

ENVE 301

Environmental Engineering Unit Operations

Lecture 4

Gas Transfer - I

SPRING 2014

Assist. Prof. A. Evren Tugtas



Gas Transfer



Lecture notes from

- **Reynolds, T. D., and P. A. Richards. Unit Operations and Processes in Environmental Engineering. 2nd ed. Boston, MA: PWS Publishing Company, 1996. (Textbook)**
- American Water Works Association. Water Quality and Treatment: A handbook of community water supplies. 5th ed. McGraw Hill, 1999 ISBN: 0-0070016593

Gas Transfer

Gas is transferred from one phase to another.

Gas phase → **Liquid phase** **Absorption**

Liquid phase → **Gas phase** **Desorption**



Fig:<http://www.spartanwatertreatment.com/ozone-fine-bubble-diffusers.html>

Ömerli wtp, Courtesy of Prof.
Dr. A. M. Saatç1

Gas Transfer in Water Treatment

Systems involving gas transfer are used for variety of water treatment applications;

1. Absorption of reactive gases for water stabilization or disinfection
 - Aeration or bubble systems are used for the absorption of reactive gases (O_2 , O_3 , Cl_2)
 - Ozone is used for disinfection and oxidation of total organic carbon (TOC)
 - Chlorine is used for disinfection and sometimes preoxidant for the oxidation of Fe and Mg

Gas Transfer in Water Treatment

2. Precipitation of inorganic contaminants

- Oxygen is used for the oxidation/precipitation of iron and manganese

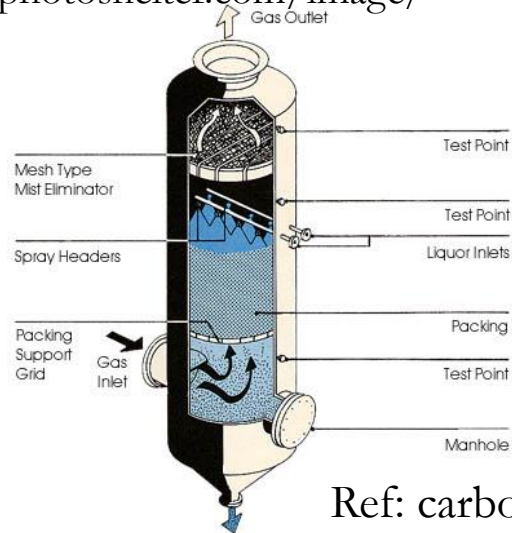
3. Air stripping of volatile organic compounds, NH_3 , CO_2 , H_2S , O_2

- Diffused-aeration systems are used for the stripping of odor causing chemicals and VOCs
- Surface aerators primarily used for VOC removal
- Packed-tower or spray nozzle systems are used for the removal of NH_3 , CO_2 , H_2S , VOCs



Ref:
<http://markduehmig.photoshelter.com/image/I0000gcq5vE3gUHk>

Ref: aqua-engg.com



Ref: carbo-tech.com

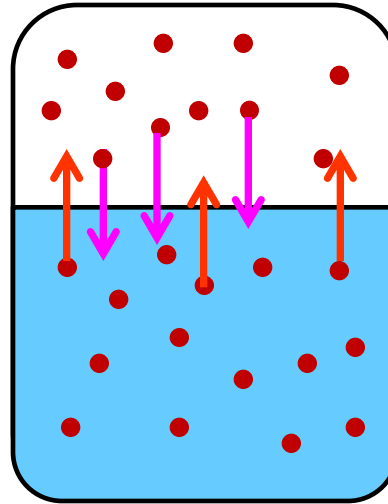
Theory of Gas Transfer

To design and operate aeration/air stripping devices understanding of;

- Equilibrium partitioning of chemicals between air and water
- Mass transfer rate across the air-water interface is required

Both equilibrium and mass transfer equations are incorporated into mass balance equations

Theory of Gas Transfer



If the system is at equilibrium;

Number of molecules leaving the system \uparrow = \downarrow Number of molecules entering the system

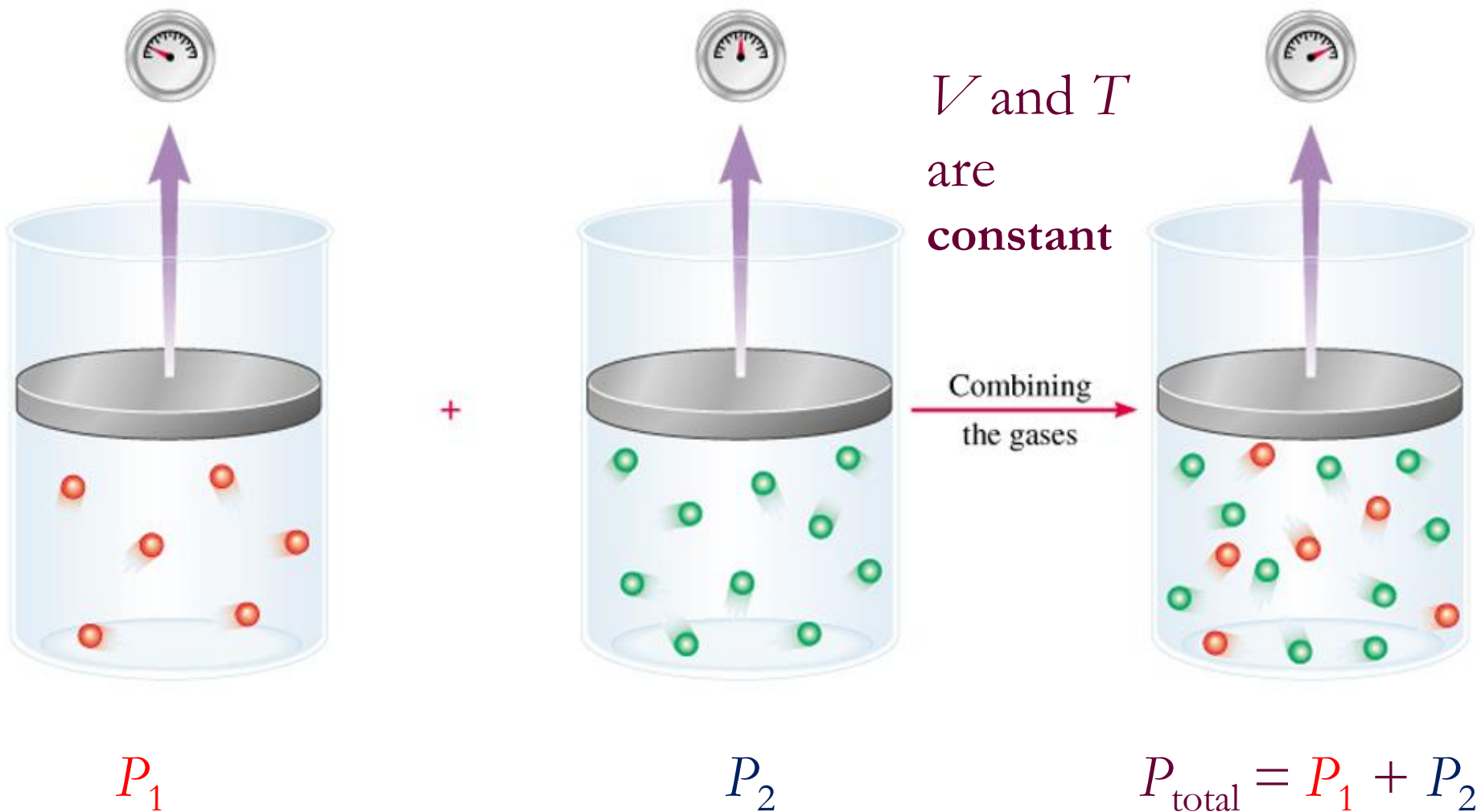
Dalton's Law of Partial Pressures

- The total pressure of a mixture of gases equals the sum of the pressures that each would exert if it were present alone.

$$P_{\text{total}} = P_1 + P_2 + P_3 + \dots$$

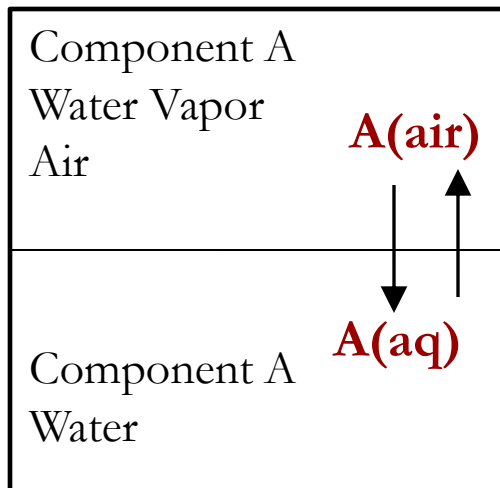
$$P_i = n_i \left(\frac{RT}{V} \right)$$

Dalton's Law of Partial Pressures



Henry's Law

- Equilibrium partitioning of a gas or organic contaminant between air and water is described by Henry's Law



A closed system

If component A is in equilibrium with both phases at constant pressure, equilibrium can be described by;

$$K_{eq} = \frac{\{A\}_{air}}{\{A\}_{aq}}$$

K_{eq} = Equilibrium constant

$\{A\}_{air}$ = activity of component in the gas phase

$\{A\}_{aq}$ = activity of component in the aqueous phase

Henry's Law

At a pressure of 1 atm, the gas behaves ideally, so the equation becomes,

$$H = K_{eq} = \frac{P_A}{\gamma[A]}$$

H: Henry's law constant (atm-L/mol)

γ : the activity of A in the aq. Phase

[A]: Molar concentration of A (mol/L)

P_A : Pressure A exerts in the gas phase (atm)

For dilute solutions (eg. Environmental eng applications
conc < 0.1 gmol/L),

$$P_A = H[A]$$

Unit of Henry's law constant is variable

Henry's Law

Factors affecting the equilibrium partitioning between air and water;

Temperature

Pressure

pH

Ionic Strength

Surfactants

Henry's Law

- H tends to increase with increasing temperature
- Aqueous solubility of components decrease as the temperature increase
- The change in H with temperature can be calculated using Van't Hoff Equation

$$H_2 = H_1 \times \exp \left[\frac{-\Delta H^\circ}{R} \left(\frac{1}{T_2} - \frac{1}{T_1} \right) \right]$$

ΔH° = Standard enthalpy change in water due to dissolution of component (kcal/kmol)

R = Universal gas constant

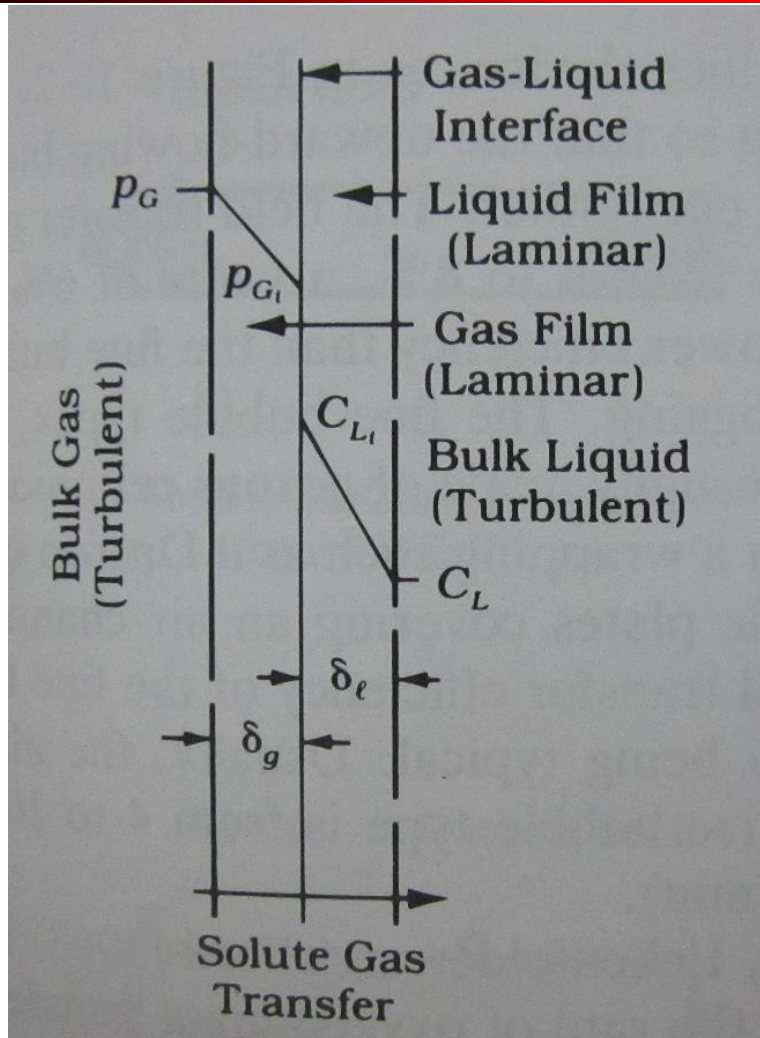
Henry's Law

- pH does not directly affect Henry's Law constant, however, it does affect the distribution of species between ionized and unionized forms
- Only unionized species are volatile
- Therefore, pH affects the overall gas-liquid distribution

Henry's Law

- Surfactants lower volatility of compounds by several mechanism
- Most important mechanism is that, surfactants tend to collect at the air-water interface
- In untreated water, solubility of oxygen can be lowered 30-50% due to the presence of surfactants

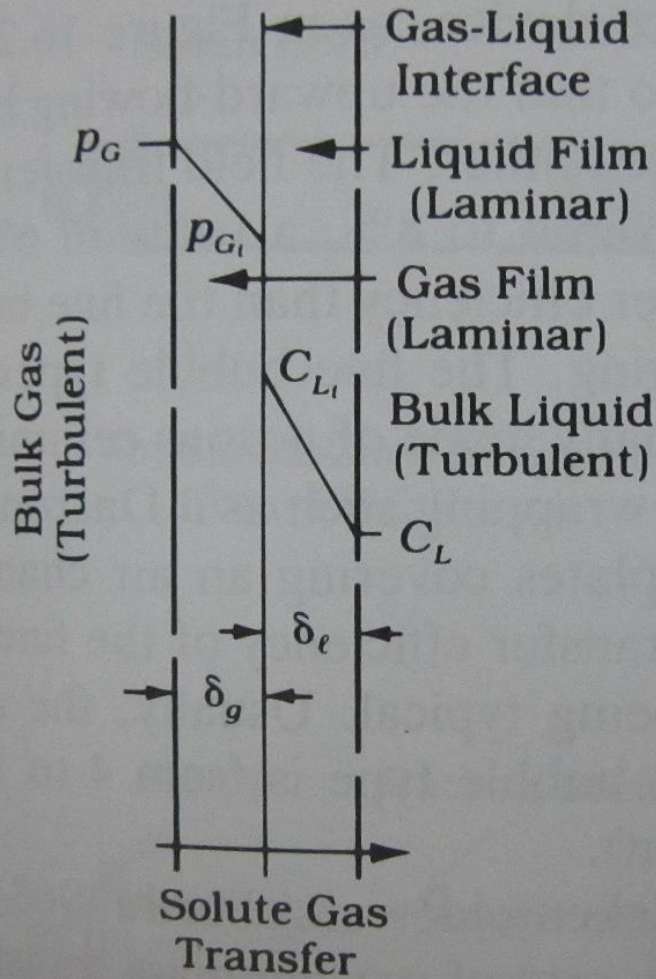
Mass Transfer



The driving force for mass transfer from one phase to another derives from the displacement of the system from equilibrium

Ref: American Water Works Association. Water Quality and Treatment: A handbook of community water supplies. 5th ed. McGraw Hill, 1999, page 499

Mass Transfer



P_G : Partial pressure of the solute gas in the bulk

P_{Gi} : Partial pressure of the solute gas at the gas interface

C_L : Concentration of the solute gas in the bulk liquid

C_{Li} : Concentration of the solute gas at the liquid interface

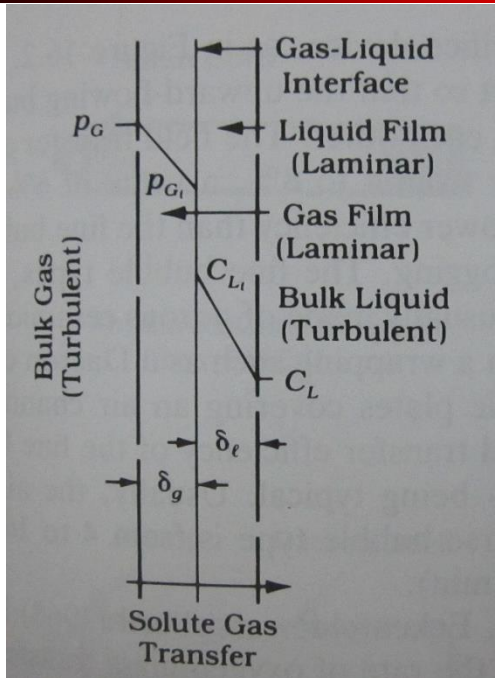
Mass Transfer

Two Film Theory

The transfer of a solute gas from a gas mixture into a liquid that is in contact with the mixture can be described by the two-film theory of Lewis and Whitman.

- For gases that are very soluble in water/liquid, the rate limiting step is the diffusion of the solute gas through the gas film (**GAS-FILM CONTROLLED**)
 - Ammonia
- For gases that are slightly soluble in water (O_2 in water), the rate limiting step is the diffusion of solute gas through the liquid film (**LIQUID FILM CONTROLLED**)
- For gases with intermediate solubility, equal resistance from both films (**MIXED FILM CONTROLLED**)

Mass Transfer



$$\frac{dC}{dt} = K_L a (C_S - C_L)$$

dC/dt : rate of oxygen transfer, mass/volume.time

K_L : diffusion transfer coefficient

a : interfacial bubble area per unit volume of water

$K_L a$: overall liquid mass transfer coefficient, time^{-1}

C_S : Saturation dissolved oxygen concentration, mass/volume

C_L : dissolved oxygen concentration in the liquid, mass/volume

$$K_L = \frac{D}{\delta_l}$$

D : Diffusivity coefficient of oxygen in water

δ_l : Film thickness

Absorption of Gas

Unsteady state gas transfer

$$\frac{dC}{dt} = K_L a (C_s - C_L)$$

$$\int_{C_0}^{C_t} \frac{-dC}{C_s - C} = K_L a \int_0^t -dt$$

$$\ln(C_s - C_t) = \ln(C_s - C_0) - K_L a t$$

Absorption of gas into a solution $C < C_s$

Desorption of Gas

Unsteady state gas transfer

$$\frac{dC}{dt} h = -K_L (C - C_S) \quad \text{h: depth of reactor}$$

$$\int_{C_0}^{C_t} \frac{dC}{C - C_S} = \frac{K_L}{h} \int_0^t -dt$$

$$\ln(C_t - C_S) = \ln(C_0 - C_S) - \frac{K_L}{h} t$$

Desorption of gas out of a solution $C > C_S$