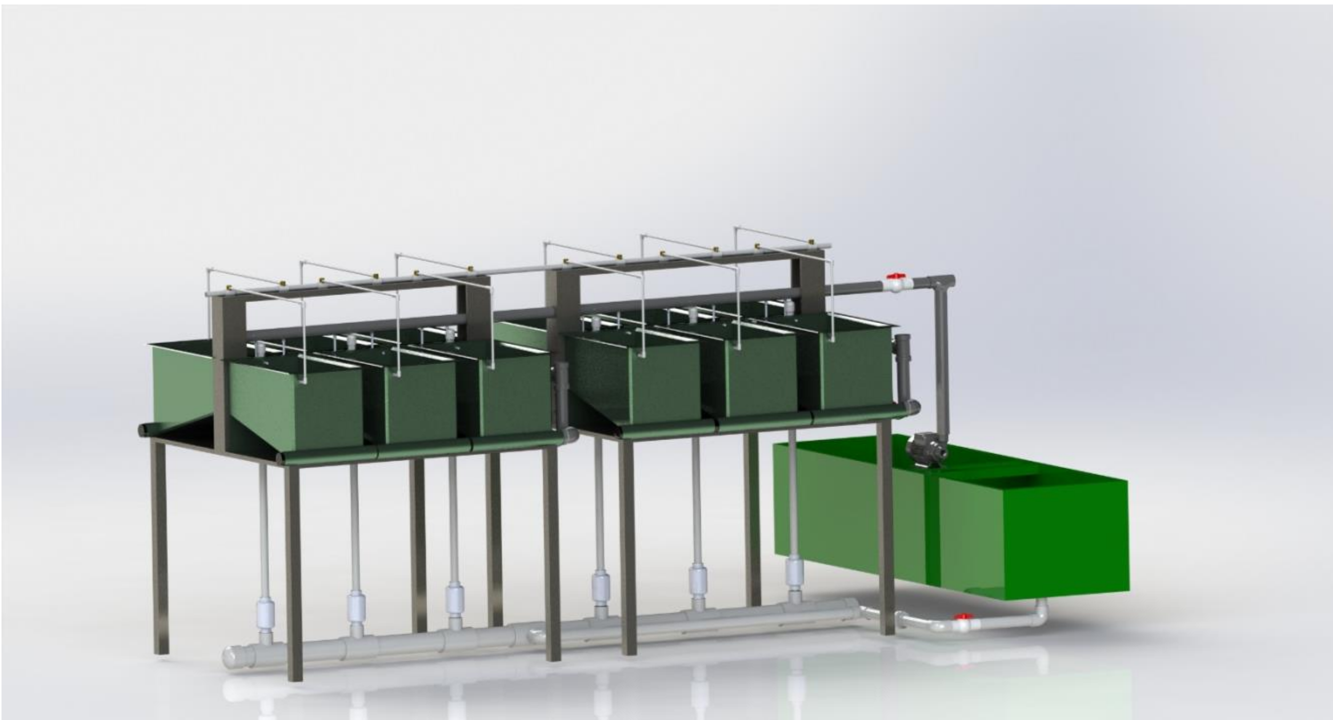
Technology Evaluation Report

Testing FloMov Pumping Technology For Energy Savings

FLONERGIA SYSTEMS

Efficient Airlift Pump for Sustainable Aquaculture Systems



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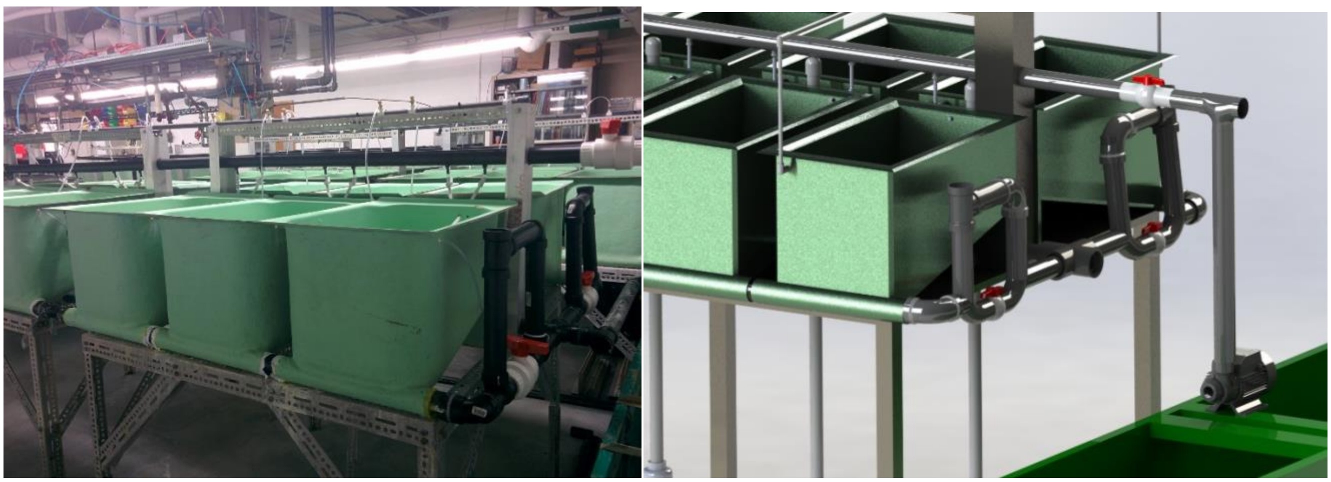
SUMMARY

In order to evaluate the new technology of airlift pump for aquaculture applications, existing recirculating aquaculture system (RAS) located in the Fish Nutrition Research Laboratory at University of Guelph was used. Two setups were used for this comparison, each setup consists of 12 fish tanks. The first System is the old system where centrifugal pump is used for water circulation along with air stones located in each tank to provide aeration. In the second system, six airlift pumps (one pump per two tanks) are used for simultaneous water circulation and aeration. The new airlift pump found to significantly reduce the total energy consumption in the recirculating aquaculture system compared to a system operating by conventional system (at least 50-70% of energy savings). Therefore, this technology is expected to have tremendous potential both in Ontario, Canada and internationally, especially for rural areas or offshore facilities where access to the energy represents a huge challenge. Given the low energy requirement to operate such pumps, solar or wind-powered units can be considered a revolutionary solution for many aquaculture sites located in remote areas. The Ontario aquaculture operations produces about 5,000 metric tonnes of fish per year valued at $20 million. Challenges associated with high production cost, slim profit margins, diseases and the high cost of energy make it imperative for this industry to adopt sustainable and economically viable technologies. Reducing the energy cost and improving productivity is critical for the sector to expand. The diversity in aquaculture production systems combine with the relatively small scale and segmentation of the industry makes it a very interesting market since it allows to encounter many different types of systems and potential adopters of the technology.

Task 1: Understanding the Old System

Aquaculture system located in the Fish Nutrition Research Laboratory is used to create a controlled interface between the culture (fish) and the natural environment. In this system, several techniques growing fish is also used to understand the nature of fishes, their behavior and their needs. Currently, the recirculating aquaculture system consists of a water pump, compressed air lines and large quantities of water. This system provides oxygen required for fish growth, as well as circulating water for living. There is one pump installed for operation of 24 water tanks. The current system also produces significant amount of noise pollution. This noise pollution is harmful for both fish and people working in the surrounding area. The old system, also consists of various tube fittings and PVC pipes, in addition to several air hoses connected to the tanks to supply air required for oxygenating the water. In this task, a solid works model is built for the whole system that simulate the whole piping, flow directions and used to design the new pumps required to operate the system without changing any part of existing system components. . Figures (1) and (2) show the actual picture of the system versus the computer simulations. The system also consists the major sources of energy supplies. These include the valves used for air supply and pipes used for water supply to the tank (Figure (3)).

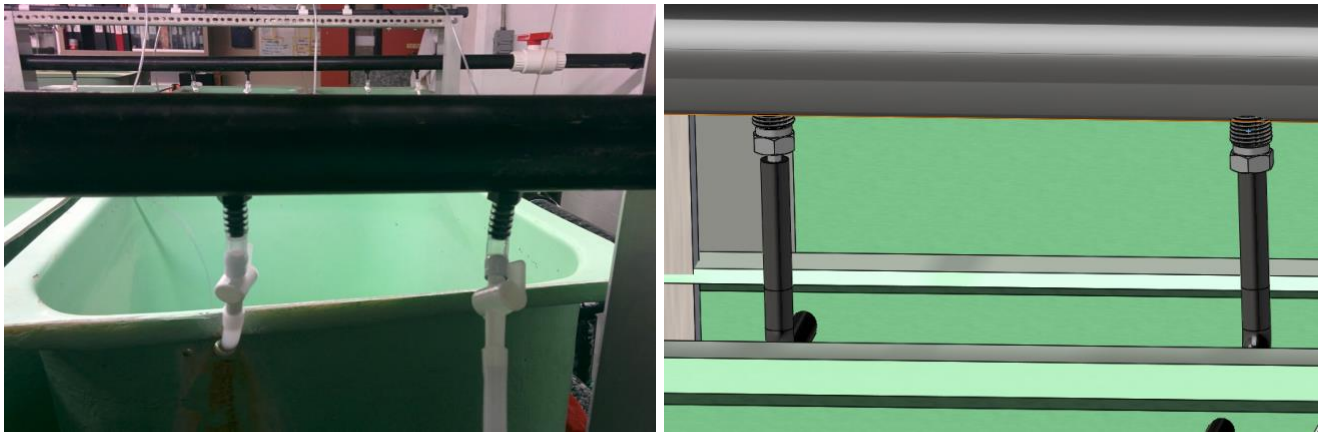


a) Actual picture

b) Computer simulation using solid works

Figure (1) Aquaculture system located in the Fish Nutrition Research Laboratory

Figure (2) Several views of the actual system vs the computer simulations



a) Water ports to the tanks

b) Air injection ports

Figure (3) Air and water ports connected to the tank

Since the main goal of this project is to evaluate the energy usage required to operate the aquaculture systems using conventional pumps and compare to the new technology, the airlift pump is designed to replace the pump in the old system under the same operating conditions. The design of the airlift pump explained in details in the US patents (8,596,989 B2, (2013), US. Patent 8,721,297, (2014) and App. 13/910,106, (2013)). On the contrary to conventional mechanical pumps, airlift pumps do not have any moving parts or require lubrication. In airlift pumps, air is injected at the lower end of a pipe to lift liquid or liquid-solid mixture using the effect of buoyancy force. Although the design theory of airlift pumps is known for many years, however existing designs uses a simple air injector which results in a very poor pump performance. The new technology utilizes both radial and axial air injections to enhance the pump performance using a patented dual air injector. This dual injector is optimized hydrodynamically to obtain the best performance of the pump. This technology offers a sustainable solution for aquaculture facilities through a simultaneous water circulation and aeration in these systems using a single device. It also offers the advantages of being simple and yet enable high flow rates, high head and high efficiency with lower capital, operation costs, maintenance, noise and vibration compared to centrifugal pumps commonly used in aquaculture

Task 2: Designing the Airlift Pump and 3D Printing

3-D printing was utilized in order to build the pump prototypes after all pump dimensions were optimized. The cross section of this design is show in Figures (4) and (5). This design consists of two compartments for both radial and axial injections. The air ports will be connected to air supply hoses and the pumps will be ready to operate for the flow conditions depending on the amount of air injected in both ports. Solids work models for the pump along with the actual printed pump prototype are shown in Figure (6).

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Figure (4) Dual injection airlift pump design

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Figure (5) Airlift pump design drawings

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Figure (6) Cross section of 3-D printed vs the solid works simulations

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Figure (7) 3-D printed vs the solid works simulations of the airlift pump

Task 3: Evaluating the Performance of the Airlift Pump

1. Equipment

In order to determine the performance of the pump experimentally, a setup was built consists of the following components:

1. Water collecting tank
2. Two 90° elbows (for a1.5 inch inner diameter PVC pipe)
3. 2 meter long PVC pipe (1.5 inch inner diameter)
4. 2 of the ¼ npts
5. 2 of Quick to Connect Adaptor MIP Reducing ¼ npts
6. 2 air valves (one for Axial and one for Radial air flow)
7. 1 valve to control the axial and radial air flow
8. An air regulating device
9. Compressed air supply
10. 2 meters of 3/8 Polyethylene Tubing (6.5mm outer diameter)

2. Procedure

The design parameters which correlate the liquid mass flow rate as a function of the air mass flow rate are considered in building the pump prototype. These parameters are: the geometric parameters (L, Hs, Ls, X, and D), the pressure conditions (P_a, Pin_1, Pin_2), and the fluid properties are given as input data to the theoretical model equations (Figure (8)). Where L is the riser-pipe length, Hs is the static head of water, Ls is the length of the suction part of the pipe, X is the distance between the two injections, D is the pipe diameter, Pa is the atmospheric pressure, and Pin is the air injection pressure to the riser pipe.

The momentum equation can be applied for each section of the airlift pipe is applied to a control volume bounded by the pipe wall and the cross sections 1 and 2.

The momentum equation may therefore be written as

$$A\{J_L \rho_L u_{L,1}\} - A\{J_{G,2}\rho_{G,2}u_{G,2} + J_L \rho_L u_{L,2}\} - \pi D\int_0^1 \tau_L dz - \pi D\int_1^2 \tau_{LG} dz$$
$$- A\int_0^1 \{\rho_L(1-\alpha)\}gdz - A\int_1^2 \{\rho_G \alpha + \rho_L(1-\alpha)\}gdz + A\{\rho_L g(L_0 + H_s)\} = 0 \quad (1)$$

where J is the volumetric flux, u is the velocity, α the volumetric fraction, ρ the density, τ the shear stress, g the gravitational acceleration. The subscripts G and L represent air and water respectively. The subscripts 0, 1 and 2 represent the cross sections of the water inlet, air injector and the outlet, respectively. The first and second terms denote the momentum which enters through 1 and leaves through 2. The third and fourth terms denote the frictional pressure loss in the air-water two-phase flow. The fifth and sixth terms denote the weight of the water and of the two-phase air-water mixture. The seventh term denotes the pressure force of the surrounding water acting on 0. The pressure at 2 is assumed to be equal to injection pressure at the second injector (Pin_2). Equation (1) can be also written between section 2 and 3 similarly. In order to developed such a model to predict the multi-stage air-lift pump performance, extensive analysis require more time and considered to be outside the scope of the present assignment.

However, the present work is concerned with the design parameters required to prove the pump operation. These parameters are:

- The ratio between the submergence (static lift) and the total length of the pipe (the sum of the static head and static lift), which is known as the submergence ratio, Sr. The submergence ratio is the most important factor in the pump design.
- Fluid volume flow rate (pump capacity), Q

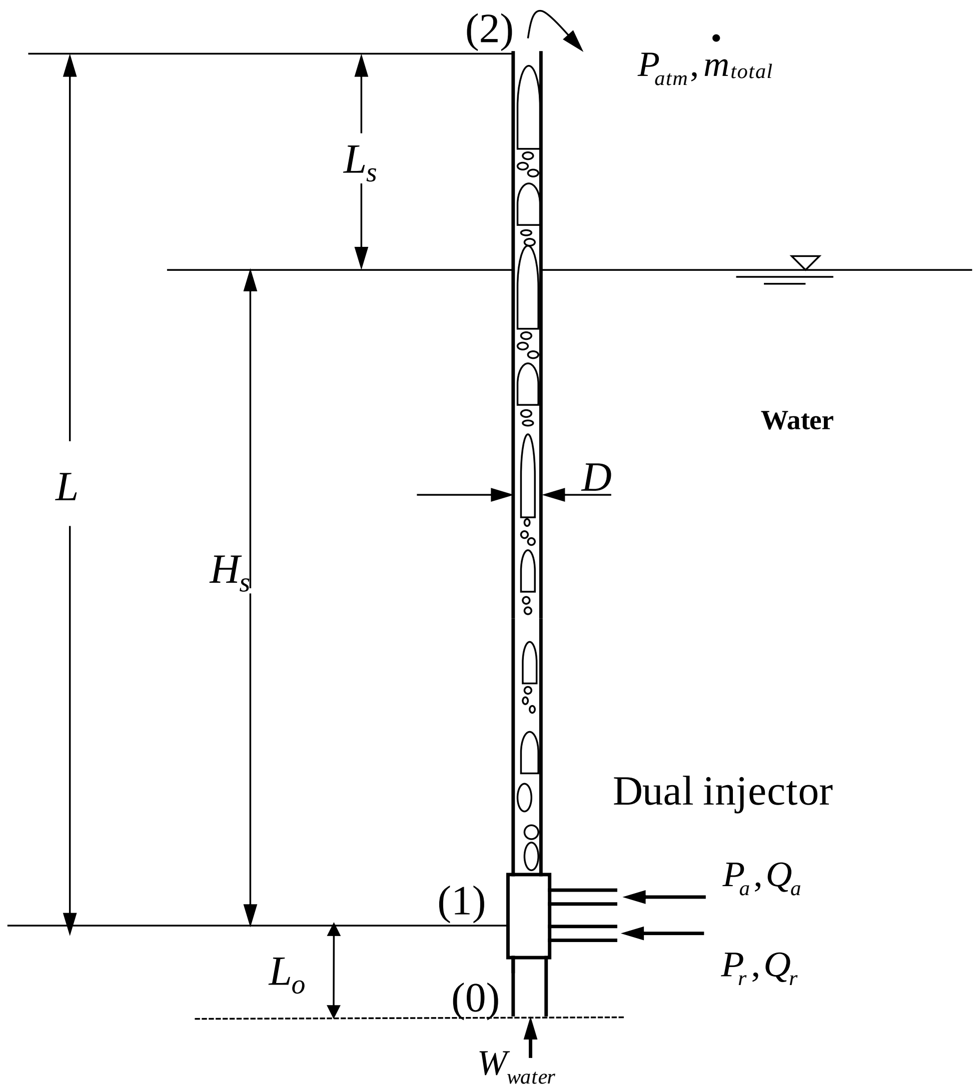


Figure (8) Schematic of the airlift pump model Parameters

Task 4: Installing airlift Pumps in the recirculating aquaculture system

1. Introduction and Equipment

In this task, the following were needed to install the pumps on the old system:

1. Standard 1 inch PVC pipe Schedule 40 Unthreaded, 30 ft. long
2. Standard 3 inch PVC pipe Schedule 40 Unthreaded, 8 ft. long
3. 12 of Quick to Connect Adaptor MIP Reducing ¼ npts
4. 6 of PVC Pipe Fitting Inline Reducing Tee, 3 Unthreaded Female x 1 NPT Female
5. 1 of PVC Unthreaded Pipe Fitting 3 x 1-1/2 x 3 Pipe Size, Reducing Tee, Schedule 80
6. 50 ft. of Polyurethane Tubing with OD of ¼ inch and ID of 0.1875 inch
7. Standard-Wall White PVC Pipe Fitting
8. 1 of 1-1/2 Pipe Size, Union, Socket Female x Socket Female
9. 2 of the Standard PVC Pipe Fitting 3 inch Pipe Size, Caps
10. 6 of the Standard PVC Pipe Fitting 1-1/2 Pipe Size, Caps
11. Barbed fittings for water supply
12. 6 Airlift Pumps designed scaled down to fit into 1 inch PVC pipe.

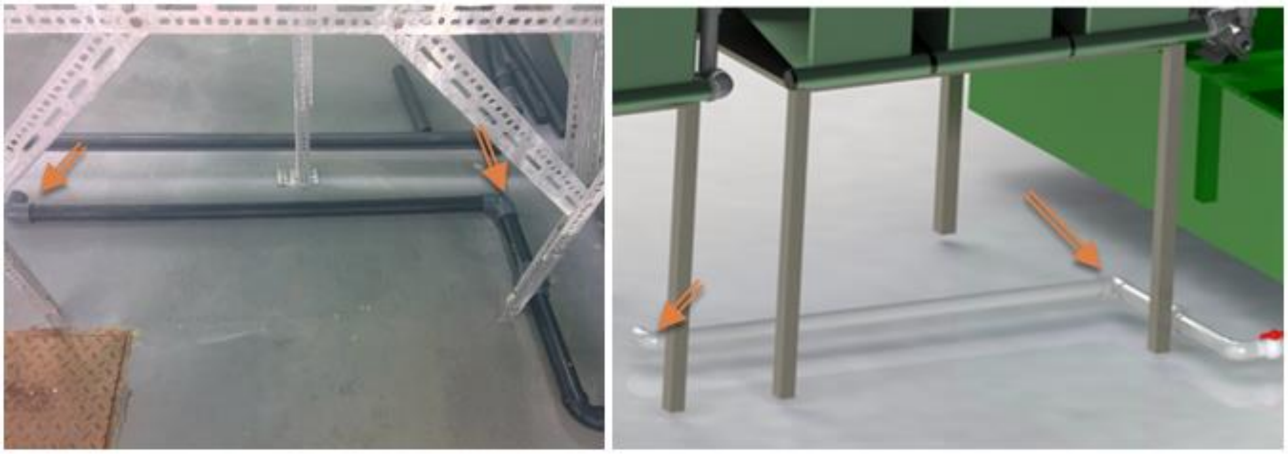
2. Procedure

Procedures of the pumps installations are summarized in Figures (9) through (14). Different view of the new system are shown in Figure (15) and (16)

1. Install a union in the old system to connect with the new system

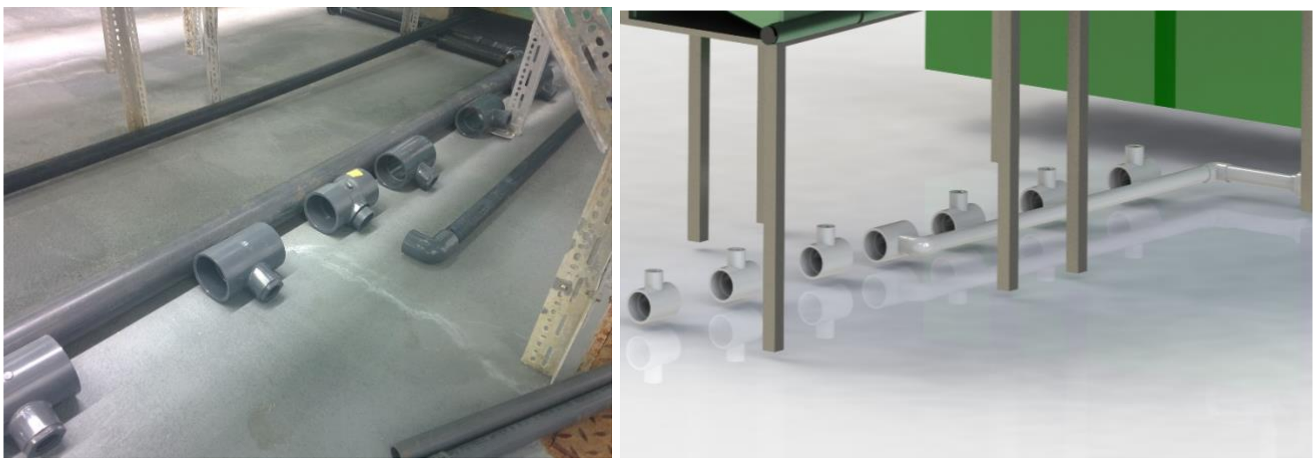
Figures (9) Installing the airlift pumps in the recirculating system step 1

2. Installing the two 90° elbows



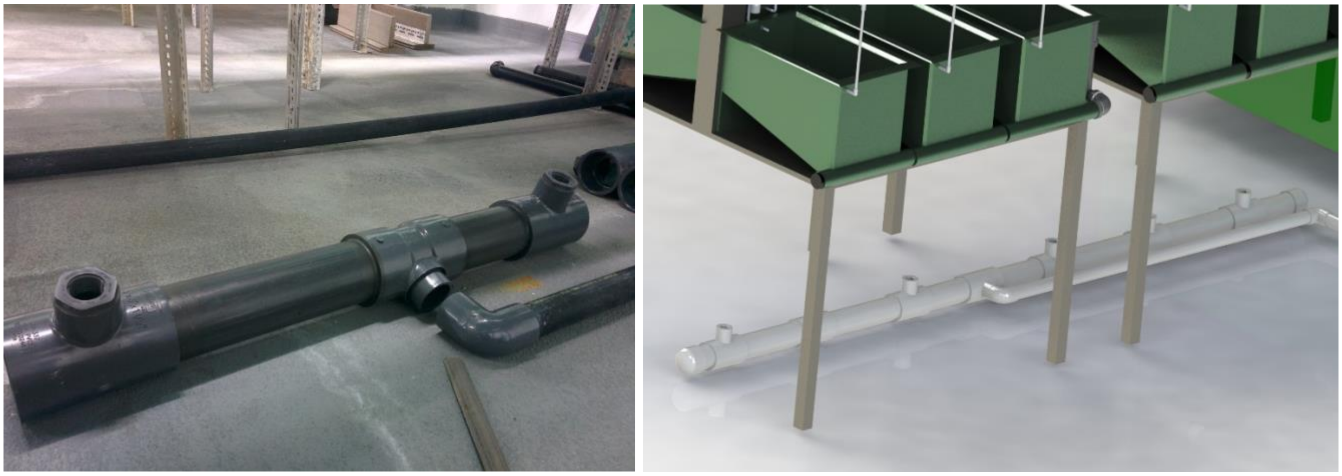
Figures (10) Installing the airlift pumps in the recirculating system step 2

3. Install 6 of 1 inch to 3 inch reducing tees



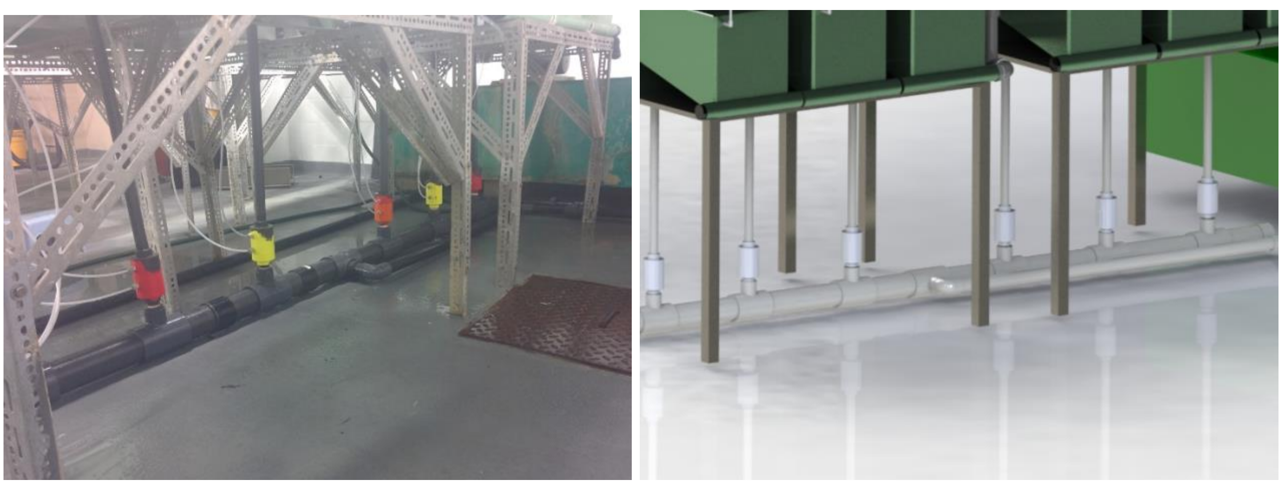
Figures (11) Installing the airlift pumps in the recirculating system step 3

4. Install connections between the tees



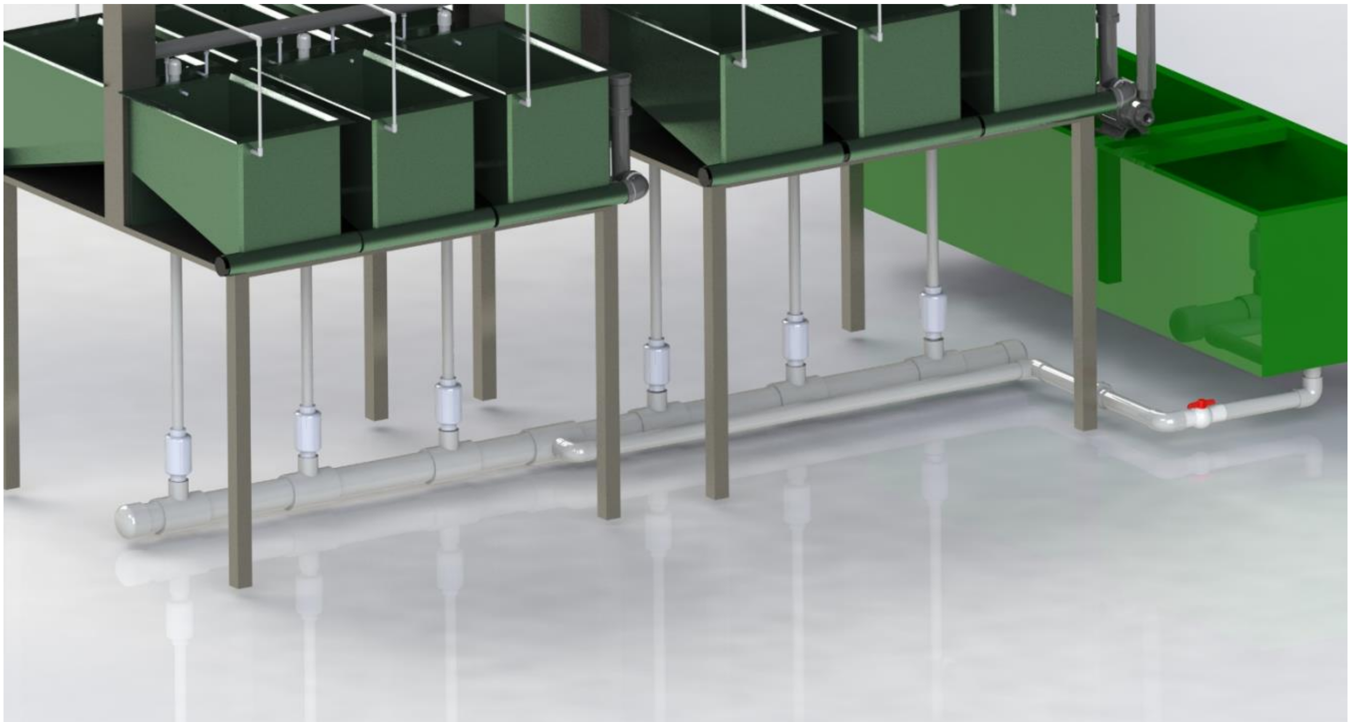
Figures (12) Installing the airlift pumps in the recirculating system step 4

5. Installing Airlift pumps on top of the tees

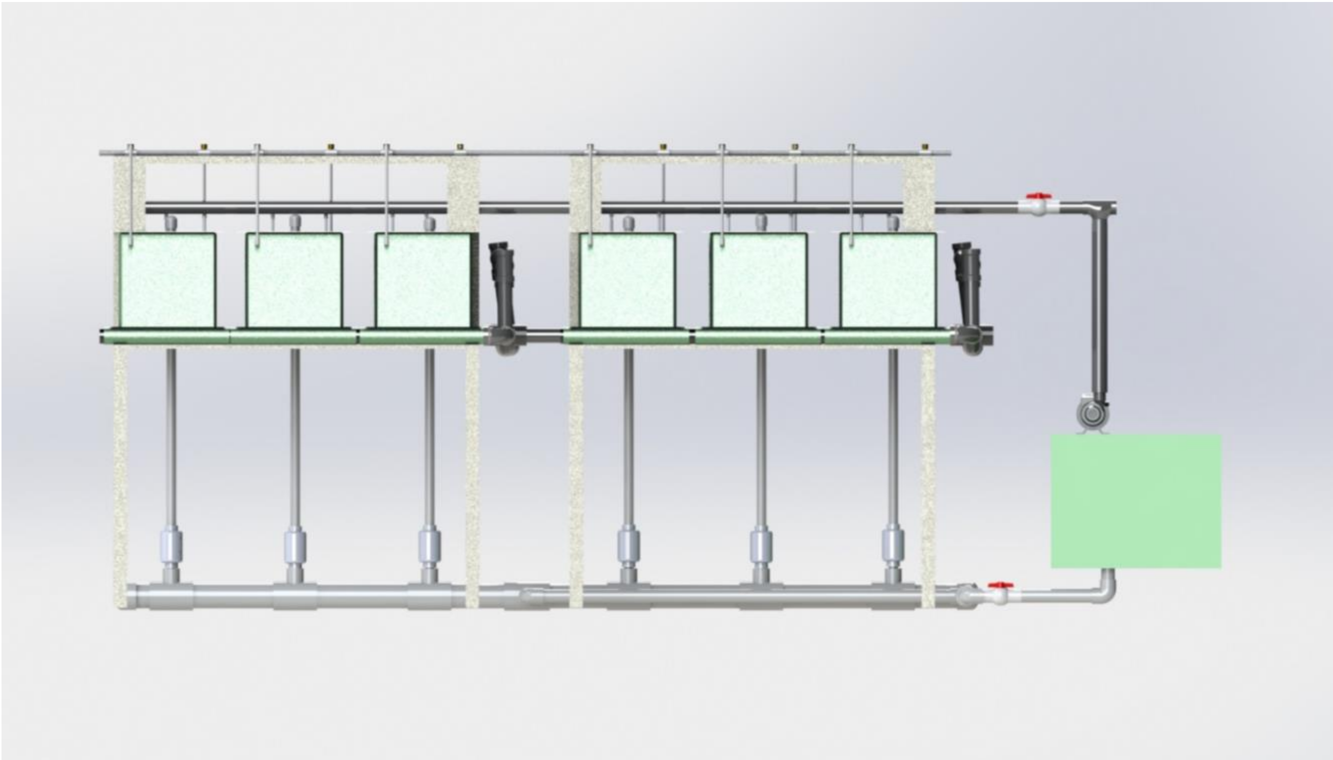


Figures (13) Installing the airlift pumps in the recirculating system step 5

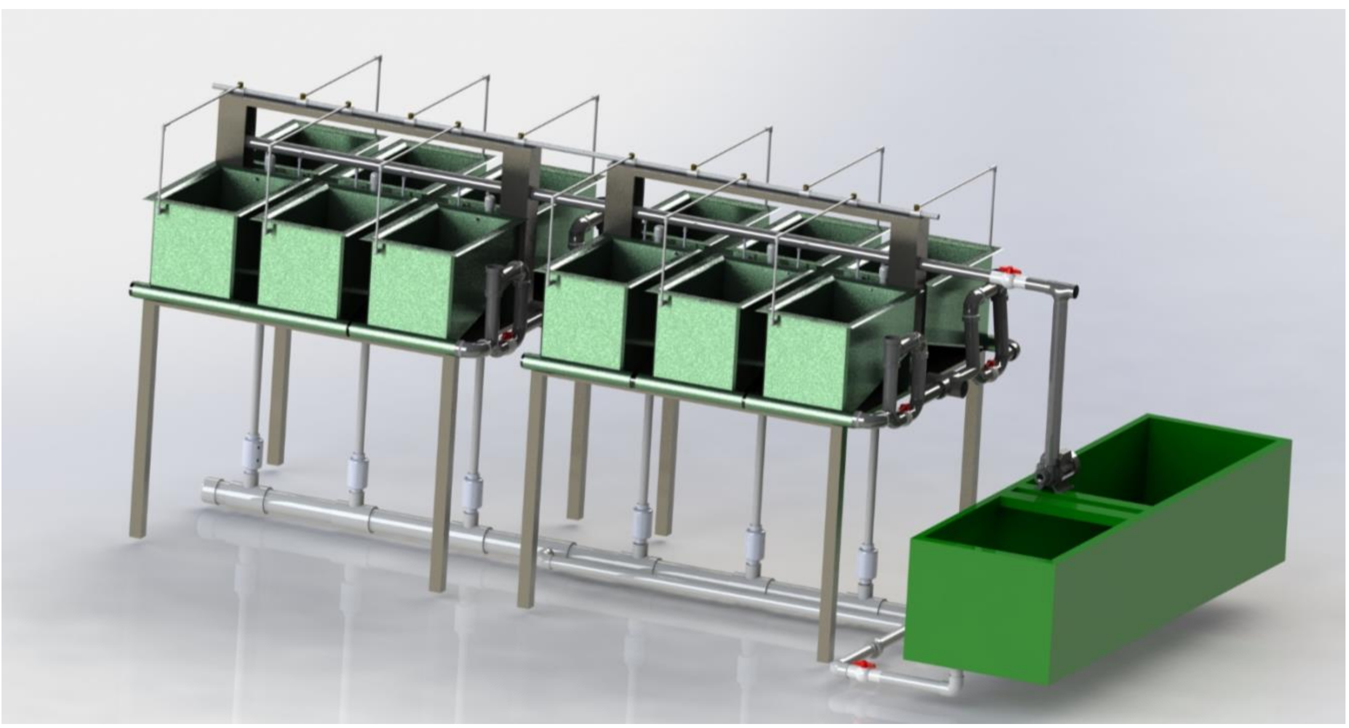
6. Supplying air and running the experiment



Figures (14) Installing the airlift pumps in the recirculating system step 6



Figures (15) Elevation of new recirculating system with airlift pumps installed



Figures (16) Isometric of new recirculating system with airlift pumps installed

RESULTS AND DISCUSSION

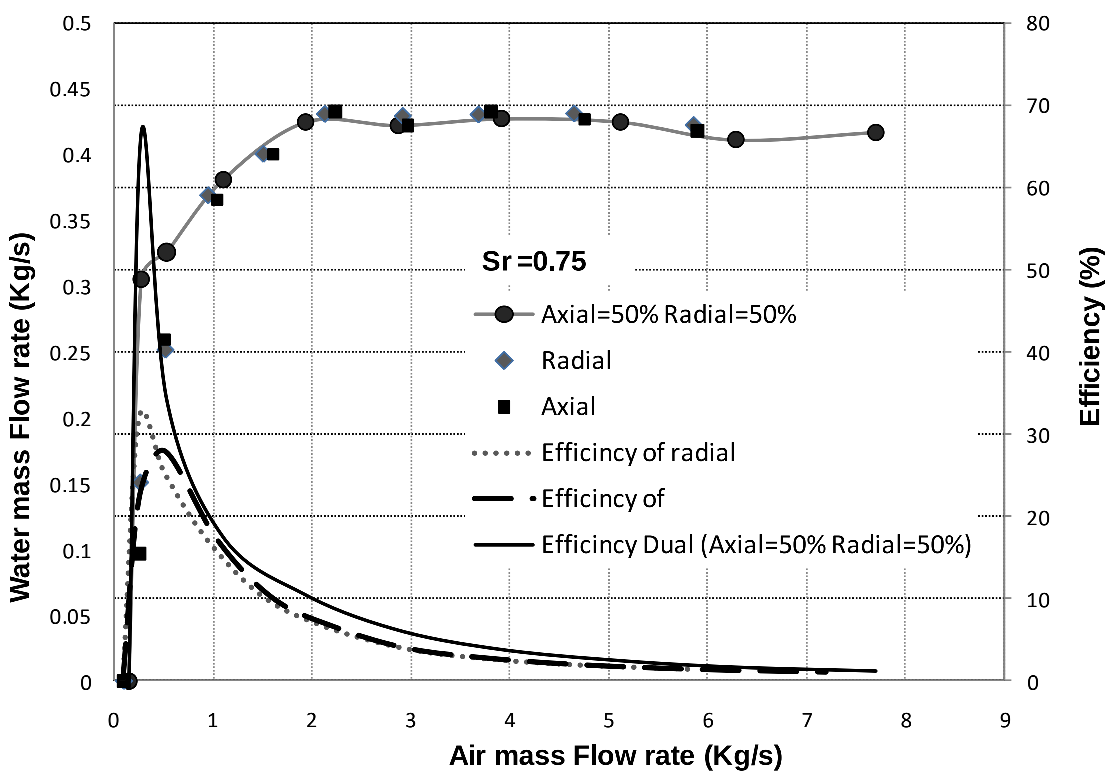
1. Airlift Pump performance

Figure (17) shows the performance curve of a single stage airlift pump operating at a submergence ratio of 0.75 and the static head of 1.18 m. It can be concluded that the amount of water lifted in this case is limited to about 0.25 L/s at an air mass flow rate of 0.1 L/s. As the air mass flow rate increases, the water mass flow rate approximately remain constant and further increases in the air mass flow rate tends to decrease the total amount of water lifted. This has been explained before in the previous study as the flow pattern approaches an annular flow and the reverse flow tends to increase in this case.

The pump efficiency is calculated in the present study using the definition:

$$\eta = \frac{\rho g Q_L (L - H_s)}{P_{atm} Q_{Gr} \ln \frac{p_r}{P_{atm}} + P_{atm} Q_{Ga} \ln \frac{p_a}{P_{atm}}}$$

where P_r and P_a are the injection pressures at the radial and the axial air injectors, Q_L is the water discharge, Q_a is the volumetric flow rate of air, P_{in} is the injection pressure of air, and P_a is the atmospheric pressure.



Figures (17) Performance characteristics of airlift pumps

For either radial or axial injection, it was noticed that, in the region in which the water flow rate increases, the flow pattern changed from bubbly to slug or slug-churn flow and then to annular flow at high air mass flow rate. This change from bubbly to slug is mainly due to the increase of the bubble coalescence with increasing the air mass flow rate. In the other hand, the change from slug to slug churn flow is due to the counter-current flows in the pipe rise. In other words, the direction of gas velocity inside the gas slug is upwards, while the water velocity direction in the thin film around the air slug is downwards. At a critical value of the air mass flow rate the gas velocity will suddenly disrupt the liquid film and therefore the slug flow will break down to form a churn flow pattern. The maximum water flow rate is reached when the frictional pressure drop, caused by the further addition of air, exceeds the buoyancy effect of the additional air. As the air mass flow increased the water mass flow rate remain approximately constant and an annular flow pattern is observed in this case. This typical transition is due to the high velocity of the air which supports the liquid film on the tube wall. In this case, the main driving force is the shear forces between phases and the pressure drop in such a case exceeds the buoyancy effect.

The efficiency curves at different values of submergence ratio are found to have similar trend for different operating conditions. The best efficiency range is always located in the first region of the performance curve and corresponds to a slug flow pattern. The experimental data for efficiency range higher than 50%. The maximum efficiency increased from ~25% to ~65% when the submergence ratio is increased from 0.5 to 0.75. Figure (17) shows the comparison between conventional injection (axial only and radial only) and the dual injection airlift pump performance for submergence ratio of 0.75. In the figure the 50% radial and 50% axial are refereeing to the ratio of the air mass flow from the radial injector and from the axial injector to the total mass respectively. The figure is showing approximately no change in the lifted water flow rate using the radial or dual injection, however, extensive reduction in the power required by the air which results in significant increase in the pump efficiency. In the dual-injection case, homogenous-type of two-phase flow was obtained downstream of the injector and the reverse liquid flow commonly observed close to the pipe wall in the conventional injection method is significantly reduced by the axial air jets introduced by the axial air injector in the current design. For submergence ratio of 0.5, the efficiency increased by 40% when dual injection is used and the total air mass flow rate equally divided between the radial and axial injectors. Similar behavior was obtained using different injection ratio, however, the percentage increase in the dual injection efficiency is less when the ratio of the axial air mass flow rate is higher than the radial air mass flow rate as shown in Figure (17) for a submergence ratio of 0.75. The experiments were performed for different submergence ratios and the efficiency of the dual injection airlift pump was increased by a value up to 90% at the same water mass flow rate in comparison with to the conventional radial injection airlift pump as shown in figure.

The new airlift pump found to significantly reduce the total energy consumption in the recirculating aquaculture system compared to a system operating by conventional pumps (50-70% of energy savings) as shown in Figure (18). Therefore, this technology is expected to have tremendous potential both in Ontario, Canada and internationally, especially for rural areas or offshore facilities where access to the energy represents a huge challenge. Given the low energy requirement to operate such pumps, solar or wind-powered units can be considered a revolutionary solution for many aquaculture sites located in remote areas. The Ontario aquaculture operations produces about 5,000 metric tonnes of fish per year valued at $20 million. Challenges associated with high production cost, slim profit margins, diseases and the high cost of energy make it imperative for this industry to adopt sustainable and economically viable technologies.

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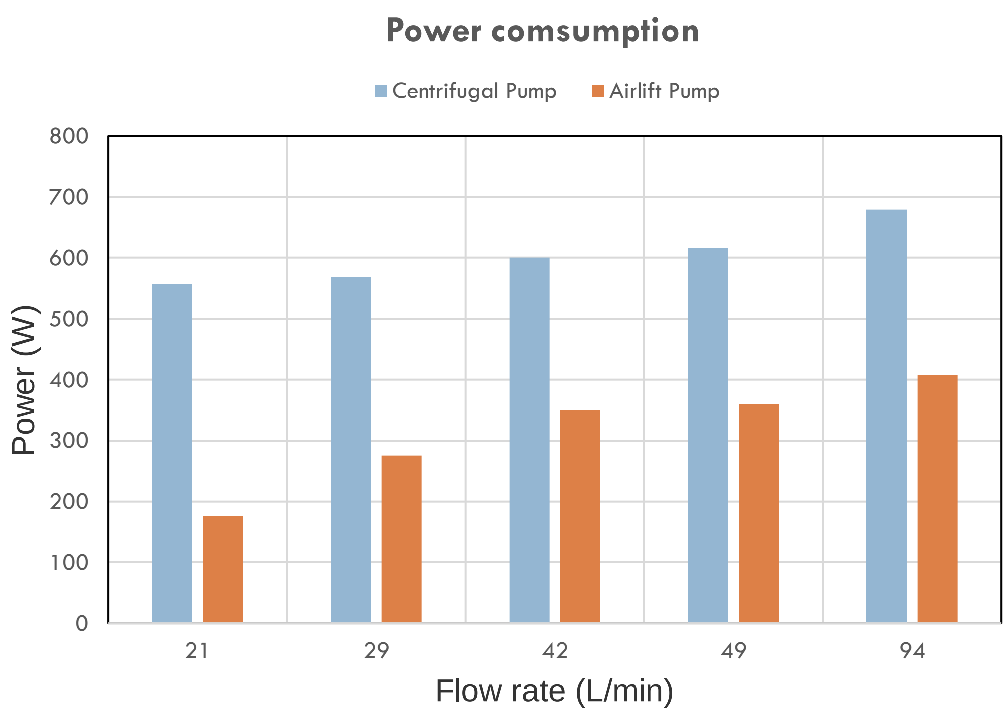

Figures (17) Comparison between energy consumption of new technology and conventional pumps