Oxygen Transfer and Liquid Mixing Performances of an Air-Lift Reactor

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The oxygen transfer capacity and the mixing time of an air-lift reactor have been investigated by using a cylindrical tank of 0.5 m diameter with a vertical cylindrical draft tube and a single circular orifice. The oxygen transfer capacity is found to depend strongly on the orifice size and the sparging power per unit volume of liquid content and less on the geometric configuration of the draft tube. The mixing time, however, is appreciably influenced by the draft tube design. The optimum conditions for the present air-lift reactor design were obtained with respect to both the oxygen transfer and the mixing time characteristics.

1. Introduction

Air-lift reactors have been used in quite a number of industrial processes; fermentation, waste water treatment, hydrometallurgy and so on. This type of reactors has several unique advantages in simple design, easiness of scale-up procedure and the resulting low cost of design, fabrication and operation. In spite of the fact that the air-lift reactors generally provide a relatively mild mixing and then vigorous agitation as occurred frequently in the conventional stirred tanks is hardly procured, a suitable choice of design and operating variables makes the air-lift reactor competitive with or more excellent than the conventional gas-liquid reactors with mechanical agitation. Typical designs of air-lift reactors are shown in Fig. 1.

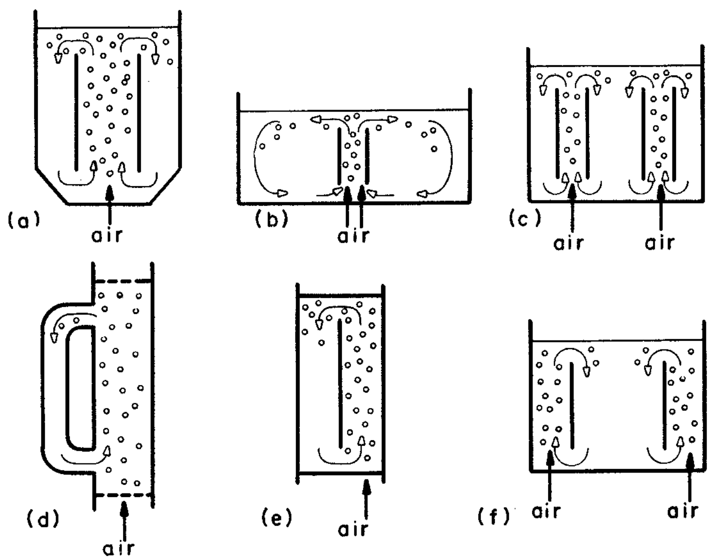

Fig. 1 Various types of air-lift equipment

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In the present paper, we have examined the performance of the air-lift reactor with a simple circular draft tube (type (a) of Fig. 1) in order to apply this reactor to large scale aeration processes such as water purification of lake or reservoirs, and large scale liquid blending. The oxygen transfer and the liquid mixing characteristics of the air-lift reactor have been experimentally investigated.

2. Experimental

The schematic diagram of the experimental apparatus is shown in Fig. 2. A cylindrical vessel of 0.5 m (diameter)×0.75 m (height) is used. Air was sparged into the vessel through a single orifice at the center of the tank bottom. The inside diameter of the air sparger (d_n), the length (L) and diameter (D_d) of the draft tube, the air flow rate (Q) and the liquid depth (Z) were varied and the effects of these variables on the rate of oxygen transfer and the mixing time were studied. The equipment geometry and the operating variables are listed in Table 1.

Pure water was used throughout the present experiments. After the liquid

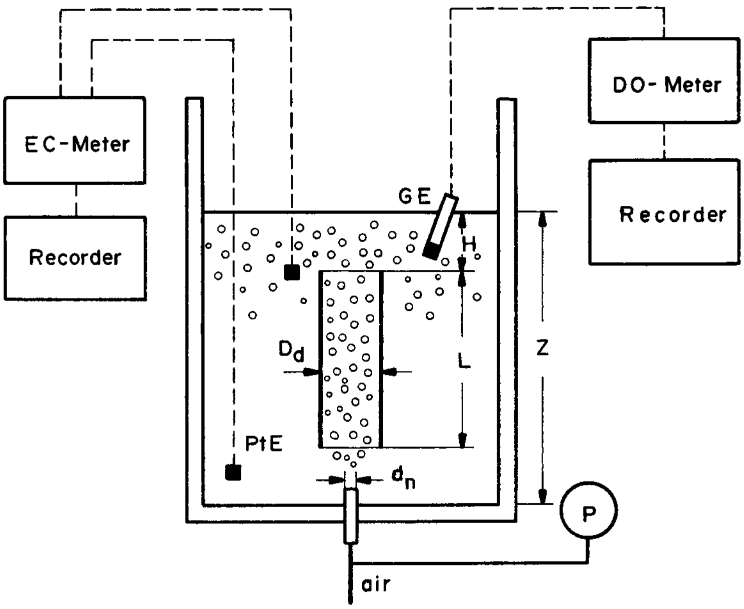

Fig. 2 Schematic diagram of experimental apparatus
GE: galvanic electrode, PtE: platinum electrode,
P: Bourdon-tube pressure gage

Table 1 Experimental conditions

Tank inside diameter, D_i	0.50 (m)
Liquid depth, Z	0.25, 0.50 (m)
Draft tube diameter, D_d	0.05, 0.08, 0.14 (m)
Draft tube length, L	0.15, 0.19, 0.30, 0.40 (m)
Setting height of draft tube, H	0.05, 0.15, 0.25 (m)
Air flow rate, Q	$0.082-0.78\times10^{-3}$ (m³/sec)

in the tank had been deoxygenated by passing nitrogen gas, the gas to the tank was replaced with air and then the dissolved oxygen concentration change with time was continuously measured by a DO meter with a galvanic electrode. The probe response time (the time required to reach 63.2% of a steady state value) was about 3 seconds, which does not cause an appreciable error in determining the true value of the volumetric mass transfer coefficient, *Ka*, in the present study[1].

Assuming perfect mixing in the liquid phase, we obtain the simple mass balance equation as follows:

$$V\frac{\mathrm{d}C(t)}{\mathrm{d}t}=Ka\,V\,\{C^*-C(t)\} \tag{1}$$

Integration of Eqn. (1) with the initial concentration C_0 yields the volumetric mass transfer coefficient *Ka*:

$$Ka=\frac{1}{t}\ln\left\{\frac{C^*-C_0}{C^*-C(t)}\right\} \tag{2}$$

The oxygen concentration change with time in the air-lift reactor is relatively slow while excellent liquid circulation throughout the tank is formed. Therefore the perfect mixing with respect to the liquid flow pattern is a valid assumption for the present air-lift reactor.

The mixing time required to achieve a state of homogeneity was determined by following the NaCl concentration fluctuation in the air-lift reactor after impulsive injection of a small amount of NaCl solution (1–5 cm^3). The mixing time in the present study is defined as the time for the concentration deviation to become less than 5% of the steady state concentration.

The power consumption was calculated by measuring the air flow rate and the pressure at the orifice. The power was calculated by using Eq. (3), assuming an isentropic expansion of air through the orifice.

$$P=2.42\times10^{-5}\frac{T_1 Q\gamma}{\gamma-1}\left\{\left(\frac{p_2}{p_1}\right)^{\gamma-1/\gamma}-1\right\} \tag{3}$$

where T_1=temperature of air after the orifice, which is assumed to be the same as liquid temperature, Q=volumetric air flow rate, γ=specific heat ratio of air=1.395 and p_1=pressure at the outlet of the vessel and p_2=pressure of air upstream from the orifice.

3. Results and Discussion

3.1 Oxygen transfer capacity

The effects of the length, *L*, inside diameter, D_d, and the setting position of the draft tube, *H*, on the oxygen tiansfer coefficient, *Ka*, have been tested and it was found that mass transfer in the air-lift reactor is hardly affected by each factor within the present experimental conditions summarized in Table 1. However, the effect of the orifice diameter, d_n, on the oxygen transfer rate is appreciable as shown in Fig. 3. It is expected that the oxygen transfer rate may be enhanced by

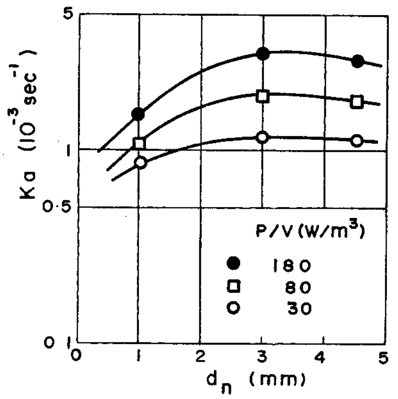

Fig. 3 Effect of nozzle diameter on the overall volumetric mass transfer coefficient

using a small sized orifice which generates the small bubbles and the resulting increase in the gas-liquid interfacial area. However, this is not the case for the present air-lift reactor. On the contrary, the small bubbles impede liquid turbulence due to less rising velocity of bubbles and a remarkable increase in the pressure loss at the orifice deteriorates the efficiency of mass transfer of the air-lift reactor with a small sized orifice. When the orifice is large, on the other hand, the bubble sizes become large and thus the interfacial area between gas and liquid is decreosed, despite the less power for sparging. Therefore, it is necessary to find an optimum orifice size for oxygen transfer in the air-lift reactor. In the present tank, we have obtained the optimum orifice size of about 0.3 cm.

The effect of liquid depth, Z, on the mass transfer coefficient, Ka, is shown in Fig. 4, where the horizontal axis means the power consumption per unit volume of liquid content. This correlation of Ka in terms of P/V has been frequently utilized for evaluation of the mass transfer efficiency of multi-phase reactors[2,3,4]. As can be seen, the power per volume, P/V, is an excellent parameter to correlate the mass transfer coefficient Ka in the air-lift reactor except in the range of large P/V level. The aim of this report is to examine the applicability of the air-lift

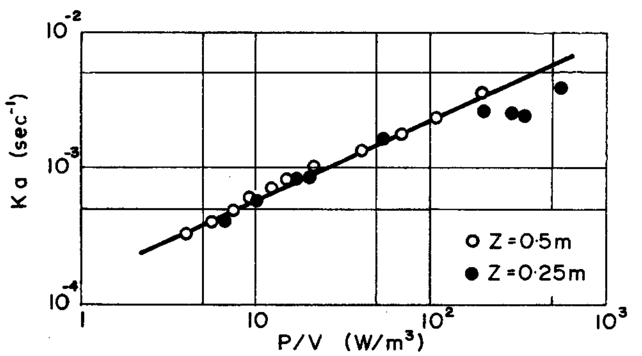

Fig. 4 Effect of power consumption per unit volume of content on the overall volumetric mass transfer coefficient; D_a=8 cm, H=5 cm, L=15 cm, —— Eq. (4)

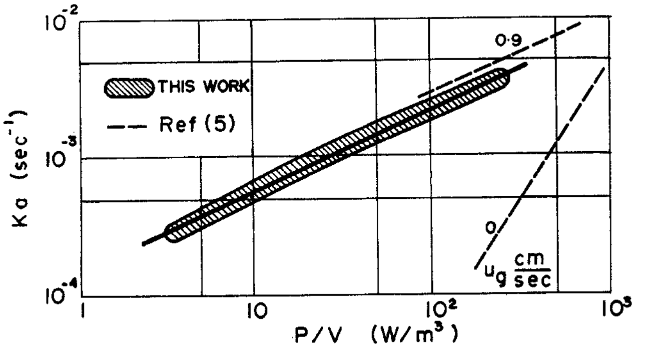

Fig. 5 *Ka* correlation for the air-lift reactor in terms of P/V; L=15–40 cm, H=5–25 cm, D_d=4–15 cm, d_a=0.3 cm, —— Eq. (4)

reactor to water purification in the large-sized vessels, lakes or reservoirs. In these practical operations, lower power level is usually preferable in order to enjoy the advantage of a high oxygen transfer capability for good power economy of air-lift reactors. Therefore, it can be concluded that the conventional correlation of *Ka* with P/V may be utilized for the air-lift reactor unless the P/V level becomes larger than about 200 W/m³. Figure 5 shows the typical correlation of the volumetric mass transfer coefficient *Ka* and the power per volume P/V. In this figure, the data of the conventional stirred tank reactor with a 6-blade flat disk turbine are also plotted for comparison; only the power for rotating the turbine is considered to evaluate P/V for the stirred tank and the gas sparging power is neglected. As can be seen from this figure, the air-lift reactor with an optimum orifice geometry is competitive with the conventional stirred tank for gas-liquid mass transfer with the respect to the mass transfer efficiency. The volumetric mass transfer coefficients for the air-lift reactor with an optimum orifice geometry (d_n=3 mm) have been correlated in terms of P/V by the following relationship:

$$Ka = 1.5\times10^{-4}(P/V)^{0.57} \quad (4)$$

The oxygen transfer capacity of the air-lift reactor used in the present study is compared with that for the other types of aeration equipment in Table 2[1]. The maximum capacity of the oxygen transfer of the air-lift reactor is 2.5 kg (O_2)/kWhr,

Table 2 Oxygen transfer capacity for various types of aeration equipment

Equipment	M_t (kg(O_2)/kWhr)
Small bubble size disperger	1.36–1.8
Large bubble size disperger	0.98
Turbine agitator	1.20–1.38
Surface aeration by mechanical agitation	1.68
Deep shaft aerator	3–6
Gas jet aerator	1.64
Eddy jet mixer	4.78
Impinging jet mixer	3.9
Air lift (Present work)	2.5

which is competitive with the other conventional aerators.

3.2 Mixing time

Typical response curves of the tracer concentration in the air-lift reactor with and without a draft tube are compared in Fig. 6. The trend of the curve with the draft tube shows clearly the liquid circulation flow throughout the tank, while it is not clear in the simple mixing tank without a draft tube. This finding shows that the draft tube in an air-lift reactor plays a very important role to circulate the liquid content throughout the tank.

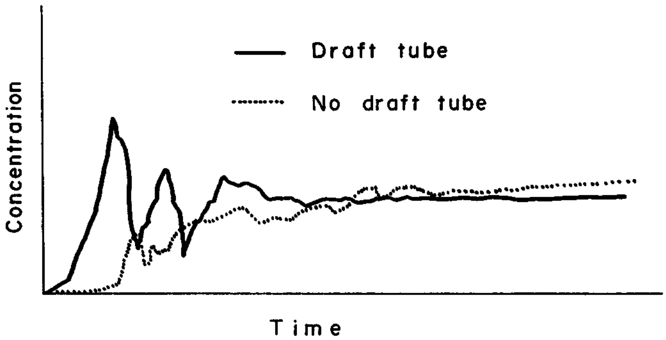

Fig. 6 Typical response curves for mixing time measurement

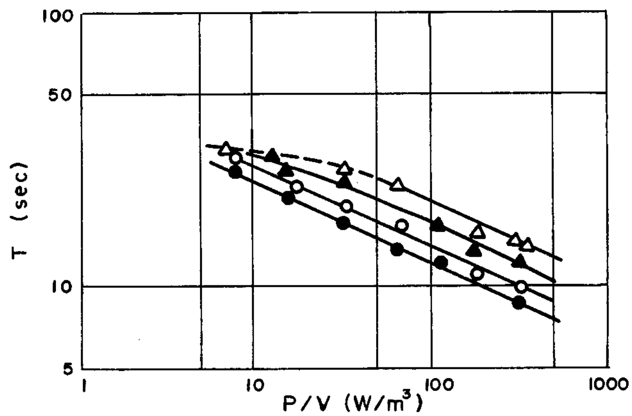

Fig. 7 Effect of P/V on mixing time T; L=30 cm, △=no draft tube, ▲=D_d/D_i=0.10, ○=0.16, ●=0.28

The effect of the inside diameter of the draft tube, D_d, on the mixing time, T, is shown in Fig. 7. As can be seen from this figure, the mixing time becomes shorter with the draft tube diameter, and the time is markedly decreased by using the draft tube. It is also found that the mixing time is proportional to the power consumption per unit volume with an exponent of about $-1/3$. This is a similar relationship obtained in conventional stirred tanks[2]. In general, the size of the draft tube in the air-lift reactor should be so determined that the cross sectional area of the tube may be half of the vessel cross sectional area in order to reduce the dead zone and to enhance the liquid flow throughout the tank. However, this design for the draft tube can not be attained actually in a large-sized air-lift reactor, in which many units of air-lift element con be distributed over a wide range of the reactor. The chart for T vs. P/V relation as shown in Fig. 7 will be useful to determine the number of units of air-lift reactor and to estimate the mixing time of the large-sized water purification problems.

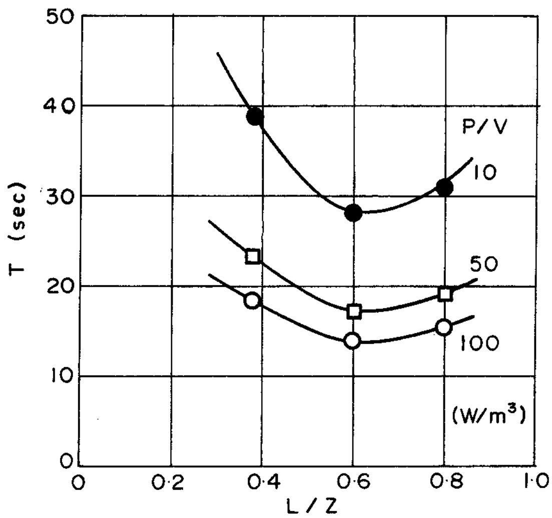

Fig. 8 Effect of draft tube length on mixing time

Figure 8 shows the effect of the length of the draft tube on the mixing time. As can be seen, the optimum length of the draft tube with respect to the mixing time is about $L/Z=0.60$.

The effect of setting height of the draft tube, H, on the mixing time was not appreciable if the length of the tube (L/Z) is larger than about 0.60. For the shorter draft tubes, higher setting position was preferable to a lower position.

4. Conclusion

The oxygen transfer and the liquid mixing characteristics of the air-lift reactor with a simple cylindrical draft tube have been investigated by using a 0.5 m cylindrical vessel with the air-water system.

The oxygen transfer capacity was appreciably influenced by the orifice size and the sparging power per unit volume of the liquid content. The optimum orifice size was to be 0.3 cm in the present air-lift reactor. The oxygen transfer capacity of the air-lift reactor was competitive with conventional aeration equipments.

The mixing time of the air-lift aerator was influenced mainly by the draft tube design and the gas flow rate. The mixing time was remarkably reduced by using the draft tube. The optimum length for the draft tube with respect to the mixing time was $L/Z=0.6$. The mixing time in the air-lift reactor was proportional to the power consumption per unit volume with an exponent of $-1/3$. This is a similar relationship obtained in conventional stirred tanks.

Nomenclature

a	interfacial area per unit volume, m^2/m^3
$C(t)$	oxygen concentration, mol/m^3
C^*	equilibrium concentration of oxygen, mol/m^3
C_0	initial oxygen concentration, mol/m^3
d_n	diameter of the orifice, m
D_d	diameter of the draft tube, m
D_i	inside diameter of the tank, m
H	setting height of the draft tube, m
K	overall mass transfer coefficient, m/sec
Ka	overall volumetric mass transfer coefficient, 1/sec
L	length of the draft tube, m
M_t	oxygen transfer capacity, kg (O_2)/kWhr
P	power consumption for gas sparging, W
p_1	pressure at the vessel outlet, Torr
p_2	pressure of air upstream from the orifice, Torr
Q	volumetric air flow rate, m^3/sec
T	mixing time, sec
T_1	temperature, K
U_g	gas superficial velocity, m/sec
V	effective volume of the tank, m^3
Z	liquid depth in the tank, m

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