Water and Wastewater Engineering (1)

Course Code: 5802333-4 Credits : (4,3,3)

Text Book:
Introduction to Environmental Engineering by Mackenzie L. Davis ; David A. Cornwell

References:
1- Note Book by Dr. Mohammad Qasaimeh
Department of Environmental Engineering, Al-Lith
2- Unit Operations and Processes in Environmental Engineering by Reynolds/Richards

Course Content

Subject	Number of weeks
1) Water and wastewater engineering concept and definitions	3
2) Design of facilities for physical and (chemical treatment) and biological treatment of wastewater	7
3) Design of the facilities for the treatment and disposal of sludge.	2
4) Exams and Quizzes	2
5) Homework and Reports	1

Notice: Mid Exam will be hold in week number 8

Water and Wastewater Engineering Concept and Definitions

Water Concept

- Types of Water:

  1- Ground Water   2- Surface Water   3- Wastewater

- Potable and palatable water:

  1- Potable water is that one not necessarily pleasing but not concern to adverse health
  2- Palatable water is that pleasing but not safe.

- Treatment:

  1- Water treatment   2- Wastewater treatment

Physical Properties of Water

1- Density: $\rho = m/V = 1\, gm/cm^3 = 10^3\ kg/m^3$

2- Specific gravity $S = \dfrac{\rho}{\rho_w} = \dfrac{1\, gm/cm^3}{1\, gm/cm^3} = 1$

3- Specific weight $\gamma = \rho\, g\ = 9.8 \times 10^3\ N/m^3$

4- Viscosity $\mu = \dfrac{\tau}{\phi} = 1\ c.poise = 0.01\ gm/cm\, s = 0.01 dyne\, s/cm^2$

5- kinematic viscosity $k = \dfrac{\mu}{\rho} = \dfrac{0.01 gm/cm\ s}{1 gm/cm^3}\ = 0.01\ cm^2/s\ = 0.01\ stoke$

Solution Impurities

- Suspended Materials (large particles)
  Can be removed by screening
- Colloidal Materials
  smaller than suspended but larger than dissolved materials that can be removed by centrifugation and membrane filtration
- Dissolved materials
  are very small materials in form of atoms and molecules that can be removed by accomplishing phase change such as distillation, extraction, adsorption, precipitation,…
- Particle Measurement:
  1- Turbidity: the degree the particles reflects light at 90^o angle.
  2- Color: the ability of the solution to absorb light.

Chemical Reactions

- Precipitation Reactions

$$A_a\ B_b \longleftrightarrow a\ A^+ + b\,B^-$$

$$Ca_3\ (PO_4)_2 \longleftrightarrow 3\ Ca^+ + 2\,PO_4^-$$

$$Solubility\ Constant = K_s = [A]^a\ [B]^b$$

$$pK = -\log K$$

- Acid – Base Reactions

1- Acid is a material that release proton

$$H\,A \longleftrightarrow H^+ + A^-$$

$$H\,A + H_2O \longleftrightarrow (H^+ + A^-) + H_2O$$

$$\longleftrightarrow (H_3O)^+ + A^-$$

$$H\,Cl \longleftrightarrow H^+ + Cl^-$$

$$H\,Cl + H_2O \longleftrightarrow (H^+ + Cl^-) + H_2O$$

$$\longleftrightarrow (H_3O)^+ + Cl^-$$

2- Base is a material that accept proton

$$B^- + H_2O \longleftrightarrow (H^+ + OH^-) + B^-$$

$$\longleftrightarrow H\,B + OH^-$$

$$Na_2\,CO_3 \longleftrightarrow 2Na^+ + CO_3^-$$

$$CO_3^- + H_2O \longleftrightarrow CO_3^- + (H^+ + OH^-)$$

$$\longleftrightarrow HCO_3^- + OH^-$$

3- Water behaves as unstable ionic phase with equilibrium reaction

$$H_2O \longleftrightarrow H^+ + OH^-$$

If a compound added to water is strong acid, water acts as a base, but When the compound added to water is strong base, water acts as an acid. The degree of ionization of water is measured by

$$K_w = [OH]^- \, [H]^+ = 10^{-14} \qquad and \qquad \log K_w = \log[OH]^- + \log[H]^+ = \log 10^{-14} = -14$$

But pure water is neutral

$$[OH]^- = [H]^+ \quad then \quad [OH]^- = [H]^+ = 10^{-7}$$

$$pOH = -\log[OH]^- = -\log 10^{-7} = 7$$

$$pH = -\log[H]^+ = -\log 10^{-7} = 7$$

$$When \;\; pH > 7 \;\; solution\ is\ basic \;,\; but\ when \;\; pH < 7 \;\; solution\ is\ acidic$$

- Buffer Solution

  It is a solution that resists changes in pH when acid is added or solution is diluted , and it also resists a change in pOH when base is added and solution is diluted.
  Dissolution of CO_2 from air in water is buffer solution

$$CO_2 + H_2O \longleftrightarrow H_2CO_3 \longleftrightarrow H^+ + HCO_3^- \longleftrightarrow 2H^+ + CO_3^{-2}$$

$$Where \;\; H_2CO_3 \; is \; carbonic \; acid \; ; HCO_3^- \; is \; bicarbonate \; ion \; ; CO_3^{-2} \; is \; carbonate \; ion$$

- Alkalinity:

  It is defined as the titratable bases down to $pH = 4.5$ and found experimentally by determining how much acid it takes to lower the pH of water to 4.5.

$$Alkalanity = [HCO_3^-] + 2[CO_3^{-2}] + [OH^-] - [H^+]$$

At

$$6 < pH < 8 \qquad Alkalanity = [HCO_3^-] + 2[CO_3^{-2}]$$

$$4.5 > pH \qquad Alkalanity = negative\ \ due\ \ to\ \ H^+$$

$$7.5 < pH < 8.3 \qquad Alkalanity = [HCO_3^-]$$

$$pH > 11.5 \qquad Alkalanity = 2[CO_3^{-2}] + [OH^-]$$

$$mg/L\ \ as\ \ CaCO_3 = (mg/L\ \ as\ species) \times \frac{EW_{\ CaCO_3}}{EW_{\ species}}$$

- Hardness

  1- Permanent Hardness (Non Carbonate Hardness) is the sum of Calcium and magnesium ions expressed in mg/L as $Ca\ CO_3$
  2- Temporary Hardness is Carbonate Hardness which is removed by heating.
  3- Total Hardness is Carbonate and Non Carbonate Hardness.
  4- When all Hardness is Carbonate then $Hardness = Alkalanity$
  5- Non Carbonate Hardness is Total Hardness in excess of alkalinity
  6- When Alkalinity is equal or greater than Total Hardness, then there is no Non Carbonate Hardness.

- Rate and Order of Reaction
  Let reaction is $a\,A + b\,B \rightarrow c\,C$
  Then rate of reaction of A and B and production of C are $r_A\,;\,r_B\ \mathit{and}\ r_C$
  where
  $$r_A = -\frac{d[A]}{dt} \quad ; \quad r_B = -\frac{d[B]}{dt} \quad ; \quad r_C = \frac{d[C]}{dt} \quad \mathit{and} \quad \frac{r_A}{a} = \frac{r_B}{b} = \frac{r_C}{c}$$
  and $r_A = -k[A]^{\alpha}\,[B]^{\beta}$ the order of reaction of A is $n = \alpha + \beta$

- The Quality of Water
  The water should satisfy the limits of contaminant based on water acts.
  Water Quality according to American water works:

Component	Al	Cu	Fe	Mn	Zn	Hardness	TSS
Content (mg/L) <	0.05	0.2	0.05	0.01	1	80	200

Turbidity	Color	Odor	Taste
< 0.1 TU	< 3 Color Unit	None	None

- Comparison between groundwater and surface water:

	Groundwater	Surface water
1	Constant Composition	Varying Composition
2	High Minerals	Low Minerals
3	Little Turbidity	High Turbidity
4	Low and no Color	Color ; Taste and Odors
5	Bacteriologically Safe	Microorganism Present
6	No dissolved Oxygen	Dissolved Oxygen
7	High Hardness	Low Hardness
8	H_2S ; Fe ; Mn	Possible Chemical Toxity

- Water Treatment:
  1- Filtration Plant is used to treat surface water.
  2- Softening Plant is used to treat groundwater.

- Water Filtration Plant
  Chart Units (Fig 3-5):
  1- Screen 2- Rapid Mix 3- Flocculation Basin 4- Sedimentation Basin 5- Rapid Sand Filter 6- Disinfection 7- Storage 8- Pump

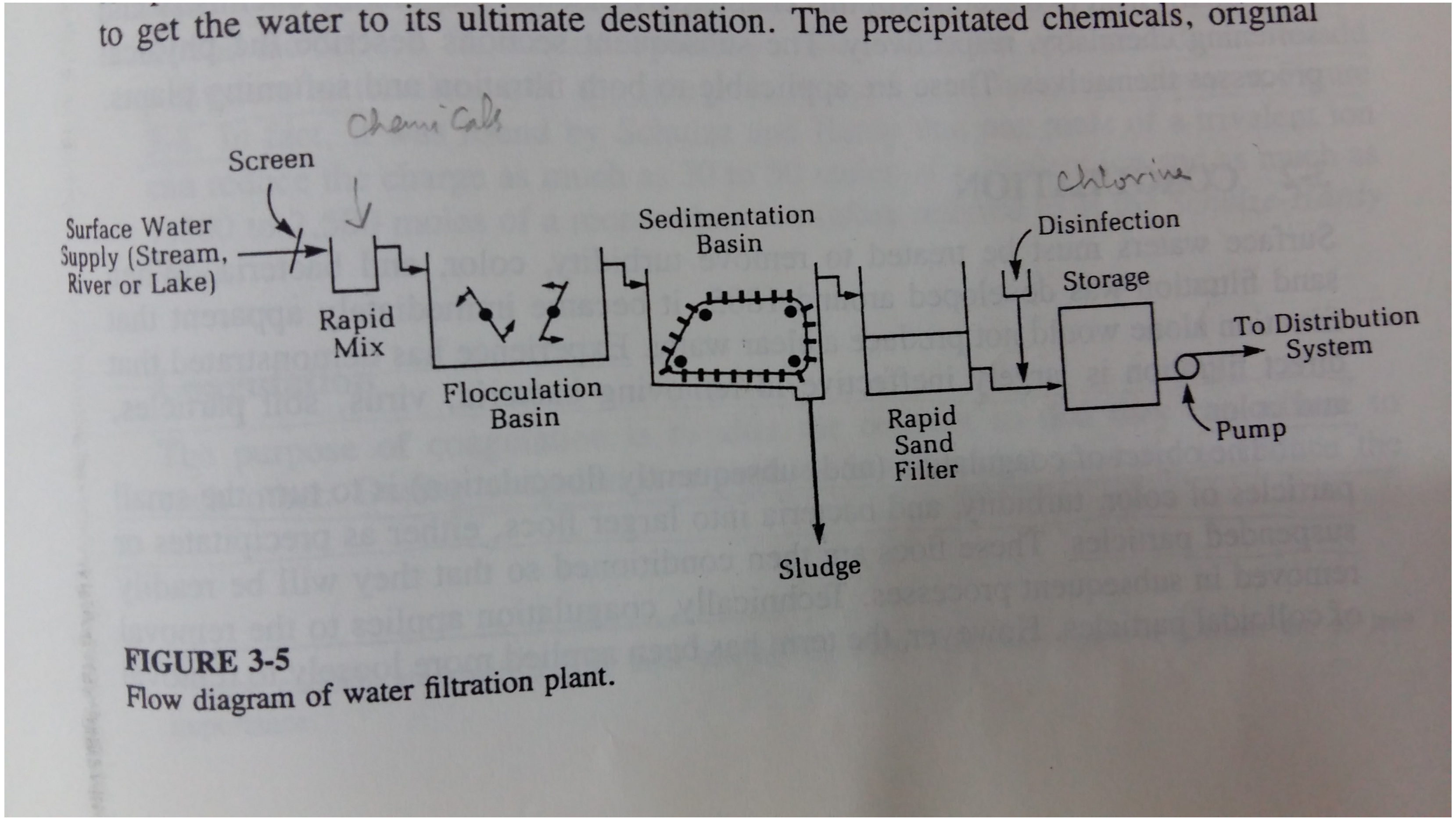
to get the water to its ultimate destination. The precipitated chemicals, original

FIGURE 3-5
Flow diagram of water filtration plant.

- Water Softening Plant
  Chart Units (Fig 3-6):
  1- Rapid Mix 2- Reaction Basin 4- Settling Tank 5- Recarbonation 6- Rapid Sand Filter 7- Disinfection 8- Pump 9- Storage

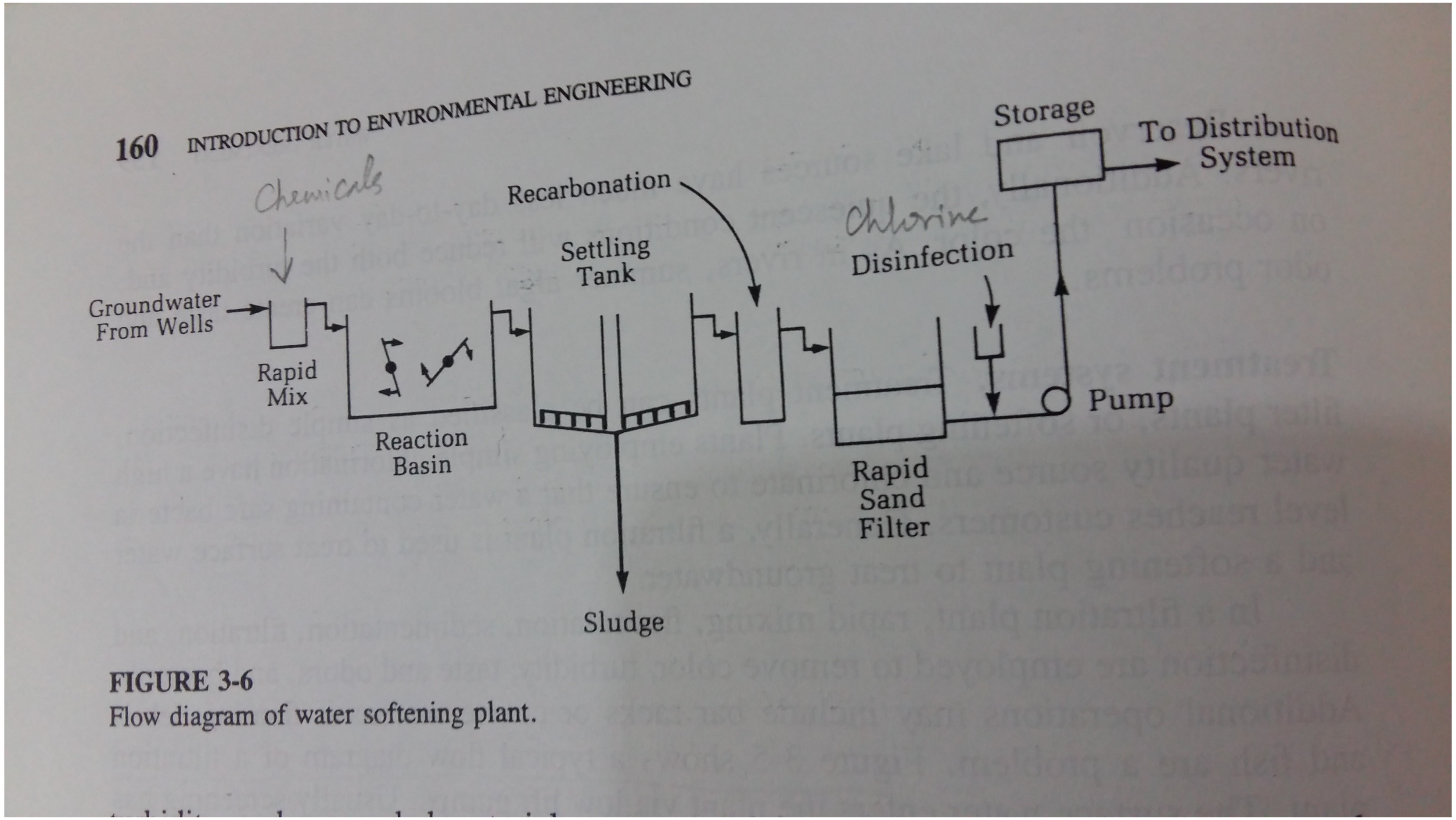

FIGURE 3-6
Flow diagram of water softening plant.

Water Quality Management

- Water Pollutants:
  1- Nonpoint sources: such as agriculture runoff.
  2- Oxygen demanding materials which are materials that can be oxidized consuming dissolved oxygen. They are biodegradable organic matter and some inorganic compounds.
  3- Nutrients: are nitrogen and phosphorus materials, where all living things require them for growth.
  4- Pathogenic Organism: microorganisms in water include bacteria, viruses, and protozoa exerted by diseased persons and animals.
  5- Suspended solids: organic and inorganic particles in water.
  6- Salts: dissolved salts from nature and from industry.
  7- Toxic metals and Toxic organic compounds: agriculture runoff contains pesticides and herbicides. Urban runoff contains lead from automobiles exhaust and zinc from wire tire. Many industrial wastes contain toxic metals and toxic organic substances.
  8- Heat: many industrial process water are hotter than receiving water. Hot water kill fish such as salmon as they usually live in cold water.

Water Tests

- **1- Electrical conductivity |Conductivity (also see salinity)**
- **2- Dissolved Oxygen(DO)**
- **3 - pH**
- **4 - Turbidity and Color of water**
- **5 - Taste and odor (gasman, 2-methylisoborneol (MIB), etc)**
- **6 - Total suspended solids (TSS)**
- **7 - Dissolved metals and salts (sodium, chloride, potassium, calcium, manganese, magnesium)**
- **8 - Chemical oxygen demand (COD)**
- **9 - Biochemical oxygen demand (BOD)**
- **10 - Microorganisms such as fecal coliform bacteria (*Escherichia coli*), Cryptosporidium, and Giardia lamblia**
- **11 - Nutrients, such as nitrogen and phosphorus**
- **12 - Dissolved metals and metalloids (lead, mercury, arsenic, etc.)**
- **13 - Dissolved organics: Colored Dissolved Organic Matter (CDOM), Dissolved Organic Carbon (DOC)**
- **14 - Temperature**
- **15 - Pesticides**
- **16 - Heavy Metals**
- **17 - Pharmaceuticals**
- **18 - Hormone analogs**

Biochemical Oxygen Demand

- Biochemical Oxygen demand:
  1- The best method to measure the quantity of organic oxygen demanding material is the biochemical oxygen demand (BOD).
  2- This test is based on the biodegradable organic matter contained in water sample that will be oxidized to CO_2 and H_2O by microorganism using molecular oxygen.

  3- An example is the reaction of glucose

$$C_6 H_{12} O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$$

  The theoretical BOD would then be

$$BOD = \frac{Grams\ of\ Oxygen\ used}{Grams\ of\ Carbon\ oxidized} = \frac{6 \times 32}{6 \times 12} = \frac{192}{72} = 2.67\ gm/gm\,Carbon$$

  4- With time t , the oxygen consumed/needed in water or the BOD_t will increase, while the oxygen remained in water will decrease.
  5- Here t is time with days; when $t = 5\ days$, then we have BOD_5 .

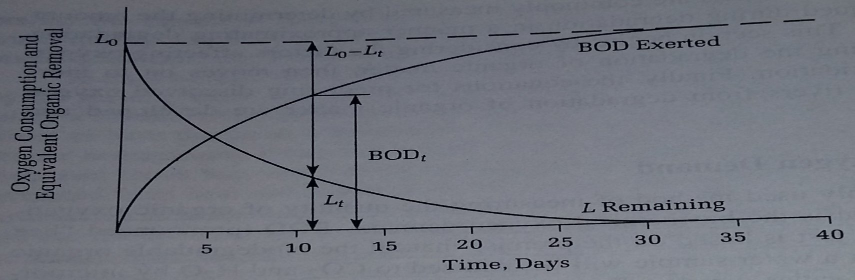

FIGURE 4-1
BOD and oxygen-equivalent relationships.

test. It is generally assumed that the rate at which oxygen is consumed is directly proportional to the concentration of degradable organic matter remaining at any time. As a result, the BOD curve in Figure 4-1 can be described mathematically as a first order reaction. Using our definition of reaction rate and reaction order from Chapter 3, this may be expressed as:

$$\frac{dL_t}{dt} = -r_A \tag{4-1}$$

where

Equal

L_t = oxygen equivalent of the organics remaining at time t, mg/L

$-r_A = -kL_t$

k = reaction rate constant, d^{-1} = BOD rate Const

Rearranging Equation 4-1 and integrating yields:

$$\frac{dL_t}{L_t} = -k\ dt$$

$$\int_{L_0}^{L} \frac{dL_t}{L_t} = -k \int_0^t dt$$

Wastewater Concept

- Types of Wastewater:
  1- Municipal wastewater   2- Industrial Wastewater

Wastewater Microbiology

- Role of Microorganism:
  1- The microorganism are used to convert the colloidal and dissolved carbonaceous organic matter into various gases and into cell tissue.
  2- The cell tissue has a specific gravity slighter greater than that of water, resulting in the removal of resulted tissue from the treated liquid by gravity settling.

$$\text{Colloidal and dissolved carbonic organic matter} + \text{Microorganism} \longrightarrow \mathit{Gases} \uparrow + \mathit{Cell\ Tissue}$$

- Classification of microorganism

1- By kingdoms: animals ; plants ; Protista

2- By energy and carbon source
- Heterotrophic: it uses organic material to supply carbon
- Autotrophs: requires CO_2 to supply carbon.
- Phototrophs: rely only on sun for energy
- Chemotrophs: extract energy from organic or inorganic oxidation-reduction reactions
- Organotrophs: use organic materials
- Lithotrophs: oxidize inorganic compounds.

3- By their relationship to oxygen
- They have an ability to utilize oxygen as a terminal acceptor in oxidation-reduction reactions such as (Obligate aerobes). Whiloxygene (obligate anaerobes) can not survive in present of oxygen and can not use oxygen as a terminal electron acceptor.

4- By their preferred temperature regime. Four temperature ranges are used to classify bacteria:
- at 20C is psychrophiles
- at (25-40) is mesophiles
- at (45-60) is thermophiles
- above 60 is stenothermophiles.

- Some Microbes of Interest in Wastewater

  1- Bacteria: They are single celled protists. they use soluble food.

  2- Fungi: They are multicellular, non-photosynthetic, heterotrophic protist. They are obligate aerobes that reproduce by a variety of methods including fission, budding, and spore formation.

  3- Algae: They are photoautotrophs either be unicellular or multicellular. They contain chlorophyll and produce oxygen greater than respiration. They use CO_2 and light.

  4- Protozoa: They are single-celled animals that produce by binary fission. Most are aerobic chemoheterotrophs. They often consume bacteria.

  5- Rotifers and crustacean: Both are aerobic, multicellular chemoheterotrophs.

- Bacterial Biology

  Metabolism:
  It describes all chemical activities performed by cell. It is divided into Catabolism and Anabolism (Fig 5-2).

  1- Catabolism: includes all biological processes by which substrate (waste) is degraded to end product with release of energy.

  2- Anabolism: includes all biological processes by which the bacterium (raw material) synthesizes new cells.

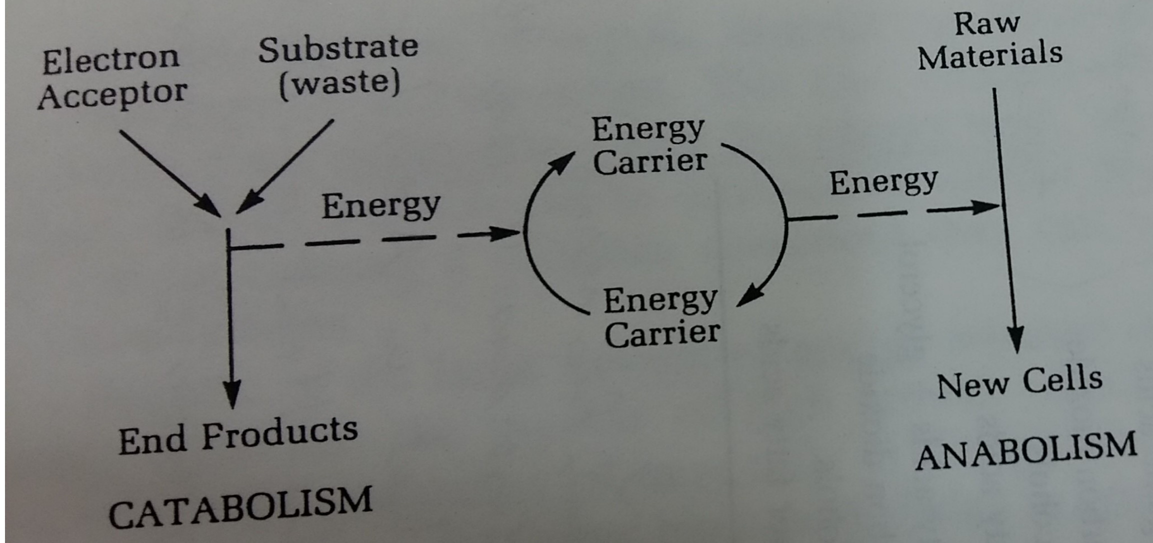

FIGURE 5-2
General scheme of bacterial metabolism.

except in underloaded lagoons. Their presence is indicative of a high level of dissolved oxygen and a very low level of organic matter.

Bacterial Biochemistry

- Decomposition of waste:

  Wastewater End Products

  1- Aerobic decomposition (Table 5-1):

  Bacterial metabolism occurs with presence of oxygen as the terminal electron acceptor to proceed by aerobic oxidation. See Table 5-1. The end product is

$$\boxed{End\ \mathrm{Pr}oduct = CO_2 + H_2O + L\mathrm{arg}e\,New\ Cell\ due\ to\ high\ released\,Energy}$$

  Because the large amount of energy is released, most aerobic organism are capable of high growth rate resulting in large production of new cells in comparison with other oxidation systems. $BOD_5 < 500\ mg/L$

  Aerobic decomposition is the method of choice for large quantities of dilute wastewater because decomposition is rapid, efficient, and has low odor.

  For high strength of wastewater ($BOD_5 > 1000\ mg/L$) , aerobic decomposition is not suitable because of difficulty of supplying enough oxygen and of large biological sludge that is produced.

2- Anaerobic decomposition (Table 5-1):

To maintain anaerobic decomposition (fermentation), molecular oxygen (O_2) and nitrogen (N_2) must be present as terminal electron acceptors. Sulfate (SO_4^{-2}) ,(CO_2) and organic compounds can be reduced and serve as terminal electron acceptors. It occurs in two steps:

- In the first, the complex organic compounds are fermented into low molecular weight fatty acid (volatile) acid.
- In the second, the organic acids are converted to methane.

Anaerobic decomposition yields CO_2 , CH_4 , water, Ammonia NH_3 , H_2S and low production of cells due to the small amounts of energy produced.

$$\boxed{End\ \mathrm{Pr}oduct = CO_2 + CH_4 + H_2O + NH_3 + H_2S + Low\,New\ Cells\,due\ to\,low\ released\ Energy}$$

3- Anoxic decomposition (Table 5-1):
Some microorganism will use nitrate (NO_3) as the terminal electron acceptor in the absence of molecular oxygen (O_2). Oxidation here is called denitrification.

The end products from denitrification are nitrogen gas, carbon dioxide, water, and new cell material.

$$\boxed{End\ \text{Product} = N_2 + CO_2 + H_2O + \text{Large}\ New\ Cells\ due\ to\ high\ released\ \ Energy}$$

The amount of energy made available to the cell during denitrification is about the same as that made available during aerobic decomposition. As a sequence, the production of cell, although as not high as in aerobic decomposition, is relatively high.

Denitrification is important in wastewater treatment where nitrogen N_2 must be removed. Here a special treatment unit is added to the treatment process for the removal of carbonaceous material.

TABLE 5-1
Waste decomposition end products

Substrates	Representative end products		
	Aerobic decomposition	**Anoxic decomposition**	**Anaerobic decomposition**
Proteins and other organic nitrogen compounds	Amino acids Ammonia → nitrites → nitrates Alcohols, Organic acids } → $CO_2 + H_2O$ + new Cells	Amino acids Nitrates → nitrites → N_2 Alcohols, Organic acids } → $CO_2 + H_2O$ + new Cells	Amino acids Ammonia Hydrogen sulfide Methane Carbon dioxide Alcohols Organic acids
Carbohydrates	Alcohols, Fatty acids } → $CO_2 + H_2O$	Alcohols, Fatty acids } → $CO_2 + H_2O$	Carbon dioxide Alcohols Fatty acids
Fats and related substances	Fatty acids + glycerol Alcohols, Lower fatty acids } → $CO_2 + H_2O$	Fatty acids + glycerol Alcohols, Lower fatty acids } → $CO_2 + H_2O$	Fatty acids + glycerol Carbon dioxide Alcohols Lower fatty acids

reduced compds + new Cell

Source: After Pelczar and Reid, *Microbiology*, New York: McGraw-Hill, 1958.