An experimental analysis of two phase flow for air lift pump design

G. K. Awari[1], P. M. Ardhapurkar[1] & D. G. Wakde[2]
[1]*Department of Mechanical Engineering, Shri Sant Gajanan Maharaj College of Engineering, Shegaon, (MS), India*
[2]*Principal, Shri Sant Gajanan Maharaj College of Engineering, Shegaon, (MS), India*

Abstract

The Air-Lift Pump is a well-established method for vertical transport of liquids and solid liquid mixtures. The objectives of the present study are to evaluate the performance of a pump under predetermined operating conditions and to optimize the related parameters for use of the pump for two phase mixtures of air and water when the compressor is readily available.

This paper is focussed on the general mathematical functions applicable to pump installations. The user friendly computer program is developed based on the optimization of influencing variables. This program will be useful for design and installations of air-lift pump handling air water mixtures. A comparative study of the air-lift pump with the centrifugal pump when handling two phase mixtures is also discussed in the paper.
Keywords: two phase flow, air-lift pump, immersion ratio.

1 Introduction

An Air-Lift Pump is a device for raising liquids or mixture of liquids (mostly water) and solids through a vertical pipe partially submerged in the liquid, by means of compressed air introduced into the pipe near the lower end. The pressurized air is introduced through the nozzle located at the bottom of the air supply pipe. A rising main covers this assembly fixed in the well. A mixture of air and water is formed within the rising main. Since the density of air water mixture is much less than that of pure water, a very long column of air water mixture will be required to balance even a very small column of pure water. As

Advances in Fluid Mechanics V, A. Mendes, M. Rahman & C. A. Brebbia (Editors)

such the flow of air water mixture will begin through the rising main and it will be issued continuously at the top of rising main so long as the supply of air is maintained. During early stages, the air lift pump was used for water lifting, later on, for lifting and transporting corrosive and radioactive liquids as well as for pumping crude oil.

There have been numerous publications suggesting calculation procedures for the design and satisfactory operation of an air-lift pump. Among others are Pickert (1931), Stenning A.H. and Martin C.B. Ambiguity in the experimental results obtained by Pickert and Martin C.B. is observed in terms of diameter of the rising main with concern to efficiency of pump. All the studies depend on either an experimental data or empirical correlation factors pertaining to specific categories of practical application. Requirements of handling two phase mixtures are increasing day by day and published test results are few and are not suitable from installation point of view. The ability of the centrifugal pump to handle entrained gases is very limited. If the air / gas percentage increases beyond the 14 percent in volumetric ratio, the pump stops working and is said to be air bound. The aim of the present study is to experimentally analyze the parameters affecting the performance of air–lift pump leading to more generalized mathematical functions. The generalized computer program will find its usefulness in the optimum design of pump for its installation.

2 Experimental apparatus

The line diagram of tested air-lift pump with a injecting device at the bottom of the rising main is shown in figure 1. Water is drawn into the rising main from an open tank where pump is installed. Whereas air, pressurized by a single stage compressor, through a reservoir, enters the suction pipe from a designed nozzle. The valve regulates the pressure of air and its velocity is monitored by a pitot tube placed in the circuit. The air water mixture is discharged through a rising main and is collected into the delivery tank. The water flow rates was measured with and normalized with the product of area of pipe and superficial water velocity indicating fractional velocity of air assuming air flowing alone in the same pipe or water flowing alone; both are fictitious. The temperature of air was observed to be constant at 34^0C through out the test. Tests were conducted by varying the different parameters such as pressure of the compressed air, immersion ratio, diameter of a rising main. Initially the need of the injecting device (nozzle) is verified experimentally and then the effect of nozzles with different diameters is studied. The pump head was obtained with a manometer installed near the water surface corresponding to higher immersion ratio. The head loss due to friction is out of discussion in the paper because of the concern for difficult to isolate and measure these losses. Volumetric concentration of liquid as a fraction of the total volume of flow is calculated as

$$\mathrm{Cw} = \frac{Vm(\sup erficial)}{Vm(true)} \quad \text{and } \mathrm{Ca} = \frac{Vm(\sup erficial)}{Vm(true)} \qquad \mathrm{Va} \,/\, \sqrt{gD} \text{ is a}$$

pipe flow criterion of the Froude type. The efficiency of the pump is evaluated

Advances in Fluid Mechanics V, A. Mendes, M. Rahman & C. A. Brebbia (Editors)
© 2004 WIT Press, www.witpress.com, ISBN 1-85312-704-3

on the basis of the energy possessed by the air to operate the well. Since the air expansion in the pipe is isothermal, the input energy to the pump is equal to $P_aV_a \log \frac{Ps}{Pa}$ and the output energy is the product of discharge and head of mixture developed by the pump.

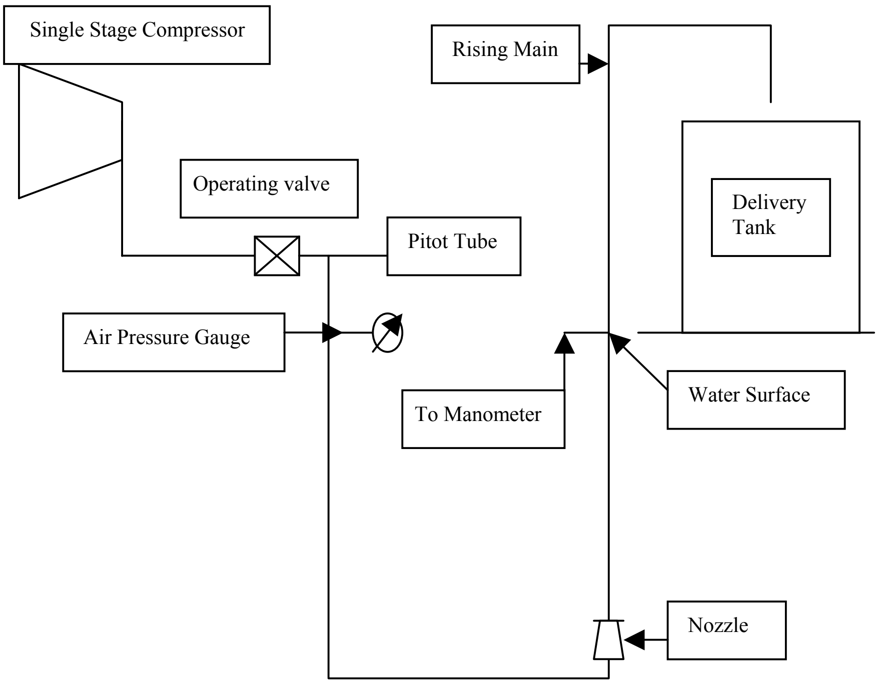


Figure 1: Outline of experimental setup.

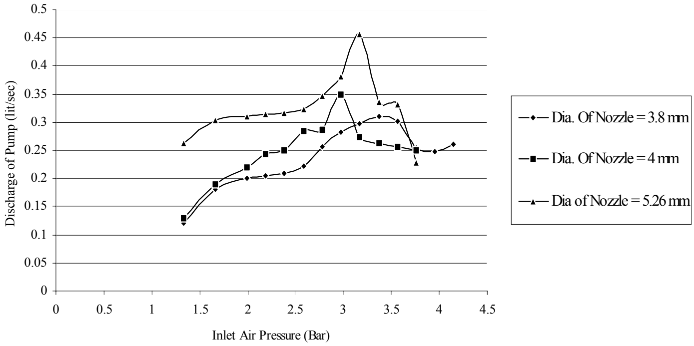


Figure 2: Comparison of nozzle diameters.

Advances in Fluid Mechanics V, A. Mendes, M. Rahman & C. A. Brebbia (Editors)

3 Result and discussions

3.1 Need of injecting device

The effects of an injecting device i.e.nozzle with different designed diameter viz. 5.26 mm, 4.0 mm, & 3.80 mm were examined. The inlet diameter of nozzle was fixed at 12.5 mm and the outlet is designed to have interchangeability for different diameters of rising main. Initially the need of a injecting device is verified experimentally on 0.5 inch, 1 inch & 1.25 inch diameter of rising main. The raising of liquid has been found to be mainly due to kinetic head. It is observed that in narrow diameter pipe the kinetic head is significant even without the nozzle and some quantity of water is lifted. The decrease in discharge without using an injecting device was observed to be near about fifty percent, which can be compensated by operating the pump at higher immersion ratio. It is worth mentioning that the pump without injecting device is capable of lifting liquid with lower pressure of air in narrow diameter rising main. Depending upon the requirement a techno-economic feasible solution may be obtained to justify the use of injecting device from energy point of view.

Table 1: Comparative data for different diameters of nozzle.

Dia. of rising main (inch)	$1\frac{1}{2}$			$2\frac{1}{2}$		
Nozzle Dia. (mm)	5.26	4.0	3.80	5.26	4.0	3.80
Discharge Q_w (lit/s)	0.4574	0.1174	0.1270	0.2076	0.1928	0.2784
Head H (m)	1.83	2.48	3.32	1.05	1.35	1.17
Efficiency η (%)	21.86	11.45	11.02	5.71	6.79	8.46

3.2 Effect of nozzle diameter

The results of the different nozzle diameters are tabulated in table 1.

The effect of air pressure on discharge of a pump with different diameters of a nozzle keeping the diameter of rising main same (2.5 inch and ε = 1.21), is shown in figure 2. From the graph it is observed that increase in pressure of air increases the discharge of a pump for all the diameters of nozzle. The nozzle having higher diameter (5.26 mm) is suitable for maximizing the discharge at any desired air pressure. The airlift pump works on the density difference principle that indicates the density of mixture is varying and density of liquid remains constant. It is observed that if the diameter of nozzle is large the more quantity of pressurized air from the entrance will mix with the water resulting in decrease of mixture density, which leads to gain in kinetic head. This ultimately results in the increase of discharge of water. The selection of nozzle diameter

Advances in Fluid Mechanics V, A. Mendes, M. Rahman & C. A. Brebbia (Editors)

depends upon the diameter of rising main. The optimum diameter of can be evaluated from the polynomial function developed

D= 0.135 d^2 + 12.26 d –21.18 (d= diameter of rising main in inches) The different diameter of rising main (0.5”, 1”, 1.5”, 2” & 2.5”) has been tested by varying the diameter of nozzle. The similar effects of increase of discharge with the diameter of nozzle are observed.

3.3 Effect of relative mass flow rates and immersion ratio

The variation of mass flow rates of water with respect to mass flow rate of air for different immersion ratio (1.5 inch pipe Dia, Nozzle Dia.= 5.26 mm) is shown in figure 3. Figure 4 shows the effect of immersion ratio on the efficiency of a pump with varying diameter of rising main (2.5 inch & 1.5 inch). The flow of water starts only when there is definite quantity of flow of air through the rising main and the amount of air required is inversely proportional to immersion ratio. For the given mass flow rate of air, the amount of water lifted decreases with the decrease in immersion ratio. Small immersion ratio will lead to uneconomical working of pump as high velocity air mixes with water outside the rising main and bubbles formed escapes through the surface of water causing the loss of energy. For constant immersion ratio, the amount of water pumped increases with increase of air flow in the beginning and reaches its maximum and further increase of air flow rate do not alter the quantity of water lifted and fairly it is constant. Hence it is not justified to increases the flow of air beyond certain optimum value. In order to lift maximum possible water with minimum amount of air, the specific mass of air $m_{asp} = (m_a/m_w)$ should be as small as possible.

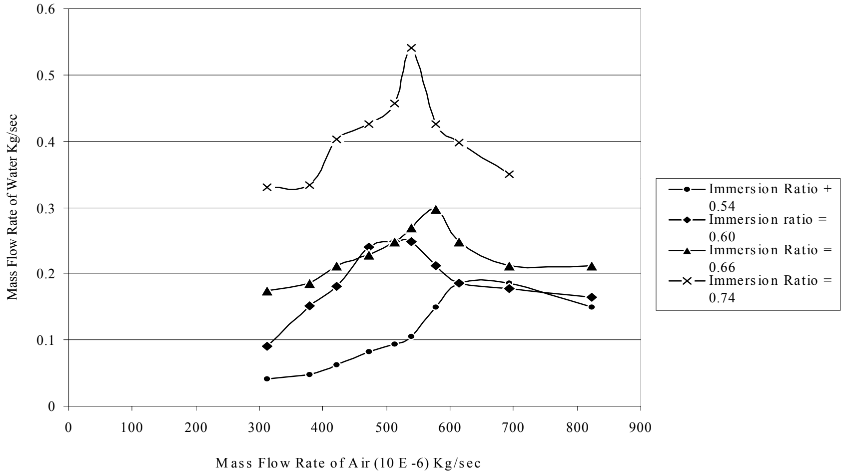
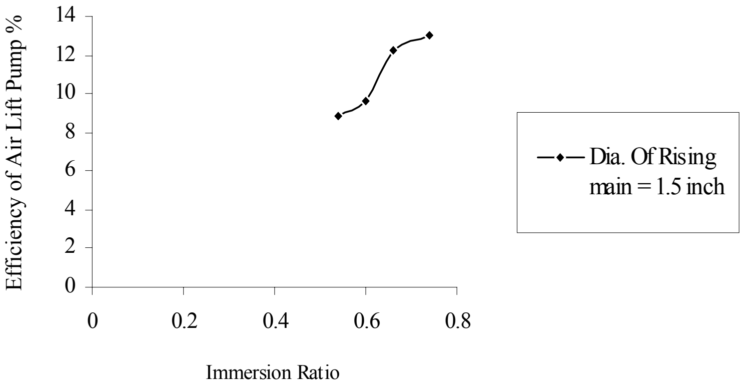


Figure 3: Comparison of mass flow rates with different immersion rates.

Advances in Fluid Mechanics V, A. Mendes, M. Rahman & C. A. Brebbia (Editors)
© 2004 WIT Press, www.witpress.com, ISBN 1-85312-704-3



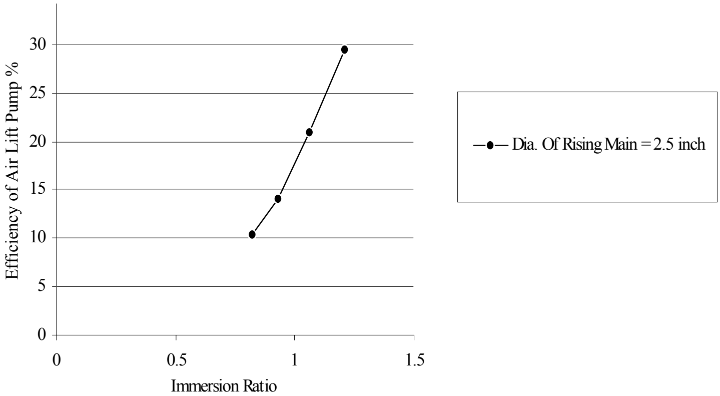


Figure 4: Effect of immersion ratio on the efficiency of pump.

3.4 Effect of the diameter of rising main

The most significant geometric parameter is the diameter of rising main and which has great effect on air lift efficiency. The cross-sectional area required by air as it goes up increases linearly and the cross-sectional area required by water decreases. Thus the water velocity increases as we go up. The difference between the mean air velocity in pipe and average velocity of water i.e. Relative air velocity determines the efficiency of pump. Higher the value of relative velocity more will be the air required from the compressor and therefore less efficiency. The relative air velocity is more in narrow pipe as compared to that in larger diameter pipe. Increasing the relative air velocity means water particles are lagging the air and discharge of a pump decreases. It is observed that the discharge is negligible in narrow pipes. The increase of diameter of pipe reduces the relative air velocity and discharge of a pump has been increased. Thus the efficiency is better for large diameter pipe as compared to narrow pipes. These results are in conformity with the results obtained by Stenning and Martin (1968)

Advances in Fluid Mechanics V, A. Mendes, M. Rahman & C. A. Brebbia (Editors)

who has challenged the results of Pickert (1931) that narrow diameter pipe are better from efficiency point of view. The functional relationship developed among the various parameters affecting the performance of air lift pump is $Q_w = V_a D^2 \phi(\ dh / D^2, \eta, \varepsilon)$ However the determination of function co-relating the parameters is presently out of discussion as the future work is focused on this issue.

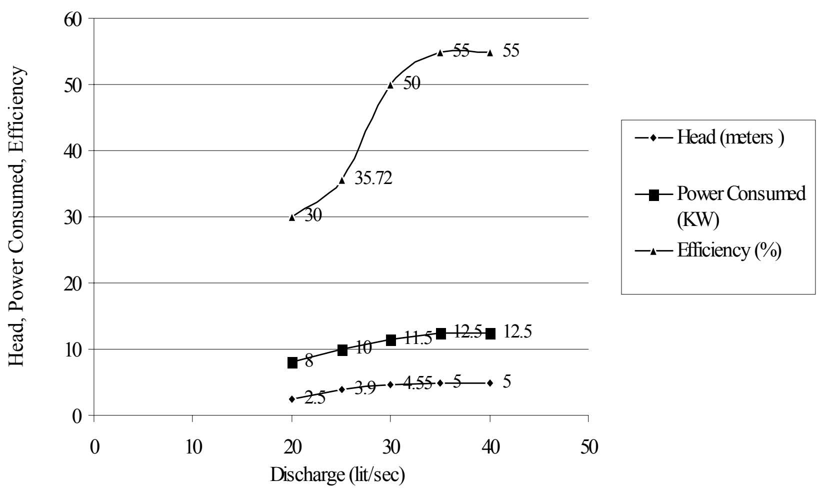


Figure 5: Effect of discharge on head, power and efficiency of centrifugal pump.

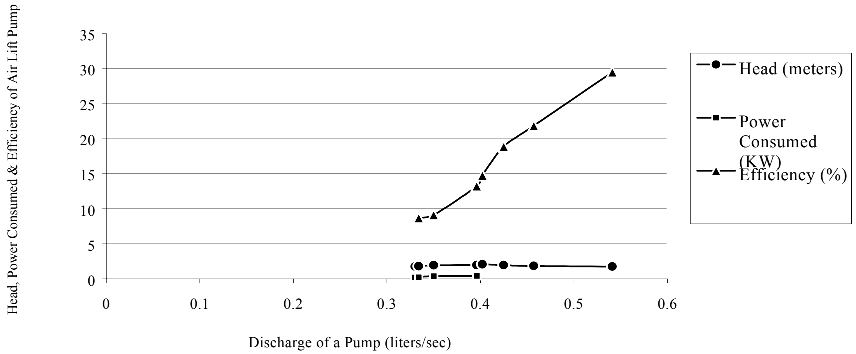


Figure 6: Effect of discharge on head, power and efficiency of air lift pump.

3.5 Comparison of two phase pump characteristics

Generally centrifugal pumps are used in deep well. Hence the discussion is confined to centrifugal pump handling two-phase mixtures. The ability of

Advances in Fluid Mechanics V, A. Mendes, M. Rahman & C. A. Brebbia (Editors)

centrifugal pump to suck liquid with entrained gases is very limited. If air / gas percentage increases beyond 14 % of the volumetric ratio then pump stops working. It is said to be “air bound”. If the gas accumulation is exceeding this percentage then it is feasible to use air lift pump. The comparative study of discharge, head, power consumed and efficiency of a centrifugal pump is shown in figure 5 and for air lift pump (36 % of air in a mixture) is shown in figure 6.The discharge of an air lift pump is less as compared to centrifugal pump. The performance of the centrifugal pump is taken at 10-inch diameter pipe, 900-rpm impeller speed with the diameter 16.5 inches, 1.3 inch wide at OD. The air lift performance was taken for 5.26 inch nozzle diameter with 2.5 inches diameter of rising main and at highest level of submergence. The head of a air lift pump increases up to certain extent and then it drops due to the increase in superficial velocity of air but in case of centrifugal pump head increases with discharge then it is fairly constant. Main difference between these two is that efficiency of centrifugal pump depends on the suction lift but in case of air lift pump its performance depends upon submergence level. Submergence required for air lift pump is twice as compared to modern centrifugal pumps for acceptable efficiency. The trend in both the pumps is same that increasing the discharge, power consumed by a pump increases and in centrifugal pump it is almost constant at higher discharge. However centrifugal pump consumes less power for lifting unit quantity of water. If the required capacity of pumping mixture is high and gas percentage in the mixture is limited to 14 % then it is always suitable to use centrifugal pump. However when the percentage of gas in the mixture is beyond 14 % there is no alternative to air lift pump even at the expense of more power. Hence depending upon the head, discharge requirement, and gas accumulation in the mixture the selection of the proper pump should be made.

4 Conclusion

An applied air lift model for air water flow has been developed based on experimental analysis and this model has a very good performance and more general mathematical form. This analysis has been combined in an easily used computer code, which is a very useful tool for the optimum design of air lift pump installation. The optimization of the installation is the more important feature of this Programme. This means the code can calculate the optimum value for the diameter of rising main, critical diameter of nozzle and the other parameters in order to maximize the efficiency of the pump. The method can be applied to an air lift pump installation with long vertical pipe line system.

The results of the present analysis are in good agreement with the existing data in the literature, but in order to approximate the phenomenon better and functional dimensional analysis is in progress now. This modeling is expected to contribute more to the optimum design of the air lift pump installation.

Advances in Fluid Mechanics V, A. Mendes, M. Rahman & C. A. Brebbia (Editors)

Acknowledgement

The authors would like to thank Shri Shrikant Patil, Director of Gajanan Shiskhan Sanstha for their financial support to this work. The support of principal, Shri Sant Gajanan Maharaj College of Engineering, Shegaon and Dr. P.D. Patil, Head of Mechanical Engineering department is appreciated.

References

[1] Gad Hetsroni, Handbook of Multiphase Systems, Hemisphere Publishing corporation, Washington, 7.42-7.45, 1982.
[2] Awari G.K., Investigation of Air Lift Pump, Proceedings of International conference on Fluid Mechanics, IIT Delhi, volume 2, 869-874, 1998.
[3] Amit Jhunjhunwala, Critical Analysis of Air Lift Pump, SSGMCE, Shegaon, 68-79, 1999.
[4] Govier and Aziz, The flow of two-phase complex mixture in pipes, Krieger Publication Ltd., New York, 324-337 1977.
[5] Margaris D.P. and Papnikas D.G., A generalized gas liquid solid three phase flow analysis for air lift pump design, Journal of fluid engineering, volume 119, 995-997
[6] Theyyunni T.K., Application of Fluid Technology in Nuclear chemical plants Journal of Engineering Advances, 63-66, 1991.
[7] Kato H., Tamiya S. and Miyazawa T., Study of an air lift pump for solid particles and its applications, International conference of BHRA Fluid Engineering, Cranfold, Bedford, 37-49
[8] Vasandani V.P., Hydraulic Machines Theory and Applications, Academic press, 1992
[9] Cherkassky V.M., Pumps Fans Compressors, Mir Publishers, Moscow, 374-379, 1977.
[10] Furukawa A., Shirasu S. and Sato S., Experimental study of Gas-liquid Two-phase flow pumping action of Centrifugal Impeller, ASME Journal of Cavitation and Gas-Liquid Flow in Fluid Machinery Devices, Volume 226, 89-95, 1995
[11] Perry R.H., Chemical Engineering Handbook, McGraw Hill Book Company Sixth edition, New York, 5.40-5.48.

Advances in Fluid Mechanics V, A. Mendes, M. Rahman & C. A. Brebbia (Editors)