Effect of design and operational parameters on jet pump performance.

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Abstract:

Experimental observations for the performance of a jet pump are presented with two different suction configurations and designs. The experimental rig was constructed in such a way it can be used with up feed (negative suction head) or down feed (positive suction head). During experimental programme water is used in both motive and pumped sides. The effect of nozzle-to-throat spacing to nozzle diameter ratio "X", on the jet pump performance was also tested, with different flow rates and motive pressures, in both cases (up feed and down feed). It was found that the best efficiency for the jet pump is attained with the up feeding configuration.

Keywords:

Hydraulic transportation, jet pump, mixing chamber, driving nozzle.

1. Introduction

Jet pump is a simple device applied widely in the fields of civil engineering to dewater foundation excavations in fine soils and dredging. It is also used in several mechanical, chemical, and industrial engineering applications for evacuating gases, lifting of liquids, and solid particles. The principle of the jet pump is to convert the pressure energy of the motive (primary) fluid into the velocity energy through driving nozzle. The resultant jet of high velocity creates a low pressure area in the suction chamber causing the pumped (secondary) fluid to flow into this chamber. Consequently, there is an exchange of momentum between the two streams in the mixing chamber resulting in a uniformly mixed stream traveling at an intermediate velocity between the motive and pumped fluid velocities. The diffuser is shaped to convert the kinetic energy of the mixture to pressure rise at the discharge flange with a minimum energy loss. The absence of moving mechanical parts eliminates the operational problems associated with bearings seals and lubrication. Therefore, such pumps are widely used because of their simplicity and high reliability (as a consequence of no moving parts). The theory of the jet pump was first suggested by Gosline and O'Brien [1] who established the governing equations to represent the processes in jet pumps. This theory was later improved to include the friction losses by investigators like Cunningham and River [2] and Vogel [3]. Mueller [4] carried out experimental study on a water jet pump to obtain the optimum dimensions of the jet pump. Reddy and Kar [5], Sanger [6], Grupping et al. [7], and Hatziavramidis [8] carried theoretical and experimental studies on a water jet pump and suggested expressions for all energy losses in the various parts of the pump. General method for the optimum design of water jet pump components and consequently for the entire pumping unit was suggested by Vyas and Kar [9]. Recently Iran et al [10] investigated the performance of low cost venturi-ejectors, during which they investigated ejectors with area ratios of 0.25, 0.35, and 0.53. Their experiments indicated that, the ejectors with area of 0.35 are the most efficient. Jet pumps are also frequently used under conditions where the primary and secondary fluids are different. Cunningham [11] presented theoretical analysis based on one-dimensional flow model for a jet pump operated with water to handle bubbly secondary fluid (air +water). Mikhail et al [12] presented theoretical and experimental study for the performance of a jet pump with different fluids. Their study based on one-dimensional theory and taking into account the effects of the difference of the viscosities and densities of primary and secondary liquids. Zandi et al [13], Fish [14] carried out experimental and theoretical work on water and slurry jet pumps to develop equations which may be used in Furthermore, Chamlong et al [15] developed a numerical prediction to the optimum mixing throat length for drive nozzle position of the central jet pump. They concluded that, the optimum ratio of the mixing throat length to nozzle diameter,(L_m/D) is 2 - 3.5.

Until now and to the author knowledge, the research work on the jet pump is limited to the effect of nozzle to mixing chamber area ratio, mixing chamber length and nozzle ratio on jet pump performance. Therefore, it is important to investigate the effect of nozzle-to-throat spacing to nozzle diameter ratio and the driving pressure on the jet pump performance for both negative and positive suction head configurations when pumping clear water.

2. Nomenclature

A_r = Area ratio = Aj/A_m , (area of nozzle to area of mixing chamber).
A_J = Cross sectional area of the jet
A_m= Cross sectional area of the mixing chamber.
D = Nozzle (jet) diameter, m
L = Nozzle-to-throat spacing (distance between the nozzle exit and the beginning of the mixing chamber).
L_m= Length of the mixing chamber
P = Total pressure = P_d - P_s
Pa = Motive pressure
P_d = Discharge Pressure
Pr = Pressure ratio
P_s = Suction Pressure
Qr = Flow ratio
X= Ratio of nozzle-to-throat spacing to nozzle diameter (L/D)
γ = Specific weight (N/m^3)
η=pump efficiency = Pr x Qr

Subscripts

d = discharge
j = Nozzle tip
mix = mixing chamber

2. Test rig description and experimental procedure

2.1 Experimental apparatus

The experimental apparatus is schematically shown in Figure (1a & b). The test rig is designed so as to carry out experiments on jet pump under two suction configurations for the pumped fluid. These include up-lifting (negative suction head) and down-feed (positive suction head) configurations.

The test rig in figure (1a) consists of a transparent jet pump(1) , a centrifugal pump (2), a 500 litre water tank (3) , Plexiglas pipes (4) and (5), suction tank (6), U-tube mercury manometers (7), angle valve (8), jet discharge globe valve (9), weighing vessel (10) and a balance (11). Tap water is pumped from the water tank to the jet pump nozzle via a 25.4 mm inner diameter pipe fitted with an angle valve for controlling the motive pressure. A by-pass valve (12) is used to control the motive flow to the jet pump. The water level in the tank is controlled by a float switch to keep constant suction head for the centrifugal pump. The centrifugal pump operating head and flow rate vary from 15 to 30 m and from 20-150 l/min respectively.

Water from the suction tank (6) is lifted up by the jet pump towards the suction chamber and then, towards the mixing chamber. After that, the water passes through the diffuser towards the graduated weighing vessel for sampling. The jet pump delivery pipe (4) and the suction pipe (5) are made of transparent Plexiglas material so that the flowing fluids can be easily visualized and monitored.

The water flow rate is measured using calibrated rota-meter (13) at the exit of the centrifugal pump, while the motive pressure is measured using calibrated glycerine pressure gauge (14). The suction and delivery pressures of the jet pump are measured using a U-tube water and mercury manometers (7). The jet pump delivery volume flow rate is measured using a graduated vessel and a calibrated digital balance respectively together with a digital stop watch.

The volume flow rate is obtained by dividing the collected volume in the graduated vessel by the collecting time. A small pump located above the graduated vessel serves as a mean to empty the graduated vessel once a set of readings are taken. The test rig has a drain valve to empty the system.

The major difference between up-feeding (negative suction head) and down-feeding (positive suction) configuration for the pumped flow are shown in figures (1-a &1-b) is that in the second case, water from the suction tank (6) located at 1.5 m above the jet pump centre line flows towards the jet pump due to both gravity effect and the negative pressure created inside the suction chamber. After that, water flows towards the mixing chamber and then through the diffuser towards the graduated weighing vessel for sampling.

Uncertainty analysis for the obtained data was carried out using the method developed by Holman [16].

The uncertainty for pressure ratio is about 1.2 %, whereas` for flow rate is about 1.1% and pump efficiency is about 0.135%.

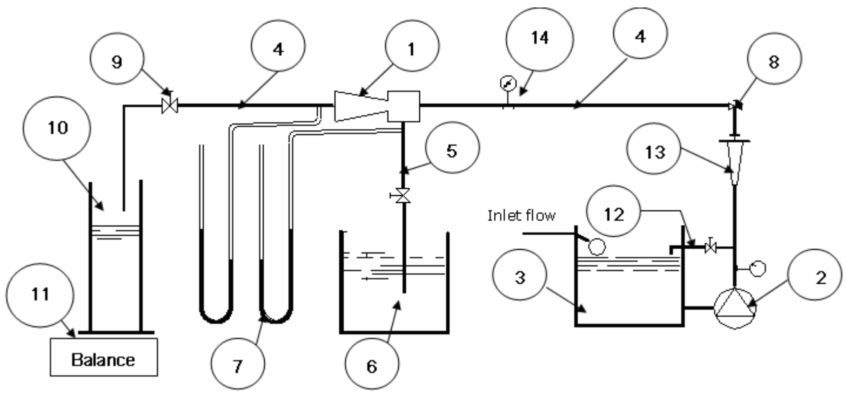

Fig. (1a) Test rig for up feed configuration (Negative suction head)

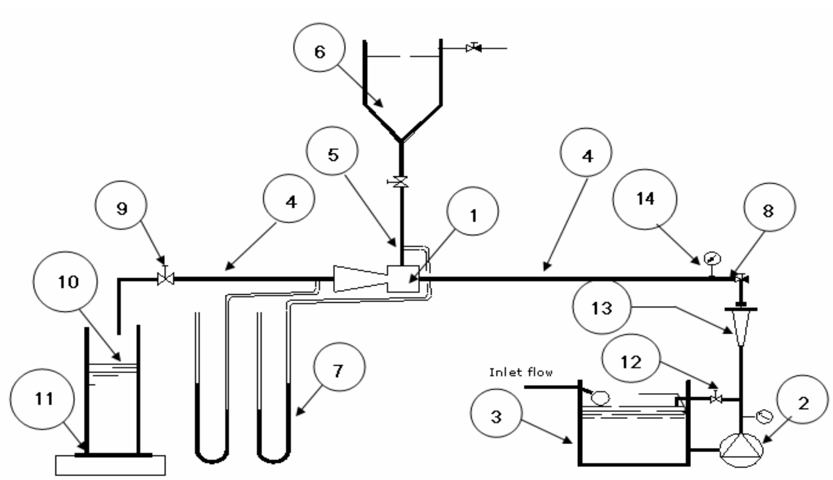

Fig. (1b) Test rig for down feed configuration (Positive suction head)

2.2 Experimental procedure

The experimental procedure applied in this study to determine the jet pump performance is detailed below:

1- Water temperature and atmospheric pressure in the laboratory are recorded.

2-The water tank is filled with fresh water and kept at constant water level, using a float switch and an overflow pipe line to maintain a constant suction head for the centrifugal pump.

3-The nozzle-to-throat spacing to nozzle diameter ratio "X" is set to 1.

4-The pump was turned on, keeping the angle-valve in the pump delivery side fully opened.

5- The pump pressure was adjusted to 3 bars and then the jet pump discharge valve was gradually closed.

6-When a steady state condition was attained; the readings of the rotameter, U-tube manometers, pressure gauges and data about the discharge mixture sample were recorded during a defined period of time.

7-The volume flow rate was then determined.

8-Steps (4) to (7) were repeated with different motive pressures 1, 1.5, 2 and 2.5 bar, while the nozzle-to-throat spacing to nozzle diameter ratio "X" is kept constant.

9- The nozzle-to-throat spacing to nozzle diameter ratio "X" was adjusted to 1.25 and steps (4) to (6) were repeated with different motive fluid pressure varying from 1.5 to 3 bar, in order to investigate the effect the nozzle-to-throat spacing to nozzle diameter ratio "X" on the jet pump performance.

10-Data was recorded for nozzle-to-throat spacing to nozzle diameter ratio "X" is varying as 1, 1.25, 1.5 and 1.75.

After completing the experimental program with up feeding (negative suction head) secondary fluid configuration, the test rig was emptied and new sets of experiments were carried out on the jet pump with down feeding (positive suction head) secondary fluid configuration.

The performance of jet pump is generally considered to be a function of the parameters defined in following:

i- Flow ratio Qr=Q suction / Q motive,

ii- Pressure ratio Pr =(Pd-Ps)/(Pa-Pd)

iii- Efficiency, η =The ratio of the total energy increase of suction flow to the total energy increase of driving flow as ,

$\eta = Pr \times .Qr$

3. Tests, results and discussion

3.1 Effect of nozzle-to-throat spacing to nozzle diameter ratio "X" on jet pump performance for up feeding (negative suction head) configuration for pumping water.

At a fixed nozzle-to-throat spacing to nozzle diameter ratio "X" and a fixed pump drive pressure; the discharge valve (9) was varied in stages until the jet flow is reversed. At each valve setting, the readings of the suction and delivery pressure of the jet pump and jet flow rates were recorded. The relation between the head ratio against the flow ratio is then constructed.

The test was repeated for different driving pressures of the centrifugal pump from 3 to 1.5 steps of 0.5 bars and for different nozzle-to-throat spacing to nozzle diameter ratio "X" = 1, 1.25, 1.5 and 1.75 . The results are presented in Fig.s 4 and 5.

Fig. (4) Presents the performance curves of water jet pump. The results show that the flow ratio is inversely proportional to the head ratio and as the drive pressure decreases from 3 to 1.5 bars, the head ratio of the jet pump increases. For nozzle-to-throat spacing to nozzle diameter ratio "X" = 1, it was found that, the maximum head ratio of the jet pump is obtained for a drive pressure of 1.5 bar which is 0.61 head ratio at a flow ratio of 0.295 and the minimum head ratio is 0.3 which corresponds to a flow ratio of 0.72. However, when the driving pressure was increased to 3 bar, the maximum head ratio of the jet pump drops to 0.53 at a flow ratio of 0.23 and the minimum head ratio is 0.15 at a flow ratio of 0.92. The probable explanation of the significant jet pressure reduction at high pump driving pressure is the increase in the head loss in the jet pump which cause swirl and eddy losses inside the jet pump.

Also in Fig. (4), the effects of flow ratio and driving pressure on the jet pump efficiency are presented. It is evident from the figure that as the head ratio decreases the efficiency increases. The curves presents a parabolic form with little asymmetry. The maximum pump efficiency obtained for nozzle-to-throat spacing to nozzle diameter ratio "X" = 1 and driving pressure of P = 1.5 bars is about 22 % at a flow ratio of 0.57. Whereas for P= 3 bar the maximum efficiency is 20 % at a flow ratio of 0. 6. This indicated a little reduction in jet pump efficiency.

Typical results of the pump performance was obtained for nozzle-to-throat spacing to nozzle diameter

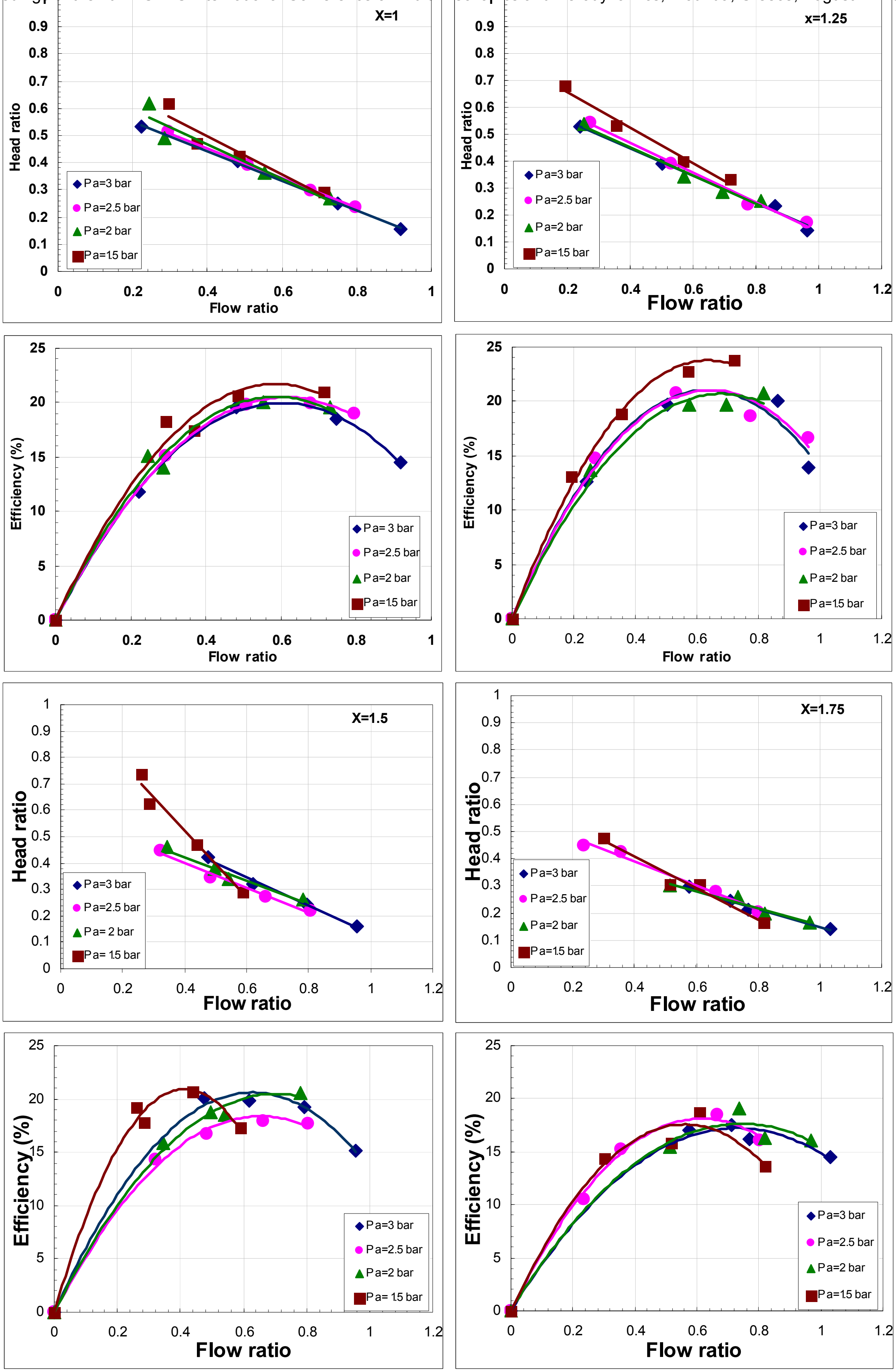

Fig. 4 Jet pump performance for different motive pressure at a specific nozzle distance ratio"X", when pumping water under negative suction head (upfeed)

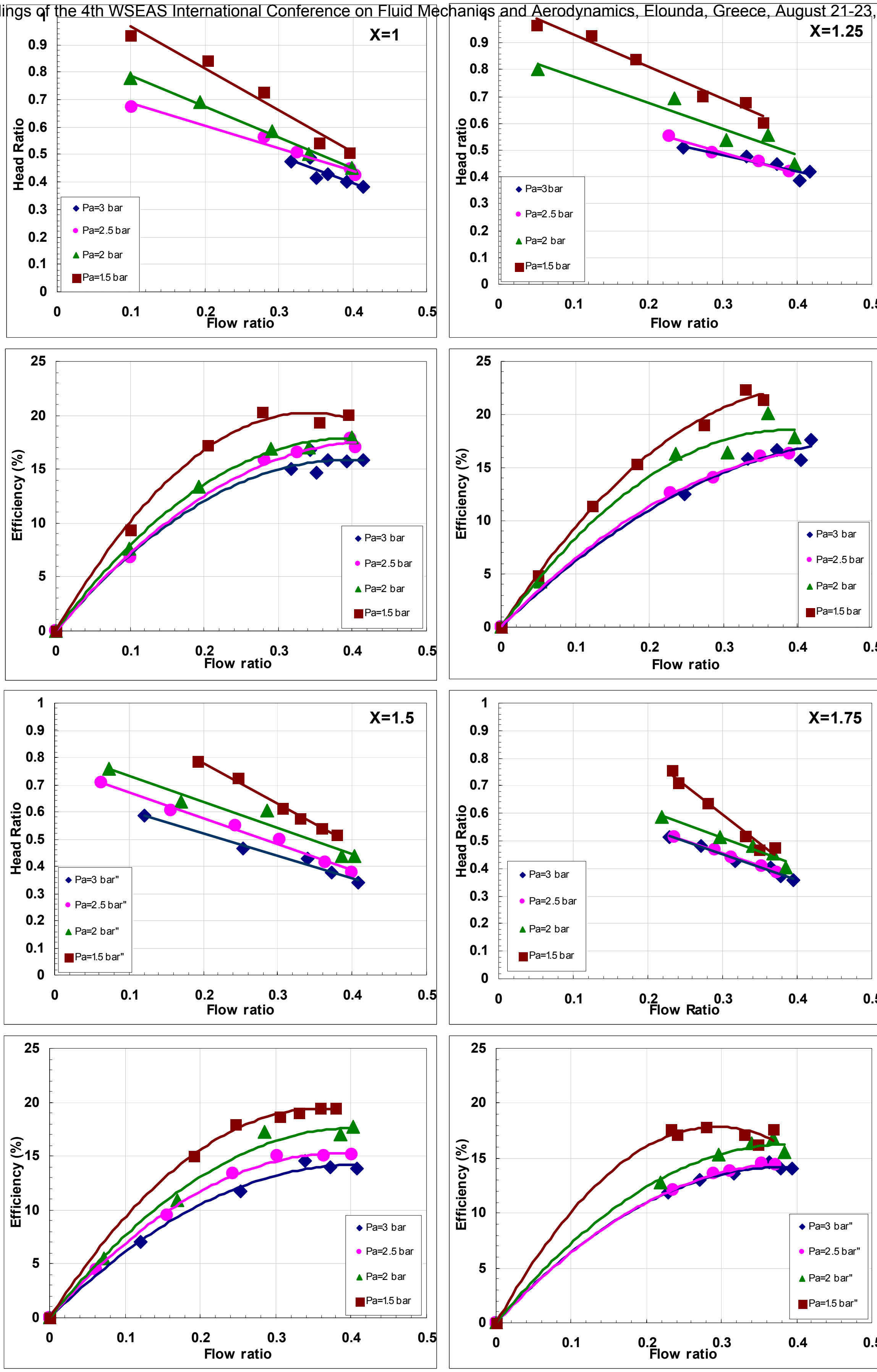

Fig. 5 Jet pump performance for different motive pressure at a specific nozzle distance ratio"X", when pumping water under positive suction head (down feed).

ratio "X" = 1.25, 1.5 and 1.75. In all cases the maximum head ratio of the pump is obtained at a driving pressure of 1.5 bars. Also it can be seen from Fig. (4) that for nozzle-to-throat spacing to nozzle diameter ratio "X" =1.25 and Pa=1.5 bar, the attained highest jet pump efficiency is about 24 %.

3.2 Effect of the nozzle-to-throat spacing to nozzle diameter ratio "X" on jet pump performance for down-feeding (positive suction head) configuration for pumping water.

Fig. 5.Similar trends were obtained with positive suction configuration. The head ratio was found to be higher than that of negative suction head configuration whereas the efficiency curves for both positive and negative head configuration are close. For the nozzle-to-throat spacing to nozzle diameter ratio "X" =1, it was found that the maximum head ratio which is 0.93 is obtained at a driving pressure of 1.5 bar and flow ratio of 0.1 and the minimum head ratio of the jet pump is about 0.53 at a flow ratio of 0.39. However, when the driving pressure was increased to 3 bars, the maximum head ratio of the jet pump drops significantly to 0.475 at a flow ratio of 0.3 and the minimum head ratio is 0.38 at a flow ratio of 0.414. A comparison between the negative and positive suction configurations results is presented in Fig. 6. The results presented in this figure are for a driving pressure of 1.5 bars and for different values of X. It is evident from the results for positive suction head configuration, the head ratio is higher than that of the other configuration and the flow ratio range is wider starting from 0.05 rather than 0.2 in the case of negative suction configuration. The efficiencies for both configurations are almost the same and their optimum X= 1.25. The increase in head in the positive head configuration is due to the increase in the static head above the suction inlet and mixing chamber.

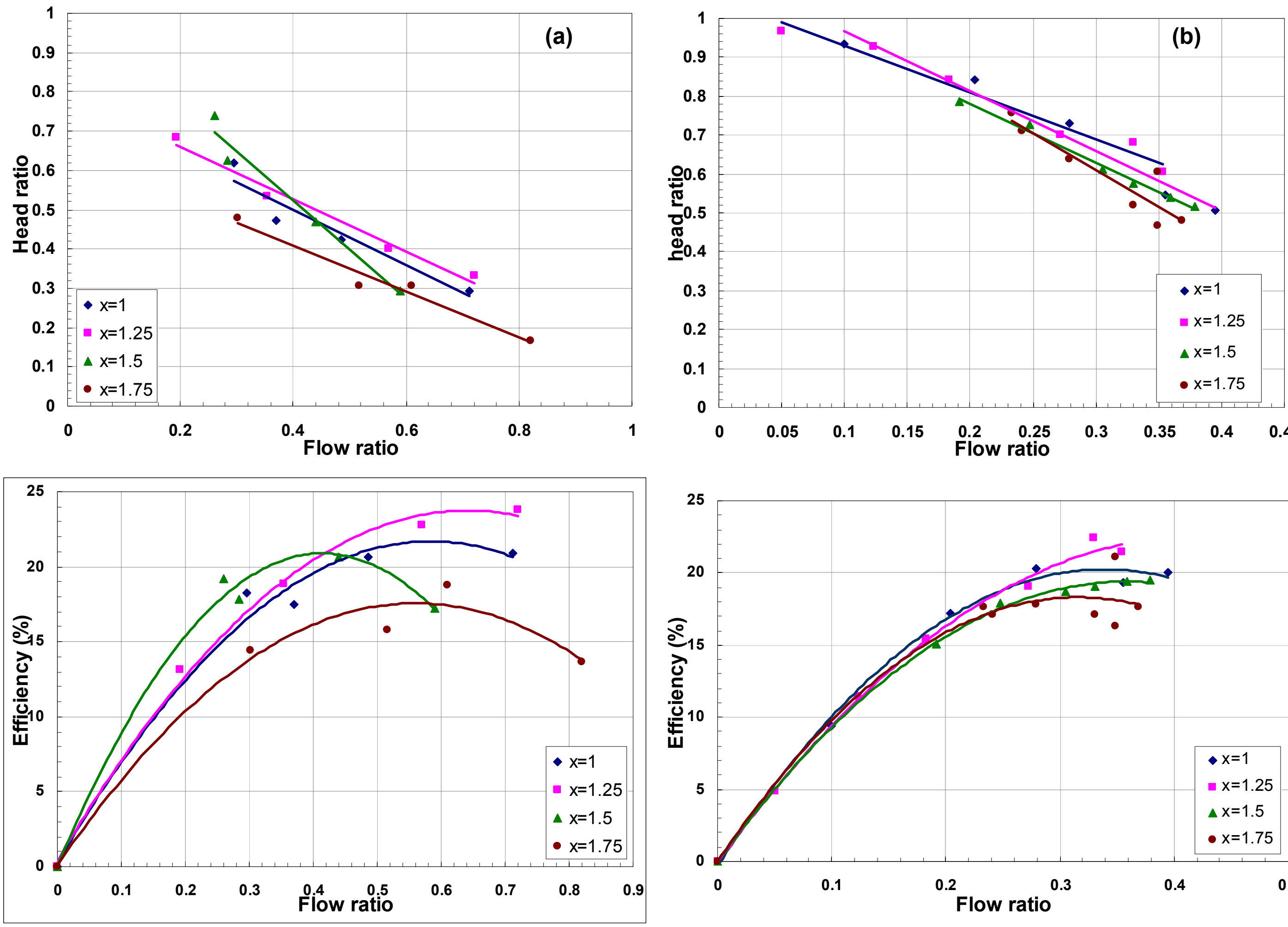

Fig.6 Jet performance at P=1.5 bar with variable X, pumping water a) upfeed b) down feed

4. Conclusions

The experimental investigation focuses on the head ratio, pump efficiency versus flow ratio. The following statements summarizing the more important conclusions.

1- The results of the jet pump show that the up-lifting (negative suction head) configuration for water yields to a higher pressure ratio and a lower pump efficiency whereas the down-feeding (positive suction head) configuration yields to a higher efficiency and a lower pressure ratio.

2- The optimum value for nozzle-to-throat spacing to nozzle diameter ratio "X" for pumping water is about 1.25.

3- The optimum value for motive fluid pressure at nozzle-to-throat spacing to nozzle diameter ratio "X" of 1.25 is about 1.5 bar when lifting water.

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