

Chapter IITHEORETICAL CONSIDERATIONSOxygen Transfer

Oxygen may be added to solution by physical, chemical or biological reactions. If the concentration of oxygen is lower than the saturation value the transfer of the gas from the atmosphere will be added to solution by passing through the interface into the mass of fluid. If the concentration of oxygen is higher than the saturation value, the supersaturation is reduced by the reverse process of transfer from the liquid phase to the gas phase. In both cases, the gas, passes from one phase to the other by virtue of the driving force created by the departure from equilibrium the process continues until equilibrium is restored at the saturation value. The driving force is the partial pressure gradient in the gas phase and the concentration gradient in the liquid phase. (Eckenfelder & O'Connor, 1961).

Even in the absence of mechanical mixing, the concentration of a substance that is dissolved in water will eventually become uniform throughout a given volume of water. The rate of transfer per unit area is proportional to the driving force, as expressed by Fick's law of diffusion:

$$\frac{W}{t} = - D A g$$

where

$$\frac{W}{t} = \text{the rate of mass transfer}$$

$$D = \text{the proportionality constant}$$

$$A = \text{the area through which transfer occurs}$$

$$g = \text{the concentration gradient.}$$

Various authors have presented Fick's Law in slightly different forms as follows:

Ippen and Carver (1952) expressed the application of the two-film theory for the consideration of the oxygen absorption rates in water as

$$\frac{d C}{d t} = \frac{10^6}{W} K A (C_i - C_L)$$

where

$$\frac{d C}{d t} = \text{rate of change of dissolved oxygen concentration in the liquid in mg/l/hr}$$

$$W = \text{weight of water in tank, lbs.}$$

$$A = \text{interfacial or absorbing area, ft}^2$$

$$K = \text{coefficient of oxygen absorption in lb. oxygen/(hr x ft}^2 \text{ x unit concentration difference in mg/l)}$$

- C_i = equilibrium concentration of oxygen at the phase interface, mg/l
 C_L = concentration of oxygen in the liquid at time t , mg/l

Fair and Geyer (1954) showed the mass transfer rate

$$\frac{\partial W}{\partial t} = K_d A \frac{\partial C}{\partial l}$$

- where:
- W = weight of dissolved substance
 t = time
 A = cross-sectional area
 C = concentration
 l = distance
 K_d = coefficient of diffusion.

The overall absorption coefficient

When oxygen is absorbed into moving water, the degree of turbulence is often sufficient to maintain the concentration below the upper most layers at a reasonably uniform value. For these conditions in pure water, it is found that the rate of change of the concentrations C at time t , is proportional to the oxygen deficit, $C_s - C$, where C_s is the saturation value. Thus

$$\frac{dC}{dt} = K (C_s - C) \text{-----(1)}$$

where K , the constant of proportionality, is called overall absorption coefficient. (Adeney and Becker, 1919).

The variation of the oxygen content of the water with time is given by integrating equation (1)

$$\ln \frac{C_s}{C_s - C} = Kt \quad \text{-----} (2)$$

If the water is initially anaerobic ($C = 0$ when $t = 0$); alternatively, the concentrations are C_1 and C_2 at times t_1 and t_2 ,

$$\ln \frac{C_s - C_1}{C_s - C_2} = K(t_2 - t_1) \quad \text{-----} (3)$$

$$\text{or} \quad \frac{C_s - C_2}{C_s - C_1} = e^{-K(t_2 - t_1)} \quad \text{-----} (4)$$

Equation (1) - (4) apply to the aeration of both static and flowing clean water, provided that the concentration of dissolved oxygen is nearly uniform throughout the depth of the water.

Eckenfelder (1966) re-expressed the oxygen transfer rate in concentration units as

$$\frac{dC}{dt} = K_L \cdot \frac{A}{V} (C_s - C_L) = K_{La} (C_s - C_L)$$

where:

K_L	=	the overall diffusion coefficient based on liquid film resistance, ft^3 of volume/sec / ft^2 of area
A	=	the total interfacial area, ft^2
V	=	the volume of liquid under consideration, ft^3
C_s	=	the oxygen concentration of O_2 in the liquid when saturated at the existing pressure and temperature, mg/l
C_L	=	the oxygen concentration at a point at time t , mg/l
K_{La}	=	overall coefficient for oxygen transfer

The use of this equation is based on two assumptions, namely

- (1) The entire liquid content is completely mixed and therefore of uniform composition at any time t .
- (2) K_{La} is constant and therefore is independent of time.

Eckenfelder & Ford (1968) explained the determination of mass transfer coefficient under nonsteady state aeration of a deoxygenated water that K_{La} is determined from the slope of a semilogarithmic plot of the concentration deficit ($C_s - C_L$) versus time of aeration.

$$K_{La} = \frac{\log(C_s - C_2)_{t_1} - \log(C_s - C_L)_{t_2}}{t_2 - t_1} \times 2.3 \times 60 \text{ hr}^{-1}$$

Factors affecting oxygen transfer

Eckenfelder (1970) explained that several factors affect the performance of aeration devices. Corrections must be made for operation in waste water systems, since aeration efficiency is estimated in water under standard conditions and the presence of salts along with other substances will affect oxygen saturation.

Gameson and Robertson (1955) found a simple relation

$$C_s = \frac{475 - 2.65S}{33.5 + T}$$

where

$$\begin{aligned} C_s &= \text{the saturation value in mg/l} \\ S &= \text{salinity g/1000g} \\ T &= \text{temperature in } ^\circ\text{C} \end{aligned}$$

A linear relationship between salinity and solubility is assumed, and this is not justifiable when the salinity is much greater than that of sea water, the values given by this equation are lower (by 3-4 %) than those previously accepted at temperature below 25 °C but are substantially the same at 30 - 40 °C.



The values of C_s obtained by Standard Methods (1965) at different temperatures are listed in the following table, starting from 20 °C to 32 °C.

Table of Solubility of Oxygen in Water Exposed to Water - Saturated Air.

STANDARD METHODS (1965)

Temp. °C	Chloride Concentration in Water mg/l			Difference per 100 mg chloride
	0	5,000	10,000	
	Dissolved Oxygen mg/l			
20	9.2	8.7	8.3	0.009
21	9.0	8.6	8.1	0.009
22	8.8	8.4	8.0	0.008
23	8.7	8.3	7.9	0.008
24	8.5	8.1	7.7	0.008
25	8.4	8.0	7.6	0.008
26	8.2	7.8	7.4	0.008
27	8.1	7.7	7.3	0.008
28	7.9	7.5	7.1	0.008
29	7.8	7.4	7.0	0.008
30	7.6	7.3	6.9	0.008
31	7.5			
32	7.4			

Factor affecting K_L and K_{La}

Eckenfelder and Ford (1968) noted that there are several factors influencing K_L and K_{La} . The most significant of these are temperature and surface active agents present in the liquid. The temperature effect can be defined by the relationship:

$$K_t = K_{20^\circ\text{C}} \times e^{\theta(T - 20)}$$

where:

$$T = \text{temperature in } ^\circ\text{C}$$

$$\theta = \text{temperature coefficient}$$

The temperature coefficient has been reported to vary from 1.016 to 1.037. A study of Eckenfelder and Barhart (1960) found a value for θ of 1.028 for K_L , and a value of θ equal to 1.02 for K_{La} in bubble aeration system. So, the value of θ applied to this study is assumed to be equal to 1.024.

Surface active agents affect K_L and K_{La} when contaminants are added to water. Reported values in the reduction have ranged from a few percent to as much as 50 percent of that in pure water, depending on the nature and concentration of contaminant.

Since the evaluated absorbing liquid in this experiment is tap water, the effect due to the surface active agents is not present in this study.

Aerators

Four types of aerators are in common use :

1. gravity aerators
2. spray aerators
3. diffusers, and
4. mechanical aerators.

Their aim, each in its own way, is to create extensive, new and self-renewing interfaces between air and water, to optimize the time of gas transfer, and to accomplish these aims with a minimal expenditure of energy.

Gravity Aerators

Cascades, in which the available fall is subdivided into a series of steps.

Inclined planes, usually studded with riffle plates set into the planes in herringbone fashion and breaking up the sheet of water that would otherwise form.

Vertical stacks, through which droplets fall and updrafts of air ascend in countercurrent flow.

Stacks of perforated pans or troughs, often filled with contact media such as coke or stone, the water dropping freely from pan to pan or trough and trickling over the surfaces of the contact media present.

Spray Aerators. Spray or pressure aerators spray droplets of water into the air from stationary or moving orifices or nozzles. A whirling motion imparted to the droplets makes for turbulence at the air-water interface.

Orifices or nozzles in stationary pipes. The water rises either vertically or at an angle and falls onto a collecting apron, a contact bed, or a collecting basin serving some other useful purpose. Longer exposure in vertical jets is offset in some measure by freer access of air to the trajectory of inclined jets.

Orifice or nozzles in movable pipes. The jets issue horizontally from the openings and assist in rotating horizontal, radial pipes suspended from a central inlet column or in propelling horizontal, traveling pipes supported at both ends by carriages running on a rail. Both rotary and rectilinear distributor pipes may be driven hydraulically or electrically.

Stationary orifices and nozzles are common in water purification plants, movable distributors in wastewater works (trickling filters).

Air Diffusers. Most air diffusers or injection aerators bubble compressed air into water through orifice or nozzles in air piping, diffuser plates or tubes, or spargers. Ascending bubbles acquire smaller terminal velocities than would drops falling freely in air through the same distance. This increases the exposure time of air bubbles but reduces turbulence at the bubble interface. Spiral or cross-current flow can lengthen the path of travel of both air and water. It is conveniently induced by injecting air along one side of the tank.

Mechanical Aerators. Of the many different kinds of mechanical aerators, the following are of special interest:

Submerged paddles that circulate the water in aeration chambers and renew its air-water interface.

Surface paddles or brushes dipping lightly into aeration chambers but far enough to circulate their waters, release air bubbles, and throw a spray of droplets onto their water surface.

Propeller blades whirling at the bottom of a central downdraft tube in an aeration chamber and aspirating air into the water.

Turbine blades capping a central updraft tube in an aeration chamber and spraying droplets over its water surface.

Mechanical aerators of these kinds are employed principally in the treatment of wastewaters by the activated-sludge process.

Design of Gravity Aerators

The controlling element in gravity aerators is the available head. It can be put to use in a single or in multiple descent. At a given instant the rate of free fall $\frac{dh}{dt} = v = gt$ and

$$\int_0^h dh = g \int_0^t t dt \quad \text{or}$$

$$h = \frac{1}{2} gt^2$$

where h = the height of fall in feet
 t = the time in second
 v = the velocity in feet per second
 g = the acceleration of gravity in feet per (second)²

It follows that, in a single descent through a height h , the elapsed time is

$$t = \sqrt{2h/g} \quad \text{and that in } n \text{ descent through the same}$$

vertical distance

$$t = n \sqrt{2h/ng} = \sqrt{2nh/g}$$

In other words t is proportional to \sqrt{n} . However, it should be said that the quality of exposure is usually poorer in multiple descents, because droplets do not necessarily break away from jets of falling water as soon as they strike the air.

Gravity aerators are normally the constructions of choice when available head and floor area are small. Common values are 3 to 10 ft of head and considerably less than 100 sq. ft of area per m.g.d. capacity. Multipletray aerators generally require the least space, the clear distance between sequent tray beign 14 to 18 in.. Contact media (coke, stone, ceramic rings or balls, and plastic shapes) are 2 to 6 in. in size. Omitting distribution losses in advance of aeration (often close to 25%) the required or equivalent power input is 0.22 hp per m.g.d.- ft and the power consumption 3.9 kw-hr per m.g.- ft for a pumping efficiency of 80%.

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