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EFFECT OF AIR INJECTION METHOD ON THE PERFORMANCE OF AIR-LIFT PUMP

تاثير وسيله حقن الهواء على اداء مضخه الرفع بالهواء

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خلاصه

تستخدم مضخه الرفع بالهواء فى الحالات التى يتعذر فيها استخدام المضخات العاديه مثل ضخ السوائل المسببه للتاكل والنحر وعند استخدام السوائل المشعه نظرا لعدم احتوائها على اجزاء دواره وبالتالى فانها نظريا لا تحتاج الى صيانه كما تتميز بسهولة التركيب وقلة التكاليف.

اهتمت الدراسات السابقه بدراسة اداء المضخه من حيث معدل رفع الماء بالنسبه لمعدل تدفق الهواء المضغوط مع دراسة تاثير العوامل المؤثره على هذا المعدل مثل قطر مقطع الانبوبه ونسبة الرفع (النسبه بين الرفع والضاغط الاستاتيكى) وضغط حقن الهواء و وسيله الحقن وموضعها بالنسبه لمدخل انبوبه الرفع . غير انه فيما يختص بتاثير وسيله الحقن فقد ذكرت بعض الابحاث بانها لا تؤثر على اداء المضخه فى حين اوضحت ابحاث اخرى عكس ذلك. لذا كان الهدف الاساسي من هذا البحث دراسة تاثير وسيلة الحقن على اداء المضخه والوصول لانسب هذه الطرق.

لهذا الهدف تم تصميم و انشاء مضخه من هذا النوع وتم اعداد وتجهيز ستة طرق مختلفه لحقن الهواء واجريت تجارب معمليه مكثفه لكل نوع عند ظروف تشغيل موحده من حيث نسبة الرفع وضغط الحقن وعند قيم مختلفه لمعدل تصرف الهواء.

ولقد اثبتت التجارب ان وسيلة الحقن لها تاثير كبير على اداء المضخه من حيث القدره والكفاءه وذلك لان وسيلة الحقن تؤثر على نوع و طبيعه السريان متعدد الطور فى انبوبه الرفع ولذا فان الحجم و التوزيع الابتدائي لفقاعات الهواء لهما تاثير كبير على اداء المضخه وان استخدام وسائل حقن متعددة الثقوب و منتظمة التوزيع يحسن من اداء المضخه . كذلك وجد ان كفاءة المضخه تزداد مع نقصان نسبة الرفع و الضغط المحقون.

ABSTRACT

Different methods of air injection into the riser of an air-lift pump were experimentally tested. Measurements were carried out on a riser tube (50.8 mm diameter and 2400 mm long) at different ratios of lift to submergence (1.33, 1.89 and 2.81) and various values of injection pressure (2, 3 and 4 Kg/cm^2). Both water flow rate and pump efficiency are shown against air flow rate calculated at STP for different methods of injection. A marked effect was found on the pump performance when operated with different types of injectors. This effect is attributed to the fact that initial bubble size and distribution greatly affects the two phase pressure loss in the riser and consequently the pump efficiency.

INTRODUCTION

An ordinary air-lift pump consists of a vertical riser tube with one or several air injectors at its lower port. The tube is submerged in a liquid basin and air is introduced through the injector forming bubbles, which expand as they rise. Consequently the fluid in the tube is raised above the level of the surrounding liquid.

The air lift-pump is a reliable device for difficult pumping operations such as corrosive or abrasive liquids, slurries and under water exploration because it incorporates no moving parts to corrode and wear [1,2]. Such pumps are also ideal for handling radioactive liquids since they require virtually no maintenance. In spite of its low efficiency and the need to use relatively higher submergence values, it is widely used for pumping relatively small quantities of liquids. It has the advantage that it can be installed quickly, cheaply and easily when a suitable mechanical pump is not available [1-3].

A great deal of theoretical work has been done to explain and understand the performance of air lift pump, this can be found in many references c.f. [1,2,4-7]. The experimental study of air lift pump was the purpose of numerous studies. Most of these studies were directed toward the investigation of the pump performance and to give informations on the ratio of the air and liquid flow rates. The experiments described by Smith [3] concluded that the air lift pump requires a submergence at least equal to the lift. Also it was found that when using different methods of introducing air into the water, the difference in results were negligible, which means that the method of injection does not change the pump performance. Merchuk and Stein [8] found that the liquid velocity was a single power law function of the gas flow rate. The constant of proportionality depends on both the geometry of the system and on the regime of the two-phase flow in the riser. Also Merchuk and Stein [8] found that the measured values of the local hold up depend on the type of sparger used for the air and on the resistance of the fluid flow in the circuit. The influence of riser tube diameter, air injection type and position, and the degree of submergence were studied by Halde and Svensson [9]. It was found that the air injector should be situated at least 200 mm above the bottom orifice of the riser tube in order to keep the air from percolating the surrounding bed. The experiments of Halde and Svensson [9] showed that the maximum efficiency is little affected by the type of air injector. Wang and Chen [5] concluded that for each given operating condition, there exists a corresponding optimum rate of injected air flow. The introduction of a separating air film lining the walls of an air lift riser was studied experimentally by Khalil and ElShorbagy [10]. It was found that this method of introducing air film increases both the liquid discharge and efficiency of the riser.

As previously shown, the effect of the method of introducing air in the air lift pump is uncertain, since references [3,9] showed that it has negligible or no effect, while [8,10] reported an opposite conclusion. Accordingly the present study aims at investigating the effect of the method of air introduction on the performance of air lift pump with the objective of finding the optimum method of introducing air. Six methods were investigated experimentally under the same operating conditions. The efficiency and the water discharge were plotted against air flow rate under different lifting conditions and various values of injection pressure.

EXPERIMENTAL APPARATUS

A schematic diagram of the experimental apparatus is shown in Fig. (1). The lift pipe was constructed of plexi-glass with 50.8 mm inside diameter and the total height (L) was 2400 mm. The water was lifted from a constant head tank (lower tank), which was provided with several holes of 25.4 mm diameter to control the water level in the tank and hence the submergence level. Supply water pipe was connected to this tank to make up the lifted water. The upper tank (0.5 m^3 in volume) was held on a movable support and used to collect the lifted water, also the tank was provided with a drain hole. The water flow rate was measured by recordering the time elapsed for filling the upper calibrated tank.

Air was supplied from a compressor of 1.5 m^3 capacity storage tank of maximum pressure 12 bar. The air was flown through reducing and control valves and introduced near the bottom of the pump into the riser (200 mm above the bottom of the riser as recommended by Halde and Svensson [9]. Six injectors designed to introduce the air in different ways were tested. These injectors are illustrated in Fig. (2). The first injector consists of a single copper tube of 6 mm internal diameter, while the second is similar but of 4 mm internal diameter. Both is situated at the center of the riser tube and directed upward, Fig. (2-I, II). The third method is a straight single copper tube of 6 mm internal diameter with three holes (2 mm diameter) , the middle one is situated in the center of the riser, Fig. (2-III). The fourth method consists of a circular tube of 50.8 mm diameter, 6 mm internal diameter and having holes of 3 mm on its circumference, Fig. (2-IV). The last two methods are shown diagramaticaly in Figs. (2-V, VI). The holes diameter of the fifth method is 3mm and the last one is 2 mm. The number of holes were calculated such that the injected air velocity must be the same for both device. The air flow rate was controlled by a metal globe valve and measured by a standard ASME orifice meter of 12.7 mm inside diameter. Bourdon tube gage was used to measure the pressure upstream of the orifice meter and the temperature was measured by a copper-constantan thermocouple. The accuracy of measurements are estimated as approximately ± 3 % for air flow rate measurements and ± 1 % for liquid flow measurements.

Tests were carried out with three values of lift ratio r, which is defined as the ratio of the static lift $(L - H_s)$ to the submergence head H_s. These values are 1.33, 1.89 and 2.81 respectively. For each case the air flow rate was gradually increased to the maximum available value in small steps and the liquid flow rate was measured for each value of air flow rate.

PROCEDURE

The level in the lower tank was maintained at the required head H_s by using the overflow side holes in the tank, then the lift ratio r can be calculated $\{r = (L - H_s)/H_s\}$. The control valves were adjusted together to get the required constant pressure upstream the orifice meter. The head difference across the orifice meter was recorded and used to calculate the air flow rate at STP conditions. When reaching the steady state the time required to fill the upper tank was recorded and used to calculate the liquid flow rate. The control valves were partially closed to attain the same constant air pressure upstream the orifice meter at different values of air flow rates. The same procedure was repeated at different pressure values for various submergence ratios. For each operational condition, there exists a corresponding optimum rate of input air flow rate as stated in ref.

[9]. Therefore the different method of injection were assumed to be tested under the same operational conditions.

EXPERIMENTAL RESULTS AND DISCUSSIONS

Figures (3-I to VI) show the water discharge in lit/sec against the air flow rate in lit/sec calculated at standard temperature and pressure conditions for the six different designed methods of injection, which are illustrated in Fig. (2) Results are presented for an injection pressure of 2, 3 and 4 Kg/cm^2 and for different lift ratios of 1.33, 1.89 and 2.81. From these figures it is clear that water flow rate increases linearly with increasing air flow rate. Also the water flow rate decreases with decreasing the static submerged head H_s, i.e. with increasing the lift ratio r {r = (L - H_s)/ H_s}. The figures also indicate that the water flow rate Q_w increases as the injection pressure increases for all values of lift ratio r and air flow rate Q_a. The missing graphs means that the pump was not able to deliver water under the operating injection pressure and lift ratio. This can be attributed to insufficient air supply and formation of small bubbles which slip through water. When the injected pressure increases or at higher submergence, a slug flow pattern forms and the air bubbles become large enough to prevent slippage and hence water flow takes place. It can be seen also that for all experiments the water flow rate varies linearly with the air flow rate. The constants of this linear relation depend on both the geometry of the system and on the regime of the two phase flow in the riser, which agrees with the experimental results of Merchuk and Stein [8]. For the purpose of comparison between the different designed methods of injection, the water flow rate was drawn versus the air flow rate at the same operational conditions of pressure and lift ratios, Fig. (4-6). From these figures it is evident that the fifth method of injection gives higher values of water flow rate at the same operational conditions. The water flow rate changes drastically from one method to the other. For example the fifth method delivers water discharge of about 300% of that of the second method at the same operating condition. Higher differences in results are found at lower lift ratio, i.e. at higher submerged static head.

The efficiency of the air lift pump may be defined as the ratio of the gain in potential energy of the liquid to the work done by the air. The gain of the potential energy of the liquid is:

$$W_w = Q_w . \gamma_w . (L - H_s) \qquad \text{..................} (1)$$

If the air lift pump was analytically treated as an expansion engine, the theoretical work done by the air entering the riser at the injected pressure P_i and leaving at atmospheric pressure P_o, is given by:

$$W_a = P_i . Q_a . \ln (P_i/P_o) \qquad \text{..................} (2)$$

Thus the pump efficiency can be written in the following form [9]:

$$\eta = \frac{Q_w . \gamma_w \ (L - H_s)}{P_i . Q_a . \ln (P_i/P_o)} \qquad \text{...............} (3)$$

The variation of the riser efficiency versus water flow rate Q_w is illustrated in Figs. (7-9) for a lift ratio of 1.33 and injection pressures of 2, 3 and 4 kg/cm^2, respectively. From these figures it is clear that the fifth method of injection gives higher riser efficiency in comparison with the other methods. It must be noticed also that higher efficiencies are obtained at lower pressures.

According to Merchuk and Stein [8] a marked difference in the performance of the air lift pump can be noticed when operated with multiple-orifice or single-orifice injector. The single orifice injector creates an uneven distribution of air in the section of the riser tube and the air bubbles generated are larger. This provokes higher mixture velocity in the center of the tube and larger differences in liquid velocity, which induce a migration of the larger bubbles towards the axis. Thus a high concentration of bubbles is created around the axis which increases the probable coalescence [8]. Here a fraction of the tube cross section is used only as a riser, which decreases pump efficiency since the efficiency decreases with decreasing riser diameter. This agrees with the obtained results, since better results are shown for the cases of multiple-orifice injector.

The results show that the second method of injection gives lower pumping efficiency than the first method. This can be explained as an effect of bubbles slip, which occurs for small bubble sizes; the second method has smaller orifice diameter and consequently smaller bubble sizes. The last two methods of injection represent the more efficient ones among the tested methods. This is due to the good homogenous mixture formed in the riser, which reduces the slip ratio, especially for the fifth method where the holes diameter is larger.

CONCLUSIONS

(1) The initial bubble size and distribution in the riser section affects the pump performance and a marked improvement in pump performance was obtained when using multiple-orifice injectors.
(2) The air injector has a considerable effect on the lifted water and on the air-lift pump performance.
(3) The operation of the air lift pump depends upon several factors such as riser size, lift ratio, method of air injection, etc. Therefore no single formula can express the relation between these variables

NOMENCLATURE

H_s	static submergence head (mm)
L	riser height (mm)
P_i	injection pressure (Kg/cm^2)
P_o	atmospheric pressure (Kg/cm^2)
Q_a	air flow rate (lit/sec) at STP conditions
Q_w	water flow rate (lit/sec)
r	lift ratio $\{(L - H_s)/H_s\}$
W_a	work done by air
W_w	gain potential energy of the water
γ_w	water specific gravity
η	pump efficiency

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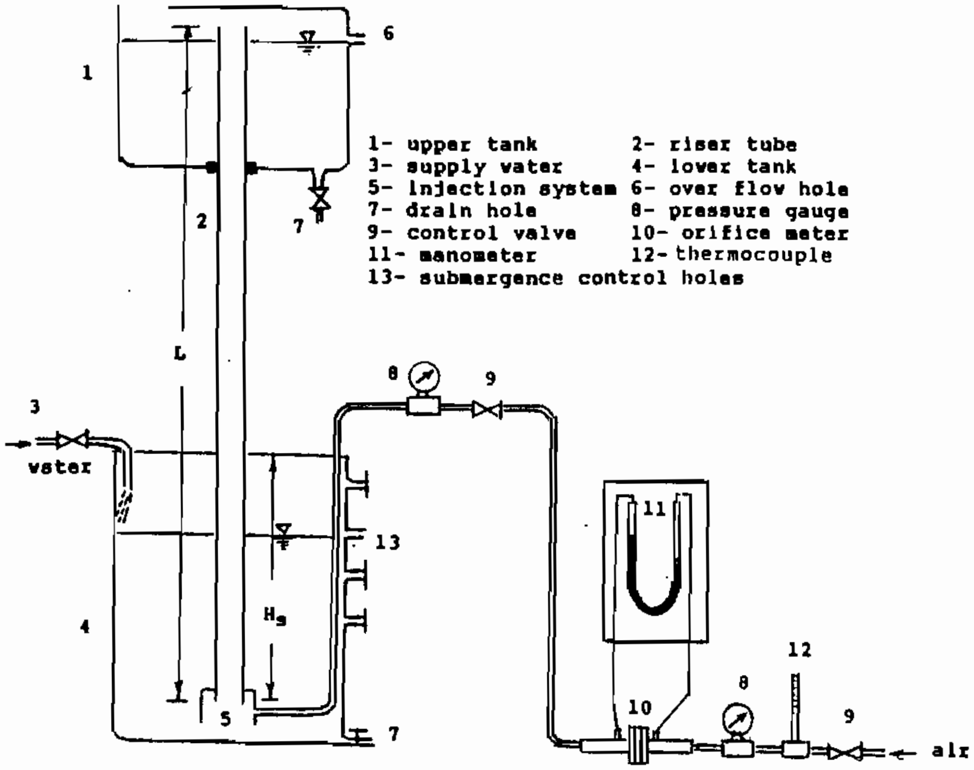
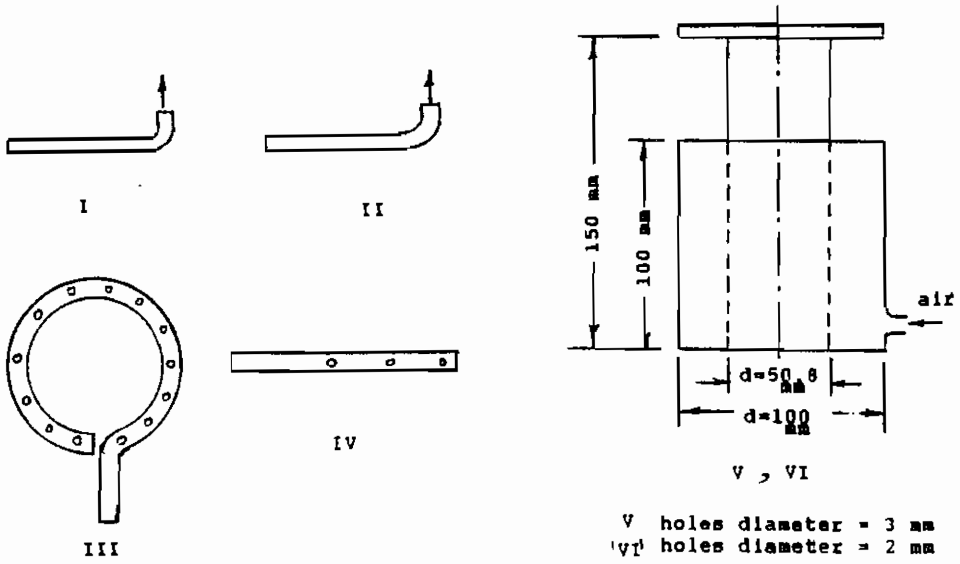


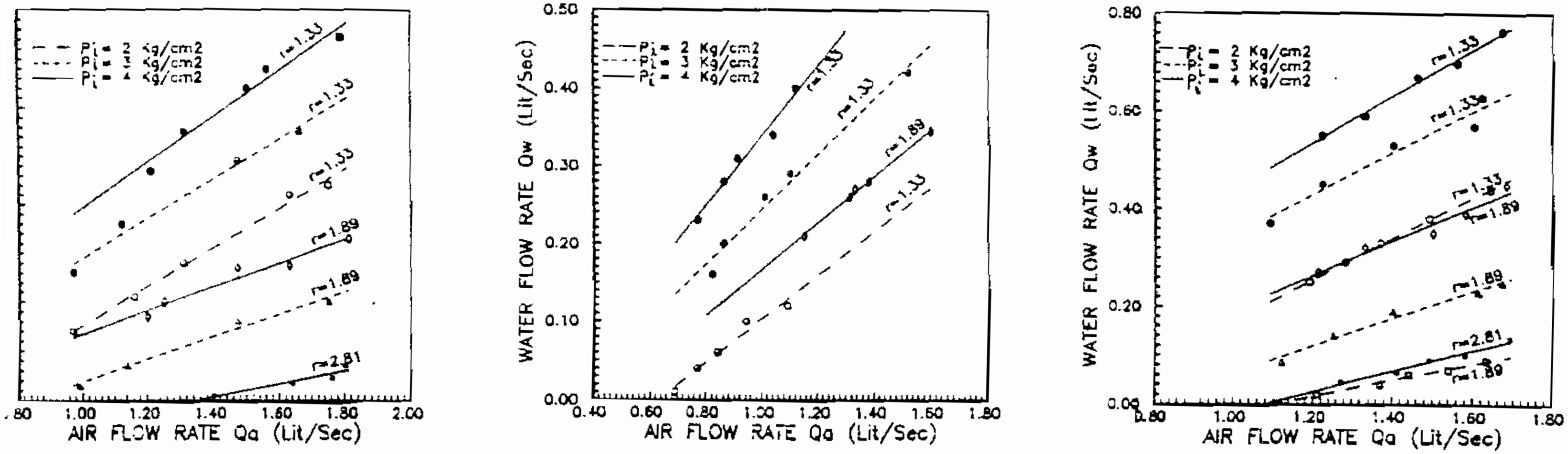
1- upper tank 2- riser tube
3- supply water 4- lower tank
5- injection system 6- over flow hole
7- drain hole 8- pressure gauge
9- control valve 10- orifice meter
11- manometer 12- thermocouple
13- submergence control holes

Fig. (1) Schematic diagram of the air lift-pump test equipment



V holes diameter = 3 mm
VI holes diameter = 2 mm

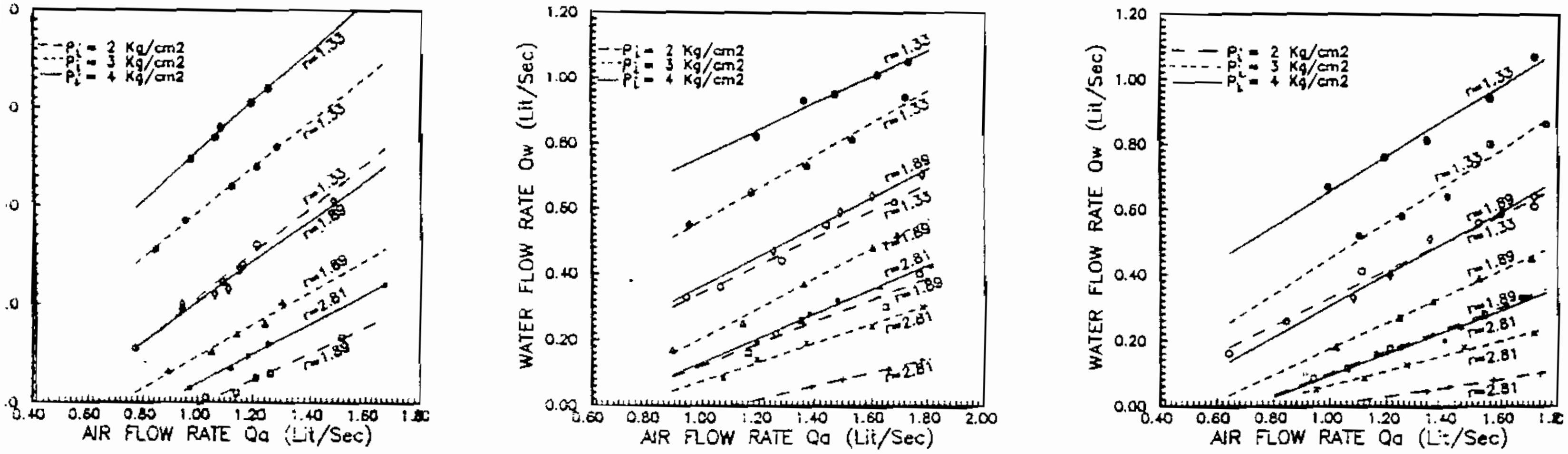
Fig. (2) Air injection devices



Injection method No. I

Injection method No. II

Injection method No. III



Injection method No. IV

Injection method No. V

Injection method No. VI

Fig. (3) Water flow rate against air flow rate at different injection pressure values and lift ratios

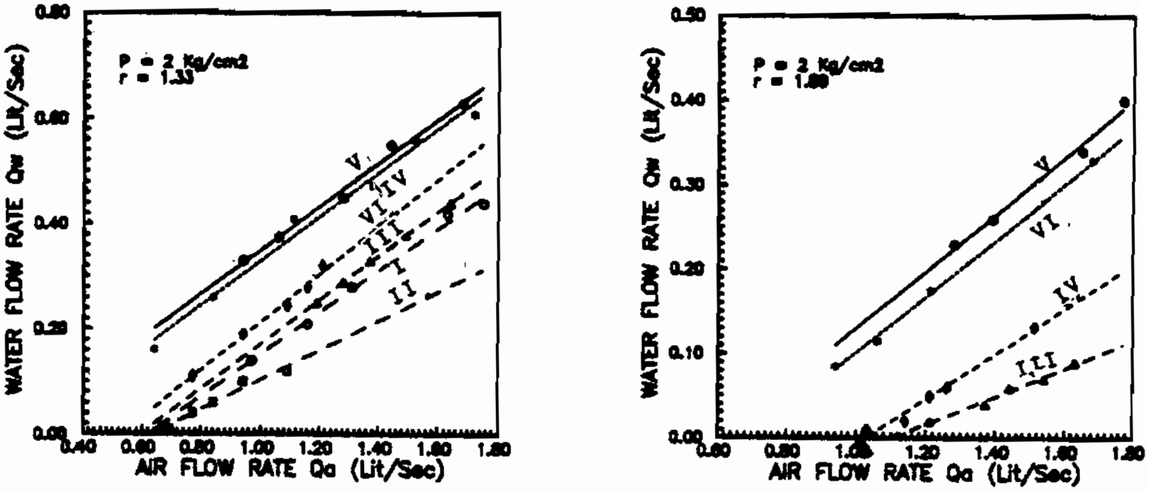


Fig. (4-a) r = 1.33

Fig. (4-b) r = 1.89

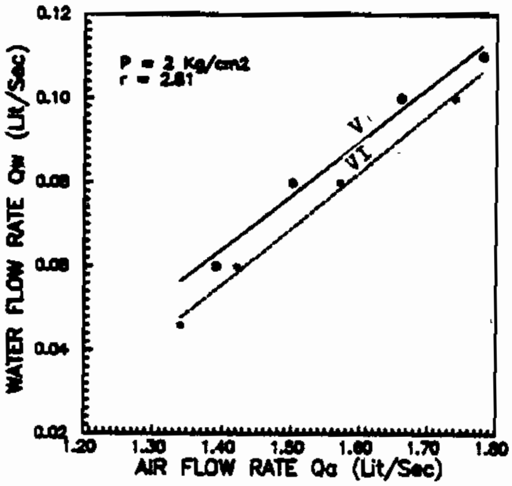


Fig. (4-c) r = 2.81

Fig. (4) water flow rate against air flow rate for different methods of injection at P = 2 Kg/cm^2 and various lift ratios

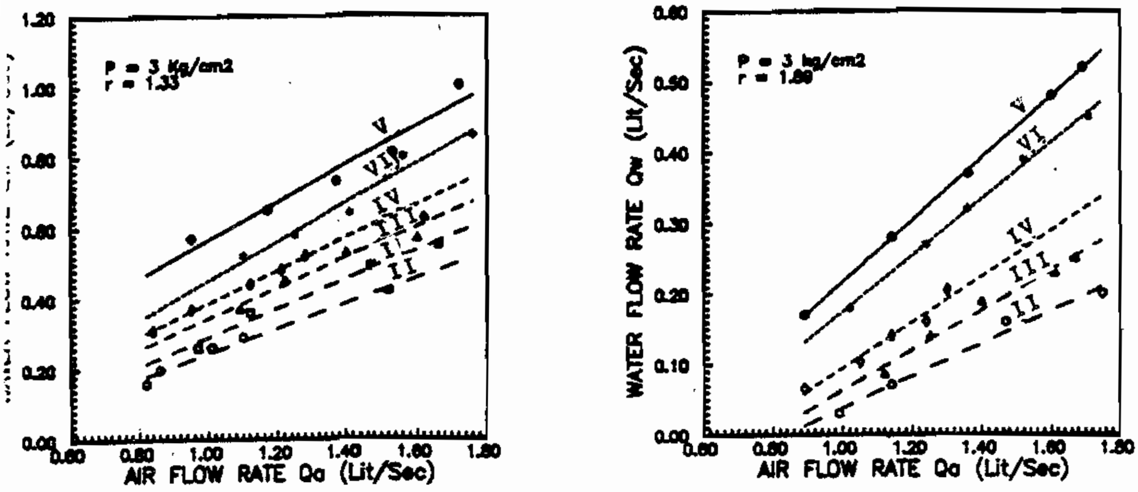


Fig. (5-a) r = 1.33

Fig. (5-b) r = 1.89

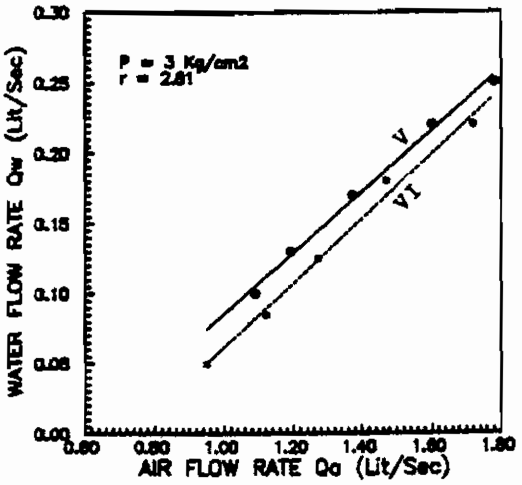


Fig. (5-c) r = 2.81

Fig. (5) water flow rate against air flow rate for different methods of injection at P = 3 Kg/cm^2 and various lift ratios

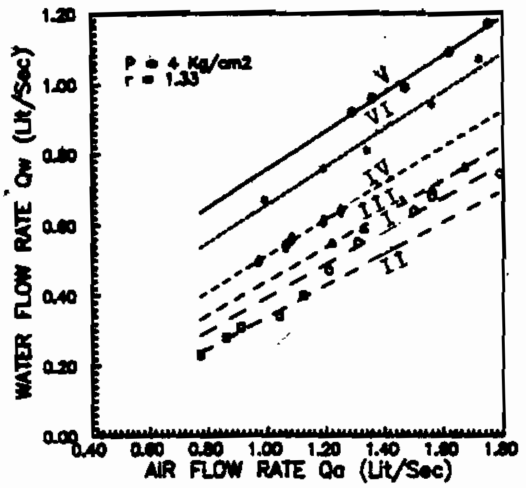


Fig. (6-a) r = 1.33

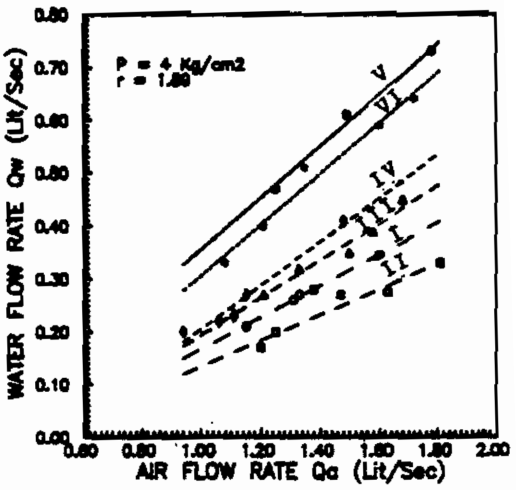


Fig. (6-b) r = 1.89

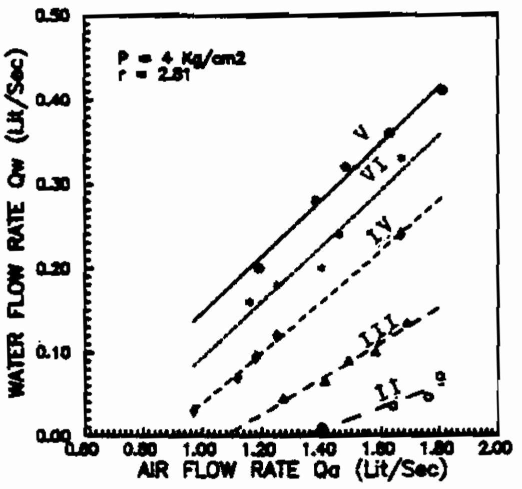


Fig. (6-c) r = 2.81

Fig. (6) water flow rate against air flow rate for different methods of injection at $P = 4\ Kg/cm^2$ and various lift ratios

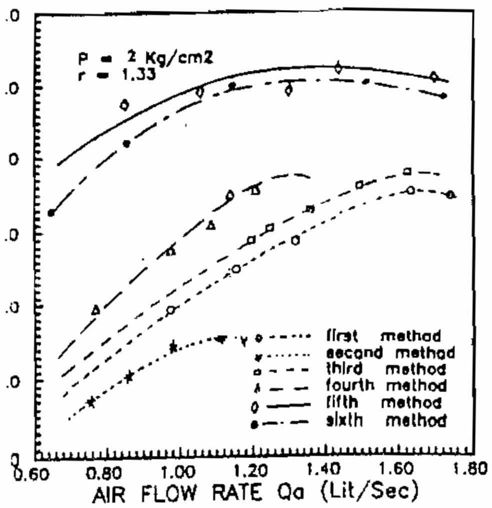


Fig. (7) Riser efficiency against water flow rate for different methods of injection at P=2 kg/cm^2 and r=1.33

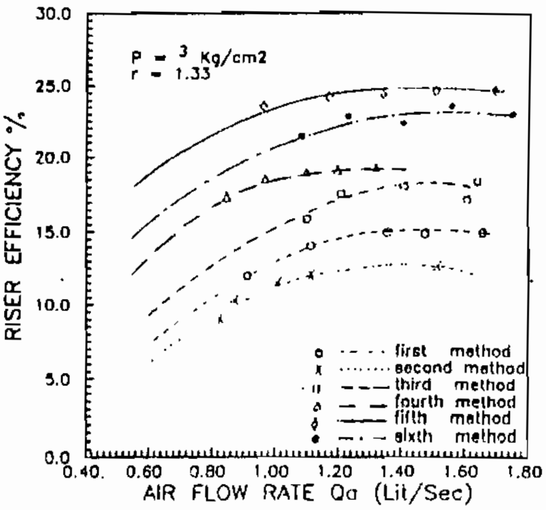


Fig. (8) Riser efficiency against water flow rate for different methods of injection at P=3 kg/cm^2 and r=1.33

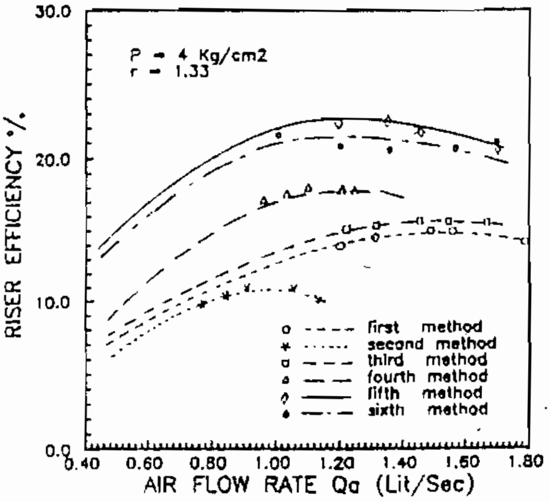


Fig. (9) Riser efficiency against water flow rate for different methods of injection at P=4 kg/cm^2 and r=1.33