



# **ENVE 301**

## **Environmental Engineering Unit Operations**

### **CHAPTER: 4**

### **Gas transfer**

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## Removal of constituents

Chemical and/or biological  
conversion reactions

Transfer of material from one  
homogenous phase to another

Mass transfer

### Principal applications of mass transfer operations in env. eng.:

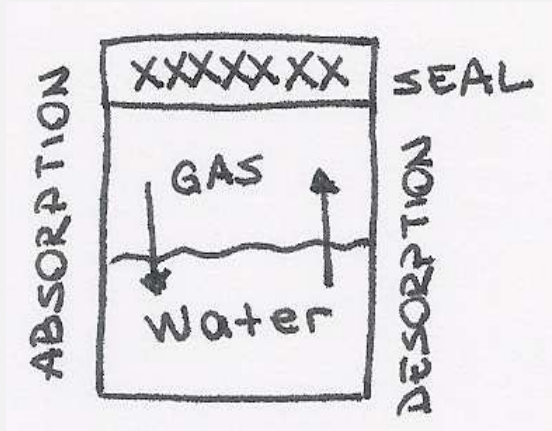
Addition of gases to water (**Absorption**) (gas  $\longrightarrow$  liquid )

Removal of organics w/activated carbon (**Adsorption**) ( liquid  $\longrightarrow$  solid ) ( gas  $\longrightarrow$  solid )

Removal of gases (gas stripping, **desorption**) ( liquid  $\longrightarrow$  gas )  
(e.g., CO<sub>2</sub>, O<sub>2</sub>, H<sub>2</sub>S, NH<sub>3</sub>, VOC)

Selective removal of chemical constituents (ion exchange) (**liquid  $\longrightarrow$  solid**)

# GAS TRANSFER



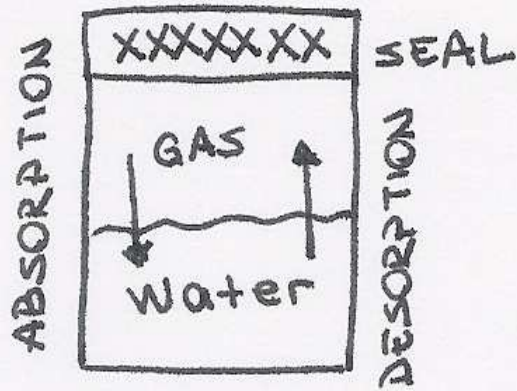
Gas transfer → process by which gas is transferred from one phase to another.

from gas phase → to liquid phase (Absorption)

from liquid phase → to gas phase (Desorption)

## Applications in environmental engineering :

- Oxygen supply in aerobic process
- Transfer of chlorine (in the gas form) into the liquid for disinfection purposes.
- Transfer of ozone into the water.
- Removal of gases dissolved in water ( $H_2S$ ,  $CH_4$ ,  $NH_3$ )



*If the liquid is initially pure with respect to the gas;*

→ Gas molecules will migrate across the gas-liquid interface and become dissolved in the liquid (ABSORPTION)

Although some molecules of gas will begin leaving the liquid and returning the gas phase, the net reaction will be toward the liquid until a state of equilibrium is reached.

@ equilibrium:

the number of molecules  
leaving the liquid

=

the number of molecules  
entering the liquid again

**Liquid is said to be SATURATED.**

*Important characteristic of this process:*

1. SOLUBILITY of gas in water
1. TRANSFER RATE (rate at which absorption or desorption occur)

## Solubility of Gas

The solubility of a gas in equilibrium with a liquid is quantified by **HENRY'S LAW**

Solubility of a gas at constant temp.  $\propto$  Partial pressure of gas in contact with liquid

### Dalton's law of partial pressure:

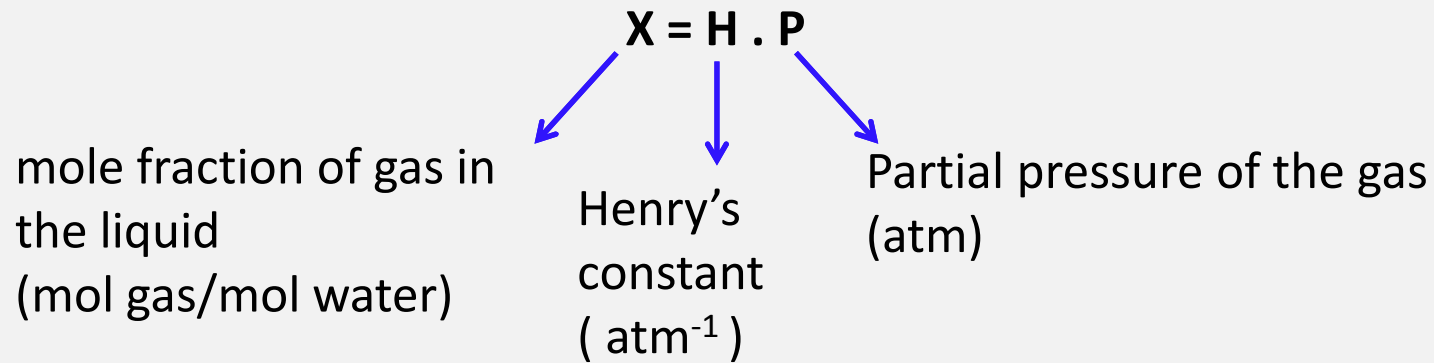
When a container is filled with a mixture of N gases, each gas exerts the same pressure as it would if it were the only gas in the vessel. The pressure of each component of the gas mixture (partial pressure) will depend solely on the number of moles of that gas present.

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

$$\therefore \underbrace{\frac{\text{Partial pressure of a gas}(P_1)}{\text{Total pressure}(P_T)}}_{\text{Mole fraction of gas}} = \frac{n_1}{n_1 + n_2 + \dots + n_N}$$

Mole fraction of gas

## HENRY'S LAW



Henry's constant → the unit of this parameter is variable (atm<sup>-1</sup>; atm/mole fraction; , mg/l/atm ...)

→ highly variable with temperature

### EXAMPLE 1:

Calculate the solubility of CO<sub>2</sub> (in air) in water at 25°C and 1atm pressure.  
(CO<sub>2</sub> in air =0,03% H=6.11.10<sup>-4</sup>atm<sup>-1</sup>)

### EXAMPLE 2:

Calculate the solubility of nitrogen (in air) in water at 0°C and 1 atm pressure.  
(N<sub>2</sub> in air =79% H= 5.29.10<sup>4</sup> $\frac{\text{atm}}{\text{mole fraction}}$  )

### EXAMPLE 3:

Calculate the solubility of O<sub>2</sub> (in air) in water at 20°C , 1atm pressure.  
(O<sub>2</sub> in air 21% H=43,3mg/L/atm )



# GAS TRANSFER RATE

The rate at which a gas transfer into solution can be described by **Fick's first law**;

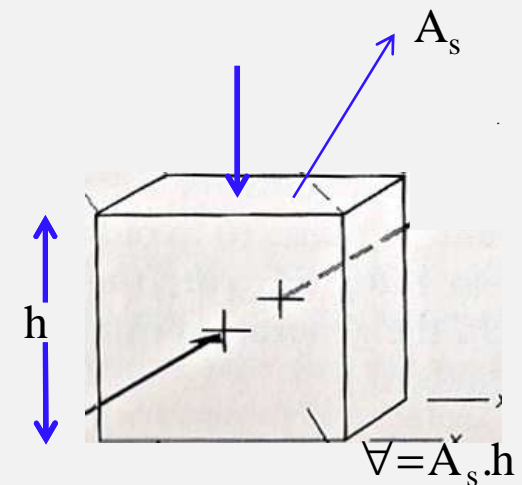
$$\frac{dc}{dt} = K L_a (C_s - C)$$

Rate of change in conc.  
of gas in solution  
mg/L.sec

Volumetric mass  
transfer coeff.  
sec<sup>-1</sup>

Actual conc. of gas  
in solution mg/L

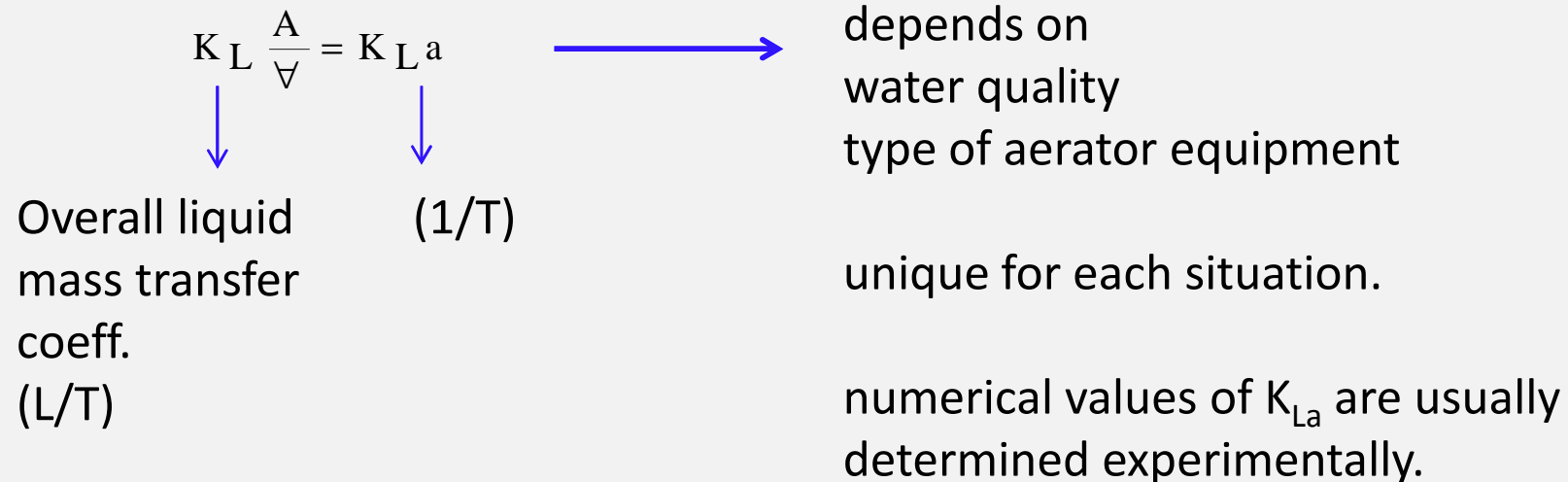
Saturation conc. of gas in  
solution.  
estimated using Henry's Law  
mg/L



$$\frac{dc}{dt} = K_L a (C_s - C)$$

Value of  $(C_s - C)$   $\rightarrow$  represents a concentration gradient.

As  $C$  approaches to  $C_s$   $\rightarrow$  transfer rate decreases.



$$\frac{dc}{dt} = K_{La} (C_s - C)$$

$$\int_{C_0}^C \frac{dc}{C_s - C} = K_{La} \int_0^t dt$$

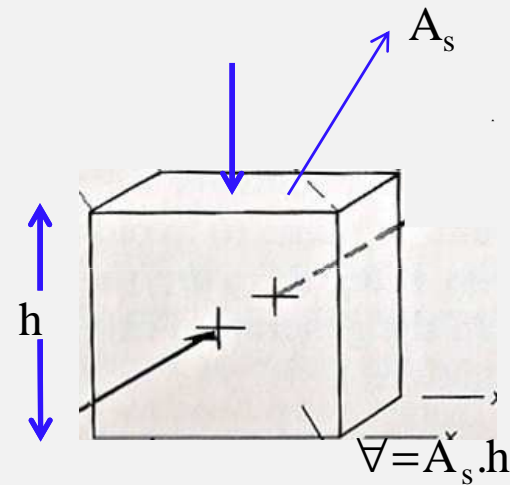
$$\left\{ \int \frac{1}{ax+b} dx = \frac{1}{a} \cdot \text{Ln}|ax+b| \right\}$$

$$-\text{Ln}(C_s - C) \Big|_{C_0}^C = K_{La} t$$

$$-\text{Ln}(C_s - C_t) + \text{Ln}(C_s - C_0) = K_{La} t$$

$$\text{Ln}(C_s - C_t) - \text{Ln}(C_s - C_0) = -K_{La} t$$

$$\text{Ln} \frac{C_s - C_t}{C_s - C_0} = -K_{La} \cdot t$$



$$\frac{C_s - C_t}{C_s - C_0} = e^{-K_{La} \cdot t}$$

ABSORPTION OF GAS INTO A SOLUTION  
(It only takes place when  $C < C_s$ )

## EXAMPLE 4 :

Dechlorinated secondary effluent is placed in a storage basin until needed for reuse. If the initial DO conc. is 1,5mg/L estimate the time required for the DO conc. to increase to 8,5mg/L due to surface re-aeration assuming the water in storage basin is circulated and not stagnant. Assume the  $K_L$  value for oxygen is equal to 0,03m/h. The surface area of the storage basin is 400m<sup>2</sup> and the depth is 0,025m. T=20°C

# DESORPTION OF GAS INTO A SOLUTION

If  $C > C_s \rightarrow$  DESORPTION OF GAS OCCURS

$$\rightarrow \frac{dc}{dt} \cdot \underbrace{A_s \cdot h}_{\forall} = 0 - 0 - rA_s$$

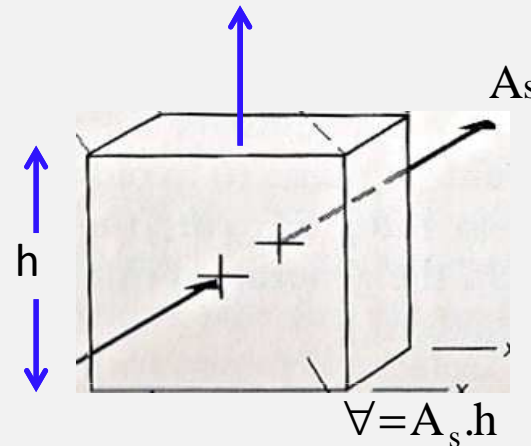
$g/m^2 \cdot \text{time}$

$$\rightarrow \frac{dc}{dt} \cdot A_s \cdot h = -K(C - C_s)A_s$$

$$\rightarrow \frac{dc}{dt} = -\frac{K}{h}(C - C_s)$$

$$\rightarrow \int_{C_0}^C \frac{dc}{C - C_s} = -\frac{K}{h} \int_0^t dt$$

$$\frac{C_t - C_s}{C_0 - C_s} = e^{-(K/h) \cdot t}$$



DESORPTION OF GAS FROM A SOLUTION  
 (If the conc. of specific volatile chemical is not common to atmosphere  $C_s \cong 0$ )

## EXAMPLE:

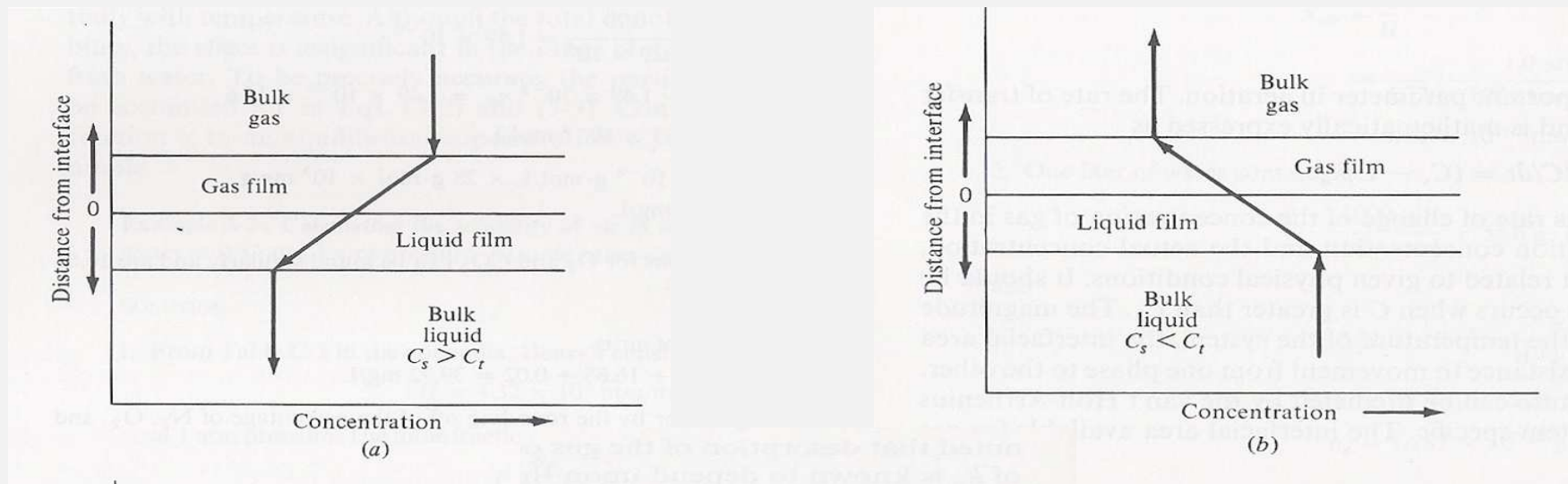
A quantity of benzene was spilled accidentally into a treated wastewater storage basin having depth of 2m. Estimate the time required for the concentration of benzene to drop out 50% from the initial concentration due to volatilization.

$K_L$  for benzene = 0,144 m/hr

# TWO FILM THEORY (Lewis – Whitman)

The resistance to movement between the phases can be explained by TWO-FILM THEORY (Lewis-Whitman)

Acc. to this theory, transfer of a gas must occur across the two films that are assumed to exist at the gas-liquid interface.



**Figure 3-2** Two-film model of the interface between gas and liquid: (a) absorption mode and (b) desorption mode.

Gases that are highly soluble in water  
(e.g. Ammonia)



Encounter more resistance in passing  
through the gas film.  
GAS-FILM CONTROLLED.

Gases that are slightly soluble in water  
(e.g. Oxygen, Nitrogen)



Encounter more resistance in passing  
through liquid film.  
LIQUID-FILM CONTROLLED.

Gases of intermediate solubility



Encounter approximately equal  
resistance through the films.  
(MIXED FILM CONTROLLED)