ENVIRONMENTAL ENGINEERING

Chapter 3 : Water Treatment (Part 1)

Physical, Chemical & Biological Processes

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Chapter Description

- Topic
  - Physical process
  - Chemical process
  - Biochemical process

- Topic Outcomes
  - State the principles and unit operation involves in physical, chemical and biochemical processes in the treatment.
  - Discuss the unit operation involves in the process

- References

  - Peavy, H.S., Rowe, D.R. and Tchobanoglous, G., Environmental Engineering, McGraw Hill, 1985.
  - Mackenze, I.D., Introduction to Environmental Engineering, 4th Edition, Davis A. Cornell, Mc Graw Hill, 2008.
  - Sawyer, C.N. Chemistry for Environmental Engineerin. 4th Edition, McGraw Hill, 1994.
  - Martin, T.A. and David, W.H. Fundamental of Environmental Engineering. 2003.
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Contents

1. Physical Processes

- Dilution
- Sedimentation & Resuspension
- Filtration
- Gas Transfer
- Heat Transfer

2. Chemical Processes

- Chemical Conversion

PART 1

3. Biochemical Processes

- Metabolic processes
- Microorganism in natural water system
- Dissolved oxygen balance
- Organic discharge & stream ecology

Water Purification Processes in Natural System

- Pollutants always present in surface water.
- **Waterborne diseases** – need to increase public water system treatment.
- Access to safe and adequate drinking water is fundamental right of all people.
- **Potable water –** water that can be consumed in any desired amount without concern for adverse health effects, not necessarily taste good.
- **Palatable water** – pleasing to drink but not necessarily safe.
- Natural purification processes were able to remove or render the materials harmless.

PHYSICAL PROCESSES

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1-Dilution

- Most economical means and good engineering practice.
- "the solution to pollution is dilution".
- Mixing zone concepts-lateral, vertical, and longitudinal dispersion characteristic of receiving water.
- Formula predicting space & time requirement for diluting certain pollutants to preselected concentration were developed.
- Aim: discharge small quantities of waste into large sizes of water.
- Standard maximum loads-results violation of in-stream water quality standard, dilution capacity is considered.

- Dilution capacity (mass balance):

$$C_sQ_s + C_wQ_w = Q_mC_m$$

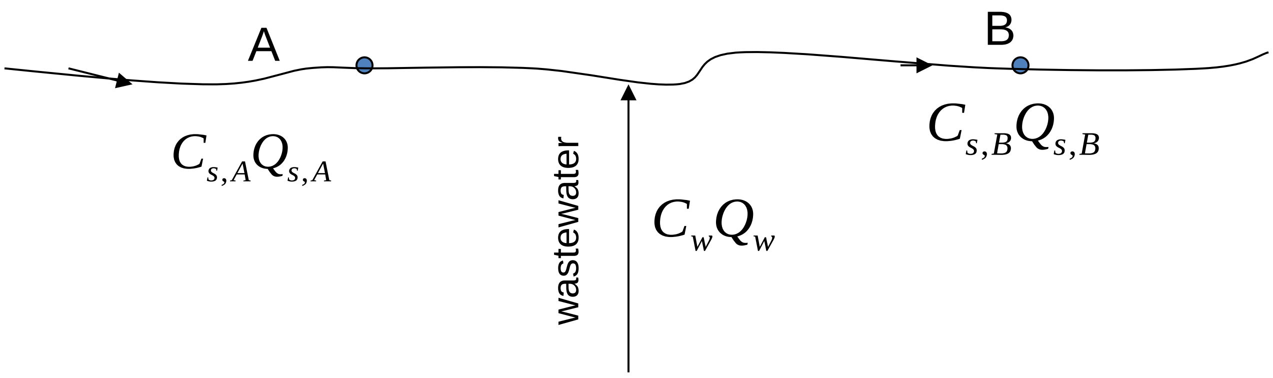
Where;

- C : concentration (mass/volume),
- Q: volumetric flow rate (volume/time),
- s: stream,
- w: waste,
- m: mixture

Example 1

Example 3-1: Measuring dilution in streams.

A treated wastewater enters a stream as shown in the figure. The concentration of sodium in the stream at point A is 10 mg/L, and the flow rate is 20m^3/s. the concentration of sodium in the waste stream is 250 mg/L and the flow rate is 1.5 m^3/s. Determine concentration of sodium at point B assuming complete mixing occurred.



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Mass balance between points A and B:

$$mass\ in = mass\ out$$

$$C_{s,B}\, Q_{s,B} = C_{s,A}\, Q_{s,A} + C_w\, Q_w$$

Since $Q_{s,B}$ is the sum of the other two flows:

$$C_{s,B} = \frac{C_{s,A}\, Q_{s,A} + C_w\, Q_w}{Q_{s,A} + Q_w}$$

$$C_{s,B} = \frac{(10 \times 20) + (250 \times 1.5)}{20 + 1.5}$$

$$\mathbf{C_{s,B} = 26.7\ mg/L}$$

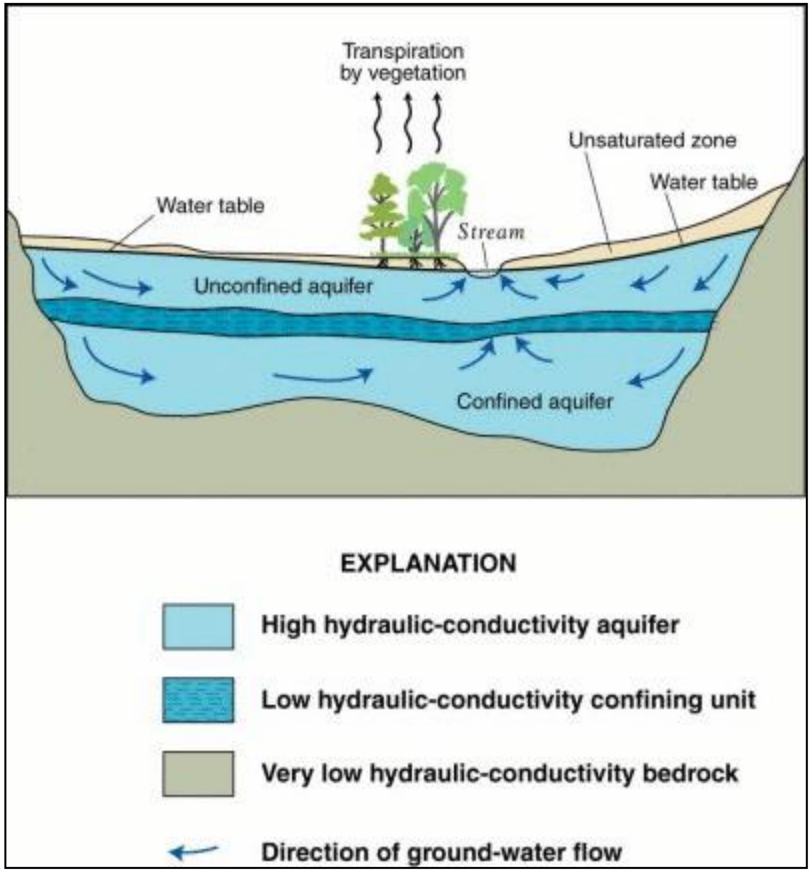
2-Sedimentation & Resuspension

- Suspended solids – organic or inorganic material
  - ❑ Can be found from domestic, industrial, agricultural, urban *etc.*
  - ❑ May vary in size, from large to tiny particles
- *Sedimentation* (settling out)- nature's method of removing suspended particles from watercourse-large particles will settle.
- Colloidal particles take periods of time but will eventually settle down.
- Sediment accumulation – develop banks of mud, reduce reservoir storage capacities and increase flooding.

- *Resuspension* – common during flooding/heavy runoff
- In such cases, increased turbulence may resuspend solids formerly deposited and carry them for considerable distance downstream
- They normally settle out again before affecting the turbidity.

3-Filtration

- Debris (that washed along streambed)-will lodge on reeds or stone
- Small organic/inorganic clays filtered by pebbles or rocks (along the streambed).
- Water percolates from surface downward to groundwater aquifer, filtered through soil layers: deep & fine enough for removal of the suspended material by the time water enters the aquifer.



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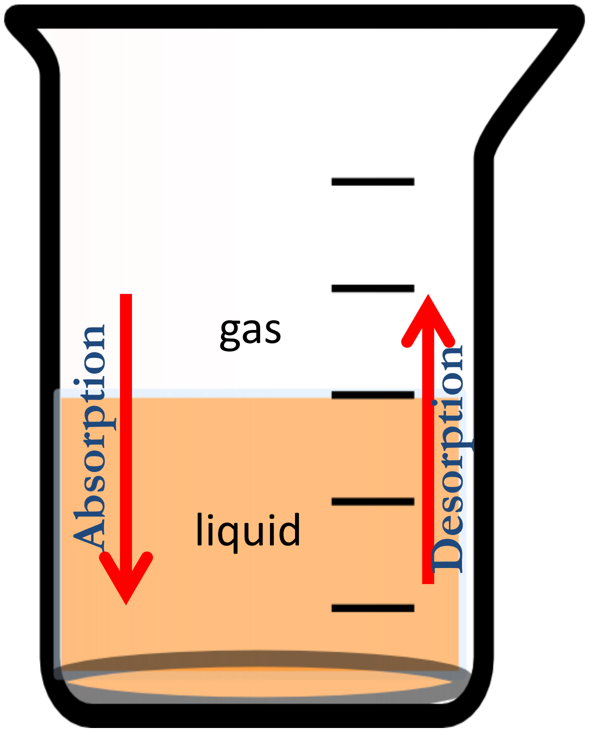
4-Gas Transfer

- Oxygen lost (bacterial degradation or organic waste).
- Oxygen refilled (from air into water).
- Number of molecules leaving the liquid is equal to number of molecules entering it – liquid saturated with gas (until reach a state of equilibrium)
- Characteristics:
  a) **Solubility :** the extent in which the gas is soluble in water
  b) **Transfer rate:** the rate at which dissolution or release occurs.



(a) Solubility

- Concentration of gas at water equilibrium.
- Henry's Law:
- Where:

$$x = \frac{P}{H}$$

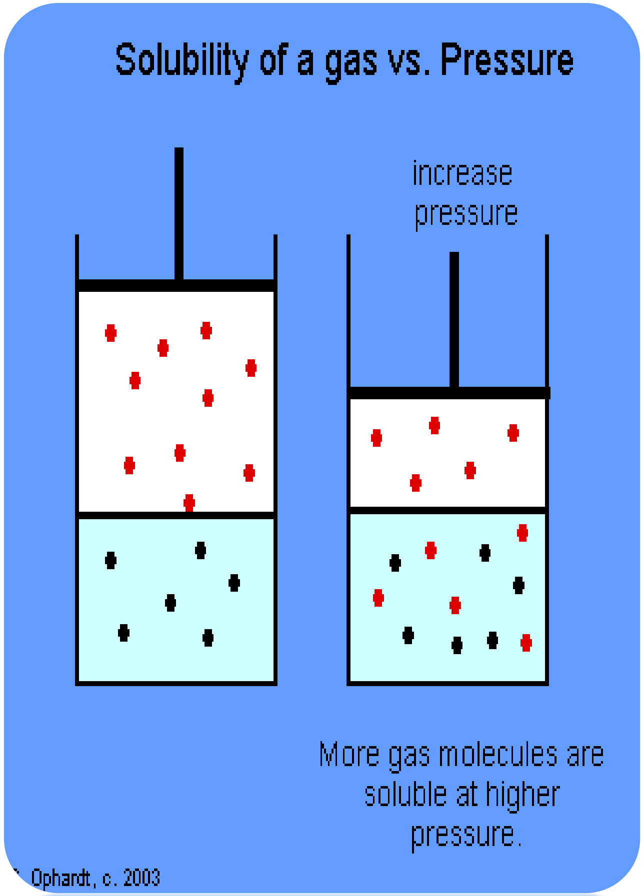
P= pressure of the gas above the liquid

H= Henry's coefficient

x = equilibrium mole fraction of dissolved gas at 1 atm

- Solubility is affected by temperature (solubility increase as temperature decrease) and concentration of other dissolved gases or solids (solubility decrease as other dissolved material in the liquid increases)

$$x = \frac{moles\ of\ gas(n_g)}{moles\ of\ gas(n_g) + moles\ of\ liquid\ (n_l)}$$



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- If the space above the liquid is occupied by a mixture of gases, each gas will have its own equilibrium mole fraction.
- Dalton's law:

$$PV = (p_1 + p_2 + p_3 + \cdots + p_n)V \quad \text{or} \quad P = \sum p_i$$

- Substituting into Henry's law:

$$x_i = \frac{p_i}{H_i}$$

$x_i = the\ equilibrium\ mole\ fraction$

$H_i = absorption\ coefficient$

$p_i = partial\ pressure\ of\ the\ ith\ gas$

Example 2

Example 3-2: Calculating the solubility of air in water.

Calculate the solubility of air in water at 0 °C and 1 atm pressure. Assume other dissolved material is negligible.

Table C-2 Henry's law coefficients for several gases that are slightly soluble in water

	H x 10^4 atm							
T, °C	Air	CO_2	CO	H_2	H_2S	CH_4	N_2	O_2
0	4.32	0.0728	3.52	5.79	0.0268	2.24	5.29	2.55
10	5.49	0.104	4.42	6.36	0.0367	2.97	6.68	3.27
20	6.64	0.142	5.36	6.83	0.0483	3.76	8.04	4.01
30	7.71	0.186	6.20	7.29	0.0609	4.49	9.24	4.75
40	8.70	0.233	6.96	7.51	0.0745	5.20	10.4	5.35
50	9.46	0.283	7.61	7.65	0.0884	5.77	11.3	5.88
60	10.1	0.341	8.21	7.65	0.103	6.26	12.0	6.29

Solution:

From Table C-2 in the appendix (page 693), Henry's constant for air at 0 °C is:

$H = 4.32 \times 10^4$ atm

The mole fraction of air in water is found by:

$$x_{air} = \frac{P}{H}$$

$$= \frac{1\ atm}{4.32\ x\ 10^4\ atm}$$

$$= 2.31\ x\ 10^{-5}$$

1 L of water contains:

$$\frac{1000\ g/L}{18\ g/mol} = 55.6\ mol/L$$

An
d,

$$2.31\ x\ 10^{-5} = \frac{n_g}{n_g + 55.6}$$

$$x = \frac{moles\ of\ gas(n_g)}{moles\ of\ gas(n_g) + moles\ of\ liquid(n_l)}$$

$$n_g - (2.31\ x\ 10^{-5} n_g) = 2.31\ x\ 10^{-5} x\ 55.6$$

$$n_g = 1.287\ x\ 10^{-3}\ mol/L$$

The saturation concentration (C_s) is:

$$C_s = moles\ of\ gas\ \left(\frac{mol}{L}\right) x\ molar\ mass\ of\ gas\ \left(\frac{g}{mol}\right)$$

$$C_s = 1.287\ x\ 10^{-3}\ \frac{mol}{L}\ x\ 28.9\ \frac{g}{mol}\ \ x\ 10^3\ \frac{mg}{g}$$

$$C_s = 37.2\ \frac{mg}{L}$$

The solubility of air can also be found by using its components and Dalton's law. The components of air by volume are approximately as follows:

$$N_2 = 79\ \%;\ O_2 = 21\ \%;\ CO_2 = 0.03\ \%$$

From Table C-2; H for N_2 = 5.29 x 10^4 atm;
O_2 = 2.55 x 10^4 atm;
CO_2= 0.0728 x 10^4 atm.

$$x_{N_2} = \frac{0.79}{5.29\ x\ 10^4} = 1.49\ x\ 10^{-5}$$

$$x_{N_2} - 1.49\ x\ 10^{-5}\ n_{N_2} = 1.49\ x\ 10^{-5} x\ 55.6 = 8.3\ x\ 10^{-4}\ mol/L$$

$$C_s = 8.3\ x\ 10^{-4}\ \frac{mol}{L}\ x\ 28\ \frac{g}{mol}\ x\ 10^3\ \frac{mg}{g} = 23.25\ \frac{mg}{L}$$

C_s for O_2 and CO_2 can be found similarly;
O_2 = 16.65 mg/L.
CO_2 = 0.02 mg/L.

Equilibrium concentration of air is:

$$C_t = 23.25 + 16.65 + 0.02 = 39.92\ mg/L$$

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(b) Transfer rate

- The rate at which dissolution or release occur
- Important in aeration, described as:

$$dC/dt = (C_s - C)k_a$$

Where dC/dt = rate of change of the concentration of gas in the liquid;

C_s: saturation concentration; C: actual concentration; k_a: constant

$C < C_s$ → absorption

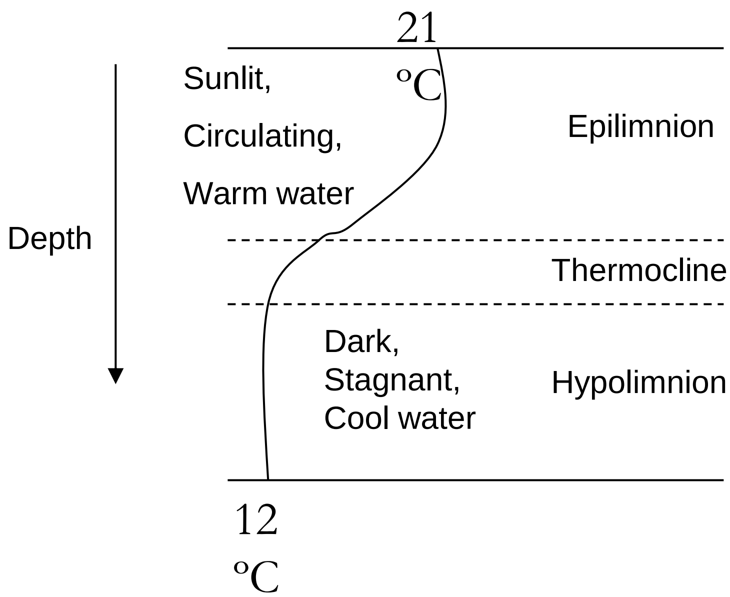
$C > C_s$ → desorption

k_a depend on:

- Temperature (the effect of T can be predicted by van't Hoff-Arrhenius rule).
- Interfacial area available for gas transfer (Larger interfacial area per given volume – greater opportunity for gas transfer).
- Resistance to movement from one phase to the other.

5 - Heat Transfer

- Increased heat tend to decrease number of species of aquatic plants and animals.
- Furthermore, increase in water temperature affect ionic strength, conductivity, solubility, corrosion potential *etc.*
- Depth, width, surface area affect the rate of heat transfer.
- In moderate zone (*e.g.* Lakes and reservoirs) – heat transfer (where the influence of turbulence and current is negligible) is controlled by phenomenon known as 'thermal stratification'.



Thermal stratification : Region of sharp thermal gradient

CHEMICAL PROCESSES

1 – Chemical Conversion

- Oxidation-reduction, dissolution-precipitation & chemical conversions.
- Natural chemical conversions- change materials (iron, manganese *etc.*) into a form that is soluble and therefore usable by various organisms.
- Chemical conversions (in lakes/streams) help to stabilize the pH of the water bodies.

$$H_2O + CO_2 \leftrightarrow H_2CO_3^*$$

$$H_2CO_3^* \leftrightarrow H^+ + HCO_3^-$$

$$CaCO_3 + H^+ \leftrightarrow Ca^{2+} + HCO_3^-$$

- For example, limestone and other forms of carbonate ($CaCO_3$) dissolve readily in water containing CO_2.
- The hydrogen ions thus formed react with slightly soluble calcium carbonate to yield highly soluble calcium and more bicarbonate ions.
- Bicarbonate then act as buffer to protect a stream from pH fluctuations that can be harmful to aquatic systems

TO BE CONTINUED…

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Credit to the author: Dr Norhanimah Hamidi

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