage, pulp mill effluent, etc.
- Three types
  - aquatic ponds
  - surface flow
  - subsurface flow

Composting

- Organic component of solid waste is biologically decomposed under controlled aerobic conditions
- End product: humus-like product useful as fertilizer
- This is one common method of sludge treatment

Land application of sludge must meet:

- pathogen reduction requirements (class A or B sludge)
- vector reduction requirements (reduction of volatile solids)
- metal loading limits
- testing requirements (for the above)

Amount of Sludge applied (Metric Tons/Year)	Frequency of testing
0 to 290	Once per year
290 to 1500	Once per quarter
1500 to 15,000	Once per 60 days
15,000 or more	Once per month

All Class A biosolids have specific pathogen requirements (can be applied to lawns and home gardens)

- **Fecal coliform densities must be less than 1,000 most probable number (MPN) per gram of total dry solids, or**
- ***Salmonella* sp. bacteria must be less than 3 MPN per 4 grams of total dry solids.**

Two Alternatives for Meeting Class "A" Pathogen Requirements

***Alternative 1:* Thermally treated biosolids**
Biosolids must be subject to one of four (4) time-temperature regimes:
example: 7 percent solid or greater biosolids must be heated to 50 degrees Celsius of higher for 20 minutes or longer.

***Alternative 2:* Biosolids treated in a high pH-high temperature process**
Biosolids must meet specific pH, temperature, and air-drying requirements.
Biosolid pH > 12 (measured at 25 C) for 72 hours or longer
Biosolids temp. > 52 C for at least 12 hours during the period that the pH > 12
Biosolids must be air dried to over 50 percent solids after the 72 hour period of elevated pH
All pathogen requirements must be met.

Pathogen requirements for Class B biosolids:

fecal coliform density < 2,000,000 MPN/g total solids

There are specific site restrictions for land applied Class B biosolids

Crops that Touch Biosolids
Food crops that have harvested parts that touch the mixture of soil and biosolids and are totally above the soil surface, cannot be harvested for 14 months after biosolid application.

Crops Embedded in the Soil
Food crops that have harvested parts growing in the soil where biosolids were applied and left on the surface for 4 months or longer before being incorporated into the soil, cannot be harvested for 20 months after biosolid application.

Food crops that have harvested parts growing in the soil where biosolids were applied and left on the surface less than 4 months before being incorporated into the soil, cannot be harvested for 38 months after biosolid application.

Feed Crops, Fiber Crops, and Food Crops that Do Not Touch the Soil
Food crops that do not touch the soil/biosolids mixture, feed and fiber crops cannot be harvested for 39 days after biosolid application.

Animal Grazing
Animals cannot graze on land treated with biosolids for at least 30 days after application of biosolids.

Turf Growing
Unless specified by the permitting authority, turf grown with a biosolids treatment cannot be harvested for 1 year after biosolid application when being use on a lawn or other area with a high potential for public access.

Public Access
Public access to land with a high potential for expose to the public is restricted for 1 year from the application of biosolids.

Public access to land with a low potential for expose to the public is restricted for 30 days from the application of biosolids.

Two alternatives for meeting Class "B" pathogen requirements

Alternative 1: **Monitoring Indicator Organisms**
Testing for fecal coliforms is used as an indicator for all pathogens and is done prior to the biosolids use or disposal.

Less than 2 million MPN or CFU/gram of dry biosolid is required to qualify as a Class B biosolid. EPA suggests that seven test samples be taken over a 2 week period because the testing procedures lack precision and the biosolids lack uniformity. Multiple samples should ensure a representable sampling of the biosolids.

Alternative 2: **Biosolids Treated with a PSRP**
Biosolids must be treated by one of the following 5 Processes to Significantly Reduce Pathogens (PSRP).

Aerobic Digestion: Biosolids are kept under aerobic conditions for a specific time ranging between 40 days at 20 C and 60 days at 15 C.

Air Drying: Biosolids are air dried on pads (sand or paved) for a minimum of 3 months, with at least 2 months having ambient average daily temperature > 0 C.

Anaerobic Digestion: Biosolids are kept under anaerobic conditions for a specified time and under a specific temperature ranging between 15 days at 35-55 C and 60 days at 20 C.

Composting: Using any of three methods of composting (in-vessel, static aerated pile, or windrowed), the temperature is raised to 40 C or higher and maintained for 5 days, 4 hours of which, the temperature of the pile must rise above 55 C.

Lime Stabilization: Enough lime is added to the biosolids to raise the pH of the biosolids to 12 after 2 hours of contact.