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Impact of fish feed on airlift pumps in aquaculture systems

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ABSTRACT

Airlift pumps are commonly used in aquaculture systems to circulate water and maintain critical gas levels. In production marine reuse systems, a significant decrease in airlift pump flowrate was visually observed immediately after feeding. In experimental systems without fish, it was found that feed additions of less than 10 mg/L decreased water flow by as much as 78% for diffuser injectors but only 10% for pumps with direct air injection. For both injector types, feed impact diminished over several hours but persisted longer in seawater than in freshwater. Video footage revealed increasing bubble coalescence with the addition of feed. The decrease in pump flow is likely attributed to water property changes due to compounds leaching out of the feed. This decrease in pumping rate has the potential to negatively impact water quality, system performance, and fish health.

1. Introduction

Airlift pumps are widely used in aquaculture for pumping (Castro et al., 1975; Murray et al., 1981), pond mixing (Parker and Suttle, 1987), aeration/degassing (Reinemann and Timmons, 1989), and carbon dioxide removal (Loyless and Malone, 1998). Compared to mechanical pumps, airlift pumps have lower initial costs, lower maintenance, easy installation, portability, freedom from clogging, small space requirements, simplicity of design, ease of construction, greater efficiencies when operated at low head and high submergence, easily regulated flow rates, and high versatility of application (Spotte, 1970).

Research focused on reducing energy consumption, production costs, and greenhouse gas emissions from reuse systems is of great interest in aquacultural engineering. Key to this research is the reduction of pump head requirements and improvement of the efficiency of aeration/degassing processes. As part of this research we constructed a rearing system that used airlift pumps to pump water from the rearing units to a centralized moving bed biofilter (a static lift of 12 cm); the water from the moving biofilter flowed back to the rearing unit by gravity. It was observed that following feeding, the airlift output was drastically reduced and took hours to recover. The only published work on the impact of feeding on airlift pump performance reported an increase in output following feeding (Barrut et al., 2012a).

Because of the potential impacts of flow reduction on water quality and systems performance, this work focused on the impacts of feed addition on pumping rates, efficiencies, and recovery times. This work will advance our understanding of the impacts of feeds on airlift pump operation and will improve system operation and reliability.

2. Background

2.1. Airlift pump operation and characteristics

Airlift pumps typically used in aquaculture are 30–80 mm in diameter, are submerged from 1 to 1.5 m, and lift the water from 0 to 0.3 m. An airlift pump consists of a vertical section of pipe (eductor) submerged in water. Typically, the upper end of the educator is fitted with an elbow to redirect discharge parallel to the water surface. Airlift pump configuration is described in terms of percent submergence (Fig. 1):

$$\text{Submergence (\%)} = \left[\frac{\text{Submergence}}{\text{Submergence} + \text{Lift}}\right]100 \tag{1}$$

Where
Submergence = Center of injector to water surface (m)
Lift = Water surface to centerline of discharge tube (m)

Typical percent submergence for aquaculture applications ranges from 70 to 110%. A submergence of greater than 100% results when the water flow is discharged under the water surface. Air is most commonly injected into the educator using either (a) single point injector, or (b) coarse bubble diffuser injector, although many other more complicated types of air injectors have been tested. The performance of an airlift

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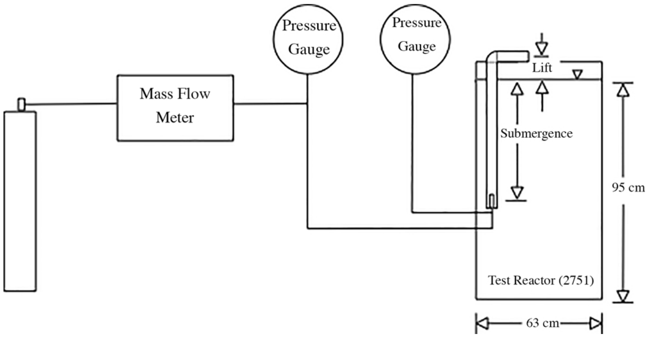

Fig. 1. Schematic diagram of the experimental system used for this study.

pump depends on eductor diameter, eductor length, airflow, submergence (%), injector type, and water properties (viscosity, surface tension, and salinity).

As air is introduced into the pipe, the overall density of the air-water mixture is reduced and the column expands. When the airflow rate Q_g is equal to Q_g^{min}, the pump starts to flow. For larger values of Q_g, the water increases up to the maximum value (Q_g^{max}) and then starts to decrease. Typical airlift pumps are most efficient at flows below the maximum flow rate (Murray et al., 1981).

Within the airlift pipe, four distinct bubble types are found (Hanafizadeh et al., 2011):

Type	Description
Bubbly flow:	Air is distributed as discrete bubbles in continuous water.
Slug flow:	The bubble coalesces and fills the entire pipe. The nose of the bubble is spherical. The slug of air pushes water above it up the tube.
Churn flow:	The slug breaks down and churns in the pipe. The transition is oscillatory and irregular.
Annular flow:	Air occupies the core of the pipe and water on the slides of the pipe is dragged upward by the air.

The transition between the different flow regimes depends primarily on eductor size, educator length, and airflow rate.

2.2. Air and water velocities in airlift pumps

The velocity of air in a pipe with uniform flow is simply equal to Flow/Cross Sectional Area. Under multiphase systems such as an airlift pump, the actual air velocity will depend on both the air and water flow rates and can change as the bubble rises up the eductor tube. The superficial air velocity (U_s) is a hypothetical flow velocity calculated assuming only air is flowing in the pipe. Superficial velocity is commonly reported in airlift research because it is can be readily computed from commonly measured parameters.

2.3. Airlift efficiency

For an airlift pump, the pumping power output is equal to (Tchobanoglous, 1981):

$$P_{water} = \gamma Q_w H_t \qquad (2)$$

Where:

P_{water} = Pumping power (kW)
γ = Specific weight of water (kN/m^3)
Q_w = Capacity or water flow rate (m^3/s)
H_t = Total dynamic head (m)

It is usual to define the pumping power in terms of the net work done lifting the liquid and assuming that H_t = static lift (Reinemann et al., 1990). The frictional and velocity heads in airlift pumps depend strongly on flow patterns; their computation is difficult.

The power required to compress the air has been either computed in terms of the adiabatic (no heat transfer) compression power or the isothermal (no temperature change) expansion power. The adiabatic compression power is equal to (Tchobanoglous and Burton, 1991):

$$P_{adb} = \frac{wRT}{29.7ne}\left[\left(\frac{p_2}{P_1}\right)^n - 1\right] \qquad (3)$$

Where:

P_{adb} = Adiabatic compression power (kW)
w = Weight of air flow (kg/s)
R = Gas constant for air (8.314 kJ/kmol K)
T = Absolute inlet temperature (K)
29.7 = Constant for SI units conversion
n = 0.283 for air
e = Efficiency, in the range of 0.70–0.90
p_1 = Absolute inlet pressure (kPa)
p_2 = Absolute outlet pressure (kPa)

The theoretical efficiency of an airlift pump is commonly computed by dividing the pumping power by the isothermal expansion power (Nicklin, 1963). The computation of the isothermal expansion power is complicated by two factors: (a) it is necessary to measure the air temperature within the supply line and (b) this may be different from the water temperature which raises questions about what temperature should be used and if the process is indeed isothermal.

The isothermal expansion power ignores how the air was actually compressed. A more realistic efficiency of an airlift pump is equal to the pumping power (Eq. (2)) divided by the adiabatic compression power (Eq. (3)). The efficiency using the adiabatic expression will be lower than the isothermal expansion because the power losses in the motor and blower are included. If one is interested in true energy use, the adiabatic compression power is more relevant and must be measured using a power meter. It is also important to note that a measured valve of p_2 in Eq. (3) may include the pressure losses that occur in the air distribution system. The magnitude of this term may vary widely between experimental and production systems.

3. Materials and methods

3.1. Systems

Two experimental systems were used in this study. The first system was used to evaluate the impact of feeding on airlift performance under production conditions. The second system was used to isolate the impacts of feed addition on pumping rate under controlled conditions.

3.1.1. System 1: rearing system

The marine production system consisted of two 973-L rearing tanks containing 2–5 kg sablefish (*Anoplopoma fimbria*). The system contained approximately 150 kg of fish and was fed 2 kg of feed (BioBrood, 9 mm), three days a week. This feed contains “premium fishmeal and fish oil, and extra vitamins & minerals for improved fecundity, sperm motility, brood health, egg quality, & fry survival” (Bio-Oregon, 2017). BioBrood is composed of 48% crude protein, 20% lipids, and 18.2 MJ/kg digestible energy. Each tank was equipped with two airlift pumps that circulated water between their respective tanks and a central moving bed biofilter.

Airlift pumps in this study were constructed out of 5 cm (2”) schedule 40 PVC and supplied air from a centralized blower. Each tank contained one airlift pump with a diffuser injector and one with a direct air injector. The diffuser injector consisted of a Pentair AS5L diffuser mounted such that the bottom of the diffuser was flush with the bottom of the eductor and the long axis of the diffuser parallel to the vertical centerline of the eductor. The remaining two pumps were fitted with