EFFECT OF SUCTION PIPE DIAMETER AND SUBMERGENCE RATIO ON AIR LIFT PUMPING RATE

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ABSTRACT

The increasingly importance for the uses of the air lift pump in widespread list of fields (mining, nuclear industries, agricultural uses, petroleum industries...etc.) makes it very interested for the researchers to find tools to raise the performance outcome of such pumps.

An air lift pump system is setup to study the effect of the suction pipe diameter and submergence ratio on the liquid (water) pumping rate. The system has a lift pipe of (0.021 m) diameter and (1.25 m) length. Five diameters for the suction pipe (0.021, 0.027, 0.033, 0.048 and 0.063 m) with a fixed length of (0.3 m), are tested for each of the submergence ratios (0.2, 0.3, 0.4, 0.5) respectively.

Results indicate that the higher the diameter of suction pipe is the higher the pumping rate for a fixed submergence ratio. From another side, the higher the submergence ratio is the higher the pumping rate for a fixed suction pipe diameter. Also, under high submergence ratios, high pumping rates are achieved by the use of lower air flow rates compared with those used with lower submergence ratios. The experimental results show good compatibility with the model suggested by Stenning and Martin for the performance of an air lift pump.

KEYWORDS: Internal Heat Exchanger, R134a, vapor Compression Refrigeration Cycle.

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NOTATIONS

Hs: Submerged length (m).

Lp: Air lift pump elevation (distance between air injection point and the pumping point),(m).

S: Slip Ratio.

C_{fs}: Velocity of water insuction pipe(m/s).

f: Coefficient of friction (dimensionless).

Q_a, Q_f: Air and water flow rate respectively (m^3/s).

L: Pipe length (m).

g: Gravitational acceleration (m/s^2).

D_s: Internal diameter of the suction pipe (m).

INTRODUCTION

Air lift pumping was invented by Carl Loscher at the end of the eighteenth century [1]. Operation is based on the pumping effect achieved when air is injected into a liquid or a solid-liquid mixture. This type of pumping system has a low efficiency in comparison with other pumping methods. However, simplicity in construction and absence of moving mechanical parts are two very important advantages that make it useful in certain applications, such as pumping corrosive liquids (sandy or salty waters)[1], and viscous liquids (e.g., hydrocarbons in oil industry)[1,2]. Air lift pumping is also used in shaft and well drilling in which, the drillings being lifted by underground water [1,3], undersea mining [1,4], and in certain bioreactors and waste treatment installations, providing excellent aeration of the pumped fluid [5, 6].

A typical air lift pump, generally involves a vertical pipe of length L divided into two parts (Fig.1); Suction pipe of length L_e between the bottom end and the air injection port (points 1 and i), and a lift pipe of length L_u between the air and pumping ports (points i and 2), which is partially submerged by a length L_s.

The type of flow in the suction pipe is either one-phase (liquid) or two-phase (solid-liquid) while in the lift pipe is either two-phase (air-liquid) or three-phase (air-liquid-solid). The lift pipe can be of constant or varying diameter, increasing from injection to pumping point (tapered systems). The latter are much more efficient when pumping from large depths, because this ensures slug flow along the lift. Otherwise, i.e., when a fixed diameter system is used, due to gas expansion, the flow changes to annular, this is characterized by poor pumping efficiency [1].

A compressed air is injected through an external or internal airline (Fig.2). At the beginning of pump operation, an initial drop in water level is observed, depending on the rate of pumping. There is also an additional drop in water level during pump operation, but it is usually very small and for simplicity omitted. Thus, two water levels are defined, one at idling conditions, and one during pump operation [7]. The first level determines the compressor hydraulic overhead, i.e., the pressure in which the compressor must initially supply air for the pump to start operating. The second level affects operation parameters (water outflow, submergence, etc.), and determines the pressure at which the pump must supply air during steady-state conditions.

Although external airline systems are more efficient, internal airline pumps are more frequently used because of their versatility and ease in assembly. As the water level inside the well fluctuates or changes, maximum efficiency can always be achieved by changing the airline length inside the lift pipe.

PUMP SIMULATION MODEL

For the purpose of this paper, Stenning and Martin model (1968) [8], was used to describe the performance of the air lift pump. It describes the performance curve of the air lift pump for the non-dimensional groups, $C_{fs}/\sqrt{2gL}$ (refers to the pumping rate) and Q_a/Q_f (refers to the compressed air flow rate);

$$\frac{Hs}{Lp}-\frac{1}{\left[1+\dfrac{Q_a}{S\cdot Q_f}\right]}=\frac{C_{fs}}{\sqrt{2gL}}\left((K+1)+(K+2)\frac{Q_a}{Q_f}\right) \qquad \text{………….. (1)}$$

Where:

$K= 4\, f\, L /D_s$

Slip ratio (S) that equals C_a/C_f (velocity of air/velocity of water) is calculated using Griffiths and Wallis formula [7];

$$S=1.2+0.2\frac{Q_a}{Q_f}+\frac{0.35\sqrt{gD_s}}{} \qquad \text{………….. (2)}$$

EXPERIMENTAL SETUP AND PROCEDURE

The schematic in (Fig.1) is adopted for the purpose of this paper. The piping system consists of the following pipes:

1. Lift pipe: circular pipe of (0.021 m) diameter and (1.25 m) length.
2. Mixing chamber: cylindrical shape of (0.063 m) diameter and (0.3 m) length. It has one inlet normal to the longitudinal axis in the middle distance between the lift and suction pipes, for the compressed air (Fig.2).
3. Suction pipe: five pipes are prepared for this paper. They are of fixed length (0.3 m) and different diameters (0.021, 0.027, 0.033, 0.048 and 0.063 m). One pipe is to be connected to the setup for each submergence ratio at a time. Results of such test will form the performance curves of the air lift pump for each submergence ratio.

Compressed air is to be supplied using a reciprocating air compressor of (1180 l/min) capacity under a pressure of (8 bar). A three phase generator of (7.5 KW) power runs the compressor through a pressure switch so as to regulate the air pressure.

RESULTS AND CONCLUSIONS

1. Twenty sets of tests are run for the air lift pump setup, to study the effect of the suction pipe diameter on the pumping rate. Each one of the five suction pipe diameters is tested for four submergence ratio; 0.2, 0.3, 0.4, 0.5. Results of these tests are shown in (Figs.3 – 6). The results may be summarized as follows:

a. With low air flow rates, the results indicate some fluctuations (especially for low submergence ratios), because of the unstable bubbly two phase flow effects. This situation changes as the air flow rate increases and leads to the slug flow regime.

b. As the air flow rate increases, the bouncy force increases, leading to an increase in the pumping rate. This situation proceeds until reaching the point of maximum pumping rate. More increase in air flow rate would result an increase in frictional losses which dominate on the bouncy force and hence reduce the pumping rate.

c. The pumping rate increases as the diameter of suction pipe increase for a fixed submergence ratio (this is illustrated in Fig.7). This increase is due to the increase in the static pressure in the suction pipe and the decrease in the water velocity in the same pipe, as a result of diameter increase. This in turn leads to a reduction in the friction losses.

d. From the other hand, Fig.7 shows that the pumping rate increases with increasing the submergence ratio for a fixed suction pipe diameter. This is due to the reduction in pumping head from one side and the increase in the submerged length from the other side.

e. Under high submergence ratios, high pumping rates are achieved by the use of lower air flow rates compared with those used with lower submergence ratios. An explanation of that is, as the submergence ratio increases, the travel distance for an air bubble increases. This leads to further expansion which causes further scavenging of liquid.

2. As illustrated in (Fig.8), experimental results are compared with those gained when applying Stenning and Martin model. The two curves, are reasonably close, especially for high values of $Cfs/\sqrt{2gL}$ (higher than 0.06). the slight differences between the two curves at $Cfs/\sqrt{2gL}$ lower than (0.006), may be explained due to that Stenning and Martin model assumes constant values for (K) and (S) which, actually, change significantly with the change of the compressed air flow rate.

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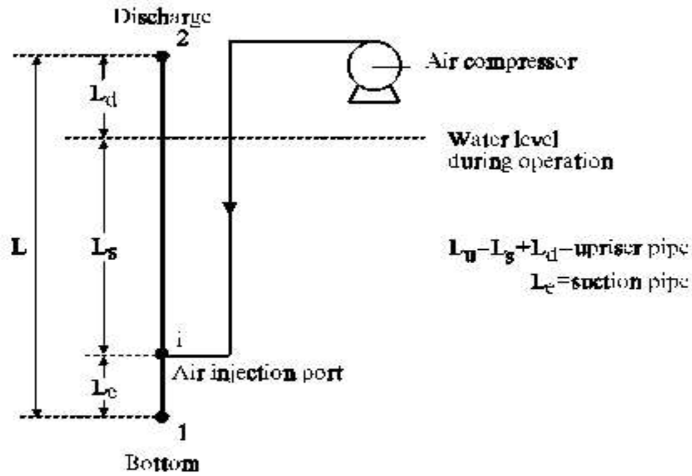

Fig.1 A schematic for the Air lift pump

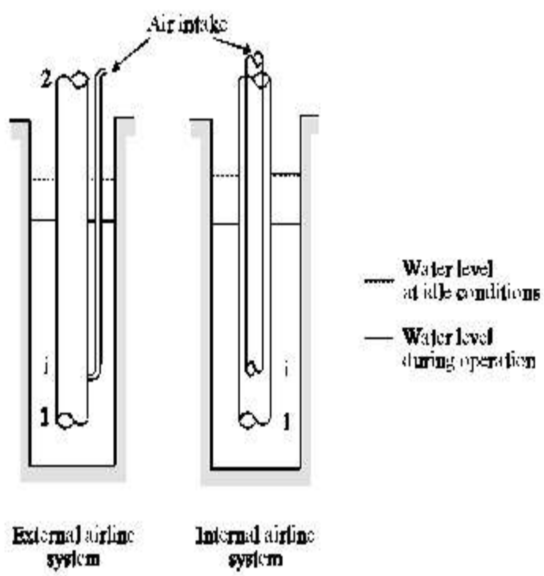

Fig.2 Types of air injection for the air lift pump [7]

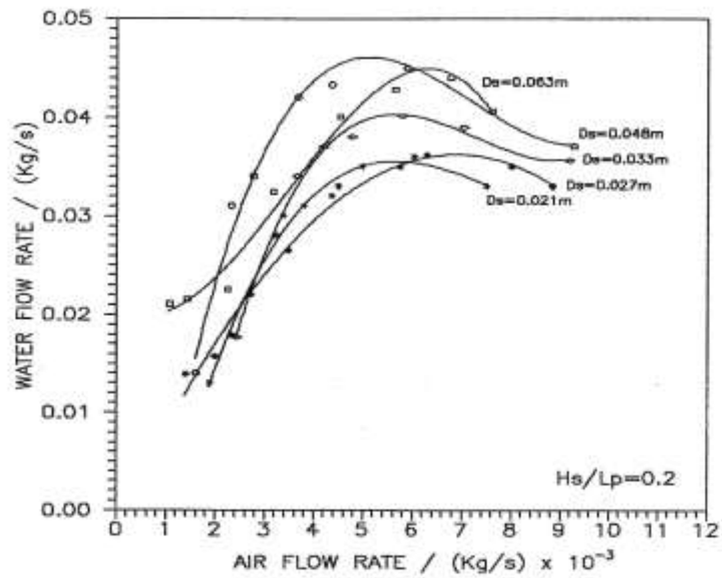

Fig. 3 Effect of suction pipe diameter on the pumping rate at submergence ratio (0.2).

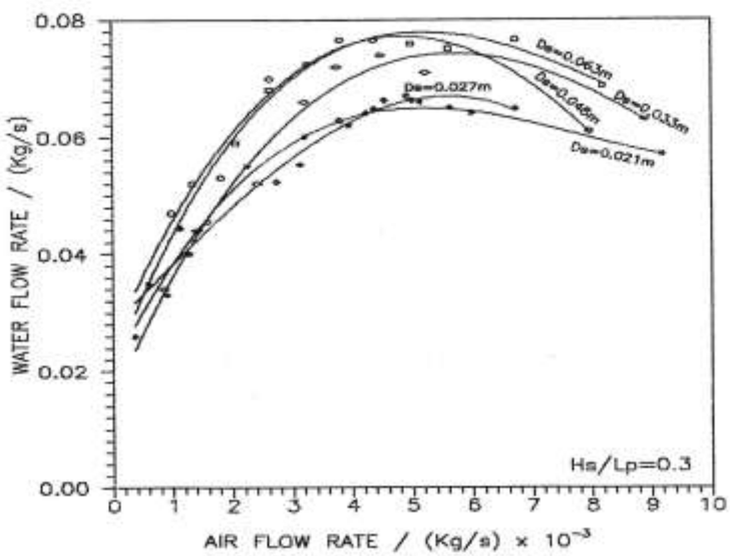

Fig. 4 Effect of suction pipe diameter on the pumping rate at submergence ratio (0.3).

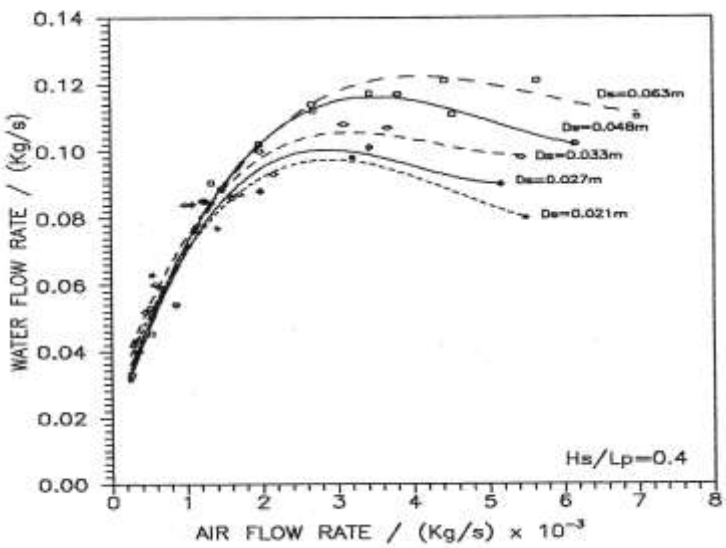

Fig. 5 Effect of suction pipe diameter on the pumping rate at submergence ratio (0.4).

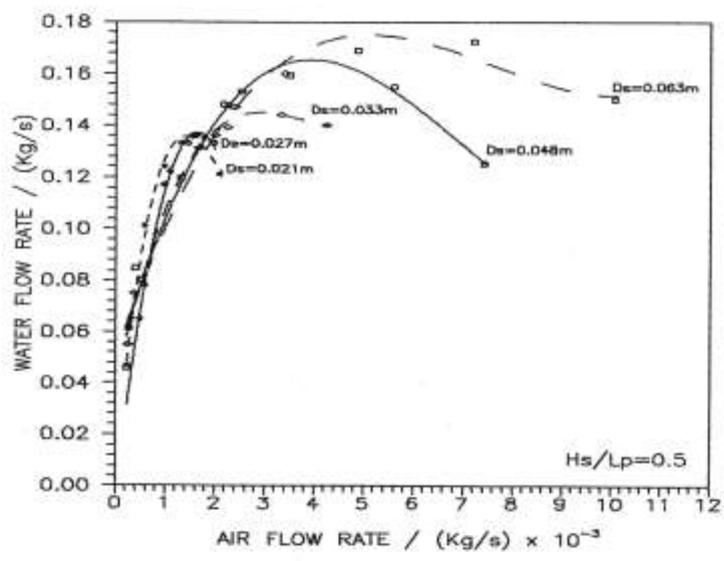

Fig. 6 Effect of suction pipe diameter on the pumping rate at submergence ratio (0.5).

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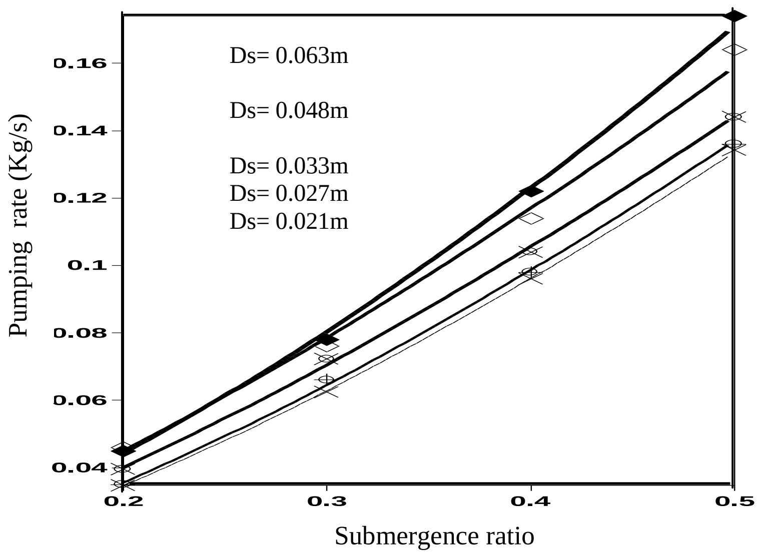

Fig.7 The relation between pumping rate and submergence ratio for the different suction pipe diameters

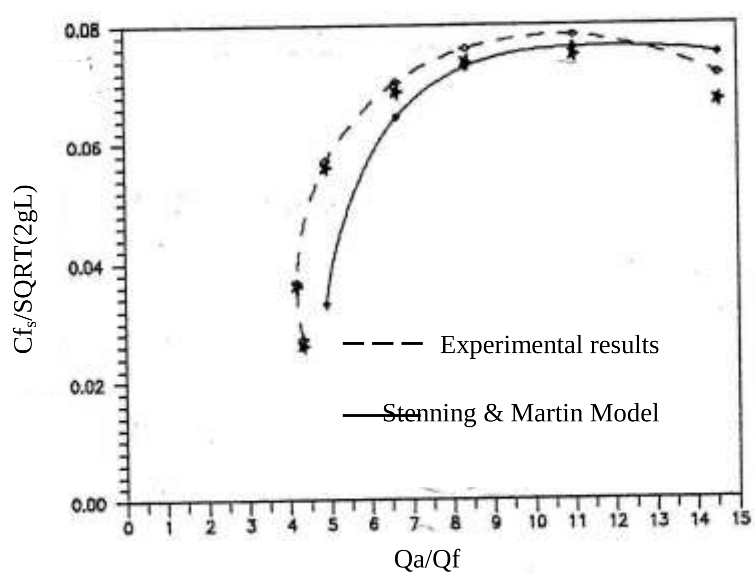

Fig.8 A comparison between the experimental and Stenning & Martin model results.

تأثير قطر أنبوب السحب و نسبة الغطس على معدل ضخ السائل للمضخة الرافعة بالهواء

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الخلاصة

إن الارتفاع المضطرد في أهمية استخدامات المضخة الرافعة بالهواء ضمن قائمة عريضة من المجالات (التعدين و الصناعات النووية و الاستخدامات الزراعية و الصناعات البترولية...الخ) قد جذب انتباه الباحثين لسبر غور هذه المضخة بحثا عن وسائل لرفع مخرجات أداءها.

تم عمل نموذج لمنظومة المضخة الرافعة بالهواء لغرض دراسة تأثير التغير في قطر أنبوب السحب و نسبة الغطس على معدل ضخ السائل (الماء). تحوي المنظومة على أنبوب رفع بقطر و طول ثابتين هما (0.021 م و 1.25 م) على التوالي. تم إجراء التجارب على خمسة أقطار مختلفة لأنبوب السحب الذي يبلغ طوله (0.3 م) و تلك الأقطار هي (0.021 م ، 0.027 م ، 0.033 م ، 0.048 م و 0.063 م)، حيث يتم تجربة كل منها باستخدام نسب الغطس (0.2، 0.3، 0.4 و 0.5) على التوالي.

أوضحت النتائج زيادة معدل الضخ عند زيادة قطر أنبوب السحب لنفس نسبة الغطس. من جهة اخرى تبين زيادة معدل الضخ عند زيادة نسبة الغطس لنفس قطر أنبوب السحب. كما تبين أيضا إمكانية الحصول على معدلات ضخ عالية عند نسب الغطس العالية باستخدام معدلات ضخ واطئة للهواء نسبة إلى تلك المطلوبة لنسب الغطس الواطئة. أظهرت التجارب العملية كذلك تطابقا جيدا مع النموذج المقترح من قبل ستيننج و مارتن لأداء المضخة الرافعة بالهواء.

الكلمات الدالة

مضخة رافعة بالهواء، نسبة الغطس، منحنى أداء.