ENVE 301
Environmental Engineering Unit Operations

Lecture 5
Gas Transfer, Aeration II

SPRING 2014

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Gas Transfer Examples

Gas Transfer - Problems

Example 1:

Henry's law constant for oxygen at 20°C is 0.739 atm-m^3/mol). What is the solubility of oxygen at 20°C as mg/L? Calculate the O_2 amount in the atmosphere at 20°C. Assume that air is used to supply oxygen. Assume zero salinity.

- Hint: Let n_i be the number of moles of gas *i* exerting a partial pressure P_i, then $P_i = X_i P_{total}$
- where X_i is the **mole fraction** (n_i/n_t).

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Gas Transfer - Problems

Example 2:

Henry's law constant for CO_2 at 25^{o}C is 1.549e3 atm. What is the solubility of CO_2 in water? Assume 0.03% CO_2 in air.

TABLE 5.1 Unit Conversions for Henry's Law Constants

$$H\left(\frac{L_{H_2O}}{L_{Air}}\right) = \frac{H\left(\frac{L \cdot atm}{mol}\right)}{RT}$$

$$H\left(\frac{L \cdot atm}{mol}\right) = H\left(\frac{L_{H_2O}}{L_{Air}}\right) \times RT$$

$$H\left(\frac{L_{H_2O}}{L_{Air}}\right) = \frac{H(atm)}{RT \times 55.6\ \frac{mol\ H_2O}{L_{H_2O}}}$$

$$H\left(\frac{L \cdot atm}{mol}\right) = \frac{H(atm)}{55.6\ \frac{mol\ H_2O}{L_{H_2O}}}$$

$$H(atm) = H\left(\frac{L \cdot atm}{mol}\right) \times 55.6\ \frac{mol\ H_2O}{L_{H_2O}}$$

$$H(atm) = H\left(\frac{L_{H_2O}}{L_{Air}}\right) \times RT \times 55.6\ \frac{mol\ H_2O}{L_{H_2O}}$$

$$R = 0.08205\ \frac{atm \cdot L}{mol\ °K} \quad T = °K$$

Ref: American Water Works Association. Water Quality and Treatment: A handbook of community water supplies. 5th ed. McGraw Hill, 1999 ISBN: 0-0070016593

AERATION

Aeration

- Aeration in water treatment is used for;
  - Precipitation of inorganic contaminants (Fe mostly)
  - Stripping of;
    - H_2S
    - CO_2
    - Volatile Organic Compounds
- Aeration in wastewater treatment is used to;
  - Supply the required oxygen for biological treatment

Aeration Types

- Packed Tower Aeration (Removal of NH_3, CO_2, H_2S, VOCs)
- Diffused or Bubble Aeration (Stripping of odor causing chemicals)
- Surface Aeration (VOC removal)
- Spray Aeration (Removal of NH_3, CO_2, H_2S, VOCs)
- Gravity-Type Aeration (Oxidation of Fe, VOC removal)

Aeration Types
Packed Tower Aeration

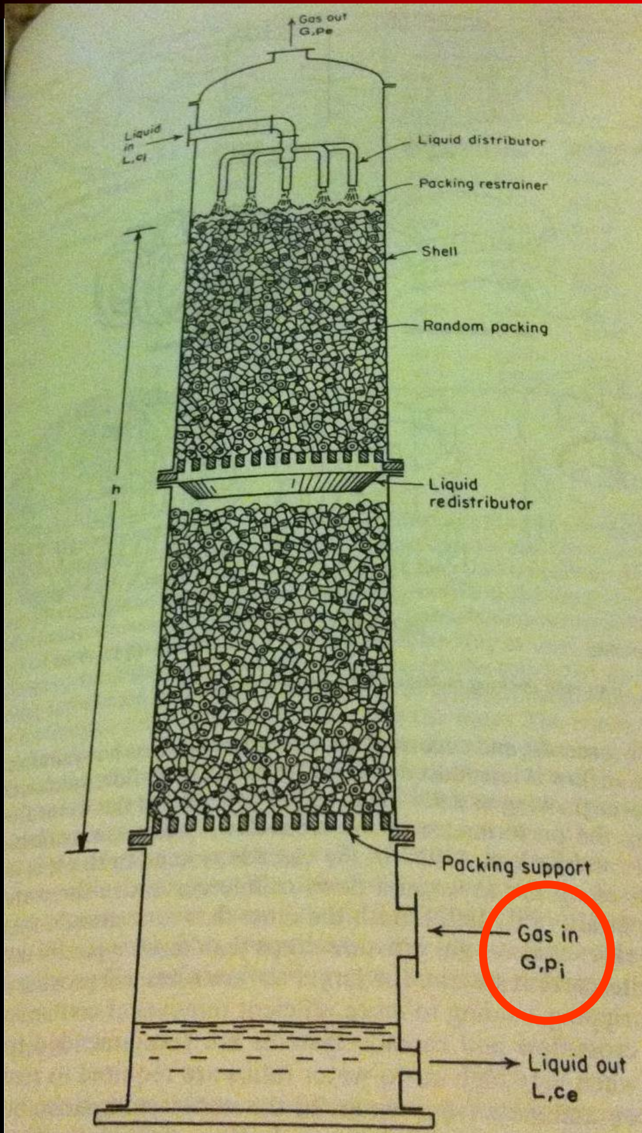


FIGURE 5.4 Schematic of a packed tower.

The primary application in water treatment are

- Stripping of VOC, CO_2, H_2S, Ammonia

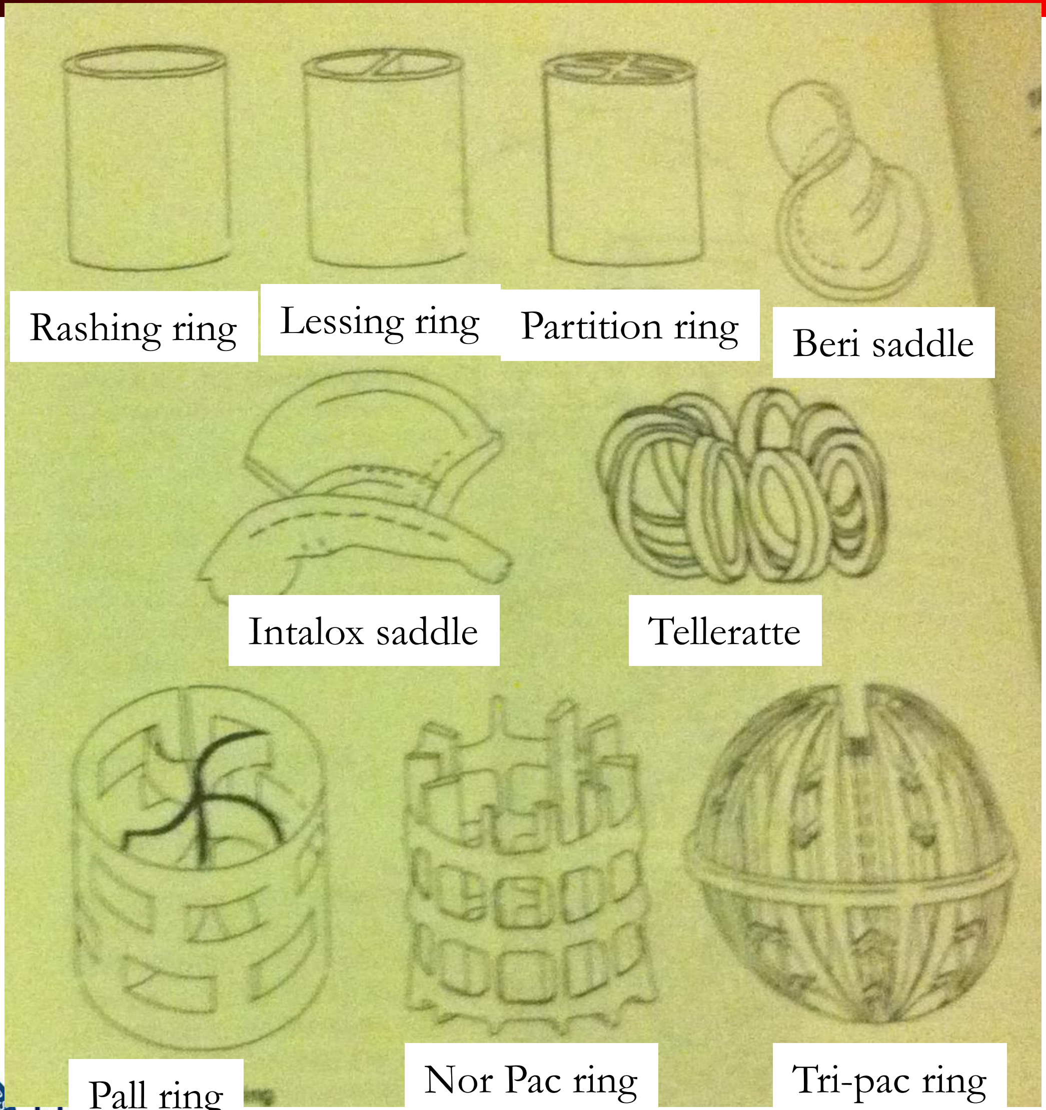
Water is pumped to the top of the tower, blower is used to introduce fresh air.

Air flow countercurrent to the water.

Air stripped water leaves from the bottom of the tower.

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

Aeration Types
Packed Tower Aeration – Packing Material



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

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Aeration Types
Diffused of Bubble Aeration

- Diffused Aeration consists of contacting gas bubbles with water for the purposes of;
  - transferring gas to the water (O_2, CO_2, O_3)
  - Removing gases from water (VOC)
- The process is carried out in reactors with 2.7-4.5 m depth
- Gas transfer is enhanced with the desing of diffusers

Aeration Types
Diffused of Bubble Aeration

- Bubble size is important in terms of gas trasfer;
  - Fine-bubble diffusers (expensive)
  - Medium-bubble diffusers
  - Coarse-bubble diffusers
- Gas transfer is proportional to size of bubbles

as the bubble gets smaller a (interfacial bubble area per unit volume of water) will get bigger

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

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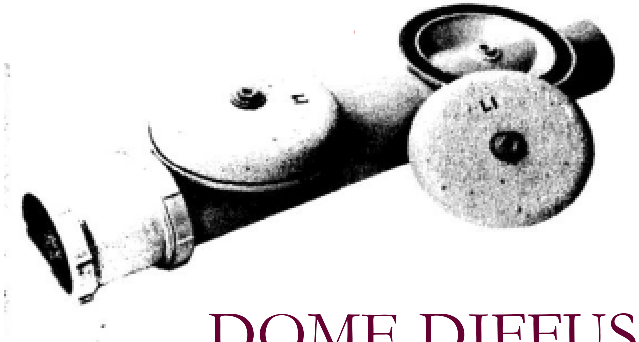
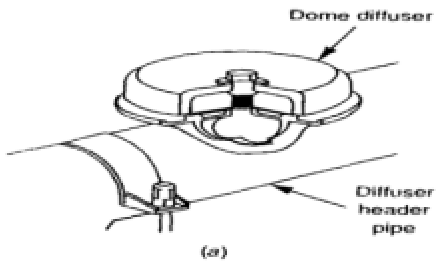
Aeration Types
Diffused of Bubble Aeration - Diffusers

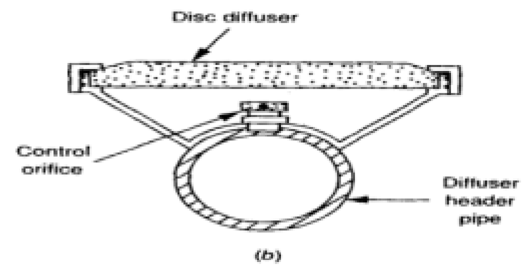
- Porous Diffusers
  - Plate-type (installed on concrete or aluminum plate holders)
  - Dome-type (mounted on manifolds)
  - Disc-type
  - Tubular type
- Non-porous Diffusers (Produce larger bubbles)
  - Fixed orifice
  - Valve Orifice
- Jet Aeration (Nozzle)

Aeration Types
Diffused of Bubble Aeration - Diffusers

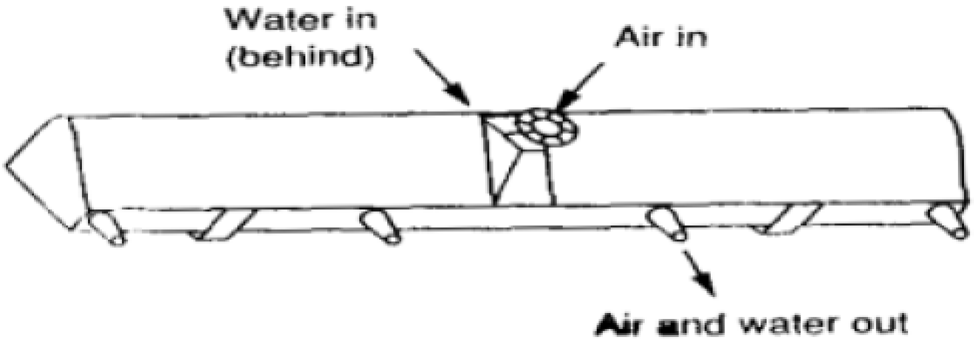




DOME DIFFUSER



DISC DIFFUSER



JET AERATOR

•Metcalf & Eddy, Inc. (2003). *Wastewater Engineering-Treatment and Reuse*, 4th ed., McGraw-Hill, New York, NY.

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Aeration Types
Diffused of Bubble Aeration - Diffusers

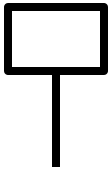
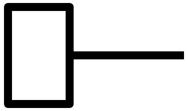
TABLE 10-6
Description of air diffusion devices[a]

Type of diffuser or device	Transfer efficiency	Description
Porous		
Plate	High	Square ceramic plates installed in fixed holders on tank floor.
Dome	High	Dome-shaped ceramic diffusers mounted on air distribution pipes near tank floor.
Disc	High	Rigid ceramic discs or flexible porous membrane mounted on air distribution pipes near tank floor.
Tube	Moderate to high	Tubular-shaped diffuser that uses rigid ceramic media or flexible plastic or synthetic rubber sheath mounted on air distribution pipes.
Nonporous		
Fixed orifice		
Perforated piping	Low	Air distribution piping with small holes drilled along the length.
Spargers	Low	Devices usually constructed of molded plastic and mounted on air distribution pipes.
Slotted tube	Low	Stainless steel tubing containing perforations and slots to provide a wide band of diffused air.
Valved orifice	Low	Device that contains a check valve to prevent backflow when air is shut off. Mounts on air distribution piping.
Static tubes	Low	Stationary vertical tube mounted on basin bottom that functions like an air lift pump.
Perforated hose	Low	Perforated hose that runs lengthwise along basin and is anchored to the floor.
Other devices		
Jet aeration	Moderate to high	Device that discharges a mixture of pumped liquid and compressed air through a nozzle assembly located near the tank bottom.
Aspirating	Low	Inclined propeller pump assembly mounted at basin surface that draws in air and discharges air/water mixture below water surface.
U-tube	High	Compressed air is discharged into the down leg of a deep vertical shaft.

•Metcalf & Eddy, Inc. (2003). *Wastewater Engineering-Treatment and Reuse*, 4th ed., McGraw-Hill, New York, NY.

Aeration Types
Surface Aeration

Ref: aqua-engg.com

- Surface aeration creates large air-water interface , therefore transfer of oxygen is enhanced.
- Surface aerators can be;
  - Vertical shaft 
  - Horizontal shaft 
- Splashing of water poses a health concern for the water treatment plant workers

Aeration Types
Spray Aeration

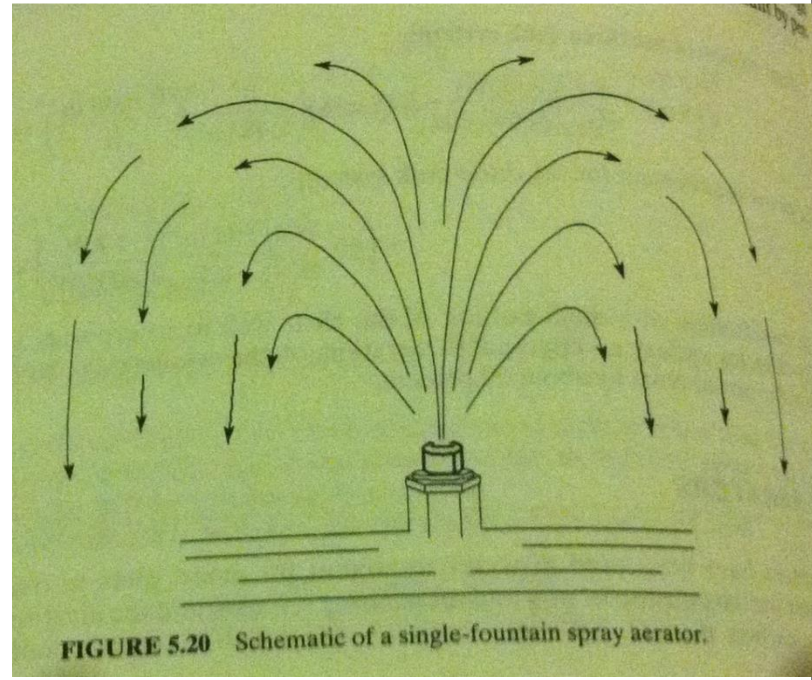
- Spray aerators have been used for many years;
  - to oxygenate groundwater for the purpose of iron/manganese removal
  - For the stripping of gases and volatile organic compounds
- Water is dispersed by means of orifices or nozzles
- Effective iron oxidation by aeration requires at least 1 h of retention time
- Manganese oxidation by aeration is very slow and not practical for waters with pH>9.5. Manganese removal requires stronger oxidant

Aeration Types
Spray Aeration

- Carbondioxide and hydrogen sulfide removals have ranged from 50 to 90% depending on the pH of the water
- VOC removals have been as high as 90%.
- Spray aeration systems consists of series of fixed nozzles on a pipe grit.
- Pressurized nozzles disperse fine water droplets into the surrounding air creating a large air-water surface for mass transfer

Aeration Types
Spray Aeration

- There are two types of pressurized spray nozzles;
- Hollow-cone (provides smaller droplets, 5mm)
- Full-cone (Uniform droplets)



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

Aeration Types
Gravity-type Aeration – Cascade Aeration

Turbulance is created due to water fall occuring due to steps

Water-air interfaces are created as a result of water fall (counter-current air-water movement)

Courtesy of Prof. Dr. A. M. Saatcı

Requires small spaces (50-200 m^2 /m^3/sec)

Not as effective as the other aeration methods

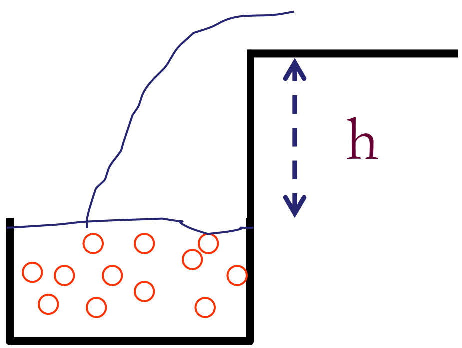
Aeration Types
Gravity-type Aeration – Cascade Aeration

There are two types of gas transfer mechanisms in cascade aeration:

- In the first mechanism, the aim is the removal of taste&odor causing dissolved gases and VOC, even chlorinated VOCs
- In the second mechanism the aim is to increase the amount of O_2 in the water.

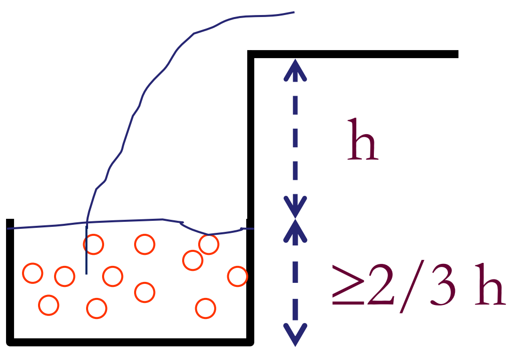
Aeration Types
Cascade Aeration – First Mechanism

$$h = \frac{1}{2} g t^2$$ freefall



$$t = \sqrt{\frac{2h}{g}}$$ t: average time of exposure of surface A to air

Aeration Types
Cascade Aeration – Second Mechanism



$$h = \frac{V^2}{2g}$$

$$V = \sqrt{2gh}$$

- When the nappe is submerged into the receiving water, significant amount of air will be entrapped
- The amount of air entrappment depends on
- Velocity of the nappe when passing the surface of tail water
- Depth of tail water

Aeration Types
Cascade Aeration – Second Mechanism

- Depth of water should be choosen to obey;

$$Velocity\ of\ water\ within\ the\ tail\ water = Velocity\ of\ rinsing\ bubbles$$

- Tail water depth should be greater than 2/3(h)
- Decreasing h → taste/odor removal
- Increasing h → aeration

Aeration Types
Cascade Aeration – Absorption of Gas

- Absorption of gas

$$\frac{C_s - C_t}{C_s - C_o} = e^{-K_L at}$$

$$1 - \frac{C_s - C_t}{C_s - C_o} = 1 - e^{-K_L at}$$

$$\frac{C_t - C_o}{C_s - C_o} = 1 - e^{-K_L at} = K(efficiency\,coef.)$$

$$C_t = C_o(1 - K) + KC_s$$

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Aeration Types
Cascade Aeration – Absorption

- If the steps of the cascade aerator is equal $K_n = K/n$;

$$C_t = C_o(1 - K) + KC_s$$

$$C_1 = C_o(1 - K_n) + K_n C_s$$

$$C_2 = C_1(1 - K_n) + K_n C_s$$

$$C_n = C_s - (C_s - C_o)\left(1 - \frac{K}{n}\right)^n$$

Aeration Types
Cascade Aeration – Absorption

- Values of K;
- **Unpolluted water**

  $$K=0.45(1+0.046T)h$$

- **Polluted water**

  $$K=0.36(1+0.046T)h$$

- **Sewage**

  $$K=0.29(1+0.046T)h$$

- T: Temperature (^oC)
- h: depth of each step (m)

Aeration Types
Cascade Aeration – Absorption

- For the temperatures 4°C -30°C, Cs is calculated by the following equation

Cs = 468/ 31.6 + T (DO saturation value)