

Theory and Practice of Aeration in Wastewater Treatment

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1. Introduction

This chapter is concerned with the transfer of oxygen from air to a wastewater subjected to biological aerobic treatment. Knowledge of the rate of oxygen transfer is essential for specification of aerators to be utilized in the process. Theory for oxygen transfer is discussed, and the determination of transfer coefficients from laboratory experiments described. Common types of aerators and the procedure for specifying aerator systems for aerobic wastewater treatment processes are also described.

The best known explanation for the mechanism of gas transfer to a liquid is given by the two-film theory. According to this theory, it is the presence of two films, one liquid and one gas, at the gas-liquid interface which provides the resistance to the passage of gas molecules from the bulk of the gas phase to that of the liquid phase.

For gases of high solubility in the liquid phase, e.g., absorption of SO_2 by water, the major resistance to absorption is that offered by the gas film. For gases of low solubility in the liquid phase, e.g., absorption of oxygen by an aqueous liquor, the controlling resistance resides in the liquid film. For intermediate solubilities, both films offer significant resistance.

Oxygen saturation values (C_s) for distilled water at standard conditions (1 atm) are presented in Table 4.1. For a more complete table with 1°C increments, consult Ref. [7].

TABLE 4.1
Oxygen Saturation Values (C_s) for Distilled Water at Standard Conditions (1 atm) [7]

Temperature (°C)	Temperature (°F)	O_2 (mg/liter)
0	32.0	14.6
5	41.0	12.8
10	50.0	11.3
15	59.0	10.2
20	68.0	9.2
25	77.0	8.4
30	86.0	7.6
35	95.0	7.1
40	104.0	6.6
45	113.0	6.1
50	122.0	5.6

2. Steps Involved in the Oxygen-Transfer Process

The process of oxygen transfer from a gaseous to an aqueous phase occurs in three steps.

Step 1. Saturation of the liquid surface between the two phases (let C_s be this saturation concentration of oxygen). This rate of oxygen transfer is very rapid since the resistance of the gas film is negligible, and thus Step 1 is never the controlling one.

Step 2. Passage of the oxygen molecules through the liquid interface film by molecular diffusion. At very low mixing levels the rate of oxygen absorption is controlled by Step 2. At higher turbulence levels, the interface film is broken up and the rate of renewal of the film controls the absorption of oxygen. Surface renewal rate is the frequency at which liquid with an oxygen concentration C_L (oxygen concentration in the bulk of the liquid phase) replaces that from the interface with an oxygen concentration equal to C_s .

Step 3. Oxygen is transferred to the bulk of the liquid by diffusion and convection.

3. Oxygen-Transfer Rate Equation

The basic equation for oxygen-transfer rate is

$$N = K_L A (C_s - C_L) \quad (4.1)$$

where N is the mass of oxygen transferred per unit time (lb O₂/day); K_L the liquid film coefficient [lb O₂/(day)(ft²)(unit ΔC)]; A the interfacial area for transfer (ft²); C_s the saturation concentration of oxygen (mg/liter); and C_L the concentration of oxygen in the body of the liquid (mg/liter).

Equation (4.1) is usually rewritten in concentration units by dividing by volume V of the system. Then [Eq. (4.2)]

$$N/V = dC_L/dt = K_L (A/V) (C_s - C_L) = K_L a (C_s - C_L) \quad (4.2)$$

where $a = A/V =$ interfacial area per unit volume (ft²/ft³); and $K_L a$ is the overall coefficient of oxygen transfer [lb O₂/(day)(ft³)(unit ΔC)].

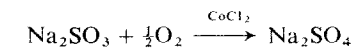
In the determination of the mass-transfer coefficient, the overall coefficient $K_L a$ is obtained without attempting to separate the factors K_L and a . It is admittedly impossible to measure the interfacial area A .

The difference ($C_s - C_L$) between saturation value and actual concentration of oxygen (C_L) in the body of the liquid phase is called oxygen deficit (hence denoted as OD). For aerobic treatment processes designed for removal of organic BOD, the range for operating dissolved oxygen level C_L is between 0.5 and 1.5 mg/liter. When nitrification is to be achieved, dissolved oxygen level is in excess of 2.0 mg/liter.

4. Determination of the Overall Mass-Transfer Coefficient $K_L a$ by Unsteady State Aeration of Tap Water

Studies of the transfer coefficient are usually made on tap water and then corrected for the wastewater, as described in Section 11 of this chapter. The procedure more commonly used for determination of $K_L a$ is the unsteady state aeration of tap water. The four steps involved in this determination are given below.

Step 1. Deoxygenate the water to an essentially zero concentration of dissolved oxygen. This is done by addition of deoxygenation chemicals, the most commonly used being sodium sulfite (Na₂SO₃). Cobalt chloride (CoCl₂) is added as a catalyst for the deoxygenation reaction.



The stoichiometric ratio is

$$\text{Na}_2\text{SO}_3/\frac{1}{2}\text{O}_2 = 126/16 = 7.9$$

This means that theoretically 7.9 ppm of Na₂SO₃ are required to remove 1 ppm of DO. Based on the DO of the test tap water, the approximate Na₂SO₃ requirements are estimated (a 10–20% excess is used). Sufficient cobalt chloride is added to provide a minimum Co²⁺ concentration of 1.5 ppm. An alternative deoxygenation procedure consists of removal of dissolved oxygen by purging with nitrogen gas.

Step 2. After DO concentration becomes essentially zero, start aeration, measuring the increasing concentrations of DO at selected time intervals. Since DO concentration increases with time, this method is termed unsteady state aeration. Steady state methods, in which DO concentration is kept constant, are discussed in Section 7. Dissolved oxygen measurements are preferably performed by instrumental methods. A properly calibrated galvanic cell oxygen analyzer and probe is the most reliable method. Experimental determination of DO by this technique is described in Section 2.3.1 of Chapter 2. Chemical analysis of dissolved oxygen (Winkler method) is also employed [7]. The aeration device is located at the center of the test basin. When circular basins are employed, baffles are placed at the quarter points of the basin, as indicated in Fig. 4.1, in order to prevent vortexing.

When testing is performed in a circular tank for pilot or full scale tests, sampling depths for the DO determinations are 1 ft from the surface and 1 ft from the bottom, at the mid- and end-points of the radii trisecting the basin.

This yields a total of 12 sampling points, as illustrated by Fig. 4.2. Samples from various test locations are analyzed for DO, and the results are averaged and recorded for the particular sampling time.

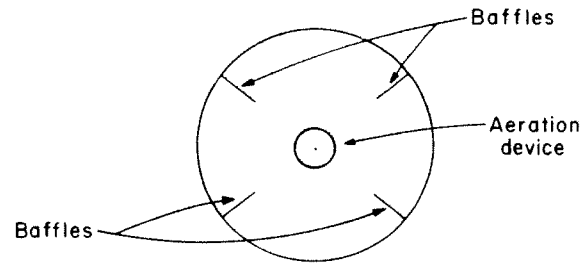
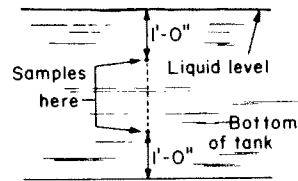


Fig. 4.1. Baffle arrangement.

(For each of the six locations indicated by dots on cross section at right)



Cross section of tank:

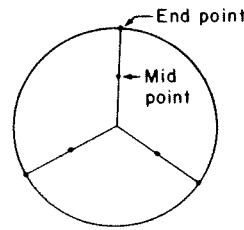


Fig. 4.2. Location of sampling points.

Step 3. Results are tabulated as shown by sample data in Table 4.2.

TABLE 4.2
Data for Example 4.1

(1) Test time (min)	(2) C_L (mg/liter)	(3) $C_s - C_L$ (mg/liter) ^a
0	0.2	10.0
10	2.6	7.6
20	4.8	5.4
30	6.0	4.2
40	7.1	3.1
50	7.8	2.4
60	8.5	1.7

^a $C_s = 10.2$ mg/liter.

Step 4. From Eq. (4.2) it follows that a plot of $(C_s - C_L)$ vs. time in semilog scale yields a straight line, the slope of which equals $(-K_L a)$. Take Eq. (4.2),

$$dC_L/dt = K_L a(C_s - C_L)$$

Separating variables, integrating, and assuming $K_L a$ to be independent of the time of sampling [Eq. (4.3)]:

$$\ln(C_s - C_L) = -K_L a t + \text{const.} \quad (4.3)$$

The plot of $\ln(C_s - C_L)$ vs. time is shown in Fig. 4.3 for data in Table 4.2. For accuracy the straight line is plotted by the least-squares method.

Determination of the overall mass-transfer coefficient $K_L a$ by the method of unsteady state aeration of tap water is illustrated by Example 4.1.

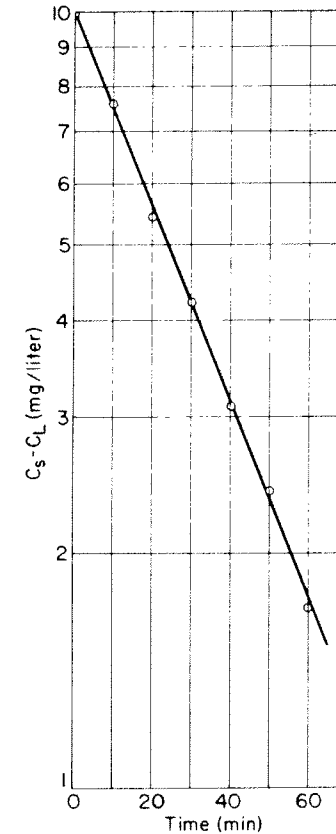


Fig. 4.3. Determination of $K_L a$ (Example 4.1).

Example 4.1

Data presented in Table 4.2 are obtained by utilizing an 8-HP surface aerator in a 150,000 gal circular test tank under the following conditions:

Water temperature: 15°C

Atmospheric pressure: 28 in. Hg

C_s : 10.2 mg/liter (at 15°C, $P = 28$ in. Hg)

Test water is deoxygenated using sodium sulfite and a cobalt catalyst.

Calculate

1. Chemical requirements (lb Na_2SO_3 /lb liquor) to deoxygenate test water with 9 ppm of DO and total lb Na_2SO_3
2. CoCl_2 requirements (lb)
3. Value of $K_L a$ lb O_2 /(hr)(ft³)Δ(mg/liter)

SOLUTION

Step 1. Establish the chemical requirements. Theoretically, 7.9 ppm of Na_2SO_3 are required to remove 1 ppm DO. Thus

$$7.9 \times 9.0 = 71.1 \text{ ppm of Na}_2\text{SO}_3$$

Utilizing a 20% excess

$$20/100 \times 71.1 = 14.22 \text{ ppm (take 15 ppm excess)}$$

Requirements

Theoretical	71.1 ppm
Excess	15.0 ppm
	<hr/>
	86.1 ppm of Na_2SO_3

$$\text{Requirements} = 86.1 \text{ ppm} = 86.1 \times 10^{-6} \text{ lb Na}_2\text{SO}_3/\text{lb liquor}$$

$$\begin{aligned} \text{Total required: } & 86.1 \times 10^{-6} \text{ lb Na}_2\text{SO}_3/\text{lb liquor} \times 8.34 \text{ lb liquor/gal liquor} \\ & \times 150,000 \text{ gal liquor} = 108 \text{ lb of Na}_2\text{SO}_3 \end{aligned}$$

Step 2. Determine the CoCl_2 requirements (lb).

Basis: 1.5 ppm of Co^{2+}

Molecular weight of CoCl_2 : 130

Atomic weight of Co: 59

Thus

$$1.5 \text{ ppm Co}^{2+} \text{ or } 1.5 \times 130/59 = 3.3 \text{ ppm CoCl}_2 = 3.3 \times 10^{-6} \text{ lb CoCl}_2/\text{lb liquor}$$

Therefore, the lb of CoCl_2 required are

$$\begin{aligned} & 3.3 \times 10^{-6} \text{ lb CoCl}_2/\text{lb liquor} \times 8.34 \text{ lb liquor/gal liquor} \times 150,000 \text{ gal liquor} \\ & = 4.13 \text{ lb CoCl}_2 \text{ (minimum)} \end{aligned}$$

Take 5 lb CoCl_2 .

Step 3. Ascertain the value of $K_L a$ (hr⁻¹). By plotting in semilog scale graph column (3) vs. column (1) of Table 4.2 one obtains Fig. 4.3. Then at 15°C

$$\begin{aligned} K_L a & = -(\text{slope}) = -2.303[(\log 10 - \log 3.1)/(0 - 40)] \times 60 \\ & = 1.76 \text{ lb O}_2/(\text{hr})(\text{ft}^3) \Delta(\text{mg/liter}) \end{aligned}$$

5. Integration of the Differential Equation for Oxygen Transfer between Limits

Integration of Eq. (4.2) between times t_1 and t_2 , corresponding to DO concentrations $C_{L,1}$ and $C_{L,2}$, yields

$$\ln[(C_s - C_{L,2})/(C_s - C_{L,1})] = -K_L a(t_2 - t_1)$$

or

$$K_L a = 2.303 \log[(C_s - C_{L,1})/(C_s - C_{L,2})]/(t_2 - t_1) \quad (4.4)$$

From Eq. (4.4) the value of $K_L a$ is calculated from only two experimental determinations of DO. However, it is preferable to utilize the semilog linear plot method with several experimental points, since this permits statistical averaging of errors.

6. Unsteady State Aeration of Activated Sludge Liquor

In aeration of activated sludge liquor, oxygen utilization (respiration rate) by the microorganisms is taken into account. Equation (4.2) is modified as follows:

$$dC_L/dt = K_L a(C_{SW} - C_L) - r \quad (4.5)$$

where r is the rate of oxygen utilization by the microorganisms; C_{SW} the saturation concentration of oxygen for the wastewater; and C_L the operating concentration of dissolved oxygen in the aerator liquor. Values of dC_L/dt are obtained by plotting C_L (measured by DO tests) vs. time and determining slopes at selected time intervals (Fig. 4.4).

Equation (4.5) is rearranged to yield

$$dC_L/dt = (K_L a C_{SW} - r) - K_L a C_L \quad (4.6)$$

Equation (4.6) indicates that a plot of dC_L/dt (values of slopes obtained from Fig. 4.4) vs. C_L yields a straight line, as indicated in Fig. 4.5. The slope of this line yields $K_L a$, and respiration rate r is determined from the intercept.

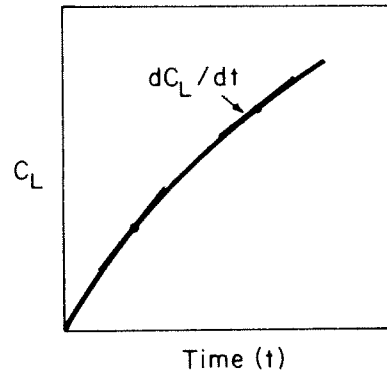


Fig. 4.4. Determination of dC_L/dt .

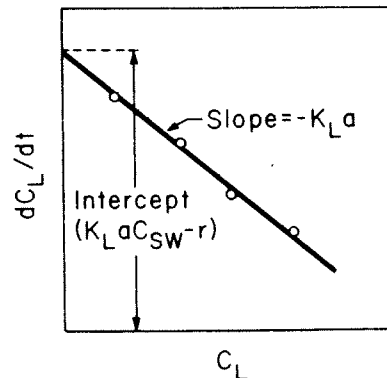


Fig. 4.5. Determination of $K_L a$ (unsteady state aeration of activated sludge liquor).

7. Steady State Determination of $K_L a$ for the Activated Sludge Liquor

Activated sludge liquor is aerated at a rate just sufficient to supply the oxygen required for respiration of the microorganisms. In Eq. (4.5) $dC_L/dt = 0$, and therefore

$$K_L a = r / (C_{SW} - C_L) \quad (4.7)$$

Respiration rate is measured (e.g., by the Warburg respirometer) when the dissolved oxygen concentration becomes stabilized. Equation (4.7) yields $K_L a$.

8. Oxygenation Capacity (OC)

In evaluation of an aerator the oxygen transferred is estimated under standard conditions (SC), corresponding to a temperature of 20°C and standard atmospheric pressure. Rate of oxygen transferred by the aerator is reported as its oxygenation capacity (OC), which is defined as the rate of oxygen transfer dC/dt at an initial oxygen concentration $C_L = 0$ and standard conditions. From Eq. (4.2)

$$\text{OC [lb O}_2\text{/(hr)(unit volume)]} = dC_L/dt = (K_L a)_{20^\circ\text{C}}(C_s - 0) = (K_L a)_{20^\circ\text{C}} C_s \quad (4.8)$$

or if V is the volume of aeration basin,

$$\text{OC (lb O}_2\text{/hr)} = (K_L a)_{20^\circ\text{C}} C_s V \quad (4.9)$$

Since the test is performed under conditions other than standard, the value of $K_L a$ obtained is corrected for temperature and pressure before application of Eq. (4.9). These corrections are discussed in Section 9.

9. Corrections for $K_L a$ and Oxygenation Capacity (OC) with Temperature and Pressure

9.1. TEMPERATURE CORRECTION

The oxygen-transfer coefficient $K_L a$ increases with temperature. The following temperature correction is used to determine $K_L a$ at 20°C:

$$K_L a_{(T)} = K_L a_{(20^\circ\text{C})} \times 1.024^{(T-20)} \quad (4.10)$$

where T is the temperature in °C.

9.2. PRESSURE CORRECTION

A barometric correction for oxygen saturation value C_s in Eq. (4.8) or (4.9) is applied as indicated by Eq. (4.11), which assumes that C_s is directly proportional to the barometric pressure.

$$C_s \text{ (corrected)} = C_s \text{ (test)} \times 29.92 \text{ in. Hg} / (\text{in. Hg at test conditions}) \quad (4.11)$$

Since oxygen saturation is related to partial pressure of oxygen in the gas phase (Henry's law), a correction is made for saturation in submerged aeration

devices (bubble aeration), where partial pressure at the point of discharge exceeds atmospheric pressure due to hydrostatic pressure. Oldshue [5] proposed the following correction:

$$C_{s,m} = C_{s,s}[(P_b/29.4) + (O_t/42)] \quad (4.12)$$

where $C_{s,m}$ is the saturation of oxygen at aeration tank mid-depth (mg/liter); $C_{s,s}$ the saturation of oxygen at standard conditions (mg/liter); P_b the pressure (psia) at the depth of air release; and O_t the oxygen in exit gas (%).

For aeration, $O_t = 21\%$ of O_2 , and Eq. (4.12) yields

$$C_{s,m} = C_{s,s} \times [(P_b/29.4) + 0.5] \quad (4.13)$$

Thus, the value for the oxygenation capacity for surface aerators (no hydrostatic correction required) is given by Eq. (4.9), which is modified as follows [Eq. (4.14)]:

$$OC = (K_L a)_{20^\circ C} \times C_s (\text{corrected}) \times V \quad (4.14)$$

where $(K_L a)_{20^\circ C}$ is calculated from Eq. (4.10), and C_s (corrected) is given by Eq. (4.11). Therefore, for surface aerators

$$OC = K_L a_{(T)} \times 1.024^{(20-T)} \times C_s (\text{test}) \times \frac{29.92 \text{ in. Hg}}{(\text{in. Hg at test conditions})} \times V \quad (4.15)$$

For bubble aerators, one utilizes Eq. (4.16).

$$OC = (K_L a)_{20^\circ C} \times C_{s,s} \times V \quad (4.16)$$

where $(K_L a)_{20^\circ C}$ is calculated from Eq. (4.10) and $C_{s,s}$ from Eq. (4.12) [or Eq. (4.13)]. Therefore, for bubble aerators

$$OC = K_L a_{(T)} \times 1.024^{(20-T)} \times \frac{C_{s,m}}{[(P_b/29.4) + 0.5]} \times V \quad (4.17)$$

Example 4.2

For the surface aerator in Example 4.1, calculate

1. Value of $K_L a$ corrected to $20^\circ C$
2. Value of C_s corrected to normal atmospheric pressure
3. Oxygenation capacity (lb O_2 /hr)

SOLUTION

Step 1. $(K_L a)_{20^\circ C}$ is calculated from Eq. (4.10).

$$(K_L a)_{20^\circ C} = 1.76 \times (1.024)^{(20-15)} = 1.98 \text{ hr}^{-1}$$

Step 2. C_s (corrected) is calculated from Eq. (4.11).

$$C_s (\text{corrected}) = 10.2(29.92/28.0) = 10.9 \text{ mg/liter} = 10.9 \times 10^{-6} \text{ lb } O_2/\text{lb liquor}$$

Step 3. Oxygenation capacity is calculated from Eq. (4.14).

$$\begin{aligned} OC &= 1.98 \text{ l/hr} \times 10.9 \times 10^{-6} \text{ lb } O_2/\text{lb liquor} \times 150,000 \text{ gal} \times 8.34 \text{ lb liquor/gal} \\ &= 27.0 \text{ lb } O_2/\text{hr} \end{aligned}$$

10. Transfer Efficiency of Aeration Units

Transfer efficiency (TE) of aeration units is commonly expressed in terms of mass of oxygen actually transferred per (HP × hr) of work expenditure, i.e. [Eq. (4.18)],

$$TE = \text{lb } O_2 \text{ transferred}/(\text{HP} \times \text{hr}) \quad (4.18)$$

Sometimes, nominal HP (nameplate HP) of the aerator is utilized for simplicity in evaluating TE. It is more accurate to base calculation upon actual HP (blade HP) measured during the test by a watt meter or an energy counter. When the power factor (cos PF) is known, blade HP is calculated from Eq. (4.19) [2].

$$\begin{aligned} \text{Blade HP} &= (\text{line voltage}) \times (\text{line amperage}) \times [\cos \text{PF} (3)^{1/2}] \\ &\quad \times (1/746) \times (\text{motor efficiency}) \times (\text{gear efficiency}) \end{aligned} \quad (4.19)$$

where 1/746 is the conversion factor HP/W. Values of TE up to 7 lb O_2 /(HP × hr) are reported for surface aerators, although for most units the values of TE range from 2 to 4 lb O_2 /(HP × hr). For turbine aerators the usual range is 2–3 lb O_2 /(HP × hr).

Example 4.3

For the aerator in Examples 4.1 and 4.2, report aerator efficiency in terms of nameplate HP and blade HP. The following data are available in addition to those from Examples 4.1 and 4.2:

Drawn voltage: 225 V (average)
 Amperage: 20 A (average)
 cos PF (measured): 0.85
 Motor efficiency (estimated): 90%
 Gear efficiency (estimated): 90%

SOLUTION Oxygen transferred had been determined in Example 4.2 as 27.0 lb O_2 /hr. Therefore

$$TE = 27.0/8.0 = 3.38 \text{ lb } O_2/\text{HP} \times \text{hr} \quad (\text{nameplate})$$

From Eq. (4.19)

$$\text{Blade HP} = (225)(20)[0.85 \times (3)^{1/2}]/(746)(0.9)(0.9) = 7.19$$

Then

$$TE = (27.0/7.19) = 3.76 \text{ lb } O_2/\text{HP} \times \text{hr} \quad (\text{blade})$$

11. Effect of Wastewater Characteristics on Oxygen Transfer

When oxygen is supplied for aerobic biological treatment of wastewater, it is necessary to define a correction factor which relates oxygen transfer to the nature of the waste. This correction factor α relates the overall mass-transfer coefficient ($K_L a$) of the wastewater to that of the tap water [Eq. (4.20)].

$$\alpha = K_L a (\text{wastewater}) / K_L a (\text{tap water}) \quad (4.20)$$

There are many variables which affect the magnitude of α . These include (1) temperature of the mixed liquor; (2) nature of the dissolved organic and mineral constituents; (3) level of agitation of aeration basin, usually expressed in terms of HP per 1000 gal of basin volume; (4) characteristics of the aeration equipment; and (5) liquid depth and geometry of aeration basin.

The temperature effect is attributable to temperature dependence of the liquid film coefficient K_L . Figure 4.8 illustrates typical temperature effect on values of α .

Since the nature of dissolved organic and mineral constituents affects α , its value is expected to increase during the course of biological oxidation, because dissolved organic materials affecting the transfer rate are removed in the biological process. A typical situation is shown in Fig. 4.6. As the final effluent approaches purity of tap water, the value of α approaches unity asymptotically.

Effect of mixing intensity in aeration basin (usually expressed in terms of HP/1000 gal) is illustrated by Fig. 4.7, which is a typical curve for a wastewater containing surface-active agents. As explained in Section 2, at low mixing intensities the rate of oxygen transfer is controlled by the passage of the oxygen molecules through the liquid interface film by molecular diffusion. The presence of surface-active agents inhibits molecular diffusion through

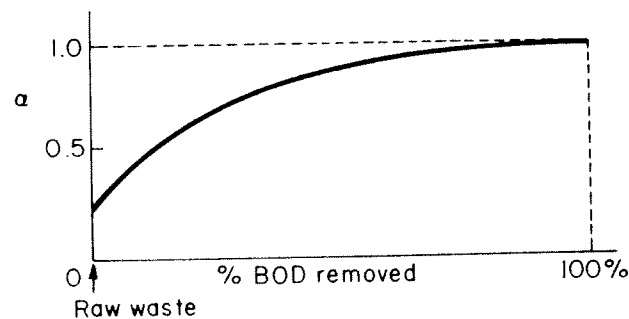


Fig. 4.6. Plot of α vs. % BOD removed.

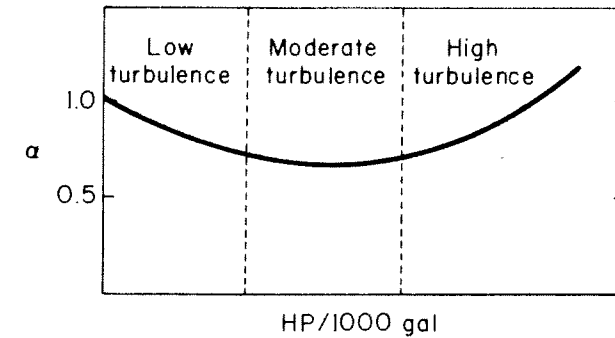


Fig. 4.7. Plot of α vs. mixing intensity.

the interface, and thus α decreases. At high mixing intensities, however, the oxygen transfer is controlled by the rate of surface renewal, and thus at conditions of high turbulence, α increases with the degree of mixing intensity. Figure 4.8 shows simultaneously the effect of temperature and mixing intensity on the value of α for a typical wastewater.

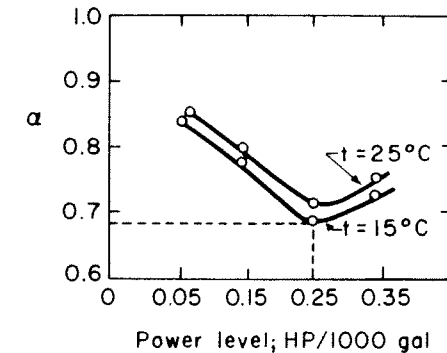


Fig. 4.8. Plot of α vs. power level at two different temperatures [3].

An interesting illustration of the effect of characteristics of aeration equipment on the value of α is bubble aeration (air diffusion or turbine units) in the presence of surface-active agents. Presence of these agents decreases bubble size, and thus increases interfacial area per unit volume.* Under these conditions the $K_L a$ value of the wastewater usually increases, because increase in a exceeds decrease of K_L caused by the surface barrier. This increase in $K_L a$ of the wastewater results in a corresponding increase of α [Eq. (4.20)].

* Since $a = A/V = k_1 r^2 / k_2 r^3 = K(1/r)$, thus as radius (r) of the bubble decreases, a (and therefore $K_L a$) increases.

12. Laboratory Determination of Oxygen-Transfer Coefficient α

This determination is based directly on the definition of α given by Eq. (4.20). Values of $K_L a$ of wastewater and tap water are determined as described in Section 4. It is interesting to make parallel determinations for wastewater and tap water at different mixing intensities and at different temperatures, in order to obtain curves such as the ones shown in Fig. 4.8.

13. Classification of Aeration Equipment—Oxygen-Transfer Efficiency

Aeration equipment commonly employed in wastewater treatment is classified into three categories: (1) air diffusion units, (2) turbine aeration units, and (3) surface aeration units. When comparing aeration devices or evaluating absorption of oxygen in various wastewaters, it is useful to consider the oxygen-transfer efficiency, which is defined as [Eq. (4.21)]

$$e = \frac{\text{weight of O}_2 \text{ absorbed/unit time}}{\text{weight of O}_2 \text{ supplied/unit time}} \times 100 \quad (4.21)$$

This definition is not applicable to surface aeration units since the oxygen supplied comes from surrounding air, and thus it is not possible to determine the weight of oxygen supplied per unit time. In aerobic biological processes, aerators perform two basic functions: (1) provision of the required oxygen transfer needed for oxidation of organic matter in the wastewater; and (2) maintenance of an adequate level of agitation in the biological reactor, in order to yield relatively uniform concentrations of dissolved oxygen and biological mass throughout.

For the activated sludge process, most of the power expenditure by the aerators is for the purpose of providing oxygen transfer. For large volume biological units (namely, aerated lagoons), the larger share of the power expenditure is for maintenance of an adequate level of agitation. Characteristics and specifications for the three categories of aeration equipment are discussed individually in the next three sections.

14. Air Diffusion Units

14.1. TYPE 1. FINE BUBBLE DIFFUSERS

Small orifice diffusion units such as porous media, plates, or tubes are constructed of silicon dioxide (SiO_2) or aluminum oxide (Al_2O_3) grains, held in a porous mass with a ceramic binder. Other units employed consist of Saran, Dacron, or nylon-wrapped tubes.

Small bubbles, having a high surface area per unit volume, provide good oxygen-liquid contact, leading to relatively high values of the oxygen-transfer efficiency. Diameter of the bubbles released from these diffusers are 2.0–2.5 mm, the oxygen-transfer efficiency depending on bubble size. (e 's from 5 to 15% are common.) Standard porous diffuser units are designed to deliver 4–15 SCFM of air per unit.

A disadvantage of small orifice diffusion units is the high maintenance costs in some applications owing to orifice clogging. Air filters are commonly used to clean and eliminate dust particles that might clog the diffusers. A sketch of a fine bubble air diffusion system is shown in Fig. 4.9.

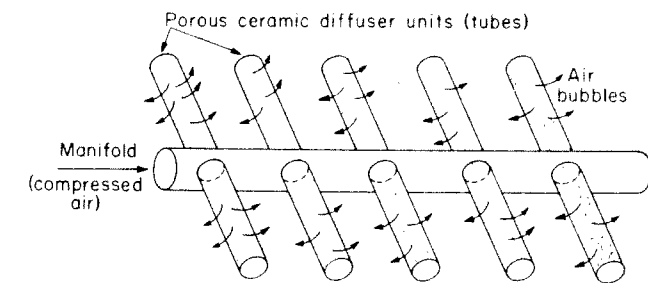


Fig. 4.9. Sketch of a fine bubble air diffusion system consisting of a series of porous ceramic diffusers.

14.2. TYPE 2. LARGE BUBBLE DIFFUSERS

These units employ large orifice or hydraulic shear devices. Large bubble units have lower oxygen-transfer efficiency than fine bubble units, since the interfacial area for oxygen transfer is considerably less. They have the advantage, however, of not requiring air filters and of generally requiring less maintenance. Sketches of two typical large bubble air diffuser units are shown in Fig. 4.10.

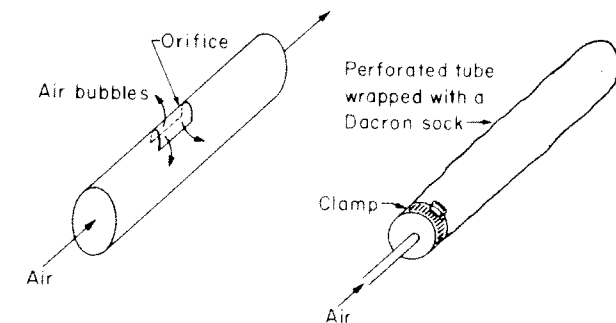


Fig. 4.10. Sketches of typical large bubble diffuser units.

14.3. PERFORMANCE OF AIR DIFFUSION UNITS

Performance data for air diffusion units are available as graphs for the lb of O₂ transferred/hr per aeration unit vs. the air flow per unit. A sample of typical data for a Saran-wrapped tube (small bubble) is shown in Fig. 4.11.

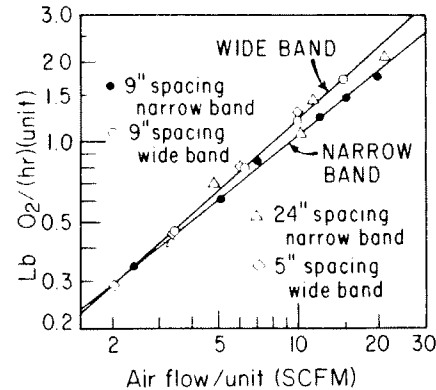


Fig. 4.11. Oxygen-transfer data from Saran tubes in water [2]. (Reprinted with permission, copyright by the University of Texas Press.)

Eckenfelder [1] recommends the following empirical equation for correlating performance of air diffusion units, and tabulates values of characteristic constants for several types of diffusers.

$$N = CG_s^{(1-n)}(H^m/W^p)(C_{sw} - C_L) \times 1.024^{(T-20)} \times \alpha \quad (4.22)$$

where N is the lb of O₂ transferred/(hr)(aeration unit); G_s the air flow (SCFM/aeration unit; SCFM are measured at 1 atm and 60°F); H the liquid depth (ft); W the aeration tank width (ft); C_{sw} the saturation concentration of DO in wastewater (mg/liter, at tank mid-depth); C_L the operating concentration of DO (mg/liter, usually 0.5–1.5 mg/liter); T the temperature (°C); α the oxygen-transfer coefficient of the wastewater [defined by Eq. (4.20)]; and C, n, m, p the constants characteristic of the aeration device. From Eq. (4.2),

$$N = K_L aV(C_{sw} - C_L) \quad (4.23)$$

By comparing Eqs. (4.22) and (4.23) the result is

$$K_L aV = CG_s^{(1-n)}(H^m/W^p) \times 1.024^{(T-20)} \times \alpha \quad (\text{ft}^3/\text{hr}) \quad (4.24)$$

Term $K_L a$ has units of hr⁻¹ and V is the volume of the aeration tank in ft³. If $(C_{sw} - C_L)$ is given in mg/liter it is multiplied by a conversion factor to express it in lb/ft³, so that N is obtained in lb/hr.

$$(C_{sw} - C_L) = \text{mg/liter} \times \text{g}/1000 \text{ mg} \times \text{lb}/454 \text{ g} \times 28.3 \text{ liter}/\text{ft}^3$$

$$(C_{sw} - C_L) \times 6.23 \times 10^{-5} = \text{lb}/\text{ft}^3$$

Factor 6.23×10^{-5} is conveniently included in constant C in Eq. (4.22), so that $(C_{sw} - C_L)$ enters the equation directly in mg/liter, and N is obtained in lb/hr.

14.4. DESIGN PROCEDURE FOR AERATION SYSTEMS UTILIZING AIR DIFFUSION UNITS

Fundamental information required is as follows:

1. Volume of aeration tank (V), calculated from biological reactor requirements (Chapter 5, Section 7)
2. Oxygen requirements (lb O₂/hr), also calculated from biological reactor requirements (Chapter 5, Section 7)
3. Operating temperature
4. Operating DO (C_L , mg/liter), usually 0.5–1.5 mg/liter except for nitrification units, when values above 2 mg/liter are employed
5. Oxygen-transfer coefficient α
6. Performance data for the air diffuser units [available as graphs, see Fig. 4.11, or expressed in terms of values for constants $C, n, m,$ and p in Eq. (4.22)]

Step 1. Select a tank depth H usually between 10 and 15 ft.

Step 2. Cross-sectional area is then $A = V/H$.

Step 3. For aeration tanks with rectangular cross section, select a width W of approximately twice the tank depth. This is necessary in order to maintain adequate mixing. Then tank length $L = A/W$. For aeration tanks with circular cross section, calculate diameter from $D = (4A/\pi)^{1/2}$.

Step 4. Select air flow rate G_s per air diffusion unit. Usual range for values of G_s is 4–8 SCFM/unit and 4–16 SCFM/unit for fine and large bubble diffusers, respectively.

Step 5. Value C_{sw} [used in Eq. (4.22)] is computed at tank mid-depth from Eq. (4.12) [or Eq. (4.13)], i.e., $C_{sw} = C_{s,m}$.

Step 6. Oxygenation capacity per aeration unit [$N = \text{lb O}_2$ transferred/(hr)(unit)] is estimated from manufacturer's data (e.g., Fig. 4.11) or computed from Eq. (4.22).

Step 7. From oxygen requirements (lb O₂/hr) calculated in Chapter 5, Section 7 and value of N calculated in Step 6, calculate the number of aeration units required to transfer required amount of oxygen.

$$\text{No. of units} = \frac{\text{lb O}_2/\text{hr (required)}}{N}$$

Step 8. Prepare a layout of the aeration tank and determine the spacing between the aeration units. Minimum spacing is about 6 in. and maximum

between 24 and 30 in. This is necessary in order to maintain solids in suspension and to minimize coalescence of air bubbles. If spacings calculated fall outside this range, double rows or adjustment in the number of units (selection of different air flow rate G_s) are made.

Step 9. Compute total air flow.

$$\text{Total air flow} = G_s \times (\text{no. units}) \quad (\text{SCFM})$$

Step 10. Compute required horsepower of the blower.

$$\text{HP} = [(\text{pressure drop, psi}) \times (\text{SCFM}) \times 144] / (33,000)(\epsilon_m)$$

where 33,000 and 144 are the conversion factors for (ftlb/min)/HP and in.²/ft², respectively, and ϵ_m is the mechanical efficiency (estimated). Usually a 6–10 psi pressure drop is adopted for the blower.

Step 11. Compute oxygenation efficiency from Eq. (4.21), where the numerator was calculated in Step 6 and the denominator obtained from values of G_s selected in Step 4 (it equals approximately 23.2% of the weight of air corresponding to G_s). The weight of air corresponding to G_s is calculated from the ideal gas equation. From

$$PV = NRT = (\text{weight/molecular weight}) \times RT$$

then

$$\text{Weight of air} = (\text{molecular weight})(PV)/RT$$

where molecular weight = 29 lb/lb mole (average molecular weight of air) $P = 1$ atm, $V = G_s$, $R = 0.73(\text{atm})(\text{ft}^3)/(\text{lb mole})(^\circ\text{R})$, and $T = 520^\circ\text{R}$ (60°F). Therefore

$$\text{Weight of air} = (29 \times 1 \times G_s) / (0.73 \times 520) = 0.076G_s \text{ lb/min}$$

and [Eq. (4.25)]

$$\text{Weight of O}_2/\text{min} = 0.232 \times 0.076G_s = 0.0176G_s \quad (4.25)$$

15. Turbine Aeration Units

15.1. DESCRIPTION OF UNIT

A sketch of a typical turbine aeration unit is shown in Fig. 4.12. These units entrain atmospheric oxygen by surface aeration and disperse compressed air by a shearing action employing a rotating turbine or agitator. Air bubbles discharged from a pipe or sparger below the agitator are broken down by the shearing action of the high speed rotating blades of the agitator. For systems of low oxygen utilization rate, oxygen is supplied by the flow of air self-induced from a negative head produced by the rotor (suction effect). For systems of higher oxygen utilization rate a blower or compressor is needed.

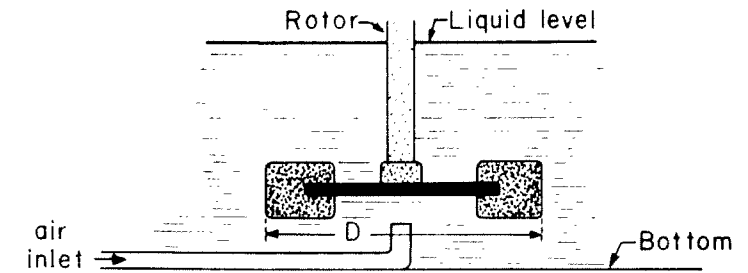


Fig. 4.12. Turbine aeration unit.

15.2. PERFORMANCE OF TURBINE AERATION UNITS

Main variables to be considered are air flow, diameter (D), and speed of impeller. These variables determine bubble size and degree of agitation in the tank, thus affecting the overall oxygen-transfer coefficient $K_L a$. Performance data for turbine aeration units are available from manufacturer's information taking these variables into consideration. Eckenfelder [1] recommends the following empirical equation for correlating performance of turbine aeration units:

$$N = CG_s^n S^x D^y (C_{sw} - C_L) 1.024^{(T-20)\alpha} \quad (4.26)$$

where N is the lb O₂ transferred/(hr)(aeration unit); G_s the air flow (SCFM/aeration unit); S the peripheral speed of the impeller (ft/sec); D the impeller diameter (ft, see Fig. 4.12); C_{sw} the saturation DO concentration in wastewater (mg/liter); C_L the operating DO concentration (mg/liter); and C, n, x, y the constants characteristic of the aeration device.*

Comparing Eqs. (4.23) and (4.26) the result is Eq. (4.27).

$$K_L a V = CG_s^n S^x D^y \times 1.024^{(T-20)\alpha} \quad (\text{ft}^3/\text{hr}) \quad (4.27)$$

where term $K_L a$ has units of hr⁻¹, and V is the volume of the aerator tank in ft³. If $(C_{sw} - C_L)$ in Eq. (4.26) is given in mg/liter, its value is multiplied by factor 6.23×10^{-5} to obtain N in lb/hr, as shown in Section 14.3.

15.3. POWER REQUIREMENTS FOR TURBINE AERATORS

Power is required for two purposes: (1) operation of rotor (corresponding horsepower is designated hence as HP_r), and (2) operation of compressor or

* Typical values for $n, x,$ and y (depending on impeller geometry) [4]: $n, 0.4-0.9$; $x, 1.2-2.4$; and $y, 0.6-1.8$.

blower (corresponding horsepower is designated hence as HP_c). Power drawn by the rotor is computed from the relationship [4]

$$HP_r = C'D^m S^p \quad (4.28)$$

C' , m , and p are constants characteristic of the aeration device. Actual drawn horsepower decreases as air flow is increased under the impeller due to decreased density of the aerated mixture. For this reason, horsepower calculated from Eq. (4.28) is referred to as ungassed horsepower. Equation (4.28) is rewritten as

$$HP_r = C''D^n n^p \quad (4.29)$$

where n is expressed in revolutions/sec. Since S is the peripheral speed in ft/sec, n and S are related as [Eq. (4.30)]

$$n = S/\pi D = (\text{ft/sec})/(\text{ft/rev}) = \text{rev/sec} \quad (4.30)$$

where πD is the perimeter of the circumference described by the rotation of the impeller.

Typical values of exponents m and p are [4]

$$4.8 \leq m \leq 5.3$$

$$2.0 \leq p \leq 2.5$$

Ungassed horsepower is correlated to actual horsepower. A correlation is presented in Fig. 4.13. Power drawn by the compressor is calculated from

$$HP_c = (\text{pressure drop, psi}) \times (\text{SCFM}) \times 144/(33,000)(\epsilon_m) \quad (4.31)$$

where ϵ_m is the estimated turbine efficiency.

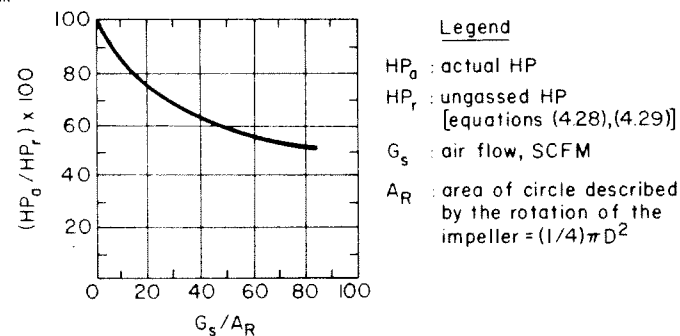


Fig. 4.13. Effect of air rate on turbine horsepower [4].

Next determine the optimum power split between rotor and compressor. A correlation between oxygen-transfer efficiency [expressed as (lb O_2 transferred)/(HP \times hr)] and a factor P_d defined as [Eq. (4.32)]

$$P_d = HP_r/HP_c \quad (4.32)$$

has been developed by Quirk [6], and its utilization is summarized by Eckenfelder [1]. P_d represents the power split between rotor and compressor. A typical correlation curve is shown in Fig. 4.14.

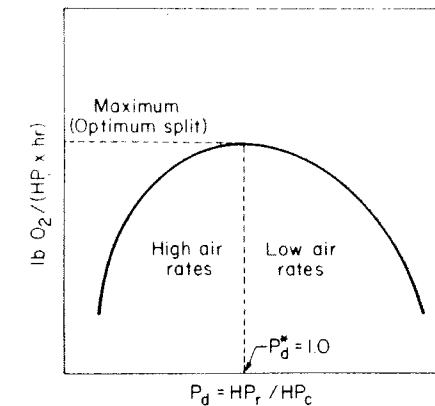


Fig. 4.14. Correlation for power split for turbine aeration units.

The value indicated in Fig. 4.14 as P_d^* is the optimum power split corresponding to the maximum oxygen-transfer efficiency. In most cases P_d^* is approximately unity, this implying an equal power expenditure by the turbine and the compressor. At extremely high air rates (high values of HP_c), values of P_d are less than 1.0, i.e., $HP_c > HP_r$ and $P_d < 1.0$. Under these conditions, large air bubbles and flooding of the impeller yield poor oxygenation efficiencies. On the other hand, at very low air rates $P_d > 1.0$ and too much turbine horsepower is spent in mixing the liquor.

15.4. DESIGN PROCEDURE FOR AERATION SYSTEMS UTILIZING TURBINE AERATION UNITS

For fundamental information required see items 1-5 for air diffusion units (Section 14.4), then obtain performance data for the turbine aeration units available from manufacturer's information, or expressed in terms of values for the constants in Eq. (4.26).

Step 1. Select a tank depth H , usually between 15 and 20 ft. In some cases deeper liquid depths are employed.

Step 2. Cross-sectional area is then $A = V/H$.

Step 3. Select a ratio $r = D/T$, where D is diameter of the turbine and T the "diameter" of the tank. For tanks of circular cross section, the meaning of ratio D/T is straightforward. For tanks with rectangular or square cross sections, select a value for T based on geometry of the system. Selection of T

for a rectangular tank with two turbine aerators is illustrated by Fig. 4.15 (T equals the diameter of influence of the aeration unit). Typical D/T ratios are 0.1–0.2.

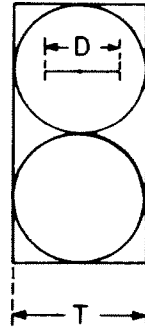


Fig. 4.15. Ratio $r = D/T$ for a rectangular tank with two turbine aerators.

Step 4. Select a tank width T approximately twice the tank depth. Therefore turbine diameter is $D = T \times r$.

Step 5. From Fig. 4.14 (manufacturer's data) determine optimum power split P_d^* .

Step 6. Select air flow rate per unit G_s (SCFM/aeration unit). Typical values are between 200 and 1500 SCFM.

Step 7. Value C_{SW} [to be used in Eq. (4.26)] is computed at tank mid-depth from Eq. (4.12) [or Eq. (4.13)], i.e., $C_{SW} = C_{s,m}$.

Step 8. Oxygenation capacity per aeration unit [$N = \text{lb O}_2 \text{ transferred}/(\text{hr})(\text{unit})$] is estimated from manufacturer's data or computed from Eq. (4.26).

Step 9. From oxygen requirements ($\text{lb O}_2/\text{hr}$) calculated in Chapter 5, Section 7 and value of N calculated in Step 8, calculate the number of aeration units needed to transfer required amount of oxygen.

$$\text{No. of units} = \text{lb O}_2/\text{hr (required)}/N$$

There should be one turbine unit for every 900–2500 ft^2 . By varying air rate per unit G_s , one adjusts calculations so that spacing falls within this range.

Step 10. Compute total air flow.

$$\text{Total air flow} = G_s \times (\text{no. of units}) \quad (\text{SCFM})$$

Step 11. Compute operating compressor horsepower from Eq. (4.31).

Step 12. Determine turbine horsepower from optimum power split established in Step 5.

$$HP_r = (P_d^*)(HP_c)$$

Step 13. Compute oxygenation efficiency from Eq. (4.21), where numerator was obtained in Step 8. Calculate denominator from Eq. (4.25).

16. Surface Aeration Units

16.1. DESCRIPTION OF UNIT

Surface aeration units are based solely on entrainment of oxygen from atmospheric air. Unlike air diffusion and turbine aerators there is *no* stream of air involved in this system.

Improved design of surface aerators has resulted in improvement of oxygen-transfer capacity, and their use has increased rapidly in the past few years. They are widely used in activated sludge plants and aerated lagoons.

The principle of operation of surface aerators is illustrated by the sketch in Fig. 4.16. Liquid is drawn from underneath the unit and sprayed upward and outward by a propeller inside a vertical tube.

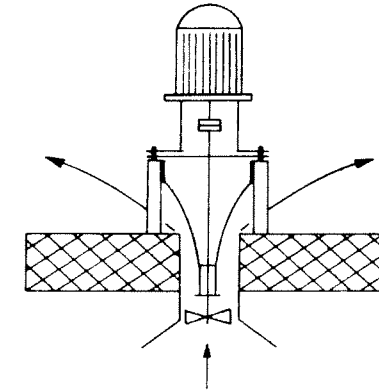


Fig. 4.16. Cross-sectional diagram of a surface aerator.

Most conventional surface aerators are fixed to piers mounted across the aerating tanks. Floating units are also available, the whole unit being supported on a reinforced fiberglass float filled with plastic foam to make it unsinkable.

Oxygen transfer in surface aerators occurs according to two mechanisms: (1) transfer at the turbulent liquid surface, and (2) transfer to droplets sprayed by the blades of the unit.

16.2. CORRELATION BETWEEN TRANSFER EFFICIENCY AND LEVEL OF AGITATION

A correlation has been developed [1] between transfer efficiency [expressed as $\text{lb of O}_2 \text{ transferred}/(\text{HP} \times \text{hr})$] and level of agitation of the basin (in $\text{HP}/1000 \text{ gal basin}$). There is an approximate linear relationship between these two parameters, as indicated by the straight line in Fig. 4.17, which is a

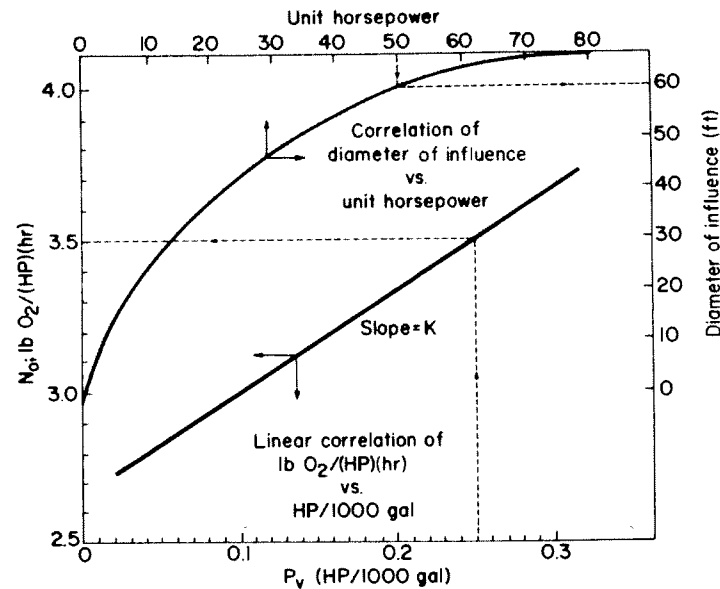


Fig. 4.17. Characteristics of surface aerator.

typical example of this correlation for a specific surface aerator unit. Correlation between diameter of influence and unit horsepower, which is also plotted in Fig. 4.17, is discussed in this section. Ordinate N_0 equals the lb of O_2 transferred to tap water at standard conditions (20°C and 1 atm, with initial zero dissolved oxygen) per (HP × hr). A correction to obtain oxygen transfer (N) for a wastewater under operating conditions is presented in this section [Eq. (4.34)].

The linear correlation indicated in Fig. 4.17 is expressed by the relationship [1]

$$N_0 = KP_v + N_s \quad (4.33)$$

where N_0^* is the total oxygen transferred to tap water under standard conditions per unit [lb O_2 /(HP × hr)]; P_v the HP per 1000 gal of basin liquid; K the constant characteristic of the aeration device (in Fig. 4.17 this corresponds to slope of the straight line); and N_s the oxygen transferred to tap water at standard conditions per unit horsepower × hr at zero turbulence (in Fig. 4.17 this corresponds to ordinate of the straight line at the origin).

In Eq. (4.33), N_s corresponds to oxygen transferred at standard conditions (N_0) for conditions of zero turbulence (i.e., $P_v = 0$). For a given aerator this

*For the specific surface aerator unit corresponding to Fig. 4.17, this relationship is

$$N_0 = 3.4P_v + 2.65$$

corresponds to its operation in a basin of infinite volume. In such cases, all oxygen transfer is accomplished by the spray mechanism alone, since turbulence is negligible.

Performance of surface aerators is related to the following factors: (1) submergence of impeller, and (2) diameter and speed of rotor. Values for transfer efficiency [lb O_2 transferred/(HP × hr)] are 2–4 for most surface aerators, although values as high as 7 are reported. Transfer efficiency remains essentially constant at an optimum submergence regardless of size of the unit.

For design of surface aerator systems, standard transfer efficiency N_0 obtained from Fig. 4.17, for example, is corrected for actual wastewater conditions and temperature. This is done by application of the following relationship [1]:

$$N = N_0 \left[\frac{C_{SW} - C_L}{9.2} \times 1.024^{(T - 20)\alpha} \right] \quad (4.34)$$

where N is the oxygen-transfer efficiency under field conditions [lb O_2 /(HP × hr)]; N_0 the oxygen-transfer efficiency at standard conditions [tap water at 20°C with initial zero dissolved oxygen at atmospheric pressure; lb O_2 /(HP × hr)]; C_{SW} the saturation concentration of dissolved oxygen in the wastewater; C_L the operating DO level in aeration basin; T the temperature of the basin (°C); and $\alpha = K_L a$ (wastewater)/ $K_L a$ (tap water).

In Eq. (4.34), $C_{SW} - C_L$ is the actual driving force for oxygen transfer under field conditions. Driving force at standard conditions with initial zero dissolved oxygen is $9.2 - 0.0 = 9.2$, where 9.2 is the oxygen saturation value at 20°C in mg/liter (Table 4.1). Thus, in Eq. (4.34) a proportionality between N and N_0 and the corresponding driving forces is assumed.

16.3. DESIGN PROCEDURE FOR AERATION SYSTEMS UTILIZING SURFACE AERATION UNITS

For fundamental information required see items 1–5 for air diffusion units (Section 14.4). Obtain characteristics for the aerator. This includes (1) correlation of N_0 vs. HP/1000 gal, and (2) correlation between unit horsepower and diameter of influence for solids in suspension (ft).

For the specific design illustrated by Example 4.5, these two correlations are presented in Fig. 4.17. Depths of aerator basins for surface aerators are usually lower than for diffusion or turbine aeration, ranging from 8 to 12 ft.

Step 1. Take Eq. (4.34) and calculate the term between brackets for summer and winter conditions to determine which is the controlling one. Note that $[C_{SW}]_{\text{summer}} < [C_{SW}]_{\text{winter}}$ [thus $(C_{SW} - C_L)$ is larger for the winter conditions] whereas $T_{\text{summer}} > T_{\text{winter}}$ [thus $1.024^{(T - 20)}$ is larger for summer

conditions]. Let the results of this calculation be

$$N = K_{\text{summer}} \times N_0 \quad (4.35)$$

$$N = K_{\text{winter}} \times N_0 \quad (4.36)$$

where K 's are values of the term between brackets in Eq. (4.34). The lower K corresponds to controlling condition (lower transfer of oxygen).

Step 2. Since power level (abscissa of Fig. 4.17) is not known, a trial and error solution is necessary for determination of N_0 (and N) based on correlation of N_0 vs. power level.

- (1) Assume a power level HP/1000 gal.
- (2) From Fig. 4.17 read N_0 .
- (3) Calculate N from Eq. (4.35) [or Eq. (4.36)], whichever is the controlling one.
- (4) Power requirements are calculated for assumed power level from

$$\text{Power requirements} = \frac{\text{O}_2 \text{ required (lb O}_2\text{/hr)}}{N \text{ (lb O}_2\text{/HP} \times \text{hr)}} = \text{HP}$$

where the oxygen requirement has been previously calculated from biological reactor requirements (item 2 on "Fundamental information required," Section 14.4)

- (5) Select HP per unit and calculate number of units.
- (6) Recalculate power level.

$$\text{Power level} = \text{HP [Step 2(4)]/volume of aeration basin}$$

where volume of the aeration basin is calculated from biological reactor requirements (item 1 on "Fundamental information required," Section 14.4). Express recalculated power level in terms of HP/1000 gal and compare it with the value assumed in Step 2(1). If agreement is within 5%, calculations are stopped. Otherwise, iterate Steps 2(1)–(6) until agreement is obtained.

Step 3. Spacing between agitators is determined from the correlation indicated in Fig. 4.17. The procedure for the aerator basin layout is illustrated in Example 4.5.

Example 4.5

Surface aerators are specified for an activated sludge plant treating an industrial wastewater. Oxygen requirements and volume of the biological reactor are calculated by the procedure described in Chapter 5, Section 7 (Example 5.7), yielding the following results.

Oxygen requirements: 665 lb O₂/hr

Volume of reactor: 1,200,000 gal

The following additional information is available.

Wastewater temperature (summer): 30°C, $C_{SW} = 7.4$ mg/liter

Wastewater temperature (winter): 18°C, $C_{SW} = 10.3$ mg/liter

Take the operating DO level at the basin as $C_L = 1.0$ mg/liter, and $\alpha = 0.72$.

Characteristics of the surface aerator selected are given by Fig. 4.17. Design the aeration system for this application.

SOLUTION

Step 1. Utilize Eq. (4.34).

Summer: $t = 30^\circ\text{C}$, $C_{SW} = 7.4$ mg/liter

Winter: $t = 18^\circ\text{C}$, $C_{SW} = 10.3$ mg/liter

Thus for summer conditions

$$N = N_0 \left[\frac{7.4 - 1.0}{9.2} \times 0.72 \times 1.024^{(30 - 20)} \right] = 0.635 N_0$$

and for winter conditions

$$N = N_0 \left[\frac{10.3 - 1.0}{9.2} \times 0.72 \times 1.024^{(18 - 20)} \right] = 0.694 N_0$$

Therefore, summer conditions control design (*lower* oxygen-transfer efficiency).

Step 2.

- (1) Assume a power level, e.g., 0.25 HP/1000 gal.
- (2) From Fig. 4.17 read $N_0 = 3.5$ lb O₂/(HP × hr).
- (3) Then $N = 0.635$; $N_0 = 0.635 \times 3.5 = 2.22$ lb O₂/(HP × hr).
- (4) Power requirements are then calculated.

Oxygen requirement: 665 lb O₂/hr

Power requirements: 665 lb O₂/hr × (HP × hr) / 2.22 lb O₂ = 299.5 HP

- (5) Select six units of 50 HP each (total HP = 6 × 50 = 300 HP).
- (6) Power level is then

$$300 \text{ HP}/1200 \text{ thousands of gal} = 0.25 \text{ HP}/1000 \text{ gal}$$

which agrees with assumed value. Thus design is satisfactory.

Step 3. Diameter of influence for 50 HP units (see Fig. 4.17) is 60 ft (or radius of influence of 30 ft). Spacing distance of 56 ft is selected to provide a minimum overlap. Arrange aerators according to layout in Fig. 4.18.

Cross-sectional area of the basin is $168 \times 112 = 18,816$ ft², and its volume in ft³ is

$$1,200,000 \text{ gal} \times \text{ft}^3/7.48 \text{ gal} = 161,000 \text{ ft}^3$$

Therefore depth is

$$161,000/18,816 = 8.6 \text{ ft}$$

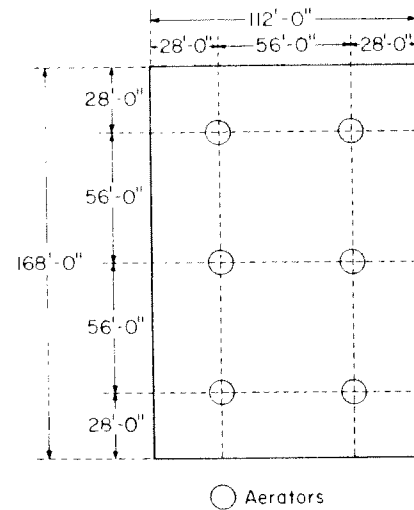


Fig. 4.18. Layout of aerator tank (Example 4.5).

Several selections of aerator units are possible for a given application, leading to various layouts. Engineering judgment and economic considerations determine final selection of aerator units and their layout.

Problems

I. The following results are obtained in an unsteady state aeration test utilizing a 5-HP surface aerator. $C_s = 9.2$ ppm (measured at 20°C; $P = 27$ in Hg). Aerator is a 100,000-gal circular test tank.

Time (min)	C_L (ppm)
0	0
12	2.6
24	4.5
36	5.8
48	6.7
60	7.4

Calculate

- Chemical requirements (lb Na_2SO_3 /lb liquor) for deoxygenation of test water with 8 ppm of DO
- Value of $K_L a$ (hr^{-1})
- If aeration tank has a capacity of 100,000 gal, calculate the lb/hr of oxygen transferred at standard conditions

4. If aerator has a nominal HP of 5, report aerator efficiency [$\text{lb O}_2/(\text{hr})(\text{HP})$] in terms of nameplate HP and blade HP.

The following information is available for the aerator:

Drawn voltage: 220 V (average)

Amperage: 13.5 A (average)

cos PF (measured): 0.8

Motor efficiency (estimated): 85%

Gear efficiency (estimated): 85%

II. Unsteady state aeration data is obtained in a diffused aerator system for water at 6.5°C and a wastewater at 0°C, and is tabulated below. Calculate coefficient α (at 20°C).

TABLE 1a
Water at 6.5°C, $C_s = 12.3$ mg/liter

Time (min)	C_L (mg/liter)
3	0.6
6	1.6
9	3.1
12	4.3
15	5.4
18	6.0
21	7.0

TABLE 1b
Wastewater at 0°C, $C_s = 14.3$ mg/liter

Time (min)	C_L (mg/liter)
3	0.9
6	1.7
9	2.5
12	3.2
15	3.9
18	4.6
21	5.2

III. A turbine aerator in an aeration tank $30 \times 50 \times 15$ ft transfers oxygen according to the relationship

$$K_L a V = 25G^{0.45} S^{1.5} D^{1.8} \quad (\text{ft}^3/\text{hr})$$

where $K_L a$ is in liter/hr; V is the tank volume (ft^3); G , the air flow (SCFM); S the peripheral speed of impeller (ft/sec); and D the impeller diameter (ft). Power drawn by the turbine is defined by the relationship

$$HP_r = 0.02D^{5.25}n^{2.75}$$

where D is the impeller diameter (ft) and n the revolutions/sec of rotor. For calculation of compressor horsepower, take a pressure drop of 5.55 psi and an efficiency $e_m = 0.65$ (65%).

1. Compute $K_L a$ (hr^{-1}). Turbine is 40 in. in diameter, rotating at 15 ft/sec peripheral speed, with an air flow of 300 SCFM.
2. Calculate O_2 transfer (lb/hr) under standard conditions. Saturation solubility of oxygen in the sewage liquid at 20°C is 8.45 ppm.
3. Calculate turbine horsepower corrected from Fig. 4.13.
4. Calculate blower horsepower.
5. Calculate transfer efficiency in terms of lb of O_2 transferred per $\text{HP} \times \text{hr}$.

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