Design of Airlift Pumps for Water Circulation and Aeration in Aquaculture

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ABSTRACT

Water flow rates were measured in airlift pumps 3.75–30 cm in diameter to develop performance data that might be useful to aquaculturists. Flows were determined when submergence of airlifts was 100% and when the center-line of the discharge was between 12.5 cm above and 5 cm below the water surface. Air was injected at 15-cm intervals from 15 cm to 120 cm below the discharge of the airlift and airflow was varied from 28 to 1416 liters min⁻¹. An increase in the vertical lift reduced flow rates greatly in large-diameter pipes, but only slightly affected flow rates in small-diameter pipes. Water flow increased linearly as air flow increased logarithmically.

INTRODUCTION

Water circulation and aeration in aquaculture ponds have increased primary productivity, reduced stratification, increased nutrient solubilization, reduced organic accumulation on the bottom, and increased fish production. Pond aeration techniques have been investigated to increase the growth, survival, and production of both fish (Ito et al., 1974; Sarig and Marek, 1974; Parker, 1979, 1983) and crustaceans (Morrissy, 1979; Apud and Camacho, 1980). Airlift pumps of various sizes and configurations have been used to circulate and aerate pond water, but due to fluctuating water level in ponds, not all systems have worked reliably and efficiently. The design and flow predictions for airlift pumps have typically been based on data derived from small systems suitable for aquaria and tanks, or from performance charts showing the vertical lift capacity of airlifts that are 40–90% submerged (Spotte, 1970; Castro et al., 1975; Murray et al., 1981).
Ivens (1914) reported that airlift pumps were tested in a laboratory in Germany as early as 1797 and that their first practical application in the United States was in pumping oil in Pennsylvania in 1846. In the aquatic sciences, airlift pumps have been used to collect samples of seawater (Tokar et al., 1981); to provide aeration, agitation, and pumping in sewage treatment plants (Andeen, 1974); and to provide aeration, destratification, and pumping for aquaculture (Rappaport et al., 1976; Wheaton, 1977; Parker et al., 1984).

Several investigators have reported the flow rates of small-diameter airlift pumps used to lift water vertically. Spotte (1970) presented data on the vertical lift capacity of airlift pumps 2.5–15 cm in diameter and 40–70% submerged. Spotte (1979) revised the water flow rates from his earlier edition and also included flow rates of air. Castro et al. (1975) reported on the pumping rate of airlift pumps 1.27–7.62 cm in diameter, 30 cm to 3.7 m long, and 40–70% submerged. Todoroki et al. (1973) developed equations for predicting the flow in airlift pumps 2.5–10 cm in diameter, 4–42 m long, and 40–80% submerged.

Airlift pumps used to circulate water in ponds operate almost totally submerged and need to move water only from the bottom of the pond to the surface. The theory of operation and equations describing performance for airlift pumps operated in this mode have previously been reported by Nicklin (1963). Murray et al. (1981) defined the nomenclature used to describe airlift pumps, discussed theory of operation, and presented performance data on pumps of 1.78–3.65 cm in diameter operated at 50–80% submergence. Performance data on airlift pumps operated at 90–100% submergence have not been presented previously. The first objective of our study was to determine the influence of three variables — pipe diameter, depth of air injection (commonly referred to as submergence ratio), and volume of air injected — on the water flow rate of airlift pumps suitable for use in aquaculture ponds. Our further objective was to report these data in a format reflecting actual and expected performance under field conditions.

**MATERIALS AND METHODS**

Water flow rates were determined in eight airlift pumps 3.75–30 cm in diameter into which various volumes of air were injected at different depths. 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 conditions.
Airlift pump operation

Airlift pumps with nominal diameters of 3.75, 5.0, 7.5, 10, 15, 20, 25 and 30 cm (actual internal diameters were 4.4, 5.2, 7.6, 10.2, 15.4, 21.0, 26.4 and 31.3 cm) were constructed from polyvinyl chloride (PVC) pipe. Each pump consisted of a vertical section of pipe fitted with a 90° elbow at the upper end (Fig. 1). Air was injected into the side of the vertical pipe through a series of 1.25-cm holes placed at 15-cm intervals from 15 to 120 cm below the horizontal arm of the PVC elbow. There was only one hole per 15-cm interval in 3.75-15 cm diameter pipes, two holes per interval in 20 cm diameter pipes and three holes per interval in 25 and 30 cm diameter pipes. Each 1.25-cm hole was tapped to receive a 1.25-cm hose adapter. The bottom of the vertical pipe (the airlift pump intake) was 130 cm below the horizontal arm of the elbow (the airlift pump discharge).

The bottom of the discharge elbow was placed 1.25 cm above the water level in a flume, located just above the water surface (Fig. 1) and

![Diagram of test apparatus for measuring water flow in airlift pumps. Each pump consisted of a 90° elbow and a vertical riser. The discharge was 1.25 cm above the surface of the water and was measured volumetrically or in a flume after passing through an egg-crate type baffle to reduce turbulence. For each test air was injected into one of eight 1.25-cm holes at 15-cm intervals in the vertical riser, while the other seven holes were plugged.](image-url)
water flow was measured as air was injected into the 1.25-cm holes. Air volume was regulated with a series of rotameter type flow gauges (Dwyer Instruments Inc., Michigan City, Indiana, USA), and adjusted from 28 to 224 liters min \(^{-1}\). Values were not corrected to standard temperature and atmospheric pressure (STP) conditions; measurements were made when water and air temperature was about 20–25°C. Reported air flow values may have a 7–8% error as compared with values at STP conditions. Air was injected at only one depth at a time while the other 1.25-cm holes were plugged. For airlift pumps 3.75–10 cm in diameter, water flow was measured by volumetric displacement during a timed interval. For airlift pumps 15–30 cm in diameter, water flow was measured in Palmer–Bowlus flumes (manufactured and calibrated by Plastic-Fab Inc.,

Fig. 2. Arrangement of plastic bag for collection of airlift pump discharge for volumetric measurement. The bag was quickly slipped under the lower edge of the discharge pipe (A) and arranged to allow escape of air as discharge filled the bag (B).
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Tualatin, Oregon, USA). Water depth in the flume was measured and flow rates were taken from tables published by Grant (1979). All measurements of water and air represent the mean of three independent measurements made at approximately 5-min intervals after flows were stabilized.

We analyzed all data using Hewlett-Packard software packages in a Hewlett-Packard-9845 computer. Best-fit equations were selected from linear, logarithmic, exponential, and polynomial regression models to predict water flow rates when air flow varied over the range of 28–224 liters min$^{-1}$.

Flow rates were calculated with linear, logarithmic, exponential, and polynomial regression equations for air volumes up to 1416 liters min$^{-1}$. Projected water flow rates at air flows above 224 liters min$^{-1}$ (up to 1416 liters min$^{-1}$) were then verified in 5 and 10 cm diameter pipes by increasing the air volume from 224 to 1138 liters min$^{-1}$ and measuring

![Air Flow (cubic feet per minute)](image)

Fig. 3. Water flow rates in airlift pumps with diameters of 3.75 cm (upper panel) and 5.0 cm (lower panel) when air was injected into the vertical riser at different distances (cm) below the surface of the water: 120 (A), 105 (B), 90 (C), 75 (D), 60 (E), 45 (F), 30 (G), and 15 (H). All measurements were made with the flow-line of the discharge 1.25 cm above the surface of the water.
water flow. The effects of depth of submergence and vertical lift were also evaluated. Air at a flow rate of 85 liters min\(^{-1}\) was injected into airlift pumps with diameters of 5-0, 7-5 and 10 cm at a depth of 60 cm below the center-line of the discharge from the pump. Under these conditions, flow rates were measured when the center-line of the airlift discharge was at the surface of the water and when elevated 2-5, 5-0, 7-5, 10 and 12-5 cm above the surface or submerged 2-5 or 5-0 cm below the surface. The maximum submergence was limited to slightly less than the diameter of the airlift pump tested; at no time was the top of the discharge pipe completely submerged. Volumetric measurements were made during the submergence tests by collecting airlift discharges in large plastic bags (with tops open to allow air to escape) held under the discharge pipes (Fig. 2).

RESULTS AND DISCUSSION

Logarithmic regression provided the best-fit model for empirically derived water flow rates for airlift pumps; data were plotted on a semilog

![Graph showing water flow rates vs. air flow](image)

Fig. 4. Water flow rates in an airlift pump 7.5 cm in diameter, when air was injected into the vertical riser at different distances (cm) below the surface of the water: 120 (A), 105 (B), 90 (C), 75 (D), 60 (E), 45 (F), 30 (G), and 15 (H). All measurements were made with the flow-line of the discharge 1-25 cm above the surface of the water.
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Flow rates in 5 and 10 cm diameter pipes with air flows of 28–224 liters min$^{-1}$ were used to project water flow beyond the range of the initial test. The predicted flow rates were verified in additional laboratory tests of 5 and 10 cm diameter pipes when air flow was 1138 liters min$^{-1}$. In airlifts of all sizes, flow rates increased as either air flow, the depth of air injection, or both, increased. The no-flow conditions described by Murray et al. (1981) were not approached in our test even in the small-diameter pipes. An increase in air flow rate increased water flow rate in all size pumps even though the increase was slight in small-diameter pipes.

Slight differences in submergence of airlift pumps altered water flow rates significantly. Water flow was highest when the center-line of the discharge was at or slightly below the surface of the water (Figs 10–12). Flows decreased as the discharge was elevated above the water surface. Pickert (1932) cautioned that only flows from airlifts of identical submergence and length could be compared with each other. Recognizing that caution, we compared the flow rates of our 3.75 cm diameter air-

![Air Flow (cubic feet per minute)](image)

**Fig. 5.** Water flow rates in an airlift pump 10 cm in diameter when air was injected into the vertical riser at different distances (cm) below the surface of the water: 120 (A), 105 (B), 90 (C), 75 (D), 60 (E), 45 (F), and 30 (G). All measurements were made with the flow-line of the discharge 1.25 cm above the surface of the water.
Fig. 6. Water flow rates in an airlift pump 15 cm in diameter when air was injected into the vertical riser at different distances (cm) below the surface of the water: 120 (A), 105 (B), 90 (C), 75 (D), 60 (E), 45 (F), and 30 (G). All measurements were made with the flow-line of the discharge 1.25 cm above the surface of the water.

The flow rates presented in Figs 3–9 are about 10–40% less than the maximum flows obtainable from airlifts of similar size with similar rates of air injection. For example, in a 5 cm diameter airlift operated with 85
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Fig. 7. Water flow rates in an airlift pump 20 cm in diameter when air was injected into the vertical riser at different distances (cm) below the surface of the water: 120 (A), 105 (B), 90 (C), 75 (D), 60 (E), 45 (F), and 30 (G). All measurements were made with the flow-line of the discharge 1.25 cm above the surface of the water.

liters min⁻¹ of air injected at a depth of 60 cm below the center-line of the discharge, the flow rate was about 12% greater when the vertical lift was zero than when it was 1.25 cm (Fig. 10). The flow in a 7.5 cm diameter airlift increased about 16% when the vertical lift was reduced from 1.25 cm to zero (Fig. 11). Changing the vertical lift in a 10 cm diameter airlift from 1.25 to zero increased flows about 38% (Fig. 12). The depth of submergence or, conversely, the vertical lift, affected flow rates in proportion to the diameter of the airlift. The effect of change in depth of submergence on flow was only slight in small-diameter airlifts, but was very substantial in large-diameter pipes.

In our test, flow rates in 7.5 cm airlift pumps were increased about 5-10% when air was injected through a series of 1.6-mm holes around the pipe rather than through a single 1.25-cm hole. However, the
Fig. 8. Water flow rates in an airlift pump 25 cm in diameter when air was injected into the vertical riser at different distances (cm) below the surface of the water: 120 (A), 105 (B), 90 (C), 75 (D), 60 (E), 45 (F), and 30 (G). All measurements were made with the flow-line of the discharge 1.25 cm above the surface of the water.

increase in flow rate was too small to justify the additional expense or effort required to provide this radial air injection. Ward (1924), who tested different types of air injectors, concluded that there should be no central air injection nozzle or other obstruction to the flow of water. He found that special devices were not required to mix air with water in airlift pumps. He also reported that small fine bubbles provided no advantage because small bubbles quickly coalesced into larger bubbles as they traveled up through the water column. Threaded holes fitted with 90° hose adaptors have worked well as injection ports in our tests and in subsequent field applications at this laboratory and in field tests in US Fish and Wildlife Service National Fish Hatcheries in San Marcos, Texas; Natchitoches, Louisiana; Edenton, North Carolina; and the Marion State Fish Hatchery, Marion, Alabama.
Fig. 9. Water flow rates in an airlift pump 30 cm in diameter when air was injected into
the vertical riser at different distances (cm) below the surface of the water: 120 (A), 105
(B), 90 (C), 75 (D), 60 (E), and 45 (F). All measurements were made with the flow-line of
the discharge 1.25 cm above the surface of the water.

Fig. 10. Water flow rates in an airlift pump 5.0 cm in diameter, into which 85 liters
min⁻¹ of air were injected 60 cm below the center-line of the discharge, while the center-
line of the airlift discharge was below, at, or above the surface of the water.
On the basis of the cost of materials, installation, and operation, we found 7.5 and 10 cm diameter airlift pumps to be more appropriate than either larger or smaller ones for destratifying 0.02- to 2.0-ha ponds. One airlift pump per 0.02- or 0.04-ha pond prevented stratification when 85 liters min\(^{-1}\) of air was injected into the vertical riser at a point 60 cm below the surface of the water. In larger ponds 7.5 and 10 cm diameter pumps have been installed at the rate of 25 per ha at this laboratory and in other US Fish and Wildlife Service facilities.

Under these conditions, a regenerative blower (see Parker, 1983, for description of types of blowers and compressors) with a nameplate rating of 1 kW (1.34 hp) operated 27 airlift pumps with water flow rates
of 150–230 liters min\(^{-1}\) each; the total combined flow rates from 27 airlifts ranged from 4050 to 6210 liters min\(^{-1}\) for 7.5 and 10 cm diameter pumps, respectively. Vertical lift was essentially zero as these airlifts were adjusted for maximum flow to produce circulation and vertical mixing of water in ponds.

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Reference to trade names in this paper does not constitute endorsement by the US Government.

REFERENCES


