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THE DEVELOPMENT OF BUBBLE PUMP PERFORMANCE CURVES FOR INDUSTRIAL ACTIVITIES

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Abstract: The complexities and concerns that are related to the safe, economic, and effective operations in many industries in the fields of mining, radioactivity, agriculture, and petrol make it very tempting for technicians and researchers to develop tools like the bubble pump to deal with the pumping process safely. A laboratory bubble pump system is built to test the potential impact of the change of system design and operation variables on the performance of the pump. This system includes a 125 cm long and 2.10 cm diameter pipe for the liquid lifting part, while five different diameters are tested for the suction part of the pump, with a fixed 30.0 cm pipe length. The effect of ratio of submergence is also examined for four setup values with gradually increased air pumping rates. The liquid pumping rate showed a proportional increase along with the increase of the suction pipe diameter for each submergence ratio. Also, the liquid pumping rate showed a similar trend with the increase of the submergence ratio for each tested diameter of the suction part of the system. An interesting finding is the possibility of achieving higher liquid pumping rates while imposing low air flow rates by the utilization of high submergence ratio as compared to that possible with a lower submergence ratio. This would mean a lower need for the energy to produce the required air flow. A very good agreement of the laboratory results is determined with the theoretical model of Stenning and Martin, which is applied as a verification base for the precision of the system design and operation to test the performance variables of an air lift pump.
Key words: Bubble pump, submergence, suction rate, two-phase flow.

1. INTRODUCTION

Pumps play very important roles in the various manufacturing and logistic processes of the battery industry, which involves many chemicals, electrolytes, and hazardous materials. Many problems are associated with the utilization of conventional pumps that, if not well-maintained, may produce harmful contaminants for the electrolyte or chemical fluids. In addition, the corrosive materials that are involved in this industry cause a significant reduction in their life time and an increase in the maintenance costs on one side, and on the other hand, the unstable pumping pressure that is required to produce the essential, precise flow rates for the various manufacturing stages [1]. The heating due to heavy loads or high speeds is one of the major potential risks when utilizing conventional pumps in the battery industry. All these problems, in addition to the corresponding vibration and noise, urged the manufacturers to explore solutions like the bubble pump to avoid them.
A wide range of industrial processes rely on the bubble pump approach instead of other conventional pumping technologies especially where biological, radioactive, explosive or other potential hazards are involved such as those related to the food processing, mining, petroleum industries, etc. [2] due to the less contacts between mechanical parts and lower energy consumption to produce the air bubbles that offer the buoyancy force for the liquid content of these industrial processes and hence enhance their flow rate throughout the needed steps [3]. That low energy requirement is interpreted to lower operational bills in addition to simpler design and handling work utilities that would in turn require less maintenance throughout their lifetime [4]. These all are achieved via the bubble pumps with the minimal impact on the environment, which are the regular consequences of the use of traditional pumps, whether during their operation, greenhouse gas emissions, or the follow-up maintenance requirements. This made bubble pumps a good selection for designers who seek sustainable and environmentally friendly industrial projects [5, 6]. The gain of higher performance levels of such an approach highly depends on the selection of the crucial dependence of design parameters for its various parts to achieve the proper flow rate, pressure, air-to-liquid ratio, and air introduction points. The principle of a typical bubble pump is based on the injection of compressed air via an airline or a pipe that is submerged in a liquid. This process would cause a pressure drop at the injection point that forces the water level in the submerged pipe to

rise and hence pulls up the liquid and its content at a rate that depends upon the system configuration and the gas flow rate [7]. This process might have a short time gap; idling, prior to the start of the liquid out of the pump [8].
The main parts of the bubble pump are the suction pipe (totally submerged in the liquid to be lifted) and the lift pipe (partially submerged). Two or single-phase flow is expected in the suction pipe, whereas two-phase flow, liquid-gas, or three-phase flow, solid-liquid-gas, is expected through the lift pipe, depending on the materials to be lifted by the pump [9, 10]. The dimensions of these pipes, length and diameter, can be constant or varying depending on the tentative performance, gas flow, the working depth, and the pumped liquid/solid. Also, the submergence length and the gas injection point play crucial roles in the bubble pump's final liquid pumping rate. Poor performance was recorded via the utilization of similar diameters for all pipes in the system due to the initiation of an annular flow as a result of the gas expansion, and their recommendation was to utilize a tapered shape to produce higher pumping rates [11].

2. MATERIALS AND METHODS

The determination of the performance curves and operational variable interactions of the understudy bubble pump is made via the utilization of the model created by Stenning and Martin as was documented by Deepak et. al [12];

$$\frac{H}{L} - \frac{1}{1+\frac{Q_a}{S.Q_f}} = \frac{C_{fs}}{\sqrt{2gL}} \cdot \left[(1+K) + (2+K)\,\frac{Q_a}{Q_f}\right] \tag{1}$$

This model distinguishes two significant groups; the pumping rate $C_{fs}/\sqrt{2gL}$, and the rate of air flow Q_a/Q_f.
where: H - Submergence length, [m]; C_{fs} - suction pipe`s water velocity, [m/s]; Q_f - Water flow rate, [m^3/s]; Q_a - Air flow rate [m^3/s]; g - Gravitational acceleration, [m/s^2]; L - Pipe length, [m].

$$K = \frac{4\,L.\,f}{D_s} \tag{2}$$

where: f - Coefficient of friction, [dimensionless]; Ds - Internal diameter of the suction pipe, [m].
The slip ratio S stands for the ratio of air to water velocity (C_a/C_f) is calculated by the application of the Griffiths and Wallis model as suggested by Stenning [13];

$$S = 1.2 + 0.2\frac{Q_a}{Q_f} + \frac{0.35\sqrt{gD_s}}{C_{fs}} \tag{3}$$

The model suggested by eq. 1, describes the performance curve of the bubble pump for the two non-dimensional groups, $C_{fs}/\sqrt{2\,g\,L}$ that represents the pumping rate, and Q_a/Q_f as a representative of the compressed air flow rate.
A bubble pump laboratory scale model is assembled to test the possible impacts of the changes in the design variables on the final pumping performance (Fig. 1). Air is used as the operational gas that is compressed via 1180 l/min and 8 bar reciprocating compressor. The air pressure regulation is achieved via a 7500W, 3-phase power generator that is supplied by a pressure switch. Five sizes are prepared for the 30.0 cm long suction pipe; dimeters of 2.1, 2.7, 3.3, 4.8 and 6.3 cm, to determine the performance curve of each for the selected ratios of submergence; Height (H)/ Length (L), that are 0.2, 0.3, 0.4, and 0.5, after each operation round. The system`s water basin in equipped with many side pores to be used as the air injection points that allow for the variation of the submergence height; H. A length of 21 cm and diameter of 30 cm are fixed for the lift pipe. The liquid-air mixing would take place through a 30 cm long and 63 cm diameter pipe that is equipped by an inlet pore, located between the aforementioned two pipes. µ-FLOW digital liquid flow meter is threaded to the discharge point to measure the exit liquid flow rate. The performance curves are made for each submergence ratio based on the measurement of the produced liquid flow rate for each change of system setup; suction pipe diameter, and air flow rate.
This paper aims the study of various design and operational setups to determine the performance curves for a bubble pump utilizing various piping sizes for the pumping of industrial effluents of a battery manufacturing factory.

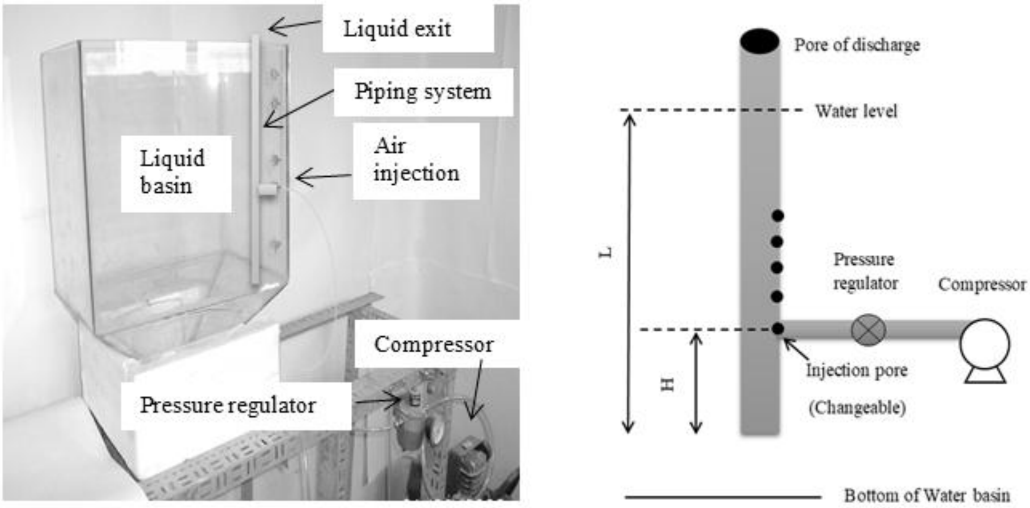

Fig.1. A schematic for the bubble pump laboratory model

3. RESULTS AND DISCUSSIONS

As the goal of this study is to determine the impact of variable setup parameters, ratio of submergence, diameter of the suction part of the piping system, and gas flow rate on the final performance of the pump, the aforementioned pipe sizes are individually utilized with each of the various piping ratios of submergence to determine the resulting flow rate. A general indication from these results is that some fluctuations are recorded for the operation at low rates of gas flow. This appeared clearly at small ratios of submergence as shown in Fig. 2, which is attributed to the formation of an unstable two-phase bubbly flow that almost disappears with the formation of more slug flow at higher gas flow rates [14, 15].

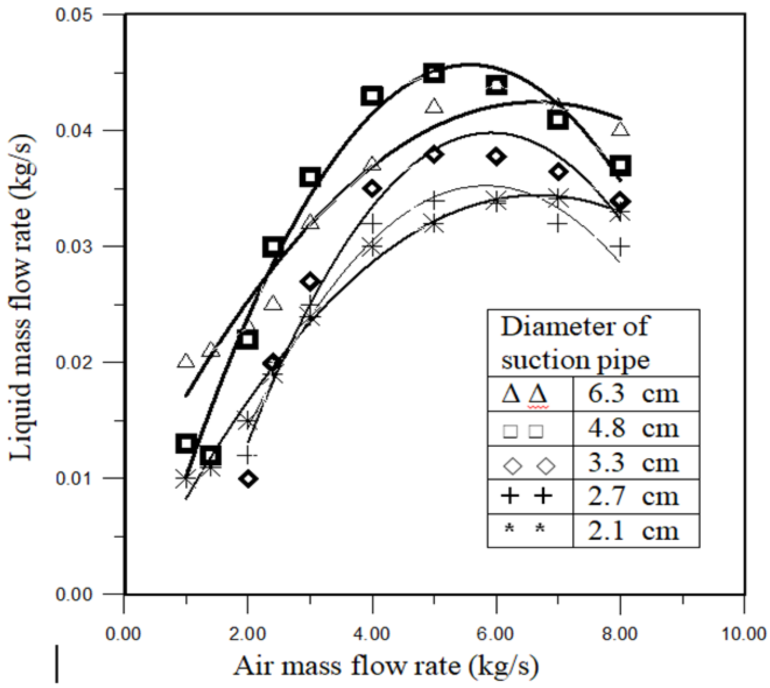

Fig.2. The output liquid flow rate due to the change of input air flow rates (H/L: 0.2)

Also, the liquid pumping rate of the system is indicated to show relative surge as a reaction to the gas flow rate increase that in turn promotes the force of bouncy, till the a point of inflection is reached that corresponds to a maximum rate of liquid flow, furtherly the liquid flow rate tends to diminish with more increase in the gas flow due to the domination of the friction loss over the bouncy forces as illustrated in Fig. 2 - Fig. 4. Although the maximum liquid pumping rate corresponds to different gas flow rate for the setting of 0.2 ratio of submergence; Fig.2, this case tends to gradually modified as increasing the ration of submergence to 0.3 and 0.4 where the different suction pipe diameter settings tend to have almost similar gas flow rate for that, in an indication for the less effect of the friction losses and the more stable two-phase flow pattern. The conclusion of the corresponding gas flow rate to the maximum liquid pumping rate is the main gain of this set of tests to save efforts and time for noticeable outlet perfection for the various design settings.

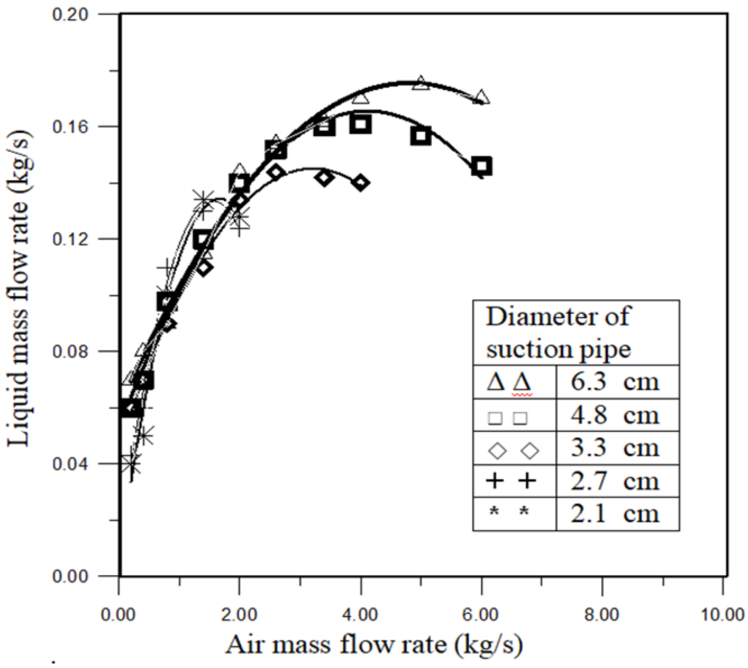

Fig.3. The output liquid flow rate due to the change of input air flow rates (H/L:0.3)

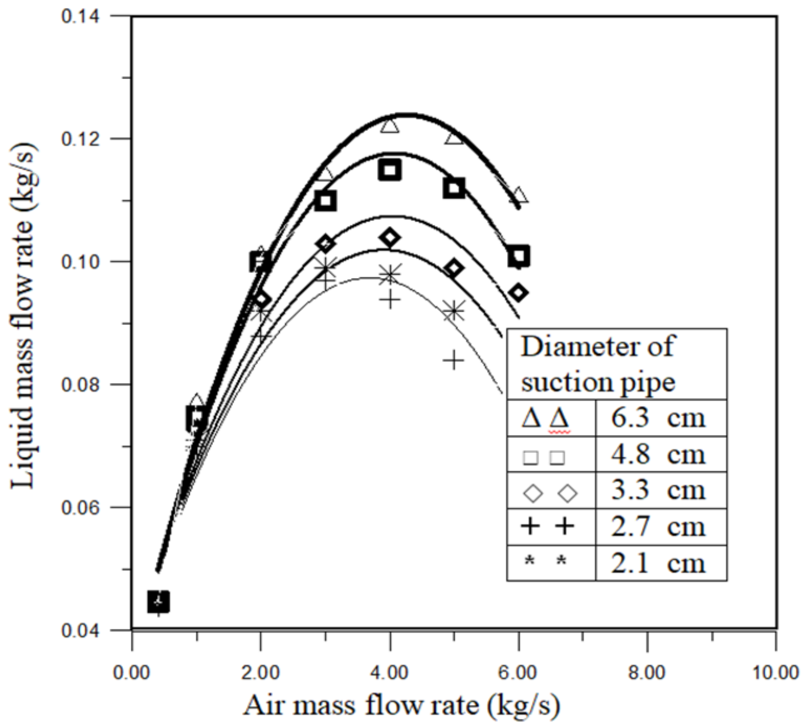

Fig.4. The output liquid flow rate due to the change of input air flow rates (H/L:0.4)

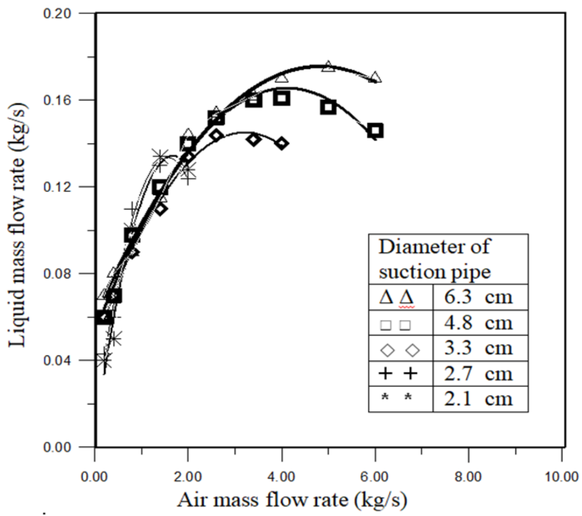

Fig.5. The output liquid flow rate due to the change of input air flow rates (H/L: 0.5)

That noteworthy inflection of the ratio of submergence shows a remarkable fade in the values with the (H/L= 0.5) as indicated in Fig. 5, mainly for the high suction pipe diameters. This can be attributed to the friction and bouncy forces.

The above results show that with a fixed ratio of submergence, the liquid pumping increases proportionally to the increase in the diameter of the suction pipe for a certain gas flow rate. This remark is clearly shown with the 0.4 ratio of submergence, which showed a separate performance curve for each suction pipe diameter. A similar notification can be said for the increase in liquid pumping rate as the gas flow rate increases for each suction pipe diameter, with a fixed ratio of submergence. This is linked to the static pressure upsurge in the suction pipe and the pipe liquid velocity decline, as a result of the diameter change, which consequently leads to a decline in the losses due to friction. The upsurge of the ratio of submergence causes a decline in the liquid rising/pumping head, and hence increases the liquid pumping rate for each of the utilized operational sets. An important remark from the above results is that higher liquid pumping flow rates are achieved with a high ratio of submergence utilizing lower gas flow rates than those utilized by a low ratio of submergence for each certain dimension set (pipe length and diameter). This is attributed to the increase in the gas bubble transmission distance due to the increase in the ratio of submergence, hence more expansion occurs to result in additional liquid scavenging.

A validation for the experimental data is made with the relevant theoretical results based on the two non-dimensional groups that are mentioned in the equation.1; Stenning and Martin model, to avoid the complexities of the analytical solution. The results are illustrated in Fig. 6, which shows a good match between the two approaches, with an average percentage of error<5%, and a very good positive correlation; correlation coefficient (r)= 0.955. That highly appears with the high pmping rate; $C_{fs} / \sqrt{2\ g\ L} > 0.07$, the assumption of the theoretical model of the constant values for S and K although they remarkably change as the gas flow rate changes, can explain the differences between the curves of the two approaches at $C_{fs} / \sqrt{2\ g\ L} < 0.07$.

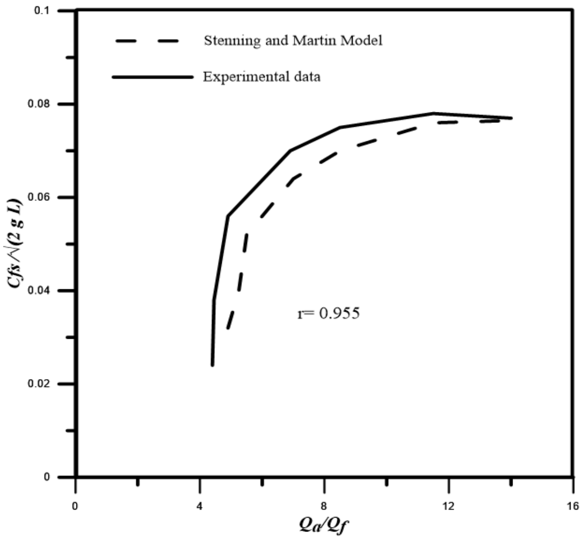

Fig.6. The non-dimensional groups for the experimental data and theoretical model.

4. CONCLUSIONS

The utilization of a bubble pump for the handling of the industrial lifting needs has attracted the managers of a wide range of manufacturing activities, especially those who deal with hazardous or sensitive materials that might cause many problems should they be handled by conventional pumping technologies. This pumping approach is examined via a laboratory model for the handling of the liquid effluent of the Battery industry to determine the effective design setups for the various operational parameters to achieve the highest pumping rate. The laboratory experimental setup included the testing of five suction pipe diameters in four ratios of submergence and gradually increased gas flow. The results of the laboratory tests suggest that, although the liquid mass flow rate proportionally increases with the gas flow rate, the most noticeable factor contributing to this increase, at a fixed submergence ratio, is the increase in the suction pipe diameter. Furthermore, the most important result from the performance curves is the significantly higher outlet gain; liquid pumping rate, with the higher submergence ratio for the same other system setups; pipe lengths and diameters, and gas flow rate, hence significant performance improvements are produced. This also leads to a significant reduction in the required energy for the supply of operational gas flow rate to produce the maximum outlet liquid flow rate. The comparison of experimental data with the theoretical derivation is made based on the model of Stenning and Martin provided an acceptable validation for the experimental setup that resulting in highly correlated data with the relevant theoretical ones.

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