amount of air required ranges from 0.075 to 1.12 m^3 air per m^3 (0.01–0.15 ft^3 per gal) of water.

12.5 AERATION IN BIOLOGICAL WASTEWATER TREATMENT

Oxygen supply is vital to all forms of aerobic biological treatment and is one of the more expensive operations in the process. Because gas transfer causes turbulence and mixing, aeration devices play a significant role in mixing and they are normally designed to supply the required degree of mixing besides providing enough oxygen.

The fundamental equation of gas transfer (Eq. 12.7) applies. The rate constant and saturation concentration are temperature dependent. Saturation concentrations of oxygen for the common temperature range are given in the Appendix. The mass transfer coefficient varies with temperature according to the Arrhenius equation:

$$K_T = K_{20}\theta^{(T-20)} \tag{12.31}$$

where

T is temperature, °C

θ is a constant

The common value of θ reported in the literature is 1.024, although many different values have been found. Furthermore, it must be remembered that θ actually varies slightly with temperature, as well as with other environmental conditions and fluid characteristics. Therefore, different values of θ should be used for different temperature ranges.

Aeration efficiency is normally tested using tap water in a basin that is different from the prototype in a number of aspects. Model studies must be carefully performed to ensure that a meaningful comparison of various aeration devices is obtained for the prototype. There are also a number of correction factors that must be considered to determine in situ rates of oxygen transfer when wastewater is the medium.

The saturation concentration of oxygen in wastewater will be different from that in tap water.

$$C_{s,ww} = \beta C_{s,Tw} \tag{12.32}$$

where

ww refers to wastewater

Tw refers to tap water

β is a correction factor

The saturation concentration of oxygen in water or tap water is calculated from Henry's law, is found from lab studies, or is available in tables for different temperatures. Besides being corrected for temperature, C_s must also be corrected for altitude because solubility of a gas varies with pressure (according to Henry's law). The equation describing this effect is

$$C_{s,alt} = C_{s,sl}\left[1 - \frac{\text{altitude (m)}}{9\,450}\right] \tag{12.33}$$

where

alt refers to altitude
sl refers to sea level

Equation (12.33) incorporates a polynomial fit to pressure variation with altitude.

The rate transfer coefficient in wastewater will also be different from that in tap water.

$$K_{\mathrm{ww}} = \alpha K_{\mathrm{Tw}} \tag{12.34}$$

where

α is a correction factor

The factors α and β are variable from waste to waste and should be measured from laboratory or field tests in each instance. However, basin geometry effects, the other major factor responsible for variation in K, are difficult to evaluate unless the prototype is used in the tests. Common values for α and β are 0.80–0.85 and 1.0, respectively.

Formulating Eq. (12.7) for a wastewater,

$$r'_{\mathrm{ww,T}} = \alpha K_{20,\mathrm{Tw}}(1.024)^{(T-20)}(\beta C_{\mathrm{s}} - C_{\mathrm{l}}) \tag{12.35}$$

where

$r'_{\mathrm{ww,T}}$ is rate of O_2 transfer for wastewater

Manufacturers commonly report their data for aeration equipment in tap water at 20°C. When they conduct their tests the tap water is deoxygenated such that $C_{\mathrm{l,Tw}} = 0$. Sulfite is added to water in excess of the stoichiometric requirement to remove oxygen (Eq. 12.36). Cobalt is added in the form of cobalt chloride to catalyze the deoxygenation reaction, which is quite fast. A cobalt concentration of no higher than 0.05 mg/L is recommended; however, if the tap water contains high concentrations of chloramines (greater than 0.3 mg/L) then the cobalt dose should be increased (Terry and Thiem, 1989). Excess cobalt ion does not interfere with DO measurement by probe, but it can cause interference with the Winkler iodometric method for DO determination.

$$2\mathrm{Na_2SO_3} + \mathrm{O_2} \xrightarrow{\mathrm{Co}} 2\mathrm{Na_2SO_4} \tag{12.36}$$

The deoxygenating agents are mixed with the water and the aeration device is activated. The change in DO concentration is measured over time.

Taking the ratio of Eqs. (12.35) and (12.7), where Eq. (12.7) is applied at these specified testing conditions results in

$$\frac{r'_{\mathrm{ww,T}}}{r'_{\mathrm{Tw,20}}} = \frac{(\beta C_{\mathrm{s}} - C_{\mathrm{l}})\alpha(1.024)^{(T-20)}}{9.09} \tag{12.37}$$

where

9.09 mg/L is the saturation concentration of O_2 in tap water at 20°C

For activated sludge and aerobic digestion processes the DO content needed is usually between 0.2 and 2.0 mg/L to prevent oxygen diffusion limitations from hindering the rate of substrate removal by the suspended microorganisms. A value of 1.0 mg/L is safe for most processes except under unusual (e.g., bulked) conditions. The higher, more conservative value (2.0 mg/L) should be used for design purposes. The Great Lakes Upper Mississippi River Board (GLUMRB) has 10 member states: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, Pennsylvania, and Wisconsin. GLUMRB (1976) has set standards for water works developed from observations of many treatment processes. GLUMRB specifies that 150% of air requirements should be available.

Manufacturers do not usually report their ratings in terms of mg/L/time (r') but in terms of oxygen transferred per unit of energy (r).

$$r = \frac{\text{kg O}_2\text{ transferred}}{\text{MJ}}\ \text{(SI)} \qquad \text{or} \qquad r = \frac{\text{lb O}_2\text{ transferred}}{\text{hp-h}}\ \text{(U.S.)} \tag{12.38}$$

where

MJ = 10^6 J

Aeration efficiency is also described by the oxygen transfer efficiency, E.

$$E = \frac{\text{mass of oxygen utilized}}{\text{mass of oxygen supplied}} \times 100 \tag{12.39}$$

The former measure is most useful because it is used for estimating energy costs for supplying oxygen. The r value relates oxygen transfer to gross energy input to the aeration device; i.e., the efficiency of the aerator is included in the r rating. Incorporating mass transfer factors, the field rate of oxygen transfer is

$$r_{\text{ww,T}} = \frac{r_{\text{Tw,20}}(\beta C_{\text{s}} - C_{\text{l}})\alpha(1.024)^{(T-20)}}{9.09} \tag{12.40}$$

Using Eq. (12.40) and knowing the amount of oxygen required in the biological treatment process, the total power requirements for the aerators may be estimated. The oxygen supplied to the wastewater is the oxygen consumed by the microorganisms. Excess oxygen supplied increases the DO content of the water in the basin and is transported out of the basin with the effluent. The total oxygen required per unit time is estimated from the anticipated process operating conditions, the flow rate, and amount of oxygen demand in the sewage. The aerators must be sized for the extreme conditions considering all of the above factors. At higher temperatures the saturation concentration of oxygen is lower but mass transfer coefficients are higher. Extreme values of sewage oxygen demand satisfied in treatment will be higher at high temperatures.

12.5.1 Aeration Devices in Wastewater Treatment

Surface and submerged aerators are employed in biological wastewater treatment units or pond systems. Mechanical surface aerators draw water up and throw it up and radially outward. Two types of mechanical aerators are shown in Figs. 12.9 and 12.10. Draft tubes may be installed with surface aerators to ensure that water is drawn up from the bottom of the basin, which promotes better mixing.

Submerged aerators are porous or nonporous diffusers with a variety of designs, some of which are illustrated in Figs. 12.6(a) and (b). Porous diffusers are made from rigid materials such as ceramic, which have small openings that control the size of the gas bubble emerging from them. Perforated membranes made of flexible rubber or plastic can also be used. Porous diffusers are available in plates, domes (Fig. 12.11),

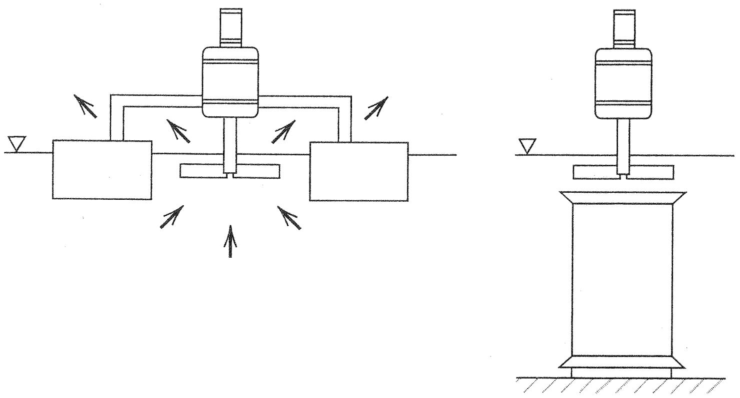

Figure 12.9 Mechanical surface aerators. Left, surface aerator; right, surface aerator with draft tube. Courtesy of Degrémont Infilco.

discs, and tubes. The USEPA (1989) has provided a thorough discussion of porous diffusers. Nonporous diffusers have orifices with larger openings than porous diffusers. Perforated piping, spargers, and slotted tubes are typical nonporous diffuser designs. The in situ oxygen transfer efficiencies of all of these devices are a function of many variables and data must be interpreted with caution. WEF and ASCE (1992) have given more detailed information on the various types of aeration systems and their performance characteristics. All types of systems are widely used.

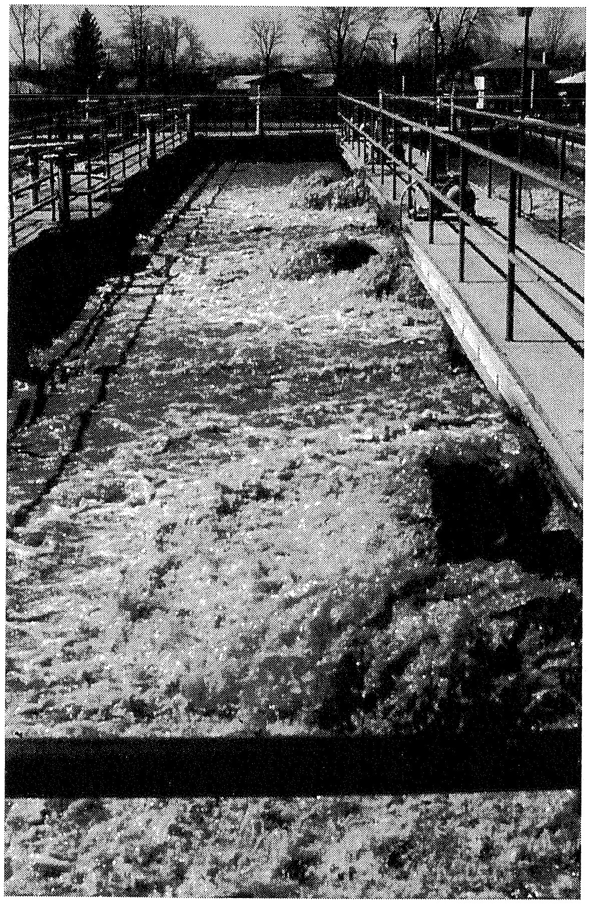

Figure 12.10 Surface aerators in an activated sludge process.

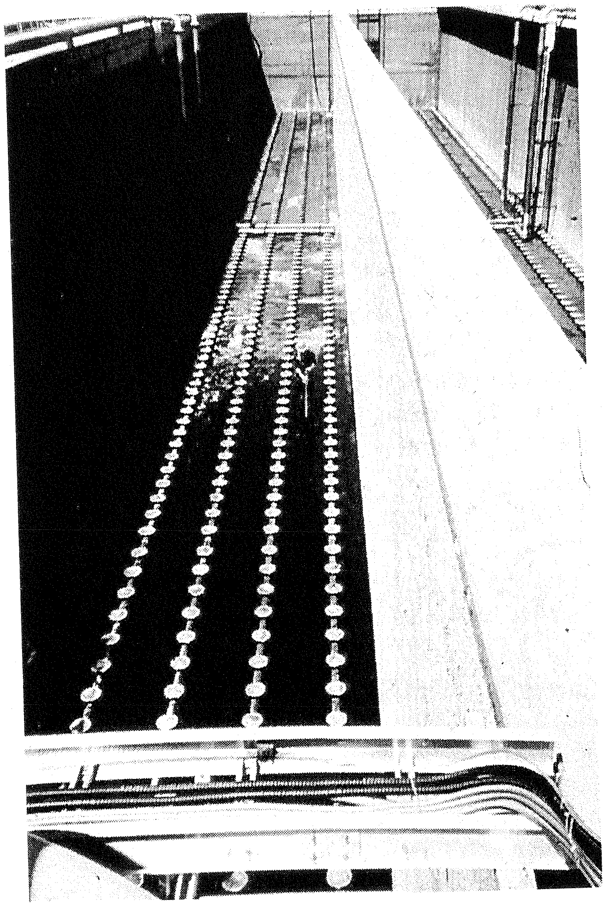

Figure 12.11 Ceramic dome diffusers in an activated sludge basin. Courtesy of Regional Municipality of Ottawa-Carleton, Ontario.

There are many factors affecting the efficiency of oxygen transfer. Groves et al. (1992) and the USEPA (1989) have conducted a number of field evaluations of diffused aeration systems and found the general trends given in Table 12.6.

A recent concept in aeration for oxidation ditches is the total barrier oxidation ditch (Fig. 12.12). A vertical barrier wall is installed across the entire cross-section of a ditch and all circulating flow is intercepted and passed through draft tube turbine aerators. In the aerators, compressed air supplied by blowers is introduced into a turbine assembly through a sparge ring located beneath the turbine blades. The turbine assembly forces the aerated wastewater through a J-tube extension and imparts sufficient energy to circulate it at the desired velocity. Oxygen transfer efficiency depends on blower air supply rates and velocities of circulation. Clean water test results for oxygen transfer at two installations were found to average 1.04 kg O_2/kWh (based on energy consumption by the blower and turbine); α values were in the range of 0.76–0.87 for process wastewater (Boyle et al., 1989). K_{Tw} was found to be 2.07 h^{-1}.

12.5.2 Power Requirements for Mixing

The other function of aeration noted earlier is mixing. The only effective method to evaluate mixing is by placing the aerators in the prototype, which is impossible at the design stage. For the initial estimates of the mixing requirement, one must rely on

TABLE 12.6 Factors Affecting Oxygen Transfer in Submerged Diffused Aeration Systems[a]

Factor	Effect on oxygen transfer
Equipment Factors	
Diffuser type	Fine bubble diffusers have higher oxygen transfer than coarse bubble diffusers.
Diffuser density	A larger number of fine pore diffusers produces higher oxygen transfer.
Diffuser submergence	As submergence increases the percentage of oxygen transfer increases.
Diffuser layout	Grid patterns produce higher oxygen transfer than diffusers placed along one side (spiral roll) or in the center.
Diffuser age	Changes in membrane materials may cause a decrease in oxygen transfer.
Flow regime	Plug flow systems have higher oxygen transfer efficiency than step feed basins.
Basin geometry	Tanks that are more square have less variation in oxygen transfer throughout the tank than long, narrow tanks.
Operation Factors	
Solids retention time	Systems with higher solids retention times have higher oxygen transfer.
Nitrification	Systems that are nitrifying have higher oxygen transfer efficiencies than those that are not.
Food : microorganism ratio	Increases in food : microorganism ratio cause a decrease in oxygen transfer.
Airflow rate per diffuser	As airflow rate per diffuser increases, the oxygen transfer efficiency of most fine bubble devices decreases. For other devices, the opposite may be true.
Mixed liquor DO concentration	The percentage oxygen transfer efficiency decreases as DO increases.
Diffuser fouling	Fouling decreases oxygen transfer.
Wastewater Characteristics	
Temperature	An increase in temperature increases oxygen transfer.
Wastewater constituents	An increase in interfering agents such as surfactants causes a decrease in oxygen transfer.

[a] After Groves et al. (1992) and USEPA (1989).

field experience gained from similarly designed units. It is evident that power should be dissipated uniformly throughout the basin volume, resulting in no dead (unmixed) zones. The power input for mixing normally ranges from 13 to 26 kW/1 000 m^3 (0.37–0.74 kW/1 000 ft^3) of basin volume. This is effective power input into the basin, which excludes mechanical and electrical losses in the aerator. The efficiency of power transfer to the liquid for a typical aerator is approximately 75–80% of the input power to the aerator. Using the previously calculated value of gross power required for oxygen input and reducing it by the efficiency factor enables one to calculate the power delivered to the basin. Model studies can be helpful. If the mixing power requirement is not met, aerators will have to be operated at higher rates than required to supply oxygen; otherwise supplemental mixers must be added.