Performance of Airlift Pumps for Water Circulation and Aeration

Se-Kyung OH

Department of Marine Engineering, Tong-Yeong National Fisheries college,
Chungmu 650-160, Korea

Airlift pumps were tested to evaluate their pumping and aeration capacities. The pumps were 34.5 inch long made of 2, 3, 4 and 6 inch nominal diameter PVC pipes. An one hp air blower was used to supply the air. The air-flow rate was measured by an anemometer type air-flow meter and air pressure was level changes in a water tank from which water was pumped. Aeration by the pumps was tested by the standard aeration test method with the center of pump outlet positioned 3 inches above water surface. Oxygen concentrations in water were measured to determine aeration rate. As pumping head increased by water level draw-down in the tank water flow decreased while air flow increased. The reduction rate of water flow was higher with 4 and 6-inch pumps. Small pumps showed very minor changes in the reduction. Aeration rates were similar among 3, 4, and 6 inch pumps. With one hp air blower 6-inch pump at the minimum pumping head achieved the best performance in terms of water circulation.

Introduction

Airlift pumps were used to raise liquids or slurries from wells or vessels, particularly where submerged mechanical pumps were undesirable or where simplicity of construction was required. In the simplest case, a vertical tube was partially submerged in liquid in a vessel, and air was introduced at or near the bottom of the tube. Being less dense than the liquid, the buoyant air-liquid mixture formed in the airlift tube rose and was expelled at the tip of the pump.

In theory, airlift pumps could operate with any interdispersion of the air and liquid phases, but in practice most airlift pumps operated in the slug flow regime, which persisted over a wide range of air and liquid velocities(Taiel et al., 1980; Clark, 1984a)

In the slug flow large bubbles of air were surrounded by an annular film of liquid in contact with the pipe wall. These bubbles were separated by slugs of liquid spanning the whole tube diameter which might contain a few smaller air bubbles.

J. F Richardson(1962) draw up an energy balance for the airlift pump by the application of the results for hold-up and two-phase friction. He searched the principal sources of energy loss in the pump. The greatest energy loss was arisen from slippage due to the relative velocity between the air and water. The loss due to the slip of the air past the liquid was normally overwhelming compared with all other losses-entrance and exit losses. Accurate prediction of the performance of an airlift pump hinged on the ability to estimate the relative movement of the phases i. e. to estimate the relative proportions of air and liquid in the test section length for various conditions of two-phase flow.

A. H. Stenning and C. B. Martin(1968) found that the slip ratio and loss coefficient did not remain constant over the flow range of a pump.

N. N. Clark (1986) developed an equation of two-phase flow theory to predict the height to which an airlift pump operating in slug flow regime can lift a given volumetric flow rate of liquid.

D. J. Nicklin (1963) reported a theoretical treatment of the airlift pump related to the theory of slug flow, and he (1962) established the velocity equation of two-phases flow in vertical tubes.

J. A. R. Bennet (1961) made the data on the vertical flow of air-water mixtures in the annular and dispersed flow regions.

In the aquatic sciences, the airlift pump was an important instrument for the aeration and water circulation. Airlift pump not only prevents thermal and chemical stratification to make the entire pond volume habitable, but also increase the primary productivity and nutrient solubility to eliminate oxygen deflection at the mud-water interface.

Parker (1979a) had used airlift pumps to reduce stratification and increase fish production in warm water ponds. He studied to determine the effects of airlift pumps on total gas pressure in warm water pond and to observe striped bass for the presence of GBD(gas bubble disease) in fish.

W. E. Castro.el (1980) studied Pump characteristics of small airlift pumps. He established an empirical design equation that was developed the best fit relationship between liquid pumped, length, eduction pipe inside diameter, and percentage submergence. Driving the pump at greater air flows resulted in pumping rates lower than or equal to the maximum.

Nick C Parker.el (1987) determined the influence of three variables – pipe diameter, depth of air injection, and volume of air injected – on the water flow rate of airlift pumps suitable for use in aquaculture ponds. He found that an increase in the vertical lift reduced flow rates greatly in large-diameter pipes, but only slightly affected flow rates in small-diameter pipes, and that water flow increased linearly as air flow increased logarithmically.

C. D Bush, J. L. Koon, R. Allison (1974) made aeration measurement and recorded hourly with Chetronic Oxygen Probes coupled to a 16 point millivolt recorder. The Chemtronic Probes were periodically checked against a YSI Model 54 Dissolved Oxygen Meter. The YSI Meter was used to gain independent morning and evening readings of the dissolved oxygen staturs of various ponds.

Performance data of airlift pumps in the literature was arranged to water pumping performance. But no papers were found about oxygen transfer rates and aeration of slug flow.

In this paper, we tested the relationship between air volume and water flow, aeration performance, and variation of slip ratio and water flow as a function of submergence ratio, H/L (ratio of submergence to length of airlift pump).

Many different types of airlift pumps were studied to solve water pollution problems in raceway culture. We researched to know how much oxygen per hour were aerated by airlift pump, and which pump was efficient in pumping water, and what was relationship between slip ratio and H/L.

Materials and Methods

Fig. 1 shows schematics of a test setup of an airlift pump and water supply tank. Water Tank volume was 273,600 inch^3(36×190 40 inch). It was rectangular in sharp with length approximately 5 times widths.

Airlift pumps were made of 2, 3, 4 and 6 inch I. D PVC pipe with 34.5 inch length form center of the elbow to the bottom of the vertical pipe. The overall distance between the air injection point and the center of the discharge was 31.5 inch. Each pump consisted of vertical section of pipe fitted with 90 degree elbow at the upper end. Air was injected the bottom of the test section and issued with the water at the top.

An one hp blower was used to supply the air. Blower was operated with limited speed. The relief valve regulated the air volume. Air pressure was measured at the inlet of the airlift pumps. The portable air velocity meter (OMEGA HH-30) was a precision microprocessor based anemometer system. The HH-30 was capable of 0.5% of reading accuracy over an exceptionally wide 35 to 7300 FPM range.

Before testing aeration performance of each pump. Water was deoxidized with Sodium Sulfite and Cobalt Chloride for two minute interval, and DO (dissolved oxygen) in water was measured by using oxygen meter (AUSSIE MODEL 54)

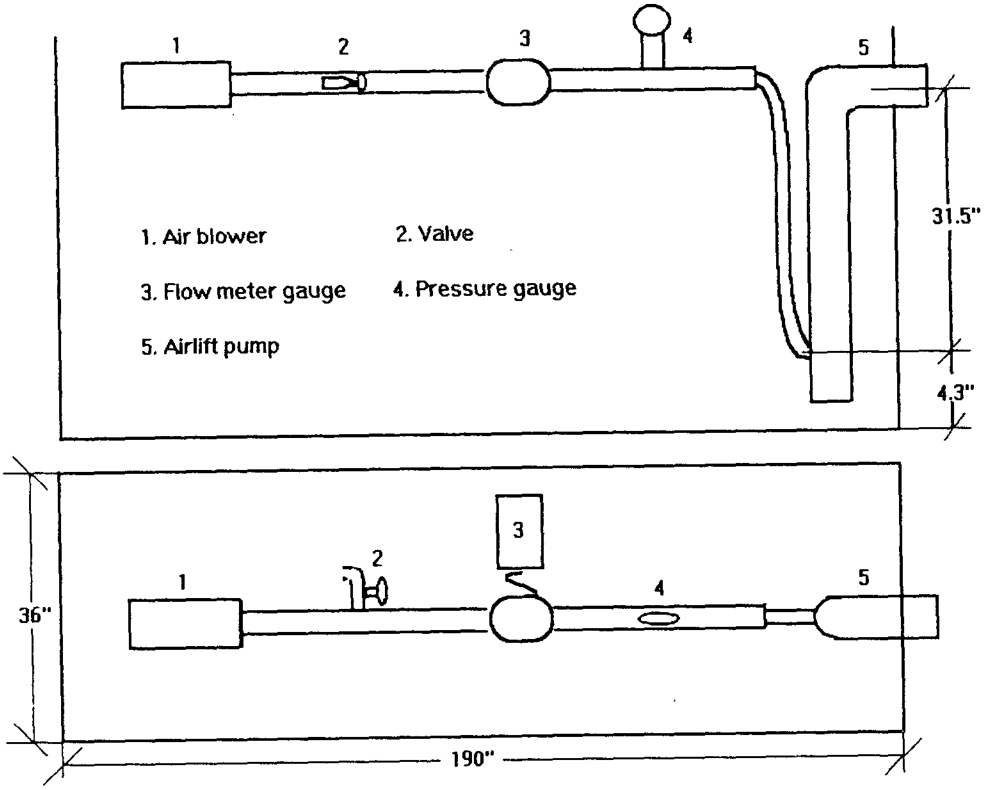

Fig. 1. Schematic diagram of airlift pump

Airlift pump test

Air was injected below 31.5 inch from center of the discharge through 1.3 inch hole, and adjusted from 10 to 50 ft³/min by relief valve. Air volume was calculated to multiply air velocity by section area of HH 30 Anemometer whose blades were rotated in the channel. Values were not corrected to standard temperature and atmospheric pressure (STP) because measurements were made when water and air temperature was about 20~25℃. Reported air flow values might have a 7~8% error as compared with values at STP condition.

Water flow was measured with volumetric displacement per unite time. Water level changes were measured with water level ruler (lory type-A) when airlift pump was perating. Water flow was measured to multiply tank area by length that water level was diminished in the tank.

The blower was operated with limited speed. The relief valve was closed when the discharging center of airlift pump was below 3 inch vertical level to avoid natural water flow, and was opened little by little to diminish air volume from 50 to 10 ft³/min. Airlift pump was operated continuously to check time at which water level was diminished and to calculate water flow that was discharged at unit time. As air volume was decreased, water flow was diminished proportionally.

The effect of submergence ratio, H/L was also evaluated. Air at a flow rate of maximum 50 ft³/min was injected into airlift pumps below a depth of 31.5 inch ffrom the discharge center line of the pump. Air and water flow rates were measured when the center line of arilift discharge was elevated 3 inch each above the surface. The maximum vertical lift was limited to 12 inch slightly less than half length of the airlift pump.

Water flow tests were carried out with variable values of H/L. With a fixed value of H, the air flow rate was gradually increased in small steps, and the water flow rate was measured for each value of air flow.

A number of flow patterns have been observed when air and water flow together in a vertical tube. One of the most persistent of these was the so-called slug flow, in which long round-nosed bubbles or slugs of gas were separated by zones of liquid. The theory and experiment showed that the rising velocity of such a bubble is:

$$u=0.35(gD)^{1/2}$$

The rising velocity of slugs was measured in upward and downward flowing streams of water. The absolute velocity of the slug was expressed as the characteristic rising velocity plus a component due to the motion of the liquid. For upward flows, the latter component was found to be 1.2 times greater than the average velocity of water (D. J. Nicklin. 1962)

The knowledge of the behavior of slugs in moving liquid streams was applied to the problem of steady two-phase flow in vertical tubes. In two-phase slug flow, the slugs were separated by zones of liquid, and the motion of this liquid made an important contribution to the rising velocity of the slugs. The theory of continuity showed that the mean velocity of the water between the air bubbles had to be $(Qa+Qw)/A$.

The absolute velocity of the slug was then taken as:

$$u'=1.2(Qa+Qw)/A+0.35(gD)^{1/2}$$

Griffith presented the following expression for s

$$s=Va/Vw=1.2+0.2Qa/Qw+0.35(gD)^{1/2}/V1$$

Where

D : pipe diameter
S : slip ratio
V1 : water velocity of pump entrance, Qw/A
Va : air average velocity
Vw : water average velocity
Qa : air volume flow rate
Qw : water volume flow rate
A : pipe cross-section area
g : acceleration of gravity

The fitted value of s was important to investigate relationship between H/L and s.

Replicate measurements were made under each test condition until three similar readings were obtained. The mean of these three readings was accepted as the flow rate under the test condition. All measurements of water and air represent the mean of three independent measurements made at approximately 5 min intervals after flown were stabilized. Performance of each airlift pump was tested by comparing with water flow rates vs. air flow, water flow vs. H/L, slip ratio vs. H/L, aeration rate vs. time.

Oxygen test

Test water was 3.240 *l*, hydrant water that dissolved 4.5 ppm oxygen. Solubility of oxygen in water was under different temperature and atmosphere pressure. So oxygen meter was calibrated at 9.1 ppm, because solubility of oxygen saturated at 760 mHg, 20.5℃ was 9.1 ppm.

Cobalt chloride catalyzed the reaction between sodium sulfite and oxygen. Sodium sulfite removed oxygen according to the following reation.

$$Na_2SO_3+\frac{1}{2}O_2=Na_2SO_4$$

The oxygen transfer tests followed the protocol suggested by Stuskenburg et al. (1977), Boyle (1979), and Boyd and Watten (1989), Water in test tank were deoxygenated by adding 0.25 *g/l* cobalt chloride and sodium sulfite at the rate of 10 *mg/l* of sodium sulfite per 1 *mg/l* of dissolved oxygen. Cobalt chloride 0.81 *g* and sodium sulfite 125 *g* were dissolved in water, splashed over the surface of the test tank, and mixed by stirring the stick.

(Cobalt Chloride:
$2.25 mg/l \times 3240 l=810 mg=0.81 g$)
(Sodium Sulfite
$10 mg/l \times \text{water } l \times \text{oxygen ppm}=10\times 3240\times 4.5=125 g$)

When airlift pumps were operating, a polarographic DO meter(YSI. Model 54) was used to measure DO concentration at timed intervals while DO rose from near 0% to 90% of saturation. Concentration of DO were measured at three different places in tank. Time intervals ranged from 2 minutes. Measurements were made over at least one hour interval in each test.

Concentration of DO at saturation was calculated by adjusting the appropriate saturation concentration for barometric pressure. Deficits of DO were estimated for each time interval by substrating measured DO concentration at saturation. Natrual logarithms of oxygen deficits were plotted versus time of aeration. Each measurement value was drawn by visual inspection of plotted point.

The oxygen transfer coefficients for the temperature of water in the test tank (20 to 31℃) were computed as follows:

$$\text{DO deficit} = Cs - Cm \ (mg/l) \cdots\cdots\cdots\cdots (1)$$

Cs : dissolved oxygen concentration at saturation in test water temperature

Cm: dissolved oxygen concentration measured in test water temperature

$$K_{L}a_{T} = \frac{\ln(C_s - C_{10}) - \ln(C_s - C_{70})}{(t_{70} - t_{10})/60}$$

$$= \frac{\ln(\text{DO deficit}_{10}) - \ln(\text{DO deficit}_{70})}{(t_{70} - t_{10})/60} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (2)$$

Discharge center of all pumps was placed 3 inch above the water surface. Probe of Oxygen Meter was placed at depth of 15 inch in a water tank.

One hp blower was used to operate each airlift pump. Following table showed pressure and water flow of each pump with the maximum air volume of blower.

	P(inch)	Qa(ft³/min)	Ow(ft³/min)
2″ pump	46.5	45.23	3.02
3″ pump	47.5	34.23	7
4″ pump	55	31.48	15.41
6″ pump	49.5	40.8	20.57

Discussion and Results

Water flow tests were carried out with variable values H/L. With a fixed value of H, the air flow rate was gradually increased from 0 to the maximum rate, 50 ft³/min, and air flow rate was available in small steps. The water flow rate was measured with each value of air flow.

In fig. 2 as H/L was increased, water flow was peak at 0.9 H/L. One of the most interesting result was the effect of airlift pump diameter. The eduction pipe diameter was used only as a normalizing factor for the pumping head to obtain H/L. These result indicated that the eduction pipe diameter was an important parameter in the pumping rate of a low lift pump. The effect of H/L change was a steep slope in large diameter pipes rather than in the small diameter pipes. H/L affected water flow rate in proportion to the diameter of airlift.

When H/L of airlift pump was increased water flow was increased in order of 6, 4, 3, and 2 inch pumps.

In 3 inch pump when H/L was 0.85 water flow was maximum and then decreased by increasing vetical lift.

The results of the experimental program correlated well with data in the literature (1980, W. E Castro). The maximum water pumping rate occurred for a specific air flow rate. Air flow rates greater or less than the optimum would result in a liquid flow rate less than or equal to the maximum. Air pressure drop reduced water flow rates that the air flow rate remained essentially constant.

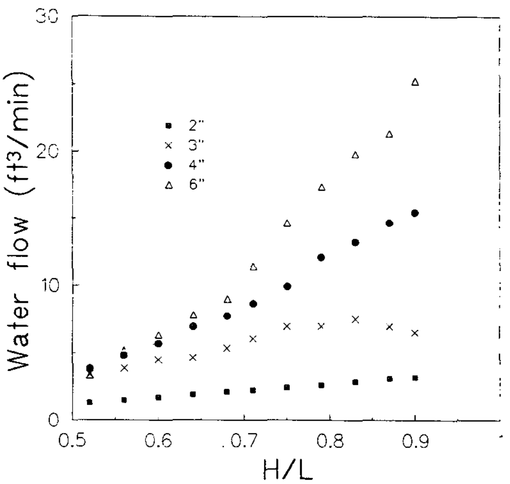

Fig. 2. Variation of water flow with H/L

As shown in fig. 3 water flow rate plotted against air flow rate was evaluated at the means static pressure in the pump. For each value of H/L, an air flow rate produced a maximum water flow rate. Increasing the air flow rate beyond this point caused a reduction in the water flow rate.

Water flow was maximum at 40 ft^3/min air volume in 6 inch pump. When air flow was increased water flows from 2 and 3 inch pumps were changed stagnantly while 4 and 6 inch pumps increased water flow rapidly.

In 4 inch pump, water flow was increased step by step as increasing air volume, and was maximum at about 30 ft^3/min air. 4 inch pump was most efficient in pumping water.

The slugs of air rose relative to the liquid. Liquid flew back in the annular film surrounding the air slug. In occupying the central region of the pipe, the slug was traveling in a region of flow which was moving faster than the cross-sectional average velocity. Both of these factors contributed to raising the slip ratio, or ratio of air to liquid average velocity Va/Vw. In the case of expanding slugs in which the liquid was taken off above the slug, the rising velocity increased with slug length, and the increase varied with the absolute pressure of the system. This increase was related to the rate of expansion of the slug, that is, to the mean velocity of the liquid across any section in front of the slug. The slug was assisted by this concentration of velocity near the center. This expectation has been confirmed by calculating the expansion velocity for slugs.

As shown in fig. 4 s was varied from 2 to 6. The pump performance was very sensitive to changes of slip ratio because of being observed slips at low air flow rates. Water flow rate was decreased in order of the pump diameter size. Physically, the maximum water flow rate occurred when the frictional pressure drop caused by further addition of air exceeded the buoyancy effect of the additional air. Although s would not remain constant over the flow range of a pump, the predicted performance was sufficiently insensitive to small changes in these parameters. It might be possible to represent the behavior of a pump with fixed H/L fairly well using constant values for s. The performance data obtained experimentally were recalculated in the form suggested by the analysis, and values of s were chosen for each H/L to fit the maximum water flow rate and corresponding air flow rate.

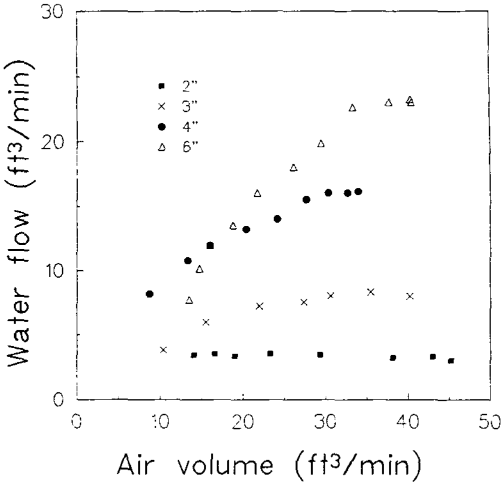

Fig. 3. Relationship of water flow with air volume

Slip ratios of 4 and 6 inch pumps were between 2 and 4. 5. But 2 and 3 inch pumps operated with slip ratios between 2.5 and 10. It meant that airlift pump was operated with high liquid velocity. For the range of water flow and pipe diameters which showed the highest water flow, slip ratio ranged between 2 and 2.5 (Stenning and Martin, 1964).

In the performance curve of airlift, water flow of 6 inch airlift pump made remarkable changes according to increasing air volume, but water flow of 2 inch airlift pump did not make changes. These results meant that slug phenomenon was serious in 6 inch pump rather than in 2 inch pump.

The pressure of oxygen in the air drove oxygen into water until the pressure of oxygen in water was equal to the pressure of oxygen in the air. When the pressure of oxygen in water and air were equal, net movement of oxygen molecules from air to water ceased. The movement of oxygen from the surface film throughout the entire volume of water was much slower than the initial entry of oxygen into the surface film.

Aerators influenced the rate of oxygen transfer from air to water by increasing turbulence and surface area of water in contact with air. Bubbler ae-

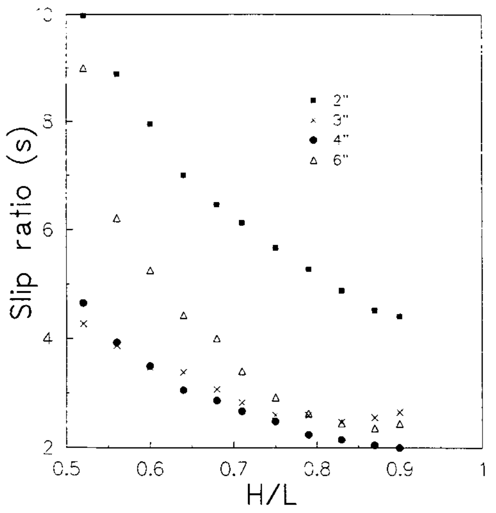

Fig. 4. Variation of slip ratio with H/L

rators relied upon release of air bubbles near the bottom of a water body to affect aeration. A large surface area was created between air bubbles and surrounding water. Rising bubbles also created turbulence within a body of water.

Airlift pumps were tested to determine the rate at which they transferred oxygen to water. Water in the test tank was deoxygenated. The cobalt chloride (0.81 *g*) and sodium sulphite (125 *g*) was added to make 100 % oxygen deficit in the test water (3240 *kg*). The aerator was operated to effect re-aeration. Concentrations of DO were measured at 2 minute intervals during re-aeration. These data were used to estimate the amount and efficiency of oxygen transfer under standard condition.

Test water was 9.0 ppm oxygen saturation at the water temperature 20.5℃, atmosphere pressure 760 mmHg.

From the equation (1), times that were spent to make dissolved oxygen 10% saturation and 70% saturation were measured as following.

In DO 10% saturation:
Cs=9.0ppm, Cm=Cs×0.1=0.9
DO 10% sat=Cs−Cm=8.1
In (DO 10% sat)=In 8.1=2.09

The logarithmic oxygen deficit 2.09 was matched with following aeration time.

2 inch pump=10min
3, 4, 6inch pump=3min

In DO 70% saturation:
Cs=9.0ppm, Cm=Cs×0.7=6.3
DO 70% sat=Cs−Cm=2.7
In(DO 70% sat)=In 2.7=0.99

The logarithmic oxygen deficit 0.99 was matched with following aeration time.

2 inch pump=55min
3, 4, 6 inch pump=35 min

As shown in Fig. 5. Aeration of 2 inch airlift pump was out of line with a gentle slope. But aerations of 3, 4, and 6 inch airlift pump were shown a same aspect each other. It meant that oxygen saturation performance of the 2 inch airlift pump was lower than that of the 3, 4, and 6 inch airlift pumps, and aeration rates of 3, 4, and 6 inch pumps were similar within 60 minutes when oxygen deficit reached about 0.7 *mg/l*(DO 70% saturation). So aeration performance of airlift pump was fit for 3, 4, and 6 inch pumps in operating 1 hp blower.

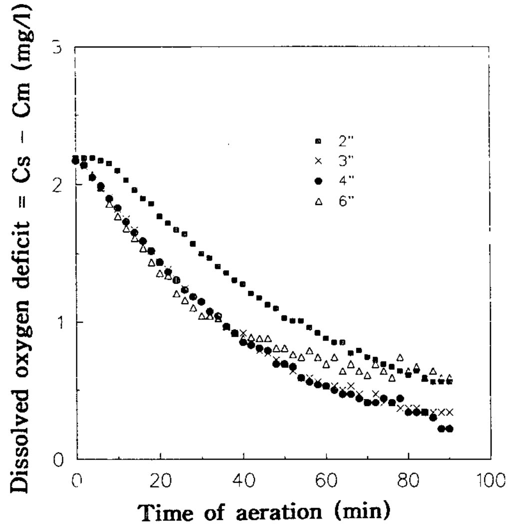

Fig. 5. Relation of oxygen deficit with time

Conclusion

1. The changes in submergence ratio, H/L slightly affected the performance by the small-diameter pumps (2 and 3 inch) but was very substantial by the large-diameter pumps (4

and 6 inch).

2. Slip ratios plotted against H/L showed similar relationships to those of other performance curves (water flow vs. H/L, water flow vs. air flow, aeration rate vs. time) obtained in this study.
3. With one-hp air blower, 6 inch pump at 3.0 inch pumping head achieved the best performance in terms of water flow.
4. The aeration performances of 3, 4, and 6 inch pumps were similar; 10% and 70% of oxygen saturation at 3 min and 35 min., respectively.

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물 循環 및 에어레이션用 에어리프트 펌프의 性能

오 세 경
통영수산전문대학 기관과

本 實驗은 에어리프트 펌프의 펌핑 性能과 에어레이션 能力을 調査하기 위해 遂行했다. 펌프로는 2, 3, 4, 6인치 內徑의 PVC 파이프를 使用했으며 펌프의 길이는 34.5인치였다. 空氣 供給裝置로는 定格 1 馬力의 불로워를 使用하였다. 空氣 流量 計測은 流量 게이지(風速計)를 使用하였으며, 空氣 壓力은 물이 펌핑될 때 水位 變化로 測定했다. 펌프에 의한 에어레이션 性能 試驗은 표준 에어레이션 테스트 方法으로 遂行했다. 그 때 펌프 出口의 中心線의 位置는 물 表面으로부터 3인치 위가 되도록 設定하였다. 水中의 酸素濃度는 에어레이션率을 算出하기 위하여 測定되었다. 탱크 속에서 水位 設定은 에어리프트 펌프의 位置를 上下로 變更시켜 調節했다. 그 結果 水面에서 펌프의 位置가 높은 狀態에서 물의 吐出量은 空氣의 供給量이 增加함에 따라 減少했다. 물 吐出量의 減少率은 4인치와 6인치 펌프에서 높았으며, 直徑이 작은 펌프에서 減少率은 그 정도가 미미했다. 시간의 變化에 따라 측정한 각 펌프의 에어레이션 性能은 2인치 펌프를 除外하고 3, 4, 6인치 펌프에서 비슷한 結果를 보았다. 6인치 펌프는 펌핑 水頭를 최소로 했을 때 가장 우수한 물 循環 效果를 얻을 수 있었다.