Aeration Systems

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Introduction

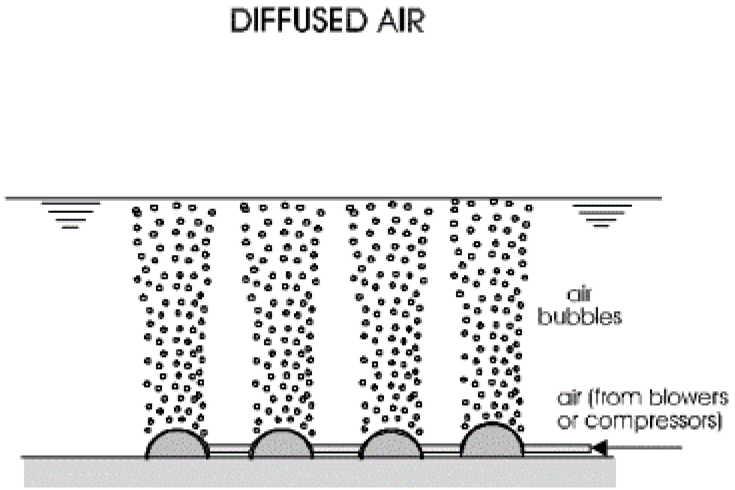
- Aeration is a unit operation of fundamental importance in a large number of aerobic wastewater treatment processes. When a liquid is deficient in a gas (oxygen, in this case), there is a natural tendency of the gas to pass from the gas phase, where it is present in sufficient concentrations, to the liquid phase, where it is deficient.

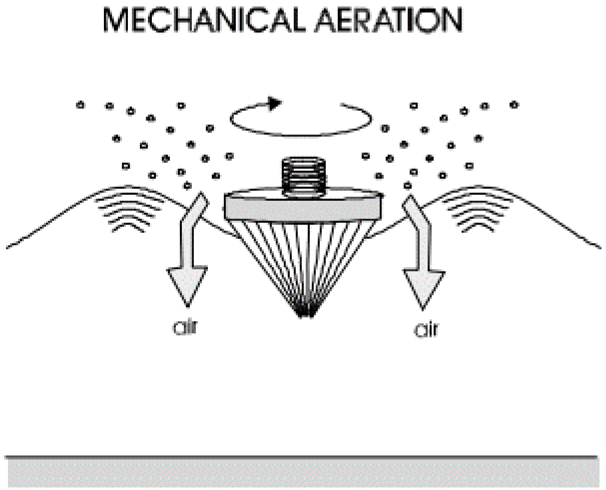
- Oxygen is a gas that dissolves poorly in the liquid medium. For this reason, in various wastewater treatment systems it is necessary to accelerate the natural process, in such a way that the oxygen supply may occur at a higher rate, compatible with the biomass utilization rate.

- Among the wastewater treatment processes that use artificial aeration are aerated lagoons, activated sludge and its variants, aerated biofilters and other more specific processes.

Artificial aeration

- In terms of sludge treatment, aerobic digesters also use artificial aeration.
- There are two main forms of producing artificial aeration:
  - introduce air or oxygen into the liquid (diffused air aeration)
  - cause a large turbulence, exposing the liquid, in the form of droplets, into the air, and also permitting the entrance of atmospheric air into the liquid medium (surface or mechanical aeration)
- Within these two types, which are presented below: aeration by diffused air and mechanical aeration

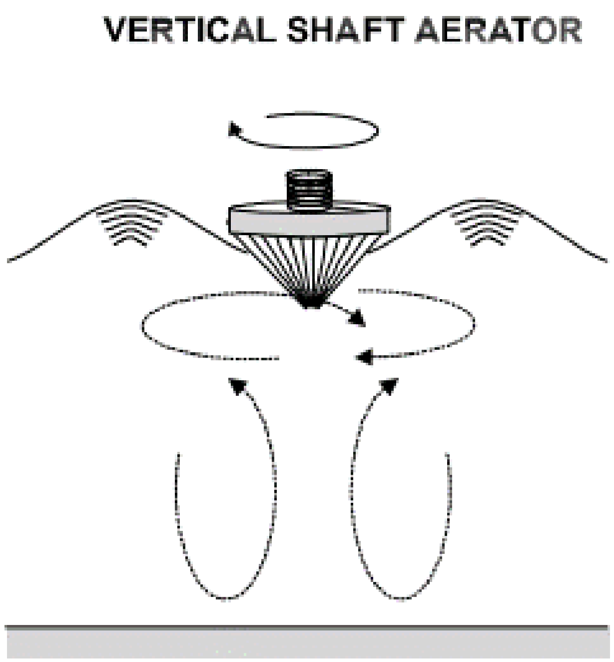


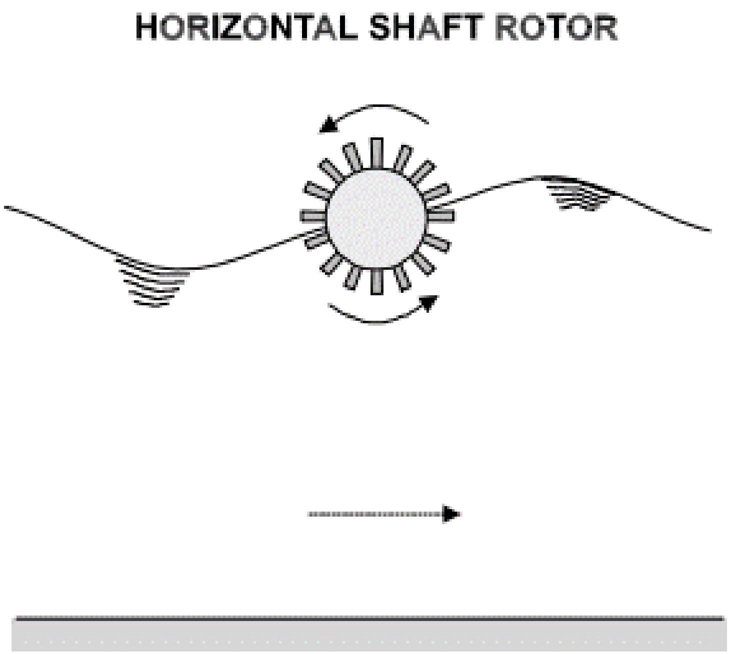


Mechanical aeration systems

- The main mechanisms of oxygen transfer by mechanical surface aerators are:
  - Atmospheric oxygen transfer to the droplets and the fine films of liquid sprayed in the air.
  - Oxygen transfer at the air-liquid interface, where the falling drops enter into contact with the liquid in the reactor.
  - Oxygen transfer by air bubbles transported from the surface to the bulk of the liquid medium.

- The more commonly used mechanical aerators can be grouped according to:
  - Classification as a function of the rotation shaft:
    - *vertical shaft aerators*
      - ✓ low speed, radial flow
      - ✓ high speed, axial flow
    - *horizontal shaft aerators*
      - ✓ low speed
  - Classification as a function of the supporting:
    - *fixed aerators*
    - *floating aerators*





- The power of mechanical aerators usually varies between 5 HP and 100 HP.

- In mechanical aerators, the submergence of the impellers in relation to the water level is a very important aspect in terms of oxygen transfer and energy consumption.

- The following situations can occur:

  - ✓ Adequate submergence. The performance is optimal. There is good turbulence and absorption of air with relation to the oxygen consumption.

  - ✓ Submergence above the optimal. The unit tends to function more as a mixer than as an aerator. The energy consumption increases without being accompanied by a substantial increase in the oxygen transfer rate.

  - ✓ Submergence below the optimal. Only a surface spray is formed in the vicinity of the aerator, without creating an effective turbulence. The energy consumption and the oxygen transfer rate decrease.

Characteristics of the main mechanical aeration systems

Type of aerator	Characteristics	Application	Components	Advantages	Disadvantages	Standard oxygenation efficiency (kgO_2/kWh)
Low speed, radial flow	Similar to a high flow and low head pump. The flow of the liquid in the tank is radial in relation to the axis of the motor. Most of the oxygen absorption results from an induced hydraulic jump. Rotation speed 20–60 rpm.	Activated sludge and variants. Aerobic digesters. Large aeration units with depths up to 5 m.	Motor, reducer, impeller. Fixation units (bridges or platforms) for the fixed aerators (more common).	High oxygen transfer. Good mixing capacity. Flexibility in the design of the tank. High pumping capacity. Easy access for maintenance.	High initial costs. Careful maintenance of the reducers is necessary.	1.4 – 2.0
High speed, axial flow	Similar to a high flow and low head pump. The flow of the liquid pumped is upwards and follows the axis of the motor, passing through the volute before reaching a diffuser, where it is dispersed perpendicularly to the axis of the motor in the form of a spray. Most of the oxygen absorption occurs due to spray and turbulence. Rotation speed: 900 – 1400 rpm.	Activated sludge and variants. Aerobic digesters. Aerated lagoons.	Motor, impeller, float (a reducer is not needed).	Lower initial costs. Easily adjustable to variations in the water level. Flexible operation.	Difficult access for maintenance. Lower mixing capacity. Oxygen transfer not very high.	1.0 – 1.4
Horizontal shaft	The rotation is around the horizontal shaft. When rotor is rotating, a large number of fins perpendicular to the shaft cause aeration by spray and incorporation of air, besides providing the horizontal movement of the liquid in the reactor. Rotation speed: 20 – 60 rpm.	Activated sludge oxidation ditches (depth less than 2.5 m)	Motor, reducer, rotor.	Moderate initial cost. Easy to fabricate locally. Easy access for maintenance.	Limited shape of the tank. Low depth requirement. Possible problems with long shaft rotors. Oxygen transfer not very high.	1.2 – 2.0

Source: Arceivala (1981), Qasim (1985), Metcalf & Eddy (2002), Malina (1992), WEF & ASCE (1992)

Diffused air aeration system

- The diffused air aeration system is composed of diffusers submerged in the liquid, air distribution piping, air transport piping, blowers, and other units through which the air passes.

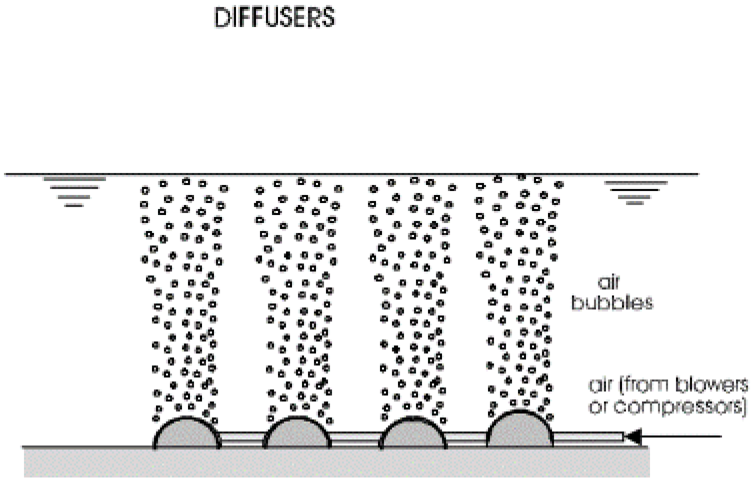
- The air is introduced close to the bottom of the tank and the oxygen is transferred to the liquid medium while the bubble rises to the surface.

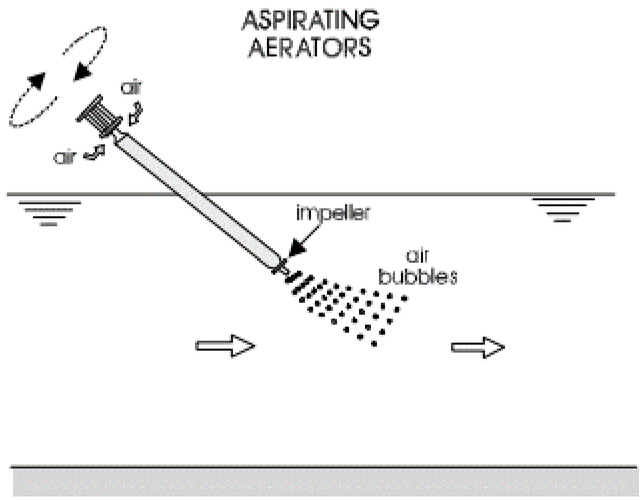
- The main diffused air systems can be classified according to the porosity of the diffuser and the size of the bubble produced:
    - porous diffuser (fine and medium bubbles): plate, disc, dome, tube (ceramic, plastic, flexible membrane).
    - non-porous diffuser (coarse bubbles): nozzles or orifices.
    - other systems: jet aerator, aspirating aerator, U-tube aerator.

- Aspirating devices have an impeller at the lower end (immersed in the liquid), which, when rotating, create a negative pressure, sucking in atmospheric air through a slot situated at the upper end (outside the liquid).

- Air is diffused into the liquid medium in the form of small bubbles, which are responsible for the oxygenation and mixing of the liquid mass.

- The aspirating aerators are presented in some texts as mechanical aerators, since they have motors that rotate outside the liquid, and in other texts as diffused air aerators, because they generate air bubbles in the liquid medium.





- The diameters of the bubbles considered in the classification of the aeration type are:

  - ✓ fine bubble: diameter less than 3 mm
  - ✓ medium bubble: diameter between 3 and 6 mm
  - ✓ coarse bubble: diameter greater than 6 mm

- In general, the smaller the size of the air bubbles, the greater the surface area available for gas transfer, that is, the greater the oxygenation efficiency. For this reason, aeration systems with fine bubbles are the most efficient in the transfer of oxygen.

- The oxygen transfer efficiency of the porous diffusers decreases with the use due to the internal or external clogging. The internal clogging is due to impurities in the air that are not removed by the filter. The external clogging is due to bacteria growth on the surface, or the precipitation of inorganic compounds.

- The oxygen transfer rate can be changed to adjust itself to the oxygen consumption through the control of the blowers and the air distribution system, thus allowing energy savings.

Characteristics of the main diffused air systems

Aeration type	Characteristics	Application	Advantages	Disadvantages	Average standard oxygen transfer efficiency (%)	Standard oxygenation efficiency (kgO_2/kWh)
Fine bubbles	The bubbles are produced in plates, discs, tubes or domes, made of a ceramic, glass or resin medium	Activated sludge	High oxygen transfer. Good mixing capacity. High operational flexibility through the variation of the airflow.	High initial and maintenance costs. Possibility of clogging of the diffusers. Air filters are necessary.	10–30	1.2–2.0
Medium bubbles	The bubbles are produced in perforated membranes or perforated tubes (coated stainless steel or plastic)	Activated sludge	Good mixing capacity. Reduced maintenance costs.	High initial costs. Air filters could be necessary.	6–15	1.0–1.6
Coarse bubbles	The bubbles are produced in orifices, nozzles, or injectors.	Activated sludge	No clogging. Low maintenance costs. Competitive initial costs. Air filters are not necessary.	Low oxygen transfer. High-energy requirements.	4–8	0.6–1.2
Aspirating aerators	The bubbles are produced by a propeller rotating at high speed at the bottom of a tube, which sucks in atmospheric air through the orifice at the upper end of the tube.	Aerated lagoons, activated sludge	No clogging. Air filters are not necessary. Conceptual simplicity. Maintenance relatively simple.	Lower oxygenation efficiency compared to mechanical aeration or fine bubble systems.	–	0.6–1.2

Source: Qasim (1985), Metcalf & Eddy (1991), Malina (1992), WEF & ASCE (1992)

Factors influencing the oxygen transfer

a) Temperature

The influence of temperature occurs according to two apparently opposite directions:

- Influence on the saturation concentration (C_s). The increase of the temperature causes a reduction in the saturation concentration C_s, which implies a reduction in the transfer rate dC/dt.

- Influence on the mass transfer coefficient K_La. The increase in the temperature causes an increase in the coefficient K_La, which implies an increase in the transfer rate dC/dt.

$$K_La_{(T)} = K_La_{(20\,^\circ C)}.\theta^{(T-20)}$$

where:

$K_La_{(T)}$ = coefficient K_La at any temperature T (s^{-1})

$K_La_{(20)}$ = coefficient K_La at a temperature of 20 °C (s^{-1})

θ = temperature coefficient. Usually adopted as 1.024.

b) Atmospheric pressure (altitude)

- The influence of the altitude is manifested in the oxygen saturation concentration (the greater the altitude, the lower the atmospheric pressure and, therefore, the lower the saturation concentration).

$$f_H = \frac{C'_s}{C_s} = \left(1 - \frac{H}{9450}\right)$$

where:

f_H = correction factor for the DO saturation concentration by the altitude (–)
C'_s = saturation concentration at the altitude H (mg/L)
H = altitude (m)

c) Dissolved oxygen concentration

- Under steady-state conditions, the greater the dissolved oxygen concentration (C) maintained in the reactor, the lower the value of $C_s - C$, that is, the lower is the oxygen transfer rate.
- For example, in activated sludge systems, the DO concentration maintained in the reactor is usually in the range of 1.0 to 2.0 mg/L.

d) Wastewater and reactor characteristics

- The specific characteristics of the wastewater being treated and the configuration of the reactor, which are different from the test conditions in which the oxygen transfer is measured, also exert an influence on the actual transfer rate in the field, under operating conditions.

- This influence occurs in two ways:

  - ***Influence on C_{sw}*,** The presence of salts, particulate matter and detergents affect the saturation concentration of the liquid in the reactor. This influence can be quantified through the following correction factor:

$$\beta = \frac{C_{sw}(\text{wastewater})}{C_s(\text{clean water})}$$

The values of β vary from 0.70 to 0.98, but the value of 0.95 is frequently adopted (Metcalf & Eddy, 1991).

- ***Influence on K_La.*** The oxygen transfer coefficient is influenced by the characteristics of the wastewater as well as the geometry of the reactor and mixing level.

The correction factor is:

$$\alpha = \frac{K_L a \text{ (wastewater)}}{K_L a \text{ (clean water)}}$$

Typical values of α vary from 0.6 to 1.2 for mechanical aeration and from 0.4 to 0.8 for diffused air aeration (Metcalf & Eddy, 1991).

Oxygen transfer rate (OTR)

$$OTR_{standard} = \frac{OTR_{field}}{\frac{\beta . f_H . C_s - C_L}{C_s(20\,^\circ C)} . \alpha . \theta^{T-20}}$$

where:

$OTR_{standard}$ = Standard Oxygen Transfer Rate – **SOTR** (kgO_2/h)

OTR_{field} = Oxygen Transfer Rate in the field, under operating conditions (kgO_2/h)

C_s = oxygen saturation concentration in clean water, at the operating temperature in the field (g/m^3)

C_L = average concentration of oxygen maintained in the reactor (g/m^3)

$C_s(20\,^\circ C)$ = saturation concentration of oxygen in clean water, under standard conditions (g/m^3)

f_H = correction factor C_s for the altitude (= 1− altitude/9450)

β = see comments

α = see comments

θ = see comments

T = liquid temperature (°C)

Example

In a wastewater treatment plant the supply of 100 kgO_2/h is necessary under operating conditions, using a mechanical aeration system. Determine the Standard Oxygen Transfer Rate knowing that:

- Liquid temperature: T = 23 °C
- Altitude = 800 m
- DO concentration to be maintained in the liquid: $C_L = 1.5$ mg/L

Solution:

Adopt the following values for the parameters of Equation 5

C_s (20 °C) = 9.2 mg/L, column 0 m altitude, for T = 20 °C
C_s = 8.7 mg/L, column 0 m altitude, for T = 23 °C
$\alpha = 0.90$ (see comments for Equation 5.24)
$\beta = 0.95$ (see comments for Equation 5.23)
$\theta = 1.024$ (see comments for Equation 5.21)
According to Equation 5.8 the value of f_H is:

$$f_H = 1 - \frac{\text{altitude}}{9450} = 1 - \frac{800}{9450} = 0.92$$

$$OTR_{standard} = \frac{OTR_{field}}{\frac{\beta.f_H.C_s - C_L}{C_s(20\,^\circ C)}.\alpha.\theta^{T-20}}$$

$$= \frac{100}{\frac{0.95 \times 0.92 \times .8.7 - 1.5}{9.2}.0.9 \times 1.024^{23-20}} = \frac{100}{0.62}$$

$$= 161 kgO_2/h$$

The final results are:

$OTR_{field} = 100\ kgO_2/h$ (given in the problem)
$OTR_{standard} = 161\ kgO_2/h$
Ratio $OTR_{field}/OTR_{standard} = 100/161 = 0.62 = 62\%$

Therefore, it can be seen that in the field the aeration system is capable of supplying only 62% of the capacity under standard conditions. For this reason, to obtain the value of 100 kgO_2/h in the field, a system that supplies 161 kgO_2/h under standard conditions must be specified.