Experimental And Theoretical Analysis Of The Airlift Pump-Nozzel Jet Bubble Generator Performance For Aquaculture Applications

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Abstract. A theoretical model using the power balance approach has been developed to predict the water discharge from the airlift pump-nozzle jet bubble generator system applied to aquaculture. The research was conducted on the ratio of the water level to the total riser pipe height of 0.83. The influence of the input air flow rate, pipe diameter, and the use of water pumps was investigated. A water pump in an airlift system can increase pump performance by 94.61%. There is a transition line as a boundary for the influence of pipe diameter between low and high air discharge. At low air flow rates (more than 4.0 lpm for systems without a water pump and less than 2.0 lpm for systems with a water pump), the larger the pipe diameter, the lower the water flow that comes out at a certain air flow rate. At high air flows (more than 4.0 lpm for systems without water pumps and less than 2.0 lpm for systems with water pumps), the larger the pipe diameter, the greater the water flow that comes out at a certain air flow rate. The proposed prediction model shows similarities with experimental data.

Keywords: airlift pump-nozzel jet bubble generator; pipe diameter; water pump effect.

1. INTRODUCTION

An airlift pump is a water-lifting device that relies heavily on gas expansion to push the liquid above it and pull the liquid below it in a vertical pipe channel. This method requires air without moving, rotating, or rubbing parts like ordinary water pumps [1]. Pressurized gas flows into a vertical pipe submerged in water so that the mixture of water and air in the pipe forms various-sized bubbles so that the specific gravity of the mixture decreases. The bubble's buoyant force is used to lift and drag liquid in the pipe. The airlift pump has been widely used in various fields with this simple working principle. Airlift pumps were used in wastewater treatment to lift sludge and filter impurities. Airlift pumps lift solid particles from the deep sea in the mining sector. Aquaculture and agriculture use airlift pumps for water circulation [2]–[4]. In chemistry, airlift pumps were used to remove corrosion and toxins. Some disadvantages of the airlift pump are low efficiency and unstable flow, making it difficult to control.

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chemistry, airlift pumps were used to remove corrosion and toxins. Some disadvantages of the airlift pump are low efficiency and unstable flow, making it difficult to control.

Research and development of airlift pumps has been widely carried out by researchers such as [5]–[17] which examine the influence of geometric and operational parameters theoretical, experimental and numerical as the results of a review by [1]. These studies used an ordinary airlift pump by injecting air into the vertical pipe. Catrawedarma et al.[1], [18]–[25] developed an airlift pump by replacing the air injector with a bubble generator. This method only uses a water pump to replace the compressor in a regular airlift pump. Michio Sadatomi et al.[18]–[20] developed an airlift pump using a spherical ball-type bubble generator while [22]–[25] developing an airlift pump using an orifice type bubble generator combined with a porous pipe. Sadatomi et al.[18]–[20] direct the bubble generator downwards to shoot solid particles, which allows some of the bubbles to come out of the vertical pipe while [22]–[25] directs the bubble generator to flow swirl in the skirt which can reduce the energy of the bubble flow into the vertical pipe.

Furthermore, theoretical models have been developed to predict water discharge and particles that can be lifted by air supplied to conventional airlift pumps using the concept of balance momentum [14], [26]–[28], using empirical correlation [29], using the power balance concept [30], [31], and using the multi-fluid model [32], [33]. Multi-fluid models have limitations because some constitutive equations cannot model the performance of a three-phase airlift pump, so the prediction results are less than satisfactory.

Stenning and Martin [34] used momentum balance to derive the theoretical equation for the airlift pump. This equation does not consider the influence of the number of injector holes. It is carried out under conditions of constant slip ratio and friction coefficient, even though the slip ratio and friction coefficient change along with changes in the injected air flow. Parker [35] developed the [34] equation by considering the influence of the number of injector holes and the slip ratio and friction coefficient, which change with changes in the injection air flow. Alasadi & Ahmed [36] developed the [35] and [34] equations by considering the injector angle. The entire [34], [35], [37] equations consider the injector to be placed at the bottom end of the riser pipe, so the influence of the injector position is not included in the equation. These equations can only be used for airlift pumps which are operated to lift water only, so that what flows in the riser pipe are two phases of water and air.

Yoshinaga & Sato [38] combine a momentum balance with several empirical correlations using gas and solid superficial velocities as input and liquid superficial velocity as output. It differs from the real conditions that use gas superficial velocity as input with liquid and solid superficial velocities as output. This condition was corrected by [8] for a conventional airlift pump by using the [34] equation as a prediction of the initial values of gas and liquid superficial velocities to simplify the iteration process, while [39] added particle fraction parameters in the liquid-solid mixture from the airlift pump bubble generator. These correlations do not consider the intake angle of the air, even though this parameter greatly influences lift force [21].

Therefore, the present study considers the influence of the injector intake position, angle, and entrance loss. This equation is derived based on the power balance concept, which is slightly different from the momentum balance concept used by [34], [35], and

[36]. This equation was also developed to apply to airlift pump systems operating in two or three phases of air-air-solid particles. In the current study, the bubble generator was directed upwards in the riser pipe to increase the momentum of the upward flow, which was very different from research conducted by [1], [18]–[25].

1.1 THEORETICAL ANALYSIS OF WATER AND SOLID DISCHARGES

The current study developed a model to predict the water and solid discharges by considering the injector intake angle. It was derived from the balance of pressure, which balances the static pressure of water outside the airlift pump system with the total pressure loss in the riser pipe. By applying the power balance concept in Fig. 1, a relationship is obtained:

$$\Delta P_{AB} - \Delta P_{CD} - \Delta P_{DE} - \Delta P_{EF} = 0 \qquad (1)$$

Where: ΔP_{AB} is the pressure drop from A-B in the surrounding and entrance, ΔP_{CD} is the pressure drop from C-D in the suction pipe, ΔP_{DE} is the pressure drop from D-E in the injector, ΔP_{EF} is the pressure drop from E-F in the riser pipe.
ΔP_{AB} is caused by hydrostatic pressure and water velocity at the lower end of the pipe:

$$\Delta P_{AB} = \rho_L . g . (L_1 + L_2) - \frac{\rho_L}{2}\left(\frac{Q_{LS}(1-\beta_S)}{A}\right)^2 \qquad (2)$$

Where: ρ_L is the liquid density (kg/m^3), A is the pipe area (m^2), $u_{L,B}$ is the liquid velocity at the inlet (m/s), β_S is the solid fraction in the liquid-solid flow, L_1 and L_2 are respectively the length of the suction and riser pipes (m).

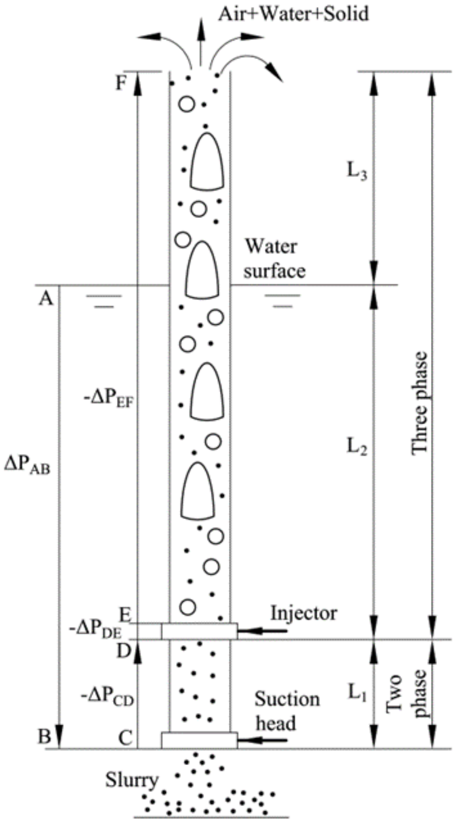


Fig. 1. Schematic diagram for analysis of modified airlift pump

ΔP_{CD} is caused by the weight and shear stress of liquid-solid two-phase flow. The mixture of liquid and solid is assumed as slurry. The force momentum is neglected at points C and D. It means that so that only the weight and shear forces of the two liquid-solid phases are affected:

$$\Delta P_{CD} = \frac{w_{LS}}{A} + \tau_{LS}\frac{\pi D L_1}{A} \tag{3}$$

Where: w_{LS} and τ_{LS} are the weight and shear stress of the liquid-solid mixture, respectively.

$$w_{LS} = \rho_{LS}.g.L_1.A \tag{4}$$

And,

$$\rho_{LS} = \rho_L(1-\beta_S) + \rho_S.\beta_S \tag{5}$$

Assume: The pressure gradient due to friction in the two-phase water-solid flow is constant, thus:

$$\tau_{LS} = \frac{A}{\pi D L_2}\left[\lambda_{LS}\frac{\rho_{LS}v_{LS}^2}{2D}L_2 + (\xi+\xi_c)\frac{\rho_{LS}v_{LS}^2}{2}\right] \tag{6}$$

ΔP_{DE} is caused by the momentum exchange of water-solid two-phase flow and gas-water-solid three-phase flow by injected gas. Assume the D-E distance is small compared to the pipe length so that the effect of weight and wall shear stress can be neglected, and also by considering the angle of the injector intake (θ) and the injector hole, then:

$$\Delta P_{DE} = -\rho_{LS}\left(\frac{Q_{LS}}{A}\right)^2 + \frac{(\rho_{LS}\cdot Q_{LS} + \rho_G\cdot Q_G)(Q_{LS}+Q_G)}{A^2} - \frac{\rho_G\cdot Q_G^2}{A.A_G}Cos\theta \quad (7)$$

Where: ρ_{LS} and ρ_G are respectively the density of slurry and gas (kg/m^3), N is the number of injector holes, A_{hole} is the area of the injector hole (m^2).

ΔP_{EF} is caused by momentum, friction, and weight liquid-gas-solid three-phase flow along the riser pipe. It is assumed that the liquid-solid-gas mixture's density and velocity do not change along the riser pipe, so the momentum change is neglected. The pressure drop due to the weight and shear stress of the liquid-solid-gas three-phase flow only are considered:

$$\Delta P_{EF} = \frac{w_3}{A} + \tau_3\frac{\pi D(L_2+L_3)}{A} \quad (8)$$

The weight of the gas-liquid-solid three-phase is equal to the weight of the liquid-solid mixture plus the weight of the gas:

$$w_3 = \frac{\rho_{LS}}{\left(1+\frac{Q_G}{s.Q_{LS}}\right)}.g(L_2+L_3)A \quad (9)$$

The slip ratio for slug flow is:

$$s = 1.2 + 0.2\frac{Q_G}{Q_{LS}} + \frac{0.35}{v_{LS}}(g.D)^{0.5} \quad (10)$$

Assume the pressure gradient due to friction in the three-phase water-solid-gas flow is constant so that:

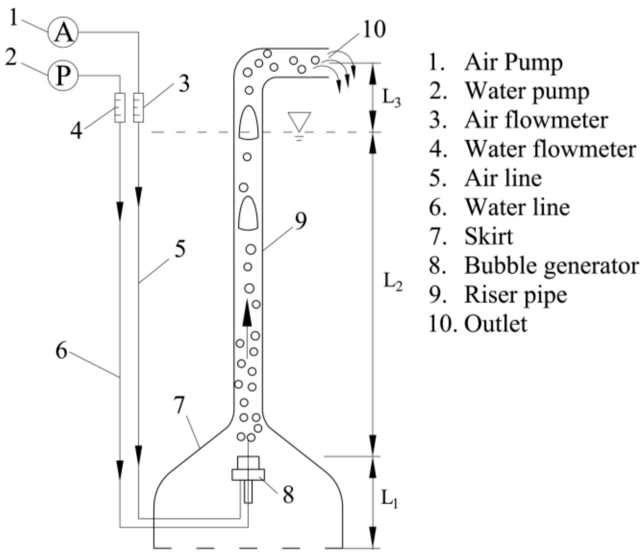
$$\tau_3 = \frac{A}{\pi D(L_2+L_3)}\left[\lambda_3\frac{\rho_3 v_3^2}{2D}(L_2+L_3) + \xi_E\left[\frac{\rho_{LS,3}}{2}\left(\frac{v_{LS}}{1-\beta_{G,3}}\right)^2 - \frac{\rho_{LS}}{2}v_{LS}^2\right]\right] \quad (11)$$

Where: L_3 is the length of the discharge pipe (m), λ_3 is the three-phase friction factor, ρ_3 and $\rho_{LS,3}$ is respectively the three-phase density and liquid-solid in three phases (kg / m3), $\beta_{G,3}$ is gas fraction in a three-phase mixture, ξ_E is the three-phase inlet loss coefficient. Substituting all the values ΔP_{AB}, ΔP_{CD}, ΔP_{DE}, and ΔP_{EF} into (1), and by running an iteration process, we get the Q_L and Q_S values for the specified Q_G values. The initial calculation step is selecting the values of D, D_{hole}, ρ_L, ρ_S, L_1, L_2, L_3, ξ, ξ_C, ξ_E, λ_{LS}, λ_3, and β_S. Next, it assigns the Q_G, assume a value of Q_{LS}, and calculate ΔP_{AB}, ΔP_{CD}, ΔP_{DE}, and ΔP_{EF}. Calculate the left-hand side of (1) and repeat steps by assuming the new Q_{LS} until the left-hand side of (1) nearly equals zero, The results of the calculation are the Q_L and Q_S values of the assigned Q_G.

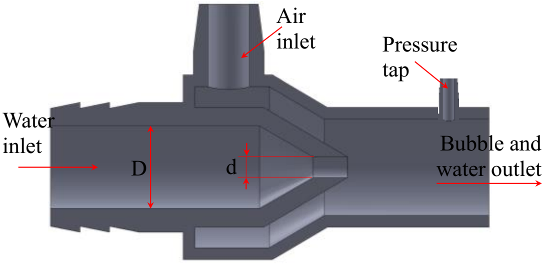
If this equation is applied in an airlift pump system that operates in two water-air phases, then β_s is the solid fraction in the liquid-solid flow which is equal to zero. Applying this equation in a system that uses a bubble generator requires adjustments to the slip ratio due to changes in upward flow momentum. So, the slip ratio, which is the ratio between air and water speed, changes significantly.

1. EXPERIMENTAL METHOD AND PROCEDURE

This research was carried out at the Mechanical Engineering workshop, Politeknik Negeri Banyuwangi, with a schematic diagram of the airlift pump-nozzle jet bubble generator shown in Fig. 2(a). This system consists of riser pipes made of Polyvinyl chloride (PVC) with diameters of 0.5in, 0.75in and 1.0in with a height of 90 cm according to the height of the fish pond. At the lower end of each riser pipe is placed a skirt with a diameter of 20cm. A nozzle jet bubble generator is installed in the centre of the skirt, with the output going to the riser pipe. The bubble generator input and outlet channels each have a diameter of 14mm, the nozzle has a diameter (d) of 4.67mm, and the air input channel has a diameter of 5mm, as in Fig. 2(b). A 38W water pump with a maximum flow rate of 30 lpm and an air pump with a maximum flow rate of 7.0 lpm are used to circulate water and air into the bubble generator. The water level in the pool is kept constant at 75 cm. By comparing the height of the water in the pool with the total height of the pipe, a submergence ratio of 0.83 was obtained.



(a)



(b)

Fig. 2. (a) Schematic apparatus of airlift pump-nozel jet bubble generator, (b) Nozzel jet bubble generator

The airlift pump-nozel jet bubble generator system was divided into two parts, namely, a system that uses a water pump and a system that does not use a water pump. The data collection step for systems that use water pumps begins by turning on the pump at its maximum discharge. Next, air begins to be injected at a flow rate of 1.0 lpm. The water at the outlet is measured using a measuring cup, stopwatch and digital scale to obtain the mass flow rate. The same steps were carried out for other air debits from 2.0 to 7.0 lpm and for different pipe diameters. For systems that do not use a water pump, only air is injected into the bubble generator from the air pump. The water discharge coming out of the outlet is then compared with the theoretically obtained water discharge, so the error value is obtained in the form of MAPE (Mean Absolute Percentage Error).

2. RESULTS AND DISCUSSION

Fig. 3 shows the relationship between the experimental data and the data from the model developed for an airlift pump system without using a water pump. The observations show that the greater the air discharge, the greater the water discharge that comes out through the outlet for each pipe diameter. For pipe diameter D=0.5in, it shows that there has been a peak at Q_G=6.0lpm for experimental data. After the peak point, the outgoing water discharge tends to remain, as shown by theoretical data. It is predicted due to the influence of the annular flow pattern formed in the riser pipe.

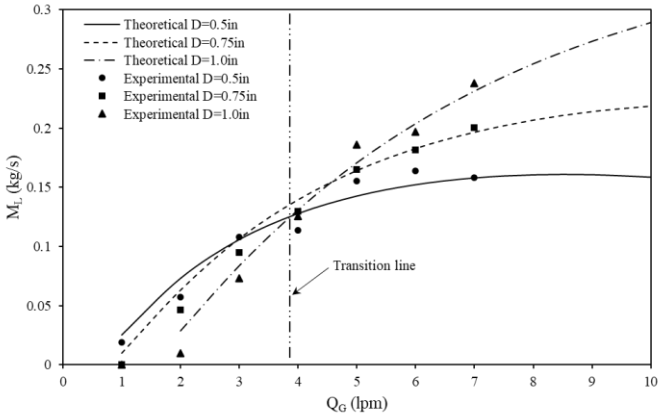


Fig. 3. Experimental and theoretical data for various pipe diameter without water pump

Therefore, it is generally known that the slug flow pattern will increase the discharge of water that comes out at the outlet to the peak point because the buoyant force possessed by the slug will increase the upward force on the riser pipe. The annular flow pattern causes a constant discharge of water because the annular flow tends to cause water to move on the pipe wall and air to move in the centre of the pipe so that the effect of wall friction becomes greater. For pipe diameters D=0.75in and D=1.0in, it has not shown a peak in the maximum airflow range of 7.0lpm. It shows that the larger the diameter of the pipe, the greater the volume of the riser pipe, which causes the air discharge needed to lift it to the peak to be greater.

From Fig. 3, it can also be seen that when the air discharge is less than 4.0lpm, it shows that the larger the pipe diameter, the lower the water discharge that comes out at a certain air discharge. When the air discharge is more than 4.0lpm, the larger the pipe diameter, the lower the water discharge that comes out. The transition line is the line that limits the two areas. This difference shows that when the diameter is large, the volume of water filling the riser pipe becomes larger, but the air supply is kept constant at low air flow (<4.0lpm), so that the slug's buoyant force cannot lift the water. A different thing happens at high air discharge (> 4.0lpm), the larger the pipe diameter, the greater the water discharge. At 4.0lpm the air flow is a transition area when the upward force exceeds the drag force that occurs in the riser pipe so that the larger the pipe diameter, the greater the water flow that comes out.

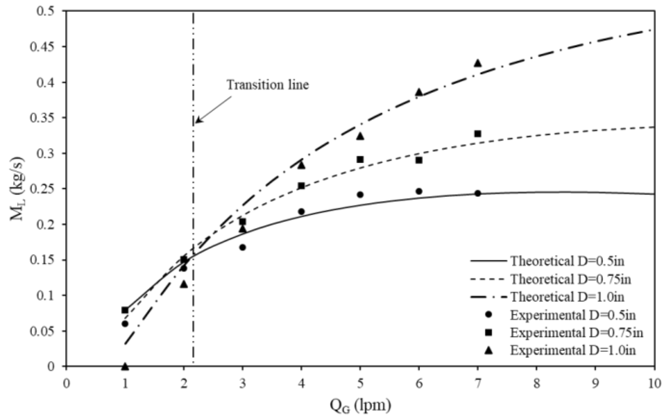


Fig. 4. Experimental and theoretical data for various pipe diameter with water pump

Fig. 4 is the experimental and theoretical data for a water pump system. Generally, the trend line for all pipe diameter variations is similar to the system without a water pump. Systems using water pumps produce output in the form of smaller bubbles than systems without pumps because the air that flows into the jet nozzle mixes with pressurized water to split into small bubbles. There are two advantages to using a system like this: it can increase the velocity of water flow in the riser pipe, which increases the momentum of the water flow. It can increase friction between the water and bubbles because more small bubbles are formed so that the contact area of the bubble becomes larger. Increased friction between the air bubbles also increases the amount of water lifted, thereby increasing the water coming out of the outlet. An increase in flow momentum can reduce the slip ratio when two phases move together in a channel. The slip ratio is the ratio of the velocity of water to air. When the slip ratio gets smaller, the velocity of the water that comes out increases. Besides that, the transition line also shifts towards an air flow rate of around 2.0 lpm, this shows that the system's performance using a water pump is higher than without using a water pump.

The difference in performance between the system without using a water pump and using a water pump is shown in Fig. 5. This figure shows that the lower the air discharge, the smaller the difference in water discharge between the system without a water pump and with a water pump. As the air flow increases, the difference tends to increase, it occurs because of the increase in the upward force on a constant drag force. The drag force occurs from the water's weight, water-air friction, and friction of water-air with the walls. The upward force arises from the buoyant force of the bubble flowing in the riser pipe. Using a water pump in an airlift system can increase pump performance by 94.61%.

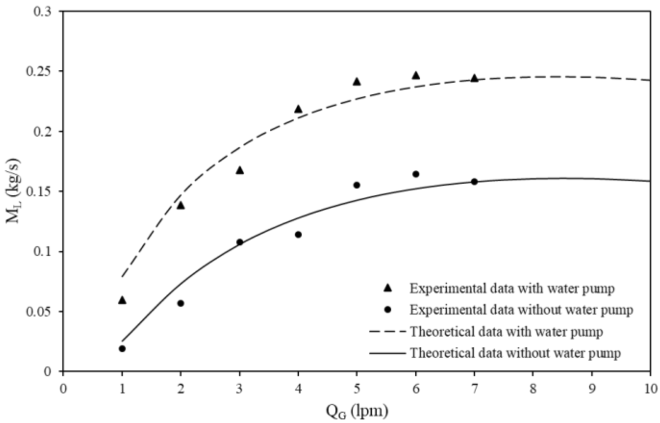


Fig. 5. Comparison of water discharge for with and without water pump in D=0.25in

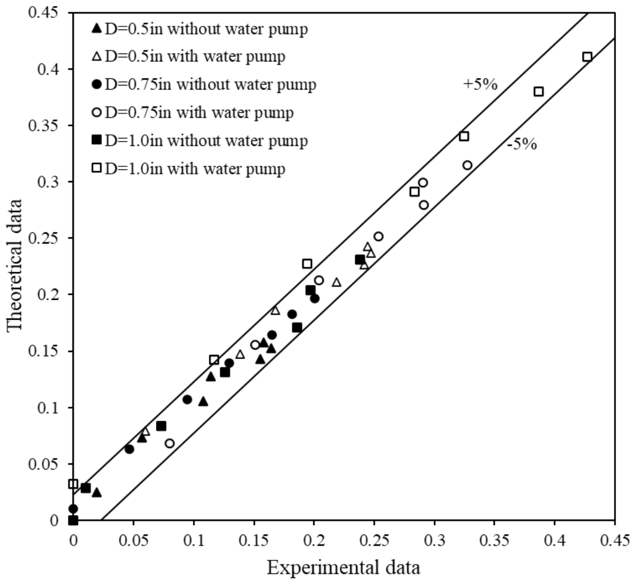


Fig. 6. Comparison of experimental and theoretical data

From the Fig. 6, it can be seen that there are three data from D=1.0in with water pumps that are outside the 5% error margin, but most of the data are within the 5% error margin. The lowest MAPE is 4.85% at D=0.75in with a water pump, It shows that there is agreement between the theoretical model and experimental data.

3. SUMMARY REMARKS

Research on the discharge of water that comes out of the airlift pump system has been carried out for various air discharges and variations of systems with and without water pumps. Summary of the results obtained as follows:

- Using a water pump in an airlift system can increase pump performance by 94.61%.
- At low air discharge (<4.0lpm for systems without a water pump and <2.0lpm for systems with a water pump), the larger the pipe diameter, the lower the water discharge that comes out at a certain air discharge.
- At high air discharge (>4.0lpm for systems without a water pump and >2.0lpm for systems with a water pump), the larger the pipe diameter, the greater the water discharge that comes out at a certain air discharge.
- Experimental and theoretical data show conformity with the lowest MAPE value of 4.85%

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