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Experimental Investigation Into The Use Of Compressed Air For Pumping Of Fluids And The Effects of Geometrical and Operational Parameters

(Pipe Diameter, Air flow Injection Rate and Air Injection Depth) on Individual Airlift Pumping Rates and Water Flow Rates.

By
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DEDICATION

I dedicate this Doctoral Dissertation to God Almighty my creator, my strength, my source, my strong pillar, my source of inspiration, wisdom, knowledge and understanding. He has been the source of my strength and on His wings only have I soared. I also dedicate this work to my wife; Patricia Aimalohi who has encouraged me all the way and whose encouragement have made sure that I give it all it takes to finish that which I have started. To my children to my children; Veralyn Eseohen, Jennifer Olohitare, Favour Osadebamen and Peace Agbomeire who have been affected in every way possible by this quest. Thank you. My love for you all can never be quantified. God bless you.

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Above all, I give all the Glory to God Almighty for His grace, mercy and favour.

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ABSTRACT

The chemical engineer is interested in many aspects of the challenges and problems involved in the flows of fluids. In the first place, in common with many other engineers, he is concerned with the transport of fluids from one location to another through pipes or open ducts; this requires determinations of the pressure drops in the system, and hence of the power required for pumping, selection of the most suitable type of pump, and measurement of the flow rates. In many cases, the fluid contains solid particles in suspension and it is necessary to determine the effect of these particles on the flow characteristics of the fluid or, alternatively, the drag force exerted by the fluid on the particles. In some cases, such as filtration, the particles are in the form of a fairly stable bed and the fluid has to pass through the tortuous channels formed by the pore spaces. In other cases the shape of the boundary surface must be so arranged that a particular flow pattern is obtained: for example, when solids are maintained in suspension in a liquid by means of agitation, the desired effect can be obtained with the minimum expenditure of energy if the most suitable flow pattern is produced in the fluid. Further, in those processes where heat transfer or mass transfer to a flowing fluid occurs, the nature of the flow may have a profound effect on the transfer coefficient for the process.

Compressed air can be used for transferring liquid from one position to another in a chemical works, but more particularly for emptying vessels. Thus, it is frequently more convenient to apply pressure by means of compressed gas

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rather than to install a pump, particularly when the liquid is corrosive or contains solids in suspension.

Furthermore, to an increasing extent chemicals are being delivered in tankers and are discharged by the application of gas under pressure.
Energy is the driving force behind global manufacturing today, and demand has increased exponentially with each generation. The global modern economy depends on its accessibility and, even more so, on its affordability.

Airlift pump is a type of deep well pumps. Sometimes, it is used for removing water from mines or pumping slurry of sand and water or other solutions.
The performance of airlift pump is affected by two sets of parameters; the geometrical and operational parameters.

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The geometrical parameters include pipe diameter, pump height, design of air injection system, and entrance geometry of the lifting pipe; while the operational parameters involve submergence ratio, conditions of injected air, and nature of lifted phase. Conventionally, airlift pump with bent riser tube is less efficient than that with vertically straight riser tube. However, in real life situations, the use of local riser tube bend or flexible riser tubes is considerably unavoidable.

The purpose of the experiments conducted in the present study is to carry out an experimental investigation into the use of compressed air for pumping of fluids vis-à-vis determining how the Airlift Design (That is; the Pipe Diameter, The Air Flow Injection Rate and The Air Injection Depth) Affect the Individual Airlift Pump Performance (that is; Pumping Rates and Water Flow Rates. And to Design a Low Cost Air-Lift Pump for Domestic Home Well-Water Pump.

In this research work, individual and combined pumping capacities were determined for floating airlift pumps, powered by a centrifugal blower. Individual airlift pumping rates ranged from 66-225 liters of water per minute (L/min) for all variables examined. Airlift pumps, 185 cm long, were made from PVC pipe of 7.6, 10.2 and 15.2 cm inner diameters. Air was injected through a 2.5-cm pipe at 50, 65, and 80 cm below the water discharge outlet. Water flow rates were measured at differing air flow injection rates (71-324 L/min). Individual airlift pumping rates increased as pipe diameter, air flow and air injection depth increased. Using the data from these experiments and a manufacturer's performance curve, it was calculated that a 1.0-horsepower (0.75 kw) centrifugal blower could pump 3107 ± 75 (SD) L/min water by combining the individual outputs of twenty-eight 7.6-cm diameter airlift pumps. To achieve this total, each airlift would require 71 L/min air flow injected at 80 cm depth (82.6 cm water pressure) to pump 111 L/min water.

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CHAPTER ONE

1.0. INTRODUCTION

An airlift pump is a pump that has low suction and moderate discharge of liquid and entrained solids. The pump injects compressed air at the bottom of the discharge pipe which is immersed in the liquid. The compressed air mixes with the liquid causing the air-water mixture to be less dense than the rest of the liquid around it and therefore is displaced upwards through the discharge pipe by the surrounding liquid of higher density. Solids may be entrained in the flow and if small enough to fit through the pipe, will be discharged with the rest of the flow at a shallower depth or above the surface. Airlift pumps are widely used in aquaculture to pump, circulate and aerate water in closed, recirculation systems and ponds. Other applications include dredging, underwater archaeology, salvage operations and collection of scientific specimens.

An air-lift pump is a device which is used to lift water from a well or a sump (Reservoir) with the use of compressed air. The compressed air is made to mix with the water. It is well known that the density of water is more than the density of air. This density difference helps to pump water through the pipe.

For pumping liquids or gases from one vessel to another or through long pipes, some form of mechanical pump is usually employed. The energy required by the pump will depend on the height through which the fluid is raised, the length

and diameter of the pipe and the rate of flow, together with physical properties of the fluid, particularly its viscosity and density. The pumping of liquids such as Tetraoxosulphate (VI) Acid, from the bulk store to process building or the pumping of fluids round the actual reaction units, are typical illustrations of the use of pumps in chemical industry.
The main function of the pump is to raise the pressure of the fluid to the required value. In general, pump used for circulating gases work at higher speeds than those used for liquids and lighter valves are used. Again the clearance between moving parts are smaller on gas pumps because of much lower viscosity of gases and increased tendency for leakage to occur.
The work done by the pump is found by setting up an energy balance equation. If Ws is the shaft work done by unit mass of fluid on the surroundings then – Ws is the shaft work done on the fluid by the pump.
In any practical system the pump will not be perfectly efficient and more energy must be supplied by the engine driving the pump then giving by – Ws.

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Considering the fact liquids are in compressible there is no change in specific volume from the inlet to delivery side of the pump. The physical properties of gases are however, considerably influenced by the pressure and the work done in raising the pressure of a gas in determined by the rate of heat flow between the gas and the surroundings.
Thus, if the process in carried out adiabatically all the energy added to the system appears in the gas and its temperature rises.
If an ideal gas is compressed and their cooled to its initial temperature, it is enthalpy will be unchanged and the whole of the energy supplied by the compressor is dissipated to the surroundings. However, if the compressed gas is allowed to expend it will absorb heat and is therefore capable of doing work at the exposes of heat energy from the surroundings.
Essentially, the same basic approach is applied for longing gases and liquids, though the construction may be very do iterant in the two cases. Under the normal range of operation pressure, the density of a gas is considerably less than that of a liquid so that higher speeds of operation can be employed and lighter valves fitted to the delivery and suction lines. Due to the lower viscosity of a gas there is a greater tendency for leakage to occur and therefore gas compressors are designed with smaller clearances between the moving parts. Further differences in construction are necessitated by the decreed in volume of gas as it is compressed and this must be allowed for in the compression appears as heat in the gas, there will normally be a considerable increase in temperature which may limit the operation of the compressor unless suitable cooling can be effected. For this reason gas compression is often carried out in a member of stages and the gas in cooled between each stage. Any gas which is not expelled

for the cylinder at the end of compression (the clearance volume) must be expanded again to the inlet pressure before a fresh charge can be admitted. The continual compression and expansion of the residual gas results in less of efficiency because neither the compression nor the expansion can be carried out completely reversibly. But with liquids this factor has no effect the efficiency because the residual fluid is not compressed.

In industry, compressed air is so widely used that it is often regarded as the fourth utility, after electricity, natural gas and water. However, compressed air is more expensive than the other three utilities when evaluated on a per unit energy delivered basis.

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1.1. Principle of The Airlift Pump

An airlift pump is a pump that has low suction and moderate discharge of liquid and entrained solids. The pump injects compressed air at the bottom of the discharge pipe which is immersed in the liquid.

The only energy required by this process is provided by compressed air, which is supplied by the centrifugal blower. This air is usually compressed by a compressor or a blower. The air is injected in the lower part of a pipe that transports a liquid. By buoyancy the air, which has a lower density than the liquid, rises quickly. By fluid pressure, the liquid is taken in the ascendant air flow and moves in the same direction as the air. The calculation of the volume flow of the liquid is possible thanks to the physics of two-phase flow.

The compressed air is made to mix with the water. It is well known that the density of water is more than the density of air. So it is obvious and evident that air floats higher than water or to understand better, water has more weight than air. So the main principle used in air-lift pumps is the density difference between water and air. Air is made to mix with the water and thus allowed to form froth. Froth here consists of mixture of water and air. So the density of this mixture is less than that of the water. It is the mixture of air which makes the density less than water. Thus a very small column of pure water can balance a very long column of air-water mixture.
The only energy required is provided by compressed air. This air is usually compressed by a compressor or a blower. The air is injected in the lower part of a pipe that transports a liquid. By buoyancy the air, which has a lower density

than the liquid, rises quickly. By fluid pressure, the liquid is taken in the ascendant air flow and moves in the same direction as the air. The calculation of the volume flow of the liquid is possible thanks to the physics of two-phase flow.

From a simple conceptual viewpoint, air bubbles act as pneumatic pistons, pushing or drawing water up a pipe or stack as they rise and expand. A more precise explanation describes the pumping action as the result of an air-water mixture. The air-water mixture is less dense than and therefore is displaced by the surrounding water of higher density.

Airlift pumps are widely used by aqua culturists. Common airlift applications are to pump, circulate and aerate water in closed, re-circulating systems as well as in ponds.

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Centrifugal blowers are one of the most effective and inexpensive methods to produce or pump air because they produce relatively high volumes of air at low operating pressures.
A centrifugal blower is a mechanical device for moving air or other gases.
It is a drum shape composed of a number of fan blades mounted around a hub. The hub turns on a driveshaft mounted in bearings in the fan housing. The gas enters from the side of the fan wheel, turns 90 degrees and accelerates due to centrifugal force as it flows over the fan blades and exits the fan housing. These fans increase the speed and volume of an air stream with the rotating impellers.
Centrifugal fans use the kinetic energy of the impellers to increase the volume of the air/gas stream which in turn moves them against the resistance caused by ducts, dampers and other components. Centrifugal fans displace air radially, changing the direction (typically by 90°) of the airflow. They are sturdy, quiet, reliable, and capable of operating over a wide range of conditions. Centrifugal fans are constant displacement devices or constant volume devices, meaning that, at a constant fan speed, a centrifugal fan will move a relatively constant volume of air rather than a constant mass.
This means that the air velocity in a system is fixed even though the mass flow rate through the fan is not.
Centrifugal fans are not positive displacement devices. Centrifugal blower has certain advantages and disadvantages when contrasted with positive-displacement blowers.
They are used in transporting gas or materials and in ventilation system for buildings. They are also well-suited for industrial processes and air pollution control systems.

The centrifugal blower is a drum shape composed of a number of fan blades mounted around a hub. As shown in the animated figure, the hub turns on a driveshaft mounted in bearings in the fan housing. The gas enters from the side of the fan wheel, turns 90 degrees and accelerates due to centrifugal force as it flows over the fan blades and exits the fan housing.

One might conclude from the results of previous works (Parker and Suttle) that individual, large-diameter pipes are the most effective airlift pumps. However, that does not take into consideration actual, and most efficient, blower operating pressures. The purpose of this study was to test airlift pumping characteristics for a specific design configuration and to determine reasonable expectations of water pumping capacity under practical field conditions.

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2.0. System Description

The system has a compressed air pipe with a nozzle introduced into the sump or the well. The compressed air is introduced into one or more nozzles at the foot of the delivery pipe, which is fixed in the well from which water is to be lifted. In the delivery pipe, which is partly open to the well or sump which contains water, a mixture of air and water is formed. The compressed air mixes with the liquid causing the air-water mixture to be less dense than the rest of the liquid around it and therefore is displaced upwards through the discharge pipe by the surrounding liquid of higher density. Solids may be entrained in the flow and if small enough to fit through the pipe, will be discharged with the rest of the flow at a shallower depth or above the surface. As already discussed, this density of air and water becomes less than the density of pure water. Hence a small column of pure water is sufficient to balance a very long column of air-water mixture. This air-water mixture is discharged through the delivery pipe. The flow will continue as long as the compressed air supply is maintained.

There are three phases to the operation of the pump. The first phase fills the pump with water. The lower check valve opens and the pump and PEX lines fill with water to the static level in the well. This is the normal condition of the pump and water when it is sitting idle. To get the pump to fill, the air line is opened to atmosphere. The water line is always open to atmosphere above ground.

The second phase involves closing the atmospheric vent in the air line and then gating the compressed air into that line. The compressed air pressurizes the system, forcing water out of the pump, up the other line, and into your tank, bucket, dog dish, or long-term survival hot tub.

The third phase starts when the pump empties and some air starts coming out of the water line. The pump valve is closed, and the remainder of the water/air mix is allowed to dribble out as the system depressurizes. The check valve in the water exit pipe inside the pump prevents any remaining water in the line from draining down into the pump again, to avoid pumping the same water multiple times. (PEX ⟶ PEX Pipe is a croslinked polyethylene tubing that provides an excellent option for plumbing).

The above cycle then repeats all over again.

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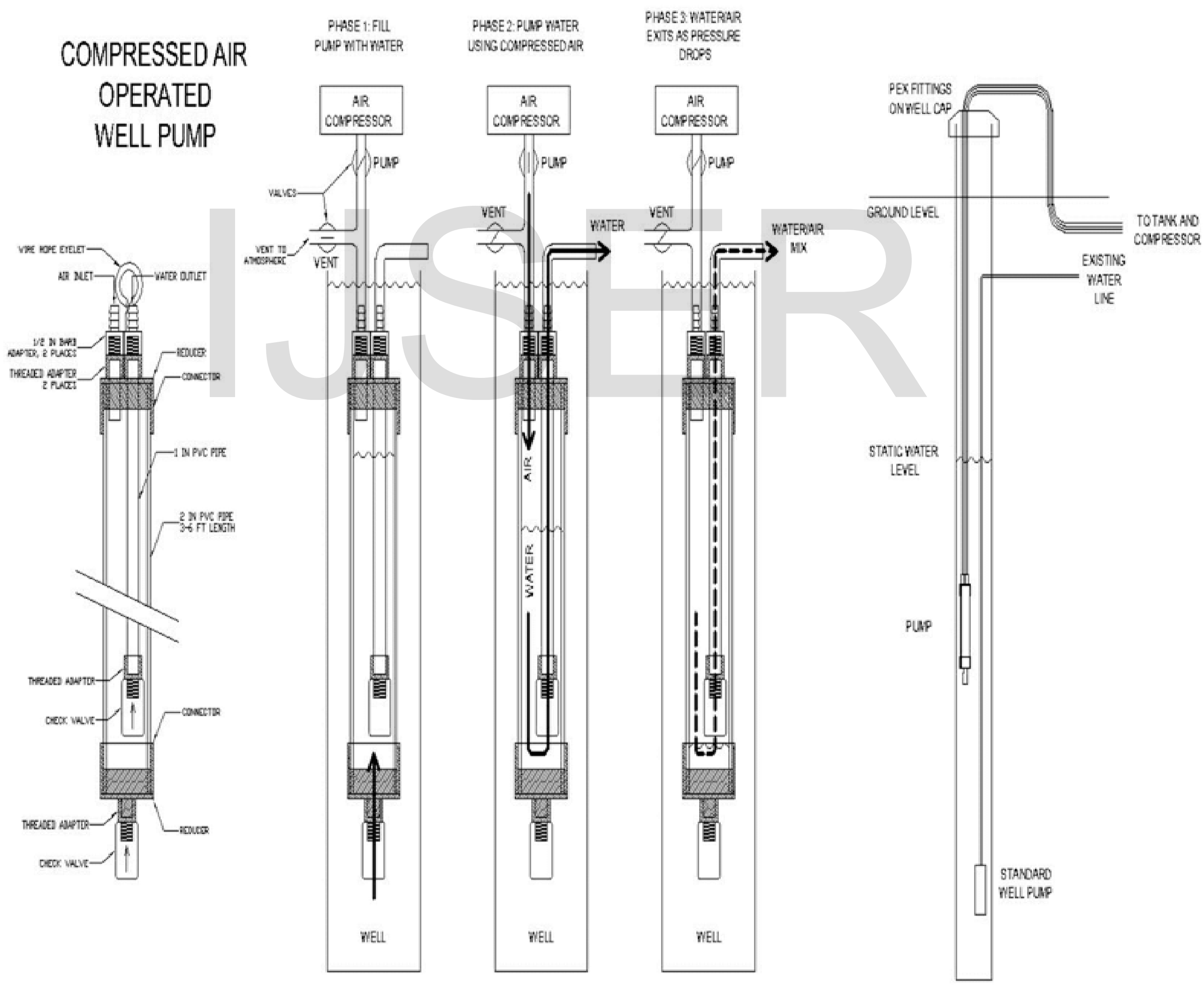

Figure 1A: Illustration of typical pump operation for a well with 85ft (25.9 metres) static water level, 130ft (39.62 metres) pump depth, pump valve is opened for 15 seconds, closed for 15 seconds, the vent valve is opened for 5 seconds, air pressure is about 50PSI and water flow is about 0.5 Gallons/Minute (1.89 Litres/Minute) for a 30iches pump.

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2.1. Construction / Arrangement

Airlift pumps were constructed from commonly used and readily available materials and equipment (PVC and polyethylene pipes, PVC fittings, stainless steel ring-clamps and a centrifugal blower). Pumping capacities were determined for floating airlift pumps (Fig. 1A, basic test configuration) powered by a 2.5-hp (1.9 kw) centrifugal blower. Airlift pumps, 185 cm long, were made from PVC pipes of 7.6, 10.2 and 15.2 cm inner diameters. Air was injected through a 2.5-cm inner diameter pipe (14.12 m long) at 50, 65, and 80 cm below the discharge outlet. The bottom of the discharge outlet ranged from 0-2.5 cm above the water surface and was buoyed with foam flotation. Air flow rates were varied between 71 and 324 litres per minute (L/min) and corresponding water flow rates were measured. Operating pressures were recorded for each airflow rate tested.

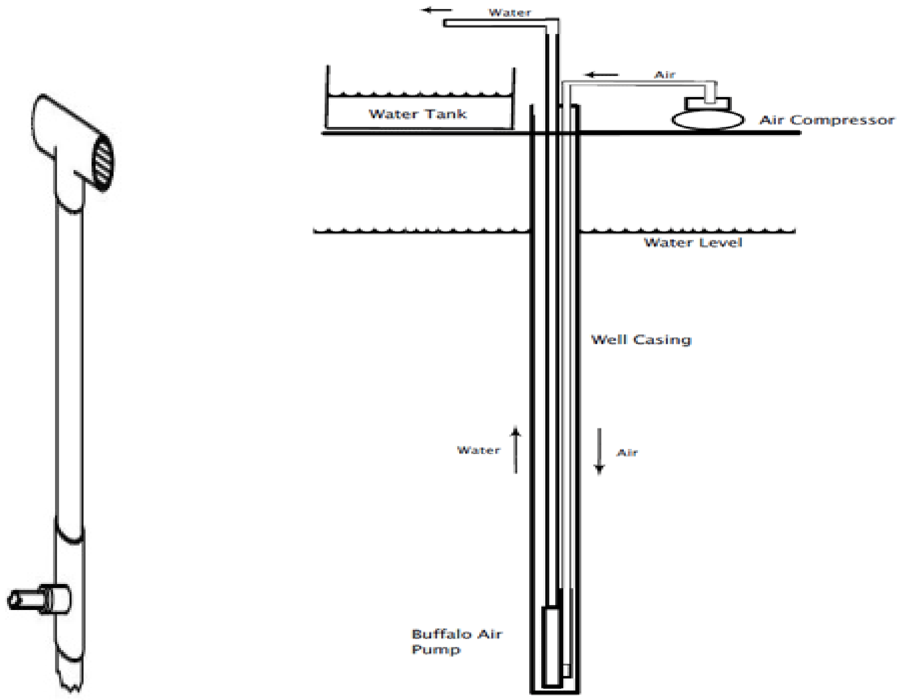

Figure 1b: Diagram of my model airlift pump designs

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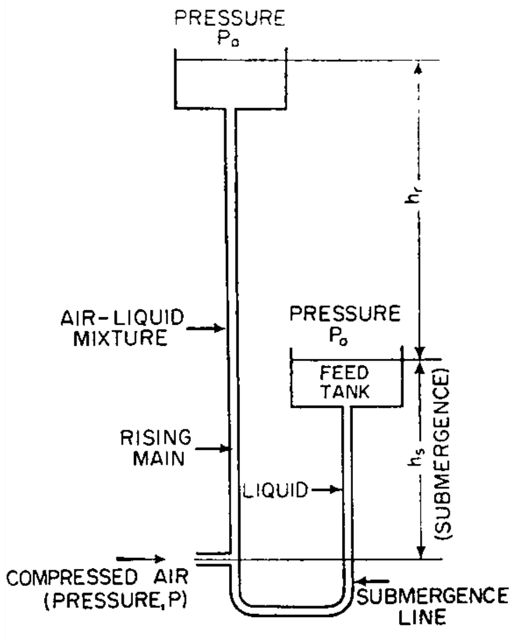
Delivery Tank



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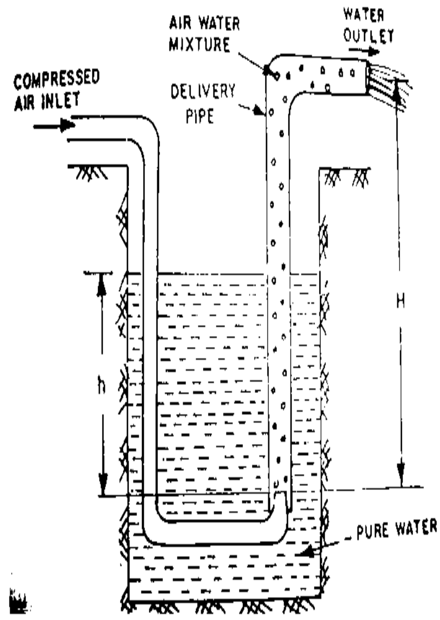

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Figures 2 and 3: Compressed Air Lift Pump Arrangement

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3.0. Experiment & Methods

To determine the overall system performance, measurements of the primary water flow rate, auxiliary water flow rate (when used), and air flow rate were made. The auxiliary water flow is the component of water flow that is being injected into the riser before pump in order to generate swirl in the riser before air injection. A closed-loop piping system was used. Figure 4 shows the system configuration with key dimensions noted.

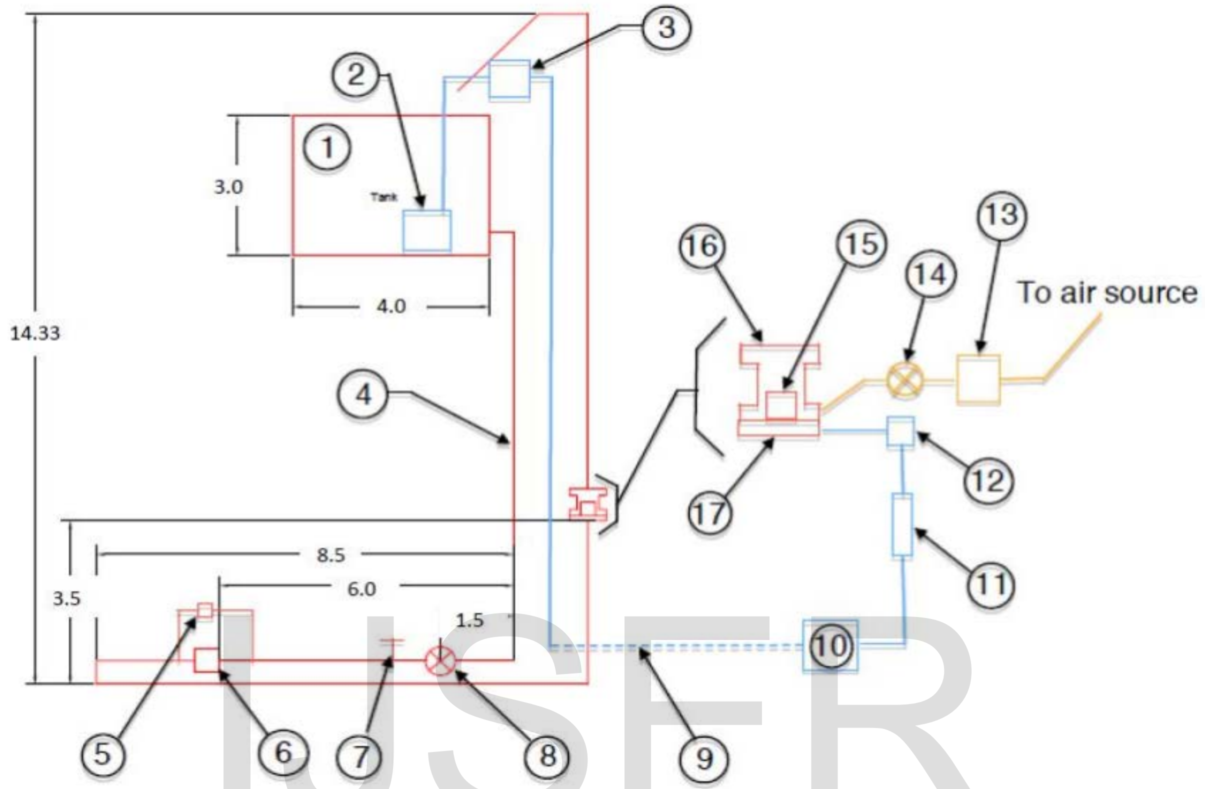

Figure 4: System diagram of the airlift pump.

Red denotes primary water delivery piping, blue denotes the auxiliary water delivery piping, and orange denotes the air flow delivery piping. The primary water delivery piping schematic is to scale. Units that are displayed are in feet. The compressed air was supplied by the centrifugal blower and was used to supply air to the nozzle (#15). A high-pressure hose connected the supply valve to the air injection point. A control valve (#14) and an air rotameter (#13) were placed in the main line to control and measure the air flow at the air injection point. The shutoff valve was placed between the air rotameter and the air injection point to prevent the back flow of water into the air rotameter and hosing while the pump is idle.

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The primary water flow is drawn through the tank outlet and then through the down comer pipe.
Pressure taps (one diameter and one-half diameter distances upstream and downstream, respectively) were placed on either side of the orifice and were

attached to a differential pressure transducer (#5). The orifice was calibrated by recording the pressure difference, in inches H2O, across the orifice plate (#6). Simultaneously, discharge water at the exit was collected in a bucket over a measured time. Weighing the contents of the bucket permitted determination of the mass flow rate. There is a positive, linear correlation between the pressure drop over the orifice and the square of the mass flow rate of the water. After passing through the orifice, the water is piped to the air injection component assembly.

The investigation and experimentation was carried using a U-tube of two limbs of relative different lengths each attached to a tank respectively.
This device was constructed using a corrosion resistant stainless steel material to form a u-tube with one limb relatively short and connected to a tank which acted as the delivery tank.
This other limb had an opening made into it near the bottom. A pipe was then attached to this opening to form T-joint where the air from compressor was injected into the system. The fluid to be pumped (or transferred) was introduced into the then allowed to flow down to fill up the short limb up to a point.
The air blower was then started allowed to build up air and the valve opened and the air was then injected into the system through the inlet near the bottom of the longer limb. The longer limb therefore contains a mixture of liquid and air which is therefore of lower density.
When the air was introduced sufficiently rapidly, the liquid (water) flowed from the short to the long limb and was discharged into the delivery tank. (See figure 3 A, B)
The water feed limb is known as the submergence line and the line caring the aerated mixture is the main. The ratio of the submergence (hs) to the total height of rising main above the air injection point (hr+hs) is know submergence ratio ($1+{}^{hr}/_{hs}$) work done on the liquid is M.g.hr . If the pressure of the entering air is P. the work done by the air in expanding isothermally to atmospheric pressure, Pa, is given by

W = Pa Va mln P/pa 1

Where Va is the specific volume of air at atmospheric pressure.

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The expansion will be almost exactly Isothermal because of the intimate contact between the liquid and the air.

The efficiency of the pump n is therefore equal to

M.ghr/mPaValn p/pa 2

The mass of air required to pump unit mass of liquid is, therefore, given by:
m/M = ghr/ηPaValn p/pa 3

There were some losses in the operation of the pump. However if all losses in the operation were neglected, the pressure at the point of introduction of the compressed air operation were neglected, the pressure together with the pressure due to the column of liquid of height hs, the vertical distance between the liquid level in the suction tank and the air inlet point.
Therefore;
Pa + haρ̇g 4

P = (ha + hs)ρ̇g 5

Where ρ̇ is the density of the liquid
Thus from equation 5, the mass of air required to pump unit mass of liquid $^{m}/_{M}$ would be equal to:

Hrg/PaValn hs + ha/ha 6

Air flow rates and operating (in-line) air pressures were measured with a hot wire anemometer, a U-tube manometer and an air pressure/flow regulator system constructed from 2.5-cm PVC pipe and gate valves (Figure 5). System operating pressures were determined for each injection depth and approximate air flow rate before adjusting actual air flow rates. Once operating pressure was determined, valve C was closed and valve A was used to adjust air flow while adjusting air pressure with valve B (Figure 5). After air flow had been adjusted for the appropriate pressure, valve C was opened, valve B was closed and water flow was then measured. Air and water temperatures were between 27 and 32°C. The study was conducted in a 0.13 ha pond (2.44 m deep) at 173.7 m above sea level.

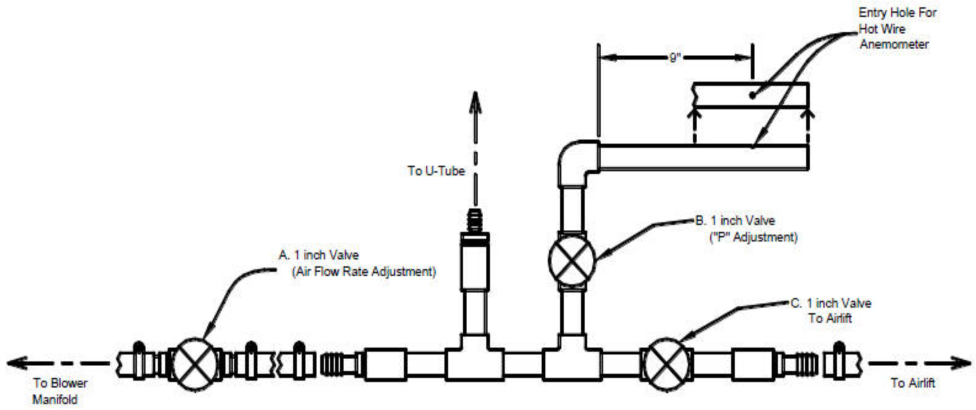

Figure 5: Air pressure flow regulator system for testing and adjusting air flow

Materials:
PVC Valves, 1 inch PVC Glue Socket – 3 each
PVC Adaptor, 1 Inch Socket to Threaded – 3 each
PVC TEE Joint, 1inch Socket – 2 each
Adaptor Barb, 1 inch Threaded to 1inch Polyethylene Hose – 2 each
PVC Pipe, Schedule 40, 1 inch
Polyethylene Hose, 1 inch
Hose, 3.8 inch

Water flow was calculated by measuring the time required to fill a 127-L, rigid plastic container. Five measurements were collected and timed for each combination of pipe diameter, air flow and air injection depth. Mean and standard deviation were calculated for each of the five water flow rates observed. Flow rates for air and water were plotted and compared with linear, power, exponential and logarithmic regressions.

Figure 6A: Airlift Performance for a 7.6 cm Pipe

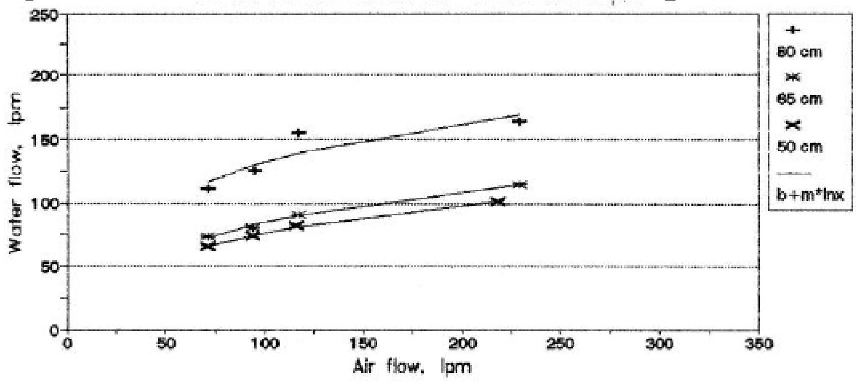

Figure 6B: Airlift Performance for a 10.2 cm Pipe

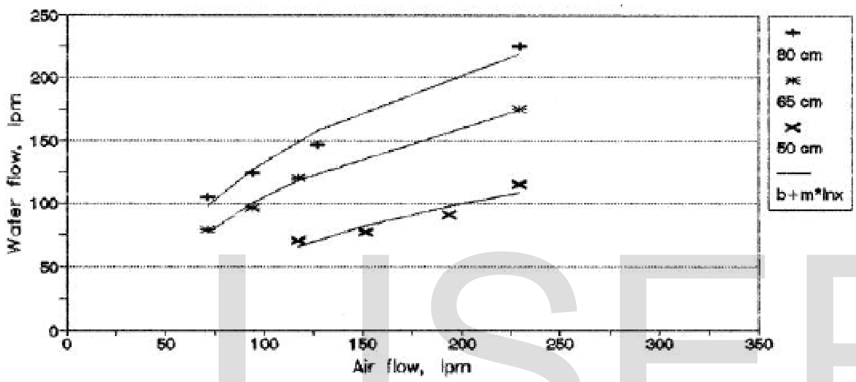

Figure 6C: Airlift Performance for a 715.2 cm Pipe

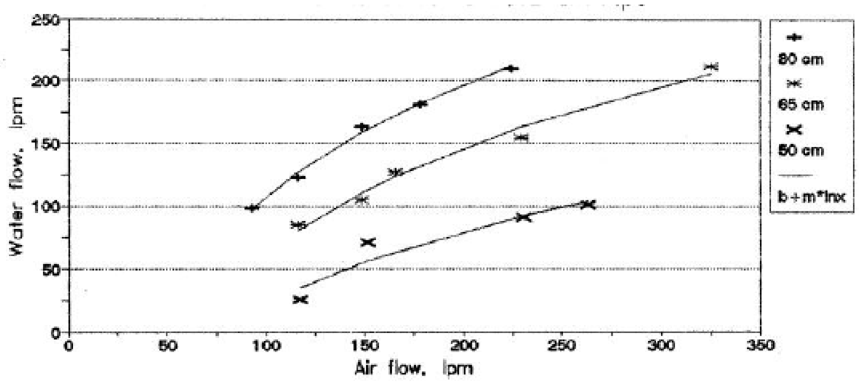

Figure 6: Regression (y = b + m*lnx) and data plots of air flow and mean water flow rates for three injection depths (50, 65 and 80 cm) and airlift pipe diameters (7.6, 10.2 and 15.2 cm).

4.0. Results and Discussion

Logarithmic regression (y=b+m*lnx) had the best fit with the data collected (Figure 6). Values for the coefficient of determination (R^2) ranged from 0.82 to 0.998. Overall, individual airlift pumping rates increased as pipe diameter, air flow and air injection depth increased. Individual airlift pumping rates ranged from 66-225 L/min water for all variables examined. Operating pressures were 0-21.6 cm water greater than corresponding injection depths and increased as air flow increased (Table 1).

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Table 1. Mean water flow rates and corresponding standard deviations produced at various air injection depths, operating pressures and air flow rates in 7.6 (A), 10.2 (B) and 15.2 cm (C) inner diameter airlift pumps.

Injection depth (cm)	Pressure (cm H_2O)	Air flow (liters/min)	Water flow (liters/min)	Standard Deviation
A. 50	55	71.1	65.5	±2.5
	55	94.3	74.5	±0.9
	55	115.8	82.7	±1.4
	55	217.8	101.6	±1.4
65	65	71.1	73.9	±2.7
	65	94.3	80.4	±2.6
	65	117.5	90.7	±3.3
	65	228.5	115.6	±1.5
80	83	71.1	111.4	±2.7
	83	94.9	125.2	±3.3
	83	117.5	155.2	±2.1
	83	228.5	163.9	±1.9
B. 50	53	117.5	70.3	±5.9
	52	151.5	77.2	±1.4
	53	193.1	91.7	±1.1
	56	228.5	114.9	±1.9
65	65	71.1	78.6	±3.1
	65	94.3	96.2	±3.8
	67	117.5	120.5	±4.8
	70	228.5	175.1	±4.0
80	80	71.1	105.1	±1.9
	80	94.3	124.2	±1.0
	80	126.6	146.9	±3.1
	83	228.5	224.8	±3.1
C. 50	56	117.5	<25.4	----
	56	148.4	70.7	±3.9
	57	230.2	83.2	±1.2
	60	230.2	98.2	±1.9
	60	262.5	100.7	±2.5
65	70	115.8	85.2	±2.2
	71	148.4	105.4	±5.2
	72	165.4	127.3	±4.7
	74	228.5	154.9	±4.0
	86	324.2	212.1	±2.1
80	84	92.6	98.2	±2.8
	85	115.8	123.0	±5.8
	87	148.4	163.6	±3.9
	88	177.5	181.7	±5.8
	88	224.0	210.3	±6.2

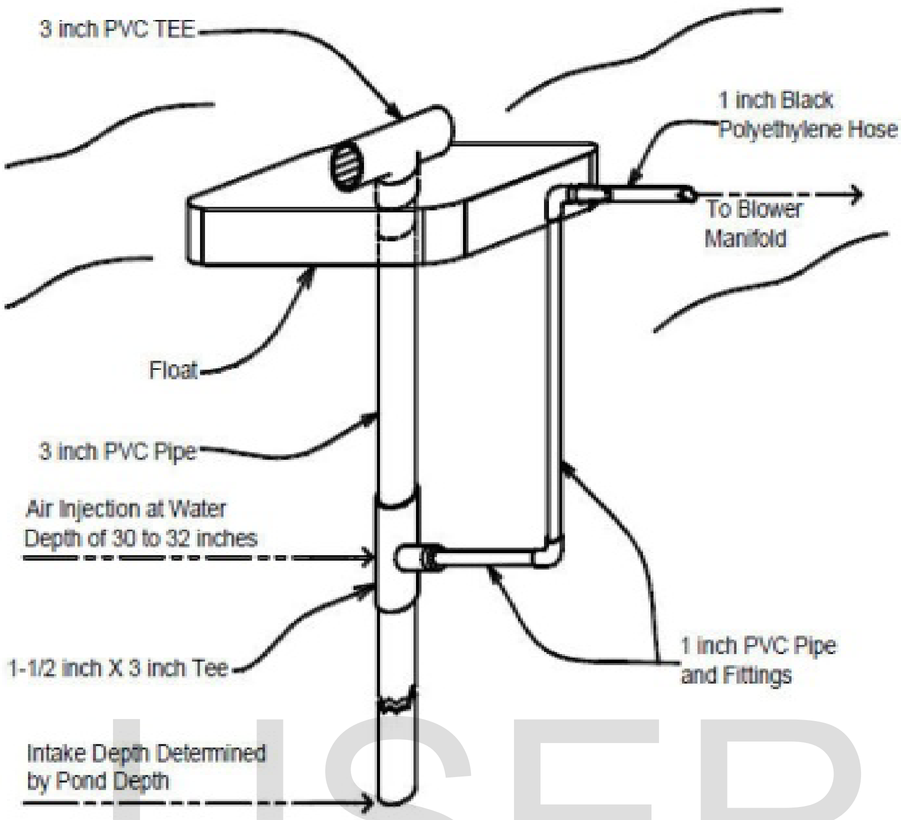

Figure 7: A diagram of an easily constructed, floating airlift.

While the water flow rates measured in this study were good, they were somewhat lower than the findings of Parker and Suttle. It is difficult to determine whether the pumping rates observed by Parker and Suttle were significantly greater than those observed in the present study without an indication of data set variability. The discrepancies observed in this study may relate to placement of the discharge pipe at slightly less than 100% submergence (0 to 2.5 cm above water level), longer pipe lengths (185 vs. 130 cm) and different test equipment (Figure 1A vs. 1B, and Figure 5). Parker and Suttle demonstrated that water flow rates in 5 to 10-cm airlifts increased as much as 12 to 38% when the water discharge pipe was lowered from 1.25 cm above the water surface, to a position level with or slightly below the water surface. Equations used by Castro and Zielinski predicted the maximum water flow rates possible for a given pipe diameter and percent submergence, but do not predict water flows for various air injection depths at virtual 100% (98.6-100%) submergence.

Of practical importance, but not readily apparent from the findings of Parker and Suttle, is that operating or system in-line pressure increases as air flow increases. For any given air flow rate, the in-line pressure increases as length of the air injection pipe increases and as pipe diameter decreases (7.6 vs 2.5 vs 1.25 cm). Air flow rates of 36.8 and 73.1 L/min, or greater, would create turbulent flow and back pressure in 1.25- and 2.5-cm inner diameter air lines, respectively. An air flow rate of 1,138 L/min would generate significant back pressure in a 1.25-cm diameter injection line. Back pressure develops as a result of line resistance (friction), and is the most plausible explanation for the observed operating pressures exceeding corresponding air injection depths in the present study. The most notable example was observed when air was injected, at a flow rate of 324 L/min and 65 cm depth, into the 15.2 cm airlift. Operating pressure increased by 16 cm water over that observed for the lowest air flow rate (115 L/min) tested at the same injection depth and airlift diameter (Table 1).

Figure 7 is a diagram of an easily constructed, floating airlift de-stratifier which will closely parallel the performance characteristics of the pumps tested in this study.

5.0. Conclusions

The performance of airlift pumps depends mainly on two groups of parameters. The first group is the geometrical parameters such as pipe diameter, pump height, design of injection system and entrance geometry of the lifting pipe, while the other group is the operational parameters such as submergence ratio, injected gas flow rate and its corresponding pressure, and nature of lifted phase. This research presents an experimental study of the effects of local bends of the riser tube on the airlift pump performance. A series of experiments on a model airlift pump with different riser tube configurations, based on the position of local riser tube bends, were carried out. Although slight improvement in the water-pumping rate can be obtained when setting the S- shaped local bend section of the riser tube close to the air injection level, the effect of bend section position of the riser tube under the current working conditions has an insignificant conditions has an insignificant contributions to improvements in the pump discharge rate.

While high air flow rates injected into large diameter airlift pumps may generate impressive water flow rates, they also produce dramatic increases in air injection line back pressure. As noted by Parker and Suttle, pressure increases of several centimetres water can substantially reduce airlift performance and efficiency. As operating pressure increases, total air output can decrease significantly in centrifugal blowers, particularly for blowers rated at 2.5 hp (1.9 kw) or less. Using standard manufacturers' performance curves for commercially available, 1.0-hp (0.75 kw) centrifugal blowers and the data in Table 1, it was calculated that the highest water pumping rates (2775-3107 L/min) could be achieved by combining the individual outputs of 25 to 28, 7.6-cm diameter airlifts. Each airlift would require 71 L/min air flow (at 82.6 cm water pressure) injected at 80 cm depth to pump 111 L/min water.

Airlift pumps appear to have excellent potential for use in cages, floating raceways, closed or recirculating systems, and for pond de-stratification or aeration. Some general design schematics are depicted in Figure 1A, B and C. Each configuration would have a more practical use depending on system design or construction and the intended application. Figure 1A might be better suited for construction of airlift cages (in-frame) while 1C would be more practical for floating airlift de-stratifiers. The basic design presented in Figure 1B could facilitate incorporation of multiple airlift outputs into a common, floating reservoir (e.g. a raceway) or into a closed, recirculating system.

6.0. Recommendation

In order to make this design, the result of my project becoming the preferred and more Efficient Solution to the hitherto challenges recognizing the current recession in my country vis-à-vis the impact of the rising cost of energy on the cost of operating a standard air-operated double diaphragm airlift pumps (AODDP), I strongly recommend interested manufacturers to carry out a further practical work on the outcome of this my research project towards:

i). Developing line of pumps that would significantly reduce the end user's cost of operation.
ii). To improve on the overall performance (with increased suction lift and flow rate) and uses less than half the compressed air of previous models.
Make Multiple modifications to my original design, including:
iii). Considerable reduction and optimization of "dead space" on the liquid and air side of the diaphragms
iv). An adjustment to the shift point of the main air valve to allow for a longer operating period during a more efficient point in the air valve's cycles
v). Modify the shift point of its air valve, towards substantial improvement in overall energy consumption. In my design, the pump was significantly less efficient near the end of the diaphragm stroke than it was at the beginning. Near the end of the stroke, the pump continued to consume large amounts of air but displaced progressively less fluid. By shifting the pump earlier in the cycle, the pump displaced slightly less fluid but used substantially less air. This yielded a dramatic improvement in overall air efficiency.
vi). The shape of the diaphragm and the outer chamber should be optimized to reduce what is known as dead space. A pump has zero liquid dead space if the diaphragm, when fully extended, conforms 100-percent to the shape of the liquid chamber. The optimized dead space on the liquid side of the diaphragm resulted in higher suction lift and higher displacement per stroke and yielded improved suction lift and a higher flow rate, respectively.

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