Wastewater Treatment (WWT)
EENV 4332

1. Introduction to Wastewater Treatment

1.1 Definition of Wastewater:-

"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.

Wastewater = clean water supply + solids

What do we mean by wastewater treatment ?

Wastewater treatment is simply the separation of solids from water.

Clean water = Wastewater - Solids

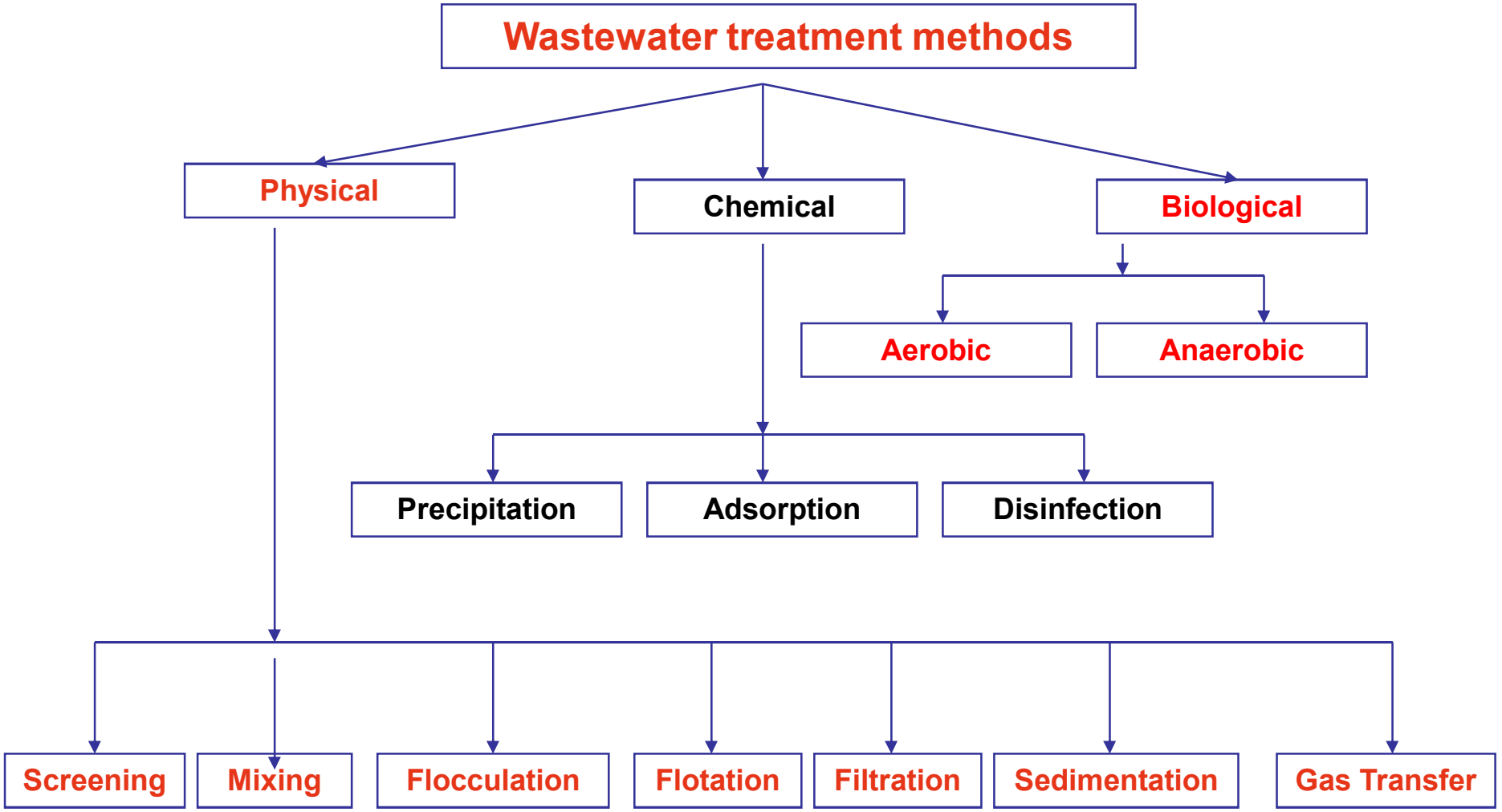
- How can we separate solids from water ?

There are many methods used to separate solids from water:

- Physical methods

-Chemical method

- Biological methods


Wastewater treatment methods
Physical
Chemical
Biological
Aerobic
Anaerobic
Precipitation
Adsorption
Disinfection
Screening
Mixing
Flocculation
Flotation
Filtration
Sedimentation
Gas Transfer

4. How can we select the separation (treatment) method?

The separation method (physical, chemical, or biological) depends on the type of the solid to be separated or removed from water.

5. So, What are the types of solids existing in wastewater?

solids in WW are:

a. Big floatable solids: (separated physically by screens)

b. Grit and sand: (separated physically by grit removal channels)

c. Suspended solids:

i. Settleable : (separated physically by sedimentation tanks)

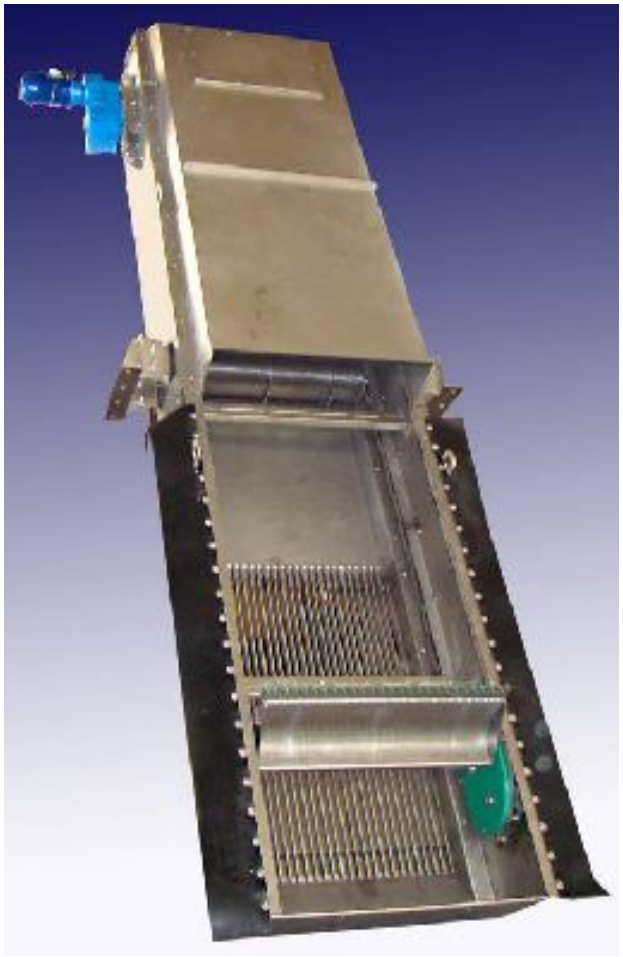
ii .non settleable:

1. floatable (separated physically by floatation tanks)
2. colloidal (separated indirectly biologically or by chemical and physical methods coagulation followed by filtration tanks)

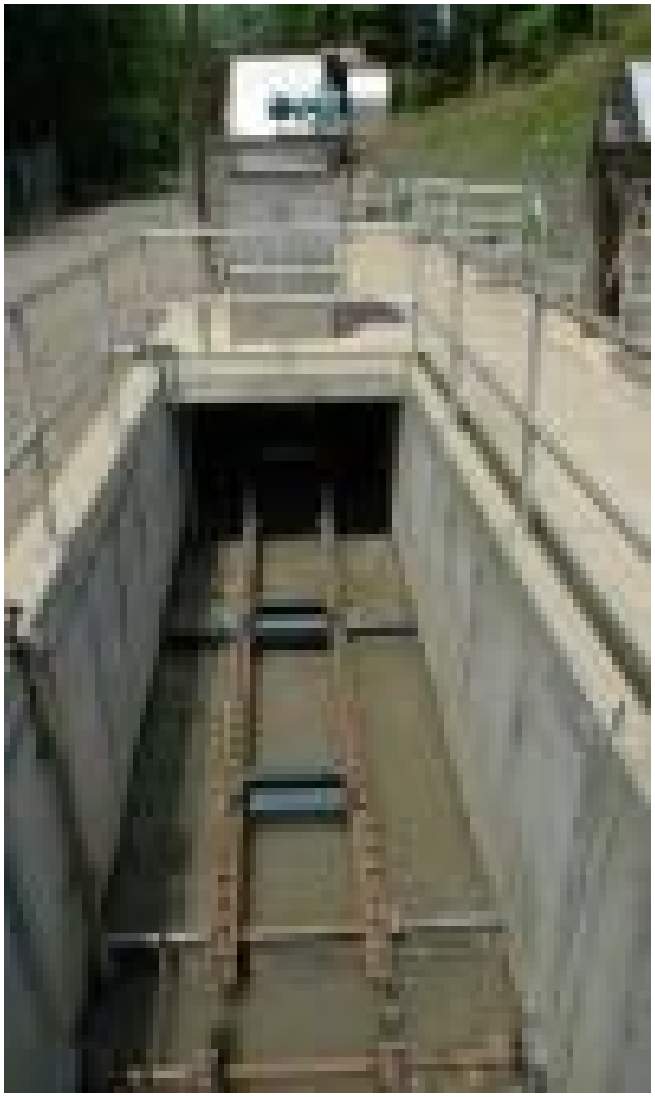
d. Dissolved solids:

i. organic (separated biologically by biological treatment tanks)

ii. Inorganic (separated chemical treatment tanks)

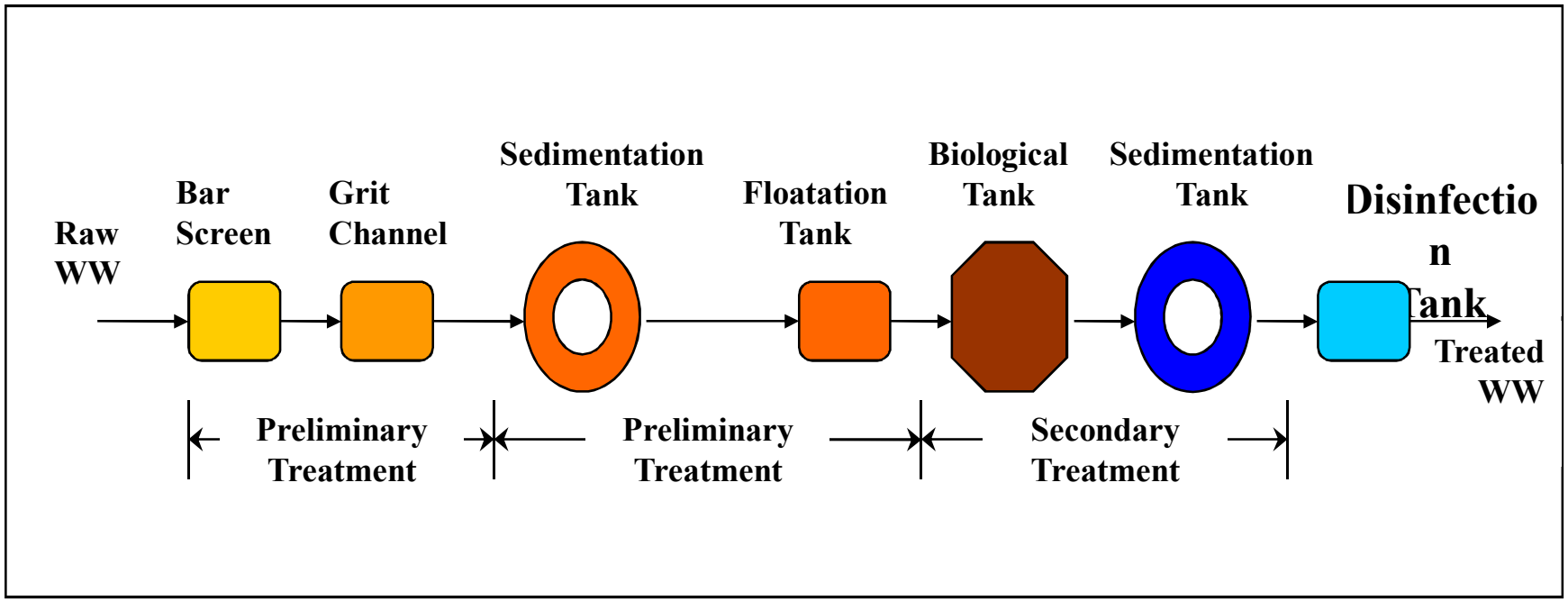


Bar screen
Channel



Grit Removal
Channel

Sedimentation Tanks



Typical Wastewater treatment plant layout

6. So what are the technical goals of Wastewater treatment?

a. Separation of solids from liquid

b. Stabilization of separated solids

c . disinfection of pathogenic micro-organisms

d. Proper reuse or disposal of treated liquid and solids

- **1.2 Goals of Wastewater Treatment:-**

  The main goals of wastewater treatment are:-

- *A- Protecting the public health*

  - Wastewater (WW) contains pathogenic microorganisms which lead to dangerous diseases to humans and animals.

  - Hazardous matter such as heavy metals that are toxic.

  - Produces odorous gases and bad smell.

B- Protecting the environment

- Raw (untreated) WW leads to septic conditions in the environment and consequently leads to the deterioration of surface and groundwater quality and pollutes the soil.
- Raw WW is rich with nitrogen and phosphorus (N,P), and leads to the phenomena of "Eutrophication" if disposed in surface water which. Eutrophication is the growth of huge amounts of algae and other aquatic plants leading to the deterioration of the water quality.
- Raw WW is rich with organic matter which consumes oxygen when disposed in rivers leading to killing aquatic creatures such as fish.
- Raw WW may contain toxic gases and volatile organic matter (VOCs) and toxic air contaminants (TACs).

C- Reuse of the treated WW and solids:-

- Treated water is reused for → Agriculture
  → industry
  → Recharge to ground water
-
- Separated and treated solids are reused for solids

Solids → Agriculture
→ Landfill
→ Energy source

- **1.3 Characteristics of wastewater**
- Physical, chemical, and biological characteristics of wastewater and their sources

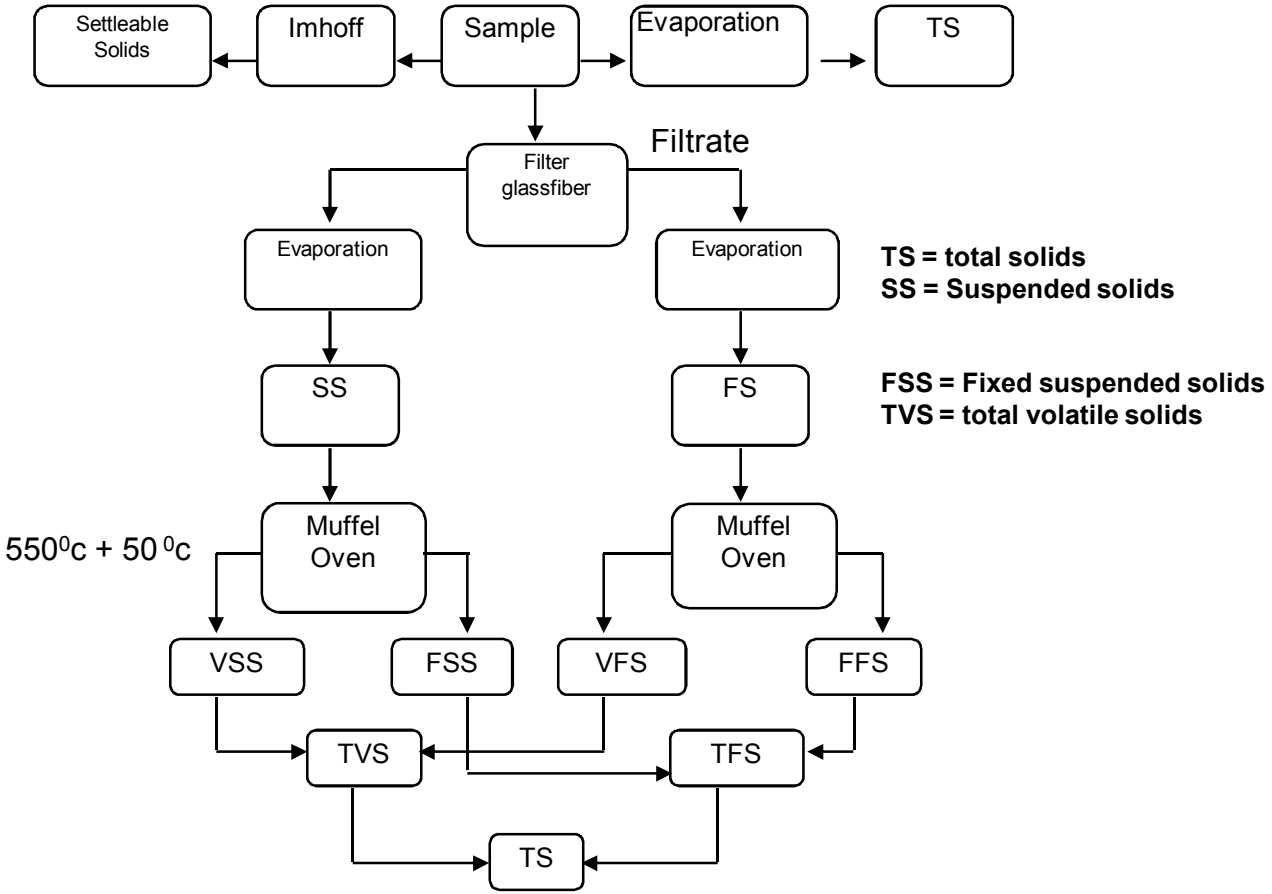
Physical, chemicals and biological properties (Table 1.1)

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

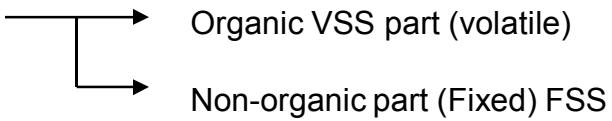
Surfactants	**Domestic, commercial, and industrial wastes**
Volatile organic compounds	**Domestic, commercial, and industrial wastes**
Other	**Natural decay of organic materials**
Inorganic: Aikalinity	**Domestic wastes, domestic water supply, groundwater infiltration**
Chlorides	**Domestic wastes, domestic water supply, groundwater infiltration**
Heavy metals	**Industrial sastes**
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**

1.3.1 Physical characteristics
A. Solids :

- Solids are classified into three main types:
- 1. Total Solids (TS)
- All the matter that remains as residue upon evaporation at 103 oC to 105 oC.
- 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).
- Filterable solids (dissolved solids):-


Settleable Solids
Imhoff
Sample
Evaporation
TS
Filtrate
Filter glassfiber
Evaporation
Evaporation
TS = total solids
SS = Suspended solids
SS
FS
FSS = Fixed suspended solids
TVS = total volatile solids
550⁰c + 50 ⁰c
Muffel Oven
Muffel Oven
VSS
FSS
VFS
FFS
TVS
TFS
TS

- **Suspended solids (SS) are divided into two main parts:**



Volatile part is the organic matter which volatile at 55o^{o} ± 50^{o}C

- **B. <u>Odor</u>**
- Odor is produced by gas production due to the decomposition of organic matter or by substances added to the wastewater.
- Odorous compounds:-
- Table 1.2 gives the most common odorous compounds associated with wastewater.

Table (1.2) Odorous compounds associated with wastewater.

Compound	Chemical Formula	Odor quality
Amines	CH_3NH_2, $(CH_3)_3H$	Fishy
Ammonia	NH_3	Ammoniacal
Diamines	$NH_2(CH_2)_4NH_2$, $(CH_2)_5NH_2H_{25}$	Rotten eggs
Mercaptans		
(E. g, methy1 and ethy1)	CH_3SH, $CH_3(CH_2)SH$	Decayed cabbage
Organic sulfides		Rotten cabbage
Skatole		Fecal matter

- Detection of odor:

Odor is measured by special instruments such as the Portable H2S meter which is used for measuring the concentration of hydrogen sulfide.

- **C. 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 oC with an average of 16 oC.
- **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° to 35°.
- Aerobic digestion and nitrification stop when the temperature rises to 50 oC.
- When the temperature drops to about 15°c, methane producing bacteria become in active.
- Nitrifying bacteria stop activity at about 5°c.

- **D. Density:-**

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

E. Color:-

Fresh waste water → light brownish gray.
With time → dark gray
More time → black (septic).
Some times pink due to alge or due to industrial colors, (die industry).

F. Turbidity:-

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

1.3.2 Chemical characteristics of wastwater:-

Points of concern regarding the chemical charatretistices of waswater are

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

A. Organic matter (CaHbOc).

* 75% SS $\rightarrow$ organic. (Suspended Solids)
* 40% FS $\rightarrow$ organic. (Filterade Solids)

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

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

- B. 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:

1- Biochemical oxygen demand (BOD).

BOD5 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

2- 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.

3- 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.

4- 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.

The following are examples on measuring the organic matter in wastewater

1- BOD:

The following are the theoritical 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.

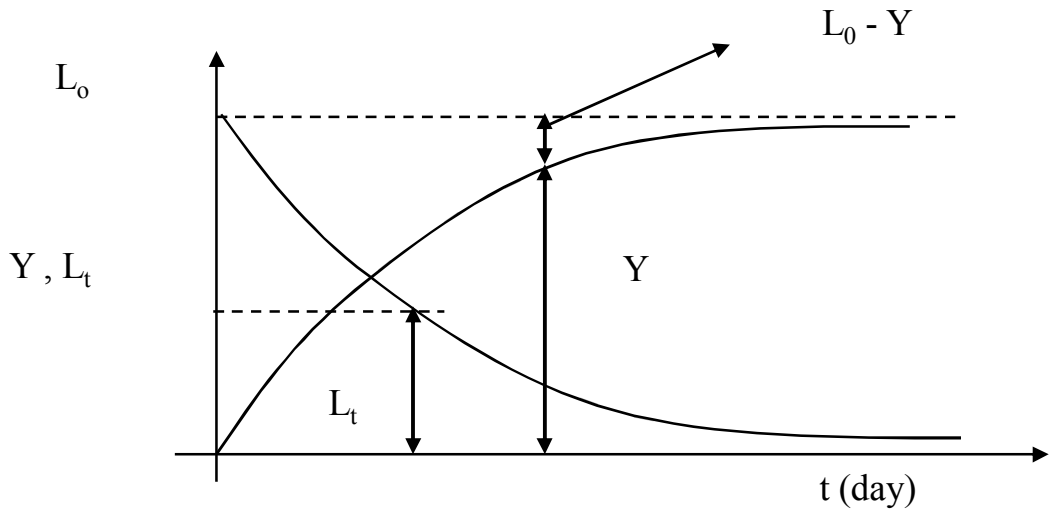
$Y_t = BOD_t$ (BOD exerted).

$L_t = L_0 e^{-kt}$ (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, $kT = k_{20}\, \theta^{T-20}$, $\theta = 1.047$ or as given



Example 1.1:-

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:-

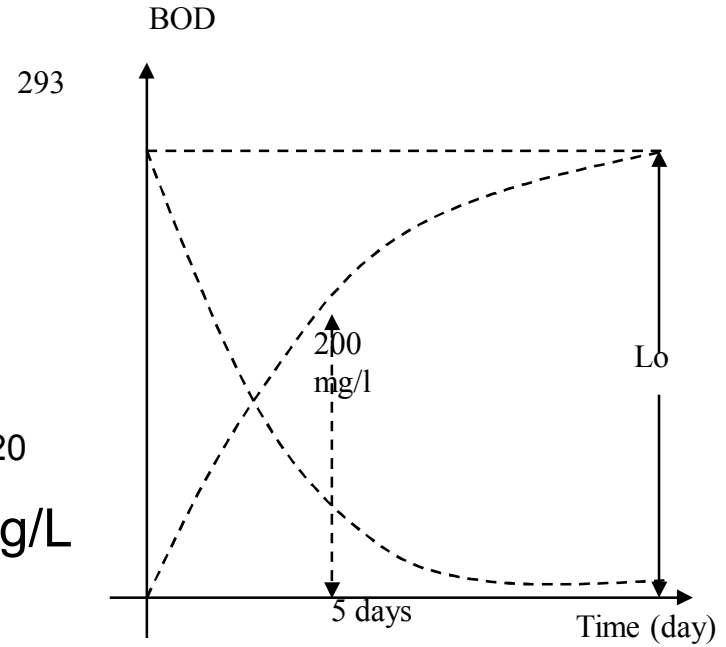
$BOD_t = L_0 (1-e^{-kt})$

$BOD_1 = 293 (1-e^{-0.23x1}) = 60.1$ mg/L

- Determine the 5-day BOD at 25°C:-

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

$BOD_5 = L_0 (1-e^{-kt}) = 293 (1-e^{-0.29x5}) = 224$ mg/L



II) ThOD:

Example 1.2:-

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 mgcarbon/L

III) COD and TOC

Example 1.3:-

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

1. determine COD:-

(Mw =113) $C_5 H_7 NO_2$ + (mw =160) $5O_2 \rightarrow 5 CO_2 + NH_3 + 2H_2O$

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

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

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

$BOD_5 = 0.68$ UBOD $\rightarrow$ but COD = UBOD

So BOD_5 = 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. $\frac{BOD_5}{COD} = \frac{0.97}{1.42} = 0.68$

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

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

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

C. 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 procces 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.

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, chrouim, cadmium, zinc, copper, iron mercury.

D. Gases:-

The following are the main gases of concern in wastewater treatment:

N_2, O_2, CO_2, H_2S, NH_3, CH_4

E. 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.

1.3.3 Biological Characteristics:-

The environmental engineer must have considerable knowledge of the biological characteristics of waste water because it is a very Important 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 waste water

A. Main groups of Microorganisms:-

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

a. Bacteria:-

Types: Spheroid, rod curved rod, spiral, filamentous.

Some important bacteria:-

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

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

3- Sphaerotilus natuns:- Causes sludge bulking in the aeration tanks.

4- Bdellovibrio:- destroy pathogens in biological treatment.

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

6- Nitrosomonas: transform NH_4^+ into NO^{2-}

7- Nitrobacter: transform NO^{2-} to NO^{3-}

8- 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)

b. Fungi:-

Important in decomposing organic matter to simple forms.

c. Algae:-

•Cause eutrophication phenomena. (negative effect)

•Useful in oxidation ponds. (positive effect)

•Cause taste and problems when decayed. (negative effect)

e. Protozoa:-

•Feed on bacteria so they help in the purification of treated waste water.

•Some of them are pathogenic.

f. Viruses:

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

g. Pathogenic organisms:-

The main categories of pathogens are:-

Bacteria, Viruses, protozoa, helminthes

Table (1.3) Infectious agents potentially present in raw domestic wastewater

Organism	Disease	Remarks
Bacteria		
Escherichia coli	**Gastroenteritis**	**Diarrhea**
(enter pathogenic)		
Legionella pneumophila	**Legionellosis**	
Leptospira (150 spp.)	**Legionellosis**	**Jaundice, fever (weil's disease)**
Salmonella typhi	**Typhoid fever**	**High fever, diarrhea, ulceration of small intestine.**
Salmonella (- 1700 spp	**Salmonellosis**	**Food poisoning**
Shigella (4 spp)	**Shigellosis**	**Bacillary dysentery**
Vibrio cholerae	**Cholera**	**Extremely heavy diarrhea, dehydration**
Yersinia enterolitica	**Yersinosis**	**Diarrhea**
Viruses		
Adenovirus (31 types)	**Respiratory disease**	
Enteroviruses (67 types,	**Gastroenteritlis, heart**	

e.g. polio, echo, and coxsackie viruses)	Anomalies, meningitis	
Hepatitls A	Infectious hepatitis	Jaundice, fever
Norwalk agent	Gastroenteritlis	Vomiting
Reovirus	Gastroenteritlis	
Rotavirus	Gastroenteritlis	
Protozoa		
Balantidium coli	Balantidiasis	Diarrhea, dysentery
Cryptosporidium	Cryptosporidiosis	Diarrhea
Entamoeba histolytica	Amebiasis (amoebic dysentery)	Prolonged diarrhea with bleeding, abscesses of the liver and small intestine
Giardia lamblia	Giardiasis	Mild to severe diarrhea, nausea, indigestion
Helminths[b]		
Ascaris lumbricoldes	Ascariasis	Roundworm infestation
Enterobius vericularis	Enterobiasis	Pinworm
Fasciola hepatica	Fasciollasis	Sheep liver fluko
Hymenolepis nana	Hymenolepiasis	Dwart tapeworm
Teenia saginate	Taeniasis	Beef tapeworm
T. solium	Taeniasis	Pork tapeworm
Trichuris trichiura	Trichuriasis	Whipworm

1.3.4 Typical Wastewater Composition

Table 1.4 gives a typical wastewater composition of untreated domestic wastewater.

Table (1.4). Typical composition of untreated domestic wastewater

				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:				
5-day, 20°C (BOD_5,20°C)	**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**

1.5 Wastewater treatment standards

The most common WWT standards are set for the secondary treatment effluent. The main effluent parameter are: BOD5, TSS, pH and CBOD5. Table 1.5 gives the "secondary treatment" standards in the USA.

Table 1.5 The "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)