A Study on Oxygen Dissolution by Air Lift Pump

기포 펌프에 의한 산소 용해에 관한 연구

S. K. Oh
오 세 경

Key Words : Aeration(기포 혼입), Air Lift Pump(기포 펌프), Slug Flow(슬러그 흐름), Oxygen Transfer Coefficient(산소 전달 계수)

요 약 : 기포 펌프는 물과 공기 사이의 접촉 면적을 증가시켜 공기로부터 물로의 산소 용해를 높이는 기능을 가지고 있다. 이 연구에서는 기포 펌프에서 여러 가지 흐름 패턴을 설정하고, 이것을 근거로 하여 슬립모델을 확립하여, 기포 펌프의 산소 용해 특성을 조사하였다. 이 연구에서 수행한 실험 결과로부터, 산소 전달 계수는 흐름 패턴(기포 흐름, 기포-슬러그 흐름, 슬러그 흐름)에는 상당한 영향을 받았으나, 시료수의 오염 정도에 따른 영향은 그다지 크지 않음을 확인하였다. 그리고, 산소 전달양은 레이놀즈 수에 비례하여 증가하며, 산소 전달면을 증가시키기 위해서는 에어 스톤이나 디퓨저의 이용이 매우 효과적임을 확인하였다. 또한, 표면 활성 물질은 물의 오염 정도나 흐름 패턴에 관계없이 산소 전달에 큰 영향을 미침을 알 수 있었다.

1. Introduction

The air lift pump is mostly used in the aquaculture industry and a waste water disposal plant of culture pond dealt with pumping a great amount of water. A typical pump is illustrated in Fig. 1.

Pumping of fluid occurs as a result of the buoyant force generated by the air entrained in the fluid. The hydrodynamics of the air lift pump were described previously[1]. Several studies[2] have been done documenting the properties of air lift pumps in particular application over the narrow range of flow conditions, but these results can not be applied to air lift pumps of arbitrary geometry that are of concern in the aquacultural application.

The transfer of oxygen and the other major atmospheric gases are actually of concern in aquacultural applications[3]. The objective of this study is to research the prediction of oxygen transfer rate typically encountered in air lift pumping and to use more advanced performance of air lift pump in the aquaculture industry.

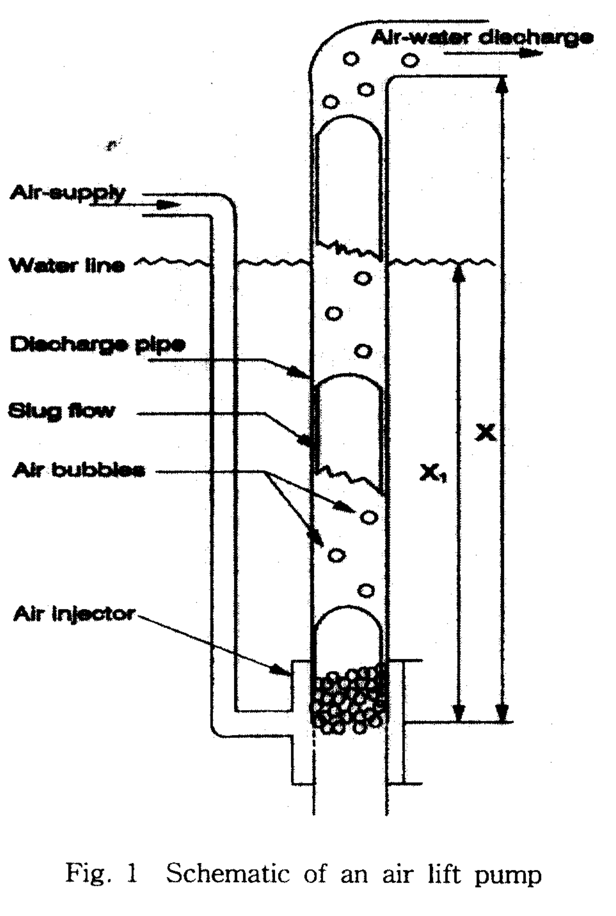

Fig. 1 Schematic of an air lift pump

접수일 : 1999년 8월 16일
오세경 : 경상대학교 기관공학과, 해양산업연구소

2. Theory

The dissolution of a gas in a liquid involves four separate physical steps. Each of which has the potential of being rate limiting. A definition sketch for the transfer process is given in Fig. 2. Gas molecules must first move from the bulk gas phase to the interface between gas and liquid. Gas molecules must then diffuse through a laminar gas and liquid film before entering the bulk liquid phase. Under normal condition, the primary resistance to gas transfer occurs during one of the two diffusion steps. Gases with high solubility, such as ammonia, are restricted in movement by the gas film. Oxygen, nitrogen, and other gases with low solubility encounter with primary resistance in liquid film. In this latter case, the rate of transfer is in a proportion to the difference between existing and saturation concentrations of gas in solution. In differential form, the relationship is expressed as:

$$dC/dt = \frac{D}{\Delta}\frac{A}{V}(C_s - C) \quad (1)$$

Gases may be removed from solution (dC/dt) in those applications in which C is greater than C_s. Gas transfer can be accelerated by reducing liquid film thickness(Δ) and by increasing the surface area(A) through which the gas can be diffused. Because it is difficult to measure A and Δ, the ratios A/V and D/Δ often are combined to establish an overall transfer coefficient, K_La, i. e.,

$$\frac{dC}{dt} = K_La(C_s - C) \quad (2)$$

$$K_La = \frac{(\ln D_1 - \ln D_2)}{t_2 - t_1} \quad (3)$$

The overall transfer coefficient reflects conditions present in a specific gas-liquid contact system. Important variables include the test basin geometry, turbulence, characteristics of the liquid, extent of the gas-liquid interface, and temperature. Temperature affects the viscosity which, in turn, influence D, Δ and A.

The quantity $C_s - C$ in Eq. (2) means the difference between the saturation concentration and the actual concentration at any moment. This is a measure of the driving gradient attempting to add oxygen to the system.

K_La often is expressed as grams of oxygen transferred per hour. A plot of the natural logarithms of D against time for a thoroughly mixed body of water gives a straight line for which K_La is the slope, as calculated from dissolved oxygen profiles for a less than thoroughly mixed body of water (Fig. 3).

In the normal temperature(20℃), the transfer coefficient value of a certain gas was usually given as a function of pipe

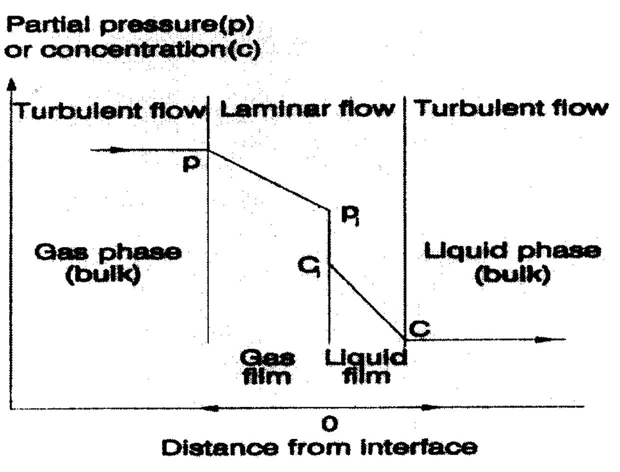

Fig. 2 Definition of the four step gas transfer process

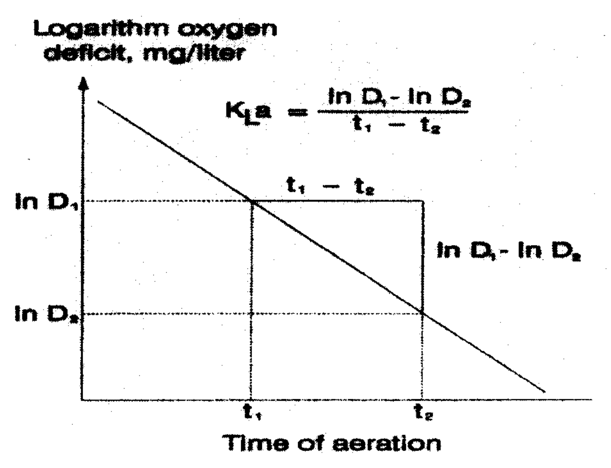

Fig. 3 Graphical illustration of the method for determining the transfer coefficient

Reynoldsnumber for two phase flow[4]. The transitional value according to temperature was shown as the following:

$$K_La = K_La^* \theta^{(T-20)} \quad (4)$$

air lift riser oxygen transfer coefficient at 20℃, K_La^* was shown as the following[5]:

$$K_La^* = 6.5 \times 10^{-6} Re \quad (5)$$

$$Re = \frac{v_m D}{\nu} \quad (6)$$

In the air lift pump, oxygen transfer coefficient depends on flow velocity and type of bubble that is concerned with Reynolds number.

3. Materials and method in experiment

A model slip of the air lift pump was built and illustrated in Fig. 4. The pump was constructed of the pipe with the replaceable pumps (5.08, 7.62, 10.16 and 15.24cm inside diameter). To test the aeration of air lift pump, the probe of oxygen meter was placed at depth of 38.1cm in a water tank. The discharge center of all pumps was placed 7.62cm above the water surface.

A blower with 1 PS capacity was used to operate each air lift pump. The blower was operated with a limited speed. The relief valve regulated the air volume. Air pressure was measured at the inlet of the air lift pumps. The portable air velocity meter (OMEGA HA-30) was a precision micro-processor based anemometer system. The HA-30 was capable of 0.5% of reading accuracy over an exceptionally wide 0.18~37m/s range.

Water was deoxidized with sodium sulfite and cobalt chloride for two minute interval, and DO (dissolved oxygen) in water was measured by using the oxygen meter (ISI, Model 54). Cobalt chloride catalyzed the reaction between sodium sulfite and oxygen. Sodium sulfite removed oxygen according to the following relation.

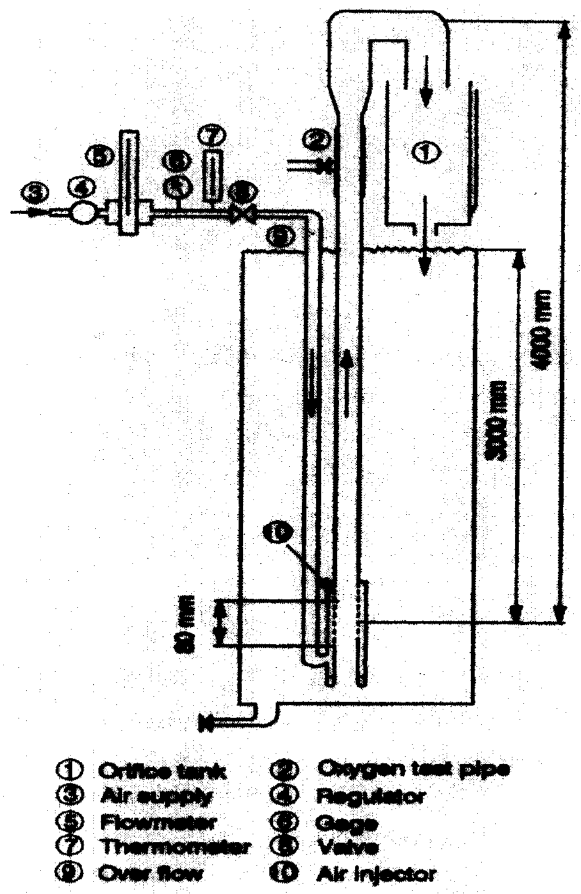

Fig. 4 Arrangement of the test apparatus

$$Na_2SO_3 + \frac{1}{2} O_2 = Na_2SO_4 \quad (7)$$

(Cobalt Chloride : 2.25 mg/L×3240 L = 810 mg = 0.81 g)

(Sodium Sulfite : 10 mg/L×water L×oxygen ppm = 10×3240×4.5 = 125 g)

Water quality parameters were determined by standard analytic techniques at Dept. of Marine Food Science and Technology Lab., the Gyeong-sang National University (Table 1).

The waste water of the culture pond was left still for 5 days in a closed container to allow the resident BOD (biochemical oxygen demand) to reduce the dissolved oxygen level. Then, oxygen was eliminated by sodium sulfite and cobalt which was an enzyme.

The tap water and the pond waste water were given to find out the process of oxygen transfer when the water went through the air lift pump.

To find out the oxygen transfer efficiency of air lift pump, the oxygen-free water was supplied into the aquarium. And then, the air was given by a blower. Air and water temperatures and barometer pressure were recorded for each trial. Air flow and water flow rates were recorded and held constant throughout each trial.

Then, using YSI model 55, oxygen concentration was measured at every 30 seconds until it reached unchanging value. This stabilized value of the oxygen concentration was taken as the effective average equilibrium dissolved oxygen concentration.

It required an increasing amount of time to dissolve a unit of oxygen the closer the oxygen concentration approached saturation. This characteristic made it impractical and uneconomical to raise the oxygen concentration of water much above 95% saturation by aeration,

Table 1 Water quality

Parameter	Tap water	Waste water
pH	7.8	6.9
BOD(mg/l)	0.0	59.8
Suspended solids(mg/l)	0.0	102.5
Conductivity(μmho/cm)	367.0	1,350.0
Chloride(mg/l)	12.8	42.5

4. Results and discussion

Points representing 10% and 70% of saturation were located on the line and the oxygen-transfer coefficient was computed as follows:

$$(K_L\,a)_T = \frac{\ln(C_s - C_{10}) - \ln(C_s - C_{70})}{(t_{70} - t_{10})/60}$$

$$= \frac{\ln(DOdeficit_{10}) - \ln(DOdeficit_{70})}{(t_{70} - t_{10})/60} \quad (8)$$

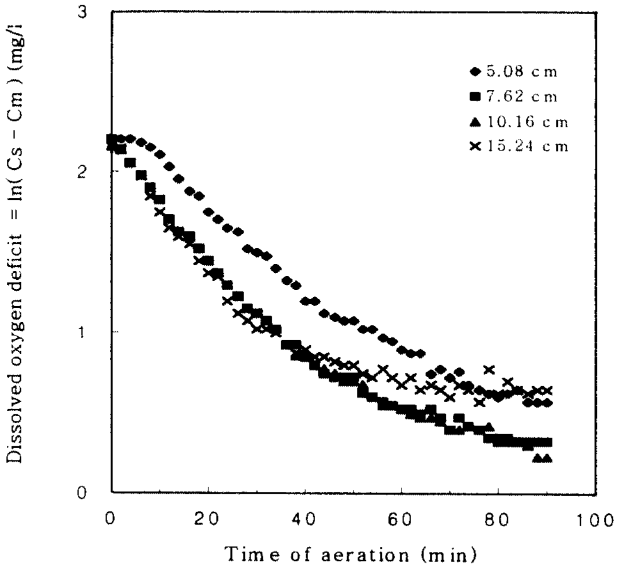

Fig. 5 Relationship between dissolved oxygen deficit and time of aeration

Oxygen transfer test of air lift pumps was done by comparing with logarithm oxygen deficit[ln(C_s-C_m)], vs. time of aeration (Fig. 5).

Oxygen transfer coefficient of the air lift pump was measured at the normal temperature(20℃). The analysis of the standard temperature oxygen transfer coefficients as a function of the pipe Reynolds number showed no significant difference between water types. But, in the matter of laminar flow (Re < 2,320), the difference between bubble flow tap water (●) and bubble flow waste water(△) could be

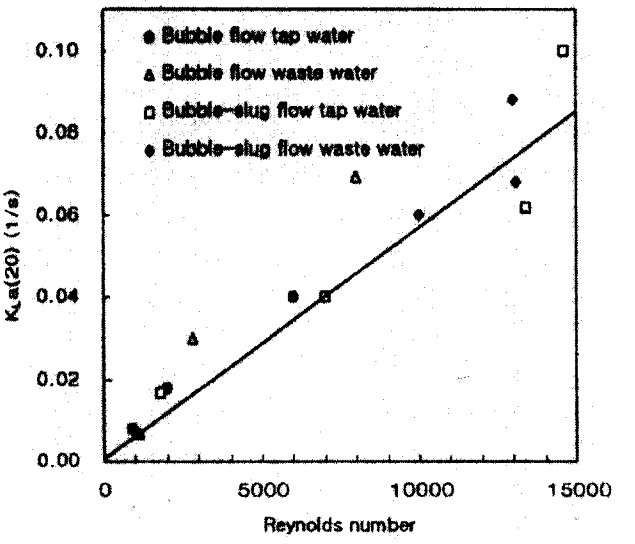

Fig. 6 Correlation between oxygen transfer coefficient and Reynolds number

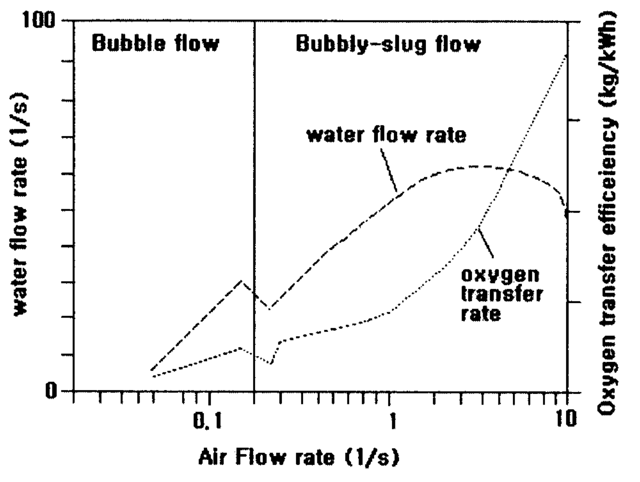

Fig. 7 Air lift pumping and aeration performance

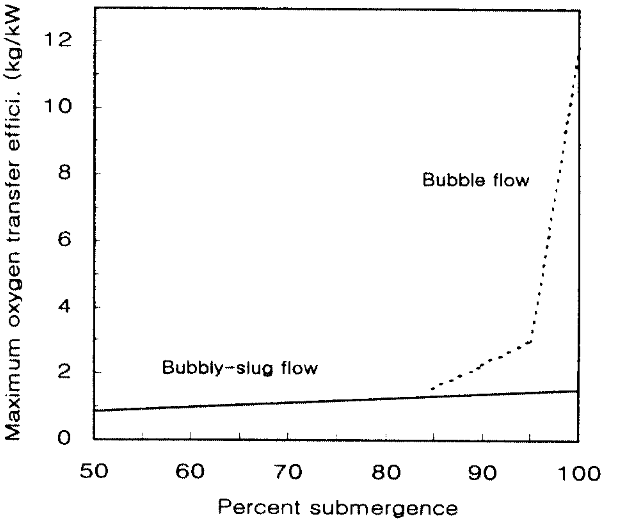

Fig. 8 Maximum oxygen transfer efficiency versus submergence ratio

neglected, in the matter of turbulent flow ($Re > 2{,}320$), the difference between bubbly-slug flow, tap water(□) and bubbly-slug flow, waste water(◆) could not be neglected (Fig. 6).

In this research, the oxygen transfer coefficient was greatly influenced by Reynolds number. It was supposed that contact area became more wide and air moving done actively because flow pattern in the pipes became the turbulence condition.

Fig. 7 showed the performance characteristics of the air lift pumping and the aeration system. In this example, the diffuser produced air bubbles in the air flow rate of less than 0.2 l/s. When air flow rate exceeded 0.2 l/s, the breakdown and cohesion of air bubble occurred, and ultimately resulted the slug flow. In the airflow, the change of bubble flow to slug flow was greatly affected by the gas flow ratio, submergence ratio, and input oxygen concentration in the tube.

The bubble flow occurred when the submergence ratio was more than 85% and the gas flow was dropped (Fig. 8). But the maximum gas transfer efficiency and the maximum pumping efficiency had taken a place in the bubble flow area which had an active fluid flow. In the bubble flow area, the maximum oxygen transfer efficiencies of air lift pump were slightly higher than those of diffused aeration system which was experimented by Colt & Tchobanolglous[6], and they were about the same as those of U-tube aerator.

5. Conclusions

Present study focused the transfer characteristics of oxygen using the slip models based on the slug flow in the various flow patterns of air lift pump. Experimental results were obtained as follows:

1) The oxygen transfer coefficient was not significantly affected by either waste water or tap water, but was affected by flow pattern (bubble flow, bubble-slug flow, and slug flow), and the surface active substances in the water influenced on the transition process.
2) The oxygen transfer coefficient was increased in a proportion to Reynolds number, and the effective oxygen transfer area was increased by breaking the air bubbles up into small particles.
3) It was impractical and uneconomical to raise the oxygen concentration of water much above 95% saturation by aeration.

References

1. D. J. Reinmann, "A Theoretical and Experimental Study of Air Lift Pumping and

Aeration with Reference to Aquacultural Applications", Ph. D. thesis, Cornell University, Ithaca, New York, 1987
2. P. Zielinski, W. E. Castro and P.A. Sandifer, "Engineering Considerations in the Aquaculture of Macrobachium Rosenbergii in South Carolina", Trans. ASAE, Vol. 21, pp. 391~94, 1978
3. J. E. Colt and H. Westers, "Production of Gas Supersaturation by Aeration", Trans. American Fisheries Society, Vol. 111, pp. 342~60, 1982
4. N. N. Clark and R. L. Flemmer, "Gas-Liquid Contacting in Vertical Two Phase Flow", Industrial Engineering Chemistry Process Design and Development, Vol. 24, pp. 231~236, 1985
5. D. J. Reinmann and M. B. Timmons, "Prediction of Transfer and Total Dissolved Gas Pressure in Air Lift Pumping", Aquaculture Engineering 8, pp. 36~37, 1989
6. J. E. Colt and G. Tchobanoglous, "Design of Aeration Systems for Aaquaculture", Proceedings of the Bio-Engineering Symposium for Fish Culture, American Fisheries Society, Bethestha, Maryland, pp. 138~48, 1981