The Islamic University of Gaza- Civil Engineering Department

Advanced Sanitary Engineering- ECIV 5325

Unit 1. Physical, chemical and biological Characteristics of Wastewater

Based on Dr. Fahid Rabah lecture notes

COURSE OUTLINE

1. Physical, chemical and biological characteristics of wastewater 2. Fundamentals of biological wastewater treatment 3. Suspended growth treatment systems Midterm Exam	4. Attached growth biological treatment system 5. Sludge treatment Final Exam

Course Evaluation

Quiz & HM	25%
Mid term Exam	25%
Final Exam	50%

Wastewater: is simply that part of the water supply to the community or to the industry which has been used for different purposes and has been mixed with solids either suspended or dissolved.

Wastewater is 99.9% water and 0.1% solids. The main task in treating the wastewater is simply to remove most or all of this 0.1% of solids.

Type of wastewater from household

Type of Wastewater	Source of wastewater
Gray water	Washing water from the kitchen, bathroom, laundry (without faeces and urine)
Black water	Water from flush toilet (faeces and urine with flush water)
Yellow water	Urine from separated toilets and urinals
Brown water	Black water without urine or yellow water

Why do we need to treat wastewater ?

- To prevent groundwater pollution
- To prevent sea shore
- To prevent soil
- To prevent marine life
- Protection of public health
- To reuse the treated effluent
    - For agriculture
    - For groundwater recharge
    - For industrial recycle
- Solving social problems caused by the accumulation of wastewater

- **Protecting the public health:**

Wastewater contains pathogenic microorganisms lead to dangerous diseases to humans and animals

Hazardous matter such as heavy metals that are toxic

Produces odorous gases and bad smell

- **Protecting the environment:**

Raw Wastewater leads to septic conditions in the environment and consequently leads to the deterioration of surface and groundwater quality and pollutes the soil.

Raw wastewater is rich with nitrogen and phosphorus (N, P) and leads to the phenomena of EUTROPHICATION.

EUTROPHICATION is the growth of huge amounts of algae and other aquatic plants leading to the deterioration of the water quality.

Raw wastewater is rich with organic matter which consumes oxygen in aquatic environment.

Raw wastewater may contains toxic gases and volatile organic matter

Physical, chemicals and biological properties of wastewater

Characteristic	Sources
Physical properties: Color	Domestic and industrial wastes, natural decay of organic materials
Odor	Decomposing wastewater, industrial wastes.
Solids	Domestic water supply, domestic and industrial wastes, soil erosion, inflow infiltration
Temperature	Domestic and industrial wastes
Chemical constituents: Organic: Carbohydrates	Domestic, commercial, and industrial wastes
Fats, oils, and grease	Domestic, commercial, and industrial wastes
Pesticides	Agricultural wastes
Phenols	Industrial wastes
Proteins	Domestic, commercial, and industrial wastes
Priority pollutants	Domestic, commercial, and industrial wastes

Surfactants	**Domestic, commercial, and industrial wastes**
Volatile organic compounds	**Domestic, commercial, and industrial wastes**
Other	**Natural decay of organic materials**
Inorganic: Aikalinity	**Domestic wastes, domestic water supply, groundwater infiltration**
Chlorides	**Domestic wastes, domestic water supply, groundwater infiltration**
Heavy metals	**Industrial wastes**
Nitrogen	**Domestic and agricultural wastes**
PH	**Domestic, commercial, and industrial wastes**
Phosphorus	**Domestic, commercial, and industrial wastes natural runoff**
Priority polluter Sulfur	**Domestic water supply; doestic, commercial. And industrial wastes**
Gases: Hydrogen sulfide	**Decomposition of domestic wastes**
Methane	**Decomposition of domestic wastes**
Oxygen	**Domestic water supply , surface- water infiltration**
Biological constituents: Animals	**Open watercourses and treatment plants**
Plants	**Open watercourses and treatment plants**
Eubacteria	**Domestic wastes, surface water infiltration, treatment plants .**
Archaebacteria	**Domestic wastes, surface-water infiltration, treatment plants**
Viruses	**Domestic wastes**

Physical characteristics- Solids

- Solids are classified into three main types:

1. Total Solids (TS): All the matter that remains as residue upon evaporation at 103^{o}C to 105^{o}C.

2. Settleable solids: Settleable solids are measured as ml/L, which is an approximate measure of the sludge that can be removed by primary sedimentation.

3. Suspended solids (SS) and Filterable solids (FS).

Physical characteristics- Odor

Odor is produced by gas production due to the decomposition of organic matter or by substances added to the wastewater.

Detection of odor: Odor is measured by special instruments such as the Portable H_2S meter which is used for measuring the concentration of hydrogen sulfide.

Compound	**Chemical Formula**	**Odor quality**
Amines	CH_3NH_2, $(CH_3)_3H$	Fishy
Ammonia	NH_3	Ammoniacal
Diamines	$NH_2 (CH_2)_4 NH_2$, $(CH_2)_5 NH_2 H_{25}$	Rotten eggs
Mercaptans		
(E. g, methy1 and ethy1)	CH_3SH, $CH_3 (CH_2) SH$	Decayed cabbage
Organic sulfides		Rotten cabbage
Skatole		Fecal matter

Physical characteristics- Temperature

Temperature of wastewater is commonly higher than that of water supply. Depending on the geographic location the mean annual temperature varies in the range of 10 to 21^{o}C with an average of 16 ^{o}C.

Importance of temperature:-

Affects chemical reactions during the wastewater treatment process.
Affects aquatic life (Fish, ……).

Oxygen solubility is less in worm water than cold water.

Optimum temperature for bacterial activity is in the range of 25°C to 35

Aerobic digestion and nitrification stop when the temperature rises to 50^{o} C.
When the temperature drops to about 15°c, methane producing bacteria become in active.

Nitrifying bacteria stop activity at about 5°c.

Density:-

Almost the same density of water when the wastewater doesn't include significant amount of industrial waste.

Color:-

Fresh waste water ⟶ light brownish gray.

With time ⟶ dark gray

More time ⟶ black (septic).

Some times pink due to algae or due to industrial colors.

Turbidity:-

It's a measure of the light – transmitting properties of water.

Chemical characteristics of wastewater:-

Points of concern regarding the chemical characteristics of wastewater are:

-Organic matter
-Measurements of organic matter
-Inorganic matter
-Gases
-pH

Organic matter ($C_a H_b O_c$).

75% SS ⟶ organic. (Suspended Solids)
40% FS ⟶ organic. (Filtered Solids)

Organic mater is derived from animals & plants and man activities.

Proteins (40-60%).
Carbohydrates (25-50%).
Fats, Oils, and Grease (10%).

Measurements of organic matter:-

Many parameters have been used to measure the concentration of organic matter in wastewater. The following are the most common used methods:

Biochemical oxygen demand (BOD).

BOD_5 is the oxygen equivalent of organic matter. It is determined by measuring the dissolved oxygen used by microorganisms during the biochemical oxidation of organic matter in 5 days at 20^oC

Chemical oxygen demand (COD)

It is the oxygen equivalent of organic matter. It is determined by measuring the dissolved oxygen used during the chemical oxidation of organic matter in 3 hours.

Total organic carbon (TOC)

This method measures the organic carbon existing in the wastewater by injecting a sample of the WW in special device in which the carbon is oxidized to carbon dioxide then carbon dioxide is measured and used to quantify the amount of organic matter in the WW. This method is only used for small concentration of organic matter.

Theoretical oxygen (ThOD)

If the chemical formula of the organic matter existing in the WW is known the ThOD may be computed as the amount of oxygen needed to oxidize the organic carbon to carbon dioxide and a other end products.

Biological Oxygen Demand (BOD):

The following are the theoretical equations used to calculate the BOD.
The Figure shown is used to describe the change of BOD with time. From the figure the following correlations are derived:

$L_0 \rightarrow$ or (BOD ultimate) or UBOD.

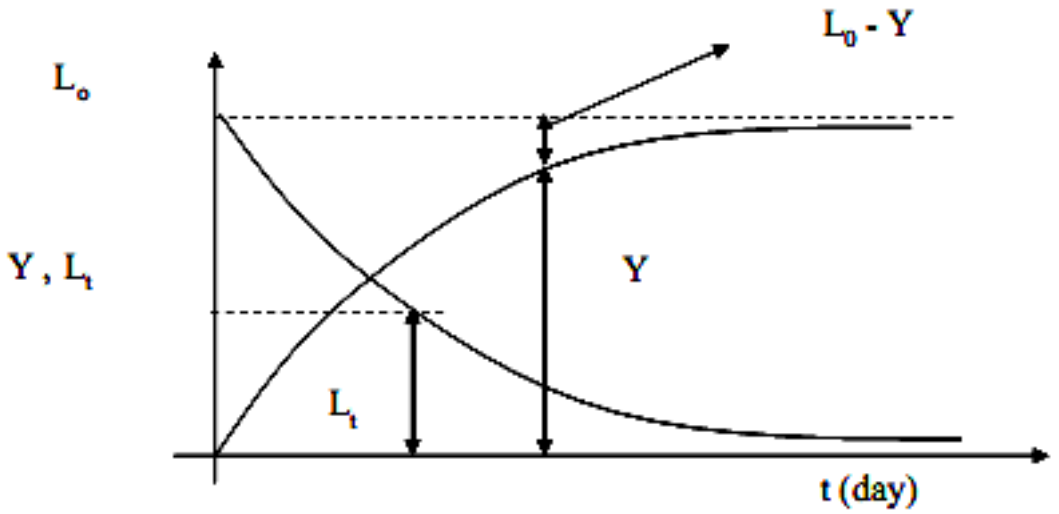
$Y_t = BOD_t$ (BOD exerted).

$L_t = L_0 e^{-kt}$ (BOD remain).

$BOD_t = L_0 - L_t = L_0 - L_0 e^{-kt} = L_0(1-e^{-kt})$

$BOD_5 = L_0 (1-e^{-k5})$

$K = 0.23 d^{-1}$ usually, $k_T = k_{20}\, \theta^{T-20}$, $\theta = 1.047$ or as given



Example

Determine the 1-day BOD and ultimate BOD for a wastewater whose 5-day 20 °C BOD is 200 mg/L. The reaction constant K= 0.23d^{-1} what would have been the 5-day BOD if it had been conducted at 25°C?

Solution:-

- $BOD_t = UBOD - BODr = UBOD\,(1-e^{-kt}) = L_0(1-e^{-kt})$

$200 = L_0\,(1-e^{-0.23x5})$

$L_0 = 293$ mg/L (this is UBOD)

- Determine the 1-day BOD:-

$BOD_t = L_0\,(l-e^{-kt})$

$BOD_1 = 293\,(l-e^{-0.23x1}) = 60.1$ mg/L

- Determine the 5-day BOD at 25°C:-

$K_T = K_{20}\,(1.047)^{T-20} \Rightarrow K_{25} = 0.23\,(1.047)^{25-20}$

$BOD_5 = L_0\,(l-e\,–kt\,) = 293\,(l-e^{-0.29x5}) = 224$ mg/L

Theoretical Oxygen demand (ThOD): Example

Calculate the Theoretical Oxygen Demand (ThOD) for sugar $C_{12}H_{22}O_{11}$ dissolved in water to a concentration of 100 mg/L. Calculate "TOC".

Solution:-

$C_{12}H_{22}O_{11} + 12O_2 \rightarrow 12\,CO_2 + 11\,H_2O$

$$\text{ThOD} = \frac{12 \times 32 g O_2}{342 g_{sugar}} = 1.123 g O_2 / g_{sugar}$$

$$\text{ThOD} = \frac{100 mg_{sugar}}{L} * \frac{1.123 g O_2}{g_{sugar}} * \frac{10^3 mg O_2}{1 g O_2} * \frac{1 g_{sugar}}{10^3 mg_{sugar}}$$

ThOD = 112.3 mg O_2 / L

TOC = 144 g carbon/ 342g sugar = 0.42 gc/ gs

TOC = 0.42 x 100 = 42 mg carbon/L

Chemical Oxygen demand (COD) and Total Organic carbon (TOC)

Example:

Determine BOD_5/COD, BOD_5/TOC, TOC/BOD_5 ratios for the following organic compound ($C_5 H_7 NO_2$). Assume "K" = $0.23 d^{-1}$.

1. determine COD:-

$C_5 H_7 NO_2 + 5O_2 \rightarrow 5 CO_2 + NH_3 + 2H_2O$

Mw =113 mw =160

COD = 160/113 = 1.42 mg O_2 / mg $C_5 H_7 NO_2$

2. Determine the BOD_5 of $C_5 H_7 NO_2$:-

$\frac{BOD5}{UBOD} = 1 - e^{-0.23x5} = 0.68$

BOD5 =0.68 UBOD $\rightarrow$ but COD = UBOD

So BOD5 = 0.68XCOD = 1.42X0.68=0.97 mg BOD/mg $C_5 H_7 NO_2$

3. Determine the TOC of the compound:-

TOC = 5X12/113 = 0.53 mg TOC/mg $C_5 H_7 NO_2$

4. $\frac{BOD5}{COD} = \frac{0.97}{1.42} = 0.68$

$\frac{BOD_5}{TOC} = \frac{0.97}{0.53} = 1.82$

$\frac{TOC}{COD} = \frac{0.53}{1.42} = 0.37$

Note: COD = THOD = UBOD This is true only when the organic compound is assumed to be completely biodegradable

Inorganic Matter

The following are the main inorganic materials of concern in wastewater treatment:

1. **Chlorides:-**

• High concentrations indicate that the water body has been used for waste disposal.
• It affects the biological process in high concentrations.

2. Nitrogen:-

TKN = Total Kjeldahl nitrogen.
= Organic Nitrogen + ammonia Nitrogen (120 mg/l).

3. **Phosphorus:-**

• Municipal waste contains (4-15 mg/l).

4. Sulfur:-

* Sulfate exists in waste and necessary for synthesis of proteins.

$$\text{Organic matter} + SO_4^{-2} \rightarrow S^{-2} + H_2O + CO_2$$

$$S^{-2} + 2H^{+} \rightarrow H_2S$$

5. Toxic inorganic Compounds:-
Copper, lead, silver, chromium, arsenic, boron.

6. Heavy metals:-
Nickels, Mn, Lead, chromium, cadmium, zinc, copper, iron mercury.

Gases:-

The following are the main gases of concern in wastewater treatment:
N_2, O_2, CO_2, H_2S, NH_3, CH_4

pH:-

The hydrogen-ion concentration is an important parameter in both natural waters and wastewaters. It is a very important factor in the biological and chemical wastewater treatment. Water and wastewater can be classified as neutral, alkaline or acidic according to the following ranges:

PH = 7 neutral.
PH > 7 Alkaline.
PH < 7 Acidic.

Biological Characteristics:-

The environmental engineer must have considerable knowledge of the biological of waste water because it is a very important characteristics factor in wastewater treatment.

The Engineer should know:-

1. The principal groups of microorganisms found in wastewater.
2. The pathogenic organisms.
3. Indicator organisms (indicate the – presence of pathogens).
4. The methods used to amount the microorganisms.
5. The methods to evaluate the toxicity of treated wastewater

Main groups of Microorganisms:-

The main microorganisms of concern in wastewater treatment are Bacteria, Fungi, Algae, Protozoa, Viruses, and pathogenic microorganisms groups.

Bacteria:-

Types: Spheroid, rod curved rod, spiral, filamentous. Some important bacteria:-

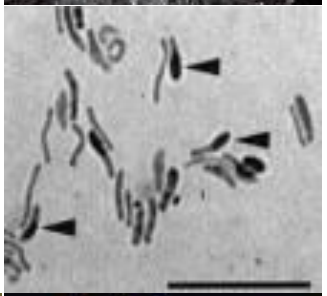
Pseudomonas:- reduce NO_3 to N_2, So it is very important in biological nitrate removal in treatment works.

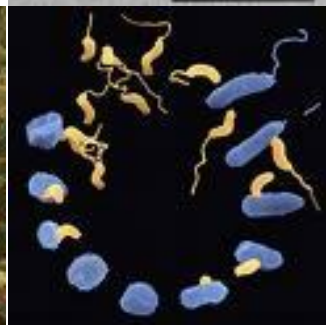
Zoogloea:- helps through its slime production in the formation of flocs in the aeration tanks.

Sphaerotilus natuns:Causes sludge bulking in the aeration tanks.

Bdellovibrio: destroy pathogens in biological treatment.

Acinetobacter: Store large amounts of phosphate under aerobic conditions and release it under an – anaerobic condition so, they are useful in phosphate removal.



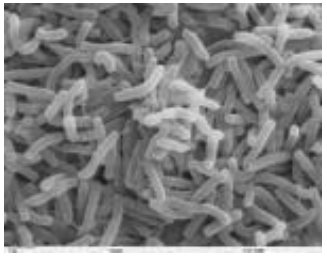


Nitrosomonas: transform NH_4 into NO_2^-

Nitrobacter: transform NO_2^- to NO_3^-

Coliform bacteria:- The most common type is E-Coli or Echerichia Coli, (indicator for the presence of pathogens).

E-Coli is measured in (No/100mL)



Fungi:

- Important in decomposing organic matter to simple forms.

Algae:

- Cause eutrophication phenomena. (negative effect)
- Useful in oxidation ponds. (positive effect)
- Cause taste and problems when decayed. (negative effect)

Protozoa:

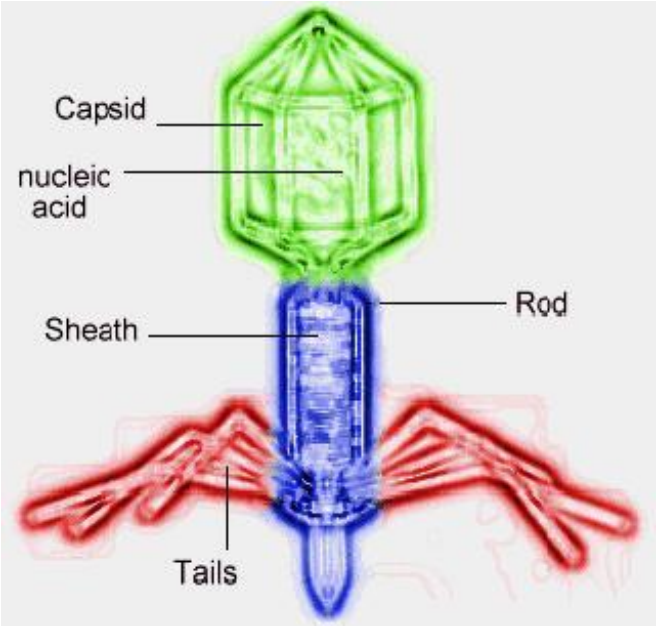
- Feed on bacteria so they help in the purification of treated waste water.
- Some of them are pathogenic.

Viruses:

Viruses are a major hazard to public health. Some viruses can live as long as 41days in water and wastewater at 20 ^{o}C. They cause lots of dangerous diseases.

Pathogenic organisms:

The main categories of pathogens are:-
Bacteria, Viruses, protozoa, helminthes



Typical Wastewater Composition

Concentration				
Contaminants	**Unit**	**Weak**	**Medium**	**Strong**
Solids, total (TS)	**mg/L**	**350**	**720**	**1200**
Dissolved, total (TDS)	**mg/L**	**250**	**500**	**850**
Fixed	**mg/L**	**145**	**300**	**525**
Volatile	**mg/L**	**105**	**200**	**325**
Settle able solids (SS)	**mg/L**	**100**	**220**	**350**
Fixed	**mg/L**	**20**	**55**	**75**
Volatile	**mg/L**	**80**	**165**	**275**
Settle able Solids	**mg/L**	**5**	**10**	**20**
Biochemical oxygen demand, mg/l:				
C) ° C (BOD_5,20°5-day, 20	**mg/L**	**110**	**220**	**400**
Total organic carbon (TOC)		**80**	**160**	**290**
Chemical oxygen demand (COD)	**mg/L**	**250**	**500**	**1000**

Nitrogen (total as N)	**mg/L**	**20**	**40**	**85**
Organic	**mg/L**	**8**	**15**	**35**
Free ammonia	**mg/L**	**12**	**25**	**50**
Nitrites	**mg/L**	**0**	**0**	**0**
Nitrites	**mg/L**	**0**	**0**	**0**
Phosphorus (total as P)	**mg/L**	**4**	**8**	**15**
Organic	**mg/L**	**1**	**3**	**5**
Inorganic	**mg/L**	**3**	**5**	**10**
Chlorides[a]	**mg/L**	**30**	**50**	**100**
Sulfate[a]	**mg/L**	**20**	**30**	**50**
Alkalinity (as $CaCO_3$)	**mg/L**	**50**	**100**	**200**
Grease	**mg/L**	**50**	**100**	**150**
Total coliform[b]	**no/100 ml**	**10^6 - 10^7**	**10^7 – 10^8**	**10^7 – 10^9**
Volatile organic compounds (VOC_s)	**Mg/L**	**<100**	**100 - 400**	**> 400**

Wastewater treatment standards

The most common WWT standards are set for the secondary treatment effluent. The main effluent parameter are: BOD_5, TSS, pH and $CBOD_5$.

*CBOD: (Carbonaceous BOD, from organic compounds and oxidation of inorganic compounds such as ferrous iron)

"secondary treatment" standards in the USA.

Characteristic of discharge	unit	Average 30-day concentration	Average 7-day concentration
BOD_5	mg/L	30	45
TSS	mg/L	30	45
pH	pH units	Within the range 6-9 always	
$CBOD_5^*$	mg/L	25	40

The standards for the removal of nitrogen and phosphorus (N,P) are not included in this table because (N) and (P) need tertiary treatment.

Removal of the coliform bacteria is also regulated according to reuse purpose:-

Fecal coliforms < 500/100 ml (disposed into recreational waters)

1000/100 >ml (for irrigations)