STUDY OF THE DIFFERENT PARAMETERS THAT INFLUENCE ON THE PERFORMANCE OF WATER JET PUMP

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ABSTRACT

The aim of this study is to investigate the performance of water jet pump. This study is reported in a series of three papers. In this paper, the performance of water jet pump was studied. The effects of the pump operating conditions and geometries on its performance were investigated. The experimental rig was constructed such a way it can be changing the driving nozzle, mixing chamber and diffuser. During experimental program water is used in both motive and pumped sides. In this study three different diameters of driving nozzles, namely (10, 12.7 and 16 mm) have been used with one mixing chamber of 25.4 mm diameter (i.e. three different area ratios of 0.155, 0.25 and 0.4). Furthermore three different mixing chamber lengths to mixing chamber diameter ratio of 6.75, 7.25 and 7.86. And three different diffuser angles of 4°, 5.5° and 7° respectively with one suction nozzle of semi cone angle of 22°. The effect of nozzle to throat spacing to nozzle diameter ratio "X" with values of 0 D, D, 1.5 D and 2 D, on the jet pump performance was also tested under different flow rates and motive pressures. In all cases, it was found that the best efficiency for the jet pump is attained with "X" equal one, and the best values for these design parameters have been obtained from the experimental work. The performance of slurry jet pump and the comparison between them will later be discussed in another further paper.

Keywords: Hydraulic transportation, Jet pump, Mixing chamber, Driving nozzle, Diffuser

1. INTRODUCTION

Jet pump is a simple device that transfers momentum from high velocity primary jet flow to a secondary flow. It is geometrically simple, since it consists of five main components, namely driving nozzle, suction nozzle, mixing chamber, diffuser and suction inlet pipe, as schematically shown in Figure (1). The absence of moving mechanical parts eliminates the operational problems associated with bearing, sealing and lubrication. Such pumps are widely used because of their simplicity and highly reliability in the fields of civil engineering in dewatering, foundation excavations in fine soils and dredging. It is also used in several industrial engineering applications especially in solid transmission.

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]. Zandi and Govatos [10] presented experimental work on water and slurry jet pumps. They developed comprehensive equations which may be used in designing a slurry (water-sand mixture) jet pump taking into consideration the effects of slip velocity of particles. Also, Fish [11] presented theoretical and experimental studies on a water and slurry jet pumps. He developed a governing equation which predicts the performance of the jet pump using two types of solid material (low grade iron ore and cast steel shot). Govatos [12] extended his previous work with Zandi [10] where the performance equations for slurry jet pump have been developed. Richardson [13] carried out full-scale laboratory tests on a center drive water and slurry jet pump. El-Sibaie and El-Haggar [14] carried out experimental study on a slurry jet pump. The objective of their work is to investigate the effect of concentration, particle size and nozzle outlet location on the performance of the slurry jet pump. Shaheen [15] carried out experimental study on a water and slurry jet pump. The aim of his research was to experimentally study the effect of some design parameters on slurry jet pump performance. El-Shaikh et al [16] studied theoretically the performance of slurry jet pump under the effect of some parameters. They recommended that the maximum efficiency is achieved at area ratio R = 0.26. El-Sawaf et al [17] studied the theoretical and experimental investigation for slurry jet pump performance and fluidization system. They concluded that the maximum efficiency is achieved at area ratio equals 0.22 and weight flow ratio M = 1. Wakefield [18] described application of jet pumps in many fields for different purposes because of its simple construction and easy operation. He designed many jet pumps that have been used frequently in dredging, deep pumping, booster pumping, tail water suppressors, as a recirculation device in atomic reactors and in many other systems. El-Shaikh [19] studied theoretically and experimentally the effects of some parameters on the performance of slurry jet pump using four different area ratios. Iran et al [20] investigated the performance of low cost venture 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 [21] 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 [22] 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. Chamlong et al [23] 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 distance, mixing chamber length, diffuser angle and nozzle area ratio on jet pump performance. Therefore, it is important to investigate the effect of nozzle-to-throat spacing to nozzle diameter ratio (X), area of nozzle to area of mixing chamber (R), mixing chamber length to mixing chamber diameter ratio (L), diffuser angle (θ_d) and the driving pressure on the jet pump performance when pumping clear water.

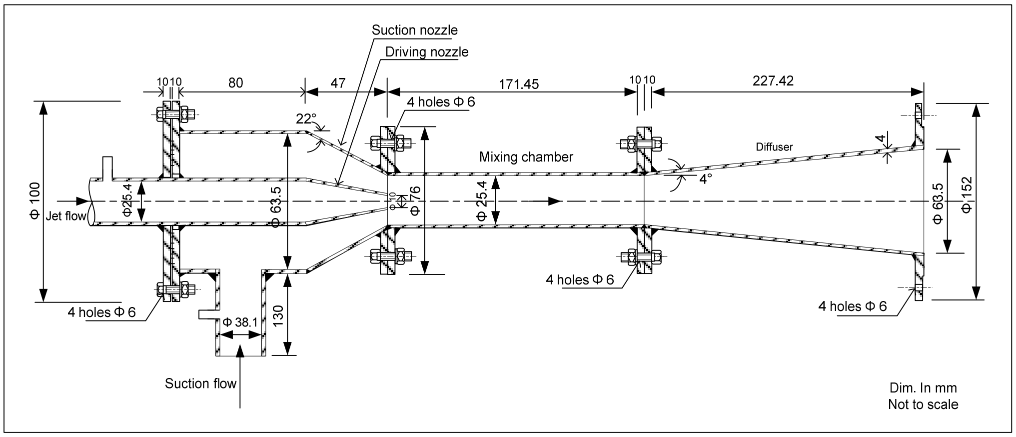


Fig. (1) Assembly of jet pump

2. TEST RIG DESCRIPTION AND EXPERIMENTAL PROCEDURE

2.1 Experimental set-up

The experimental set-up is schematically shown in Figure (2). The test rig is designed so as to carry out experiments on jet pump under varying the geometry of the jet pump. These include three different driving nozzle, three different mixing chamber length and three different nozzle angle configurations. The test rig in figure (2) consists of a flowing flume (1), a centrifugal pump (2), driving and delivery line (3, 12), control valve (4,13), suction tank (5), jet pump (8), pressure transducers and display units (10, 11), ultrasonic and magnetic flow meter (7, 14), and circulating pump (16).

Tap water is pumped from the water tank to the jet pump nozzle via a one inch nominal size galvanized pipe fitted with an control valve for controlling the motive pressure. A bypass valve (6) 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 10 to 30 m and from 30-75 l/min respectively. Water from the suction tank (5) 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 magnetic flow meter. The jet pump delivery pipe (12) and the suction pipe (3) are of diameter of 1" and 2" respectively. The water flow rate is measured using calibrated ultrasonic flow meter (7) at the exit of the centrifugal pump, while the motive pressure is measured using calibrated glycerine pressure gauge (9). The suction and delivery pressures of the jet pump are measured using calibrated pressure transducers (10) that have a span of readings from 0 to 100 psi and out put signal from o to 30 mV Dc. The digital indicator (11) also shown in Fig.(2) is used to convert the output signal of the pressure transducer into digital reading. The jet pump delivery volume flow rate is measured using a magnetic flow meter.

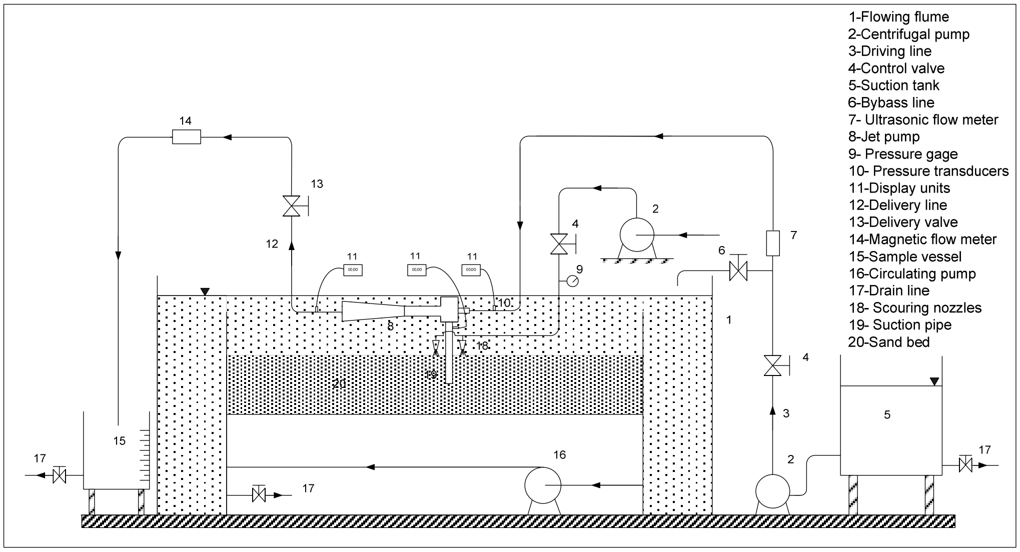
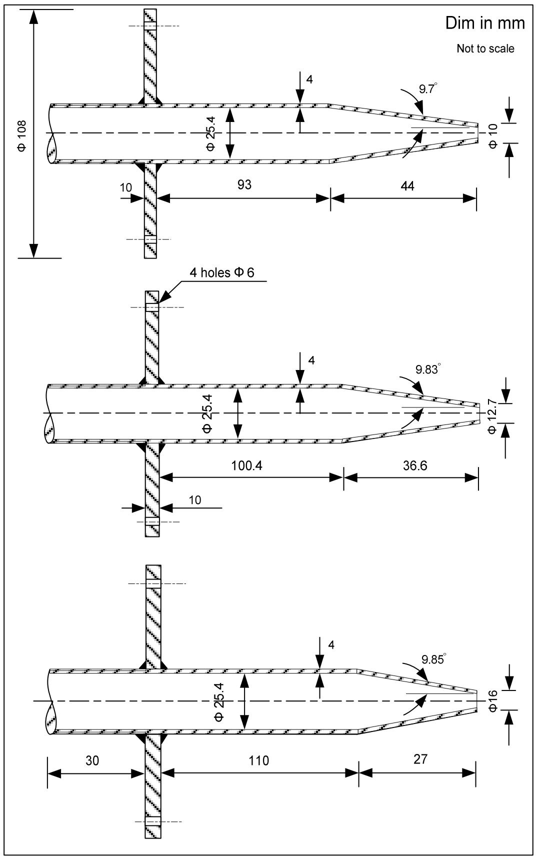


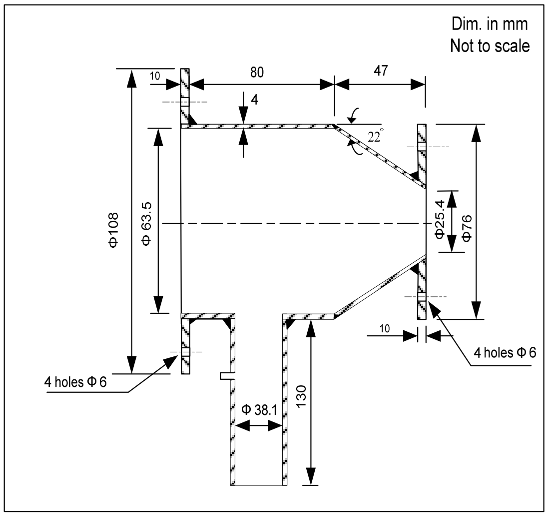
Fig.(2) Schematic diagram of experimental test rig

The jet pump combination parts are shown on a photo in Figure (3) and Figure (4) as follows: three different driving nozzles diameters with 10, 12.7 and 16 mm exit nozzle as shown in Fig. (4-a) with 25.4 mm mixing chamber diameter which give area ratios of 0.155, 0.25 and 0.4, four nozzle distance ratios of 0, 1, 1.5 and 2 D, one suction nozzle with semi cone angle of 22°, as shown in Fig. (4-b), three different mixing chamber length ratios of 6.75, 7.25 and 7.86 D_{mix} as shown in Fig.(4-c), and three different diffuser angle (θ_d) of 4°, 5.5° and 7°as shown in Fig. (4-d).

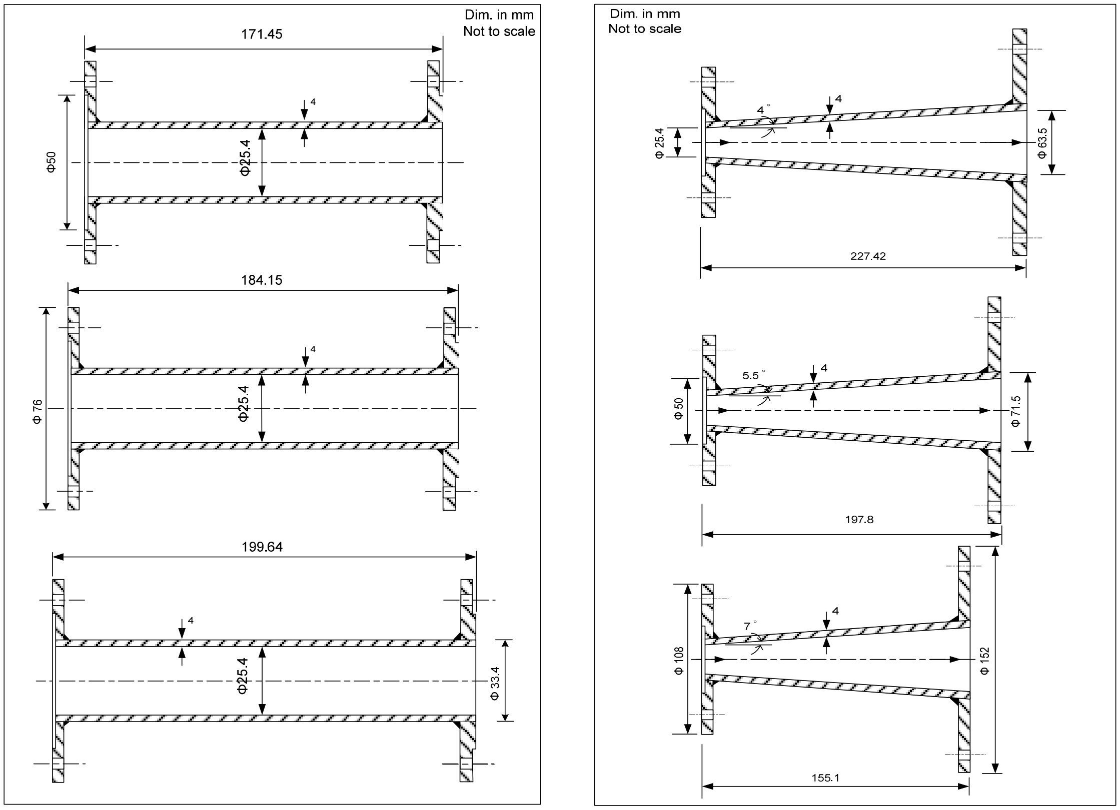
Fig.(3) Photo of the jet pump used in the experimental test rig



(a) Driving line and driving nozzles



(b) Suction nozzle



(c) Mixing chambers **(d) Diffusers**

Fig. (4) Jet pump different parts

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 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 control-valve in the pump delivery side fully opened.

5- The pump pressure was adjusted to 1 bar and then the jet pump discharge valve was gradually closed.

6-When a steady state condition was attained; the readings of the ultrasonic flow meter, magnetic flow meter and pressure transducers were recorded.

7-Steps (4) to (6) were repeated with different motive pressures 1.5, 2 and 2.5 bar, while the nozzle-to-throat spacing to nozzle diameter ratio "X" is kept constant.

8- The nozzle-to-throat spacing to nozzle diameter ratio "X" was adjusted to 1.5 and steps (4) to (6) were repeated with different motive fluid pressure varying from 1 to 2.5 bar, in order to investigate the effect the nozzle-to-throat spacing to nozzle diameter ratio “X” on the jet pump performance.

9-Data was recorded for nozzle-to-throat spacing to nozzle diameter ratio “X” is varying as 0, 1, 1.5 and 2. After completing the experimental program with first driving nozzle diameter, the test rig was emptied and new sets of experiments were carried out on the jet pump with the other driving nozzle, mixing chamber and diffuser angle.

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

i- Flow ratio $M = \dfrac{Q_{suction}}{Q_{motive}}$,

ii- Head ratio $N = \dfrac{P_d - P_s}{P_m - P_d}$,

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

η= M x N.

At a fixed nozzle-to-throat spacing to nozzle diameter ratio “X” and a fixed pump drive pressure; the discharge valve (13) as shown in Figure (2) was varied in gradually 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 (N) against the flow ratio (M) is then constructed. The test was repeated for different driving pressures of the centrifugal pump from 1 to 2.5 at the steps of 0.5 bars and for different nozzle-to-throat spacing to nozzle diameter ratio “X” = 0, 1, 1.5 and 2.

3. TESTS, RESULTS AND DISCUSSION

3.1 Effect of nozzle-to-throat spacing to nozzle diameter ratio “X” on jet pump performance

Figure (5) 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 2.5 to 1 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 bar which is 0.656 head ratio at a flow ratio of 0.125 and the minimum head ratio is 0.25 which corresponds to a flow ratio of 0.94. However, when the driving pressure was increased to 2.5 bar, the maximum head ratio of the jet pump drops to 0.475 at a flow ratio of 0.133 and the minimum head ratio is 0.15 at a flow ratio of 1.15. 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. (5), 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 bars is about 25 % at a flow ratio of 0.75. Whereas for P= 2.5 bar the maximum efficiency is 22 % at a flow ratio of 0. 77. 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 ratio “X” = 0, 1.5 and 2. In all cases the maximum head ratio of the pump is obtained at a driving pressure of 1 bars.

3.2 Effect of changing area ratio (R) on jet pump performance

In this study three different driving nozzles with different exit diameters of 10, 12.7 and 16 mm were used in combination with one constant mixing chamber diameter of 25.4 mm, which gives three area ratios of 0.155, 0.25 and 0.4.

Figure (7) shows the results of the effect of changing area ratio on the performance of water jet pump having the following specifications: mixing chamber length ratio 7.25 and diffuser angle 5.5º. It is clear from this figure for the same jet pump combination parts and increasing the area ratio the efficiency and the head ratio are increased too. The efficiency increases also with increasing the mass flow rate ratio. While the highest values of efficiency and head ratio are for area ratio of 0.25 at "X"=1 as shown in Fig. (7). It is also clear that the area ratio of 0.25 gives the best performance compared to area ratio 0.155 which gives the lower efficiency. This may be because the jet pump with area ratio of 0.25 draws more driving fluid than that with area ratio 0.155 for the same driving pressure.

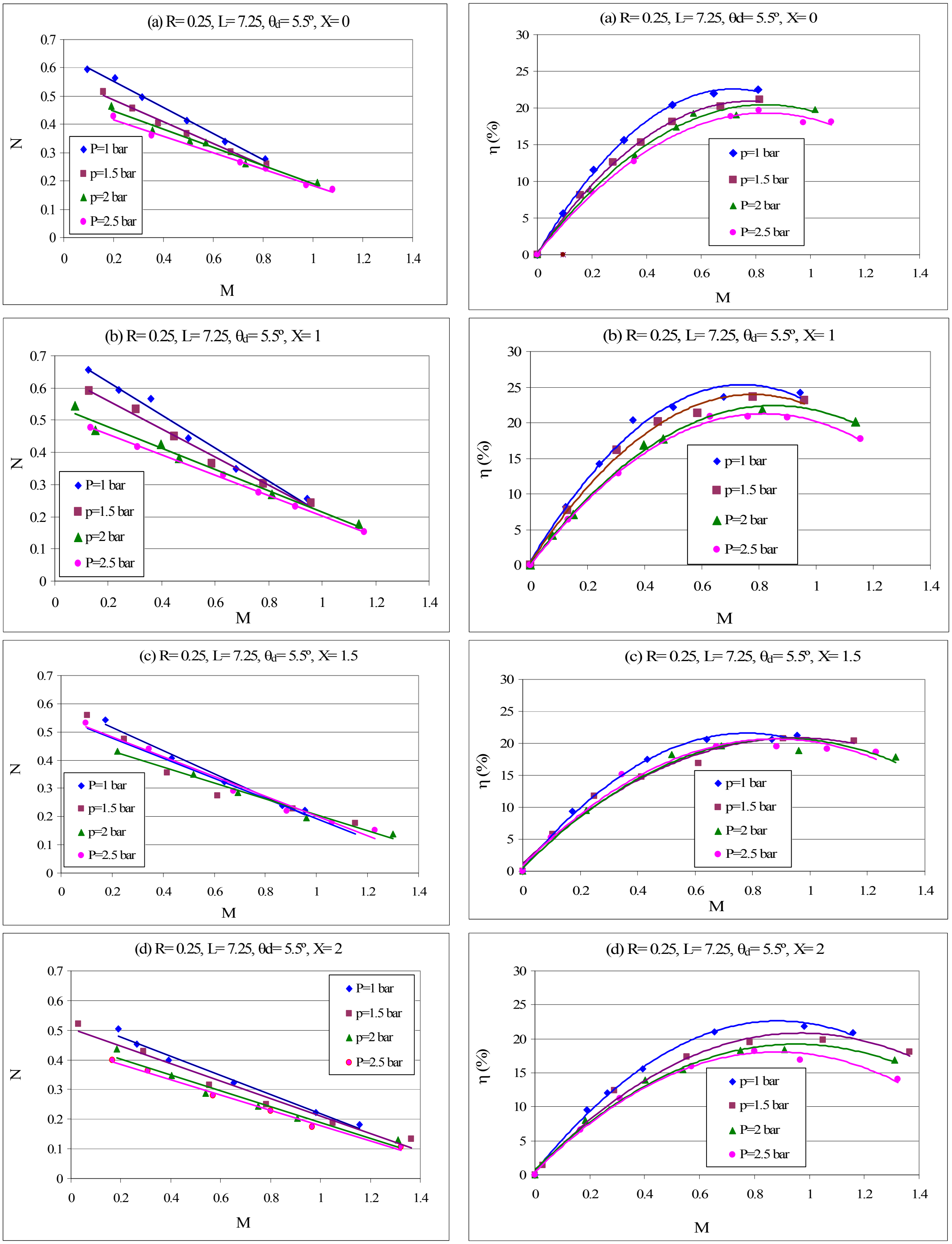


Fig.(5) Jet pump performance for different motive pressure at a specific nozzle distance (X), when pumping water at constant area ratio (R=0.25) for θ_d=5.5° and mixing chamber ratio (L =7.25)
(a) X=0, (b) X=1, (c) X=1.5, (d) X=2

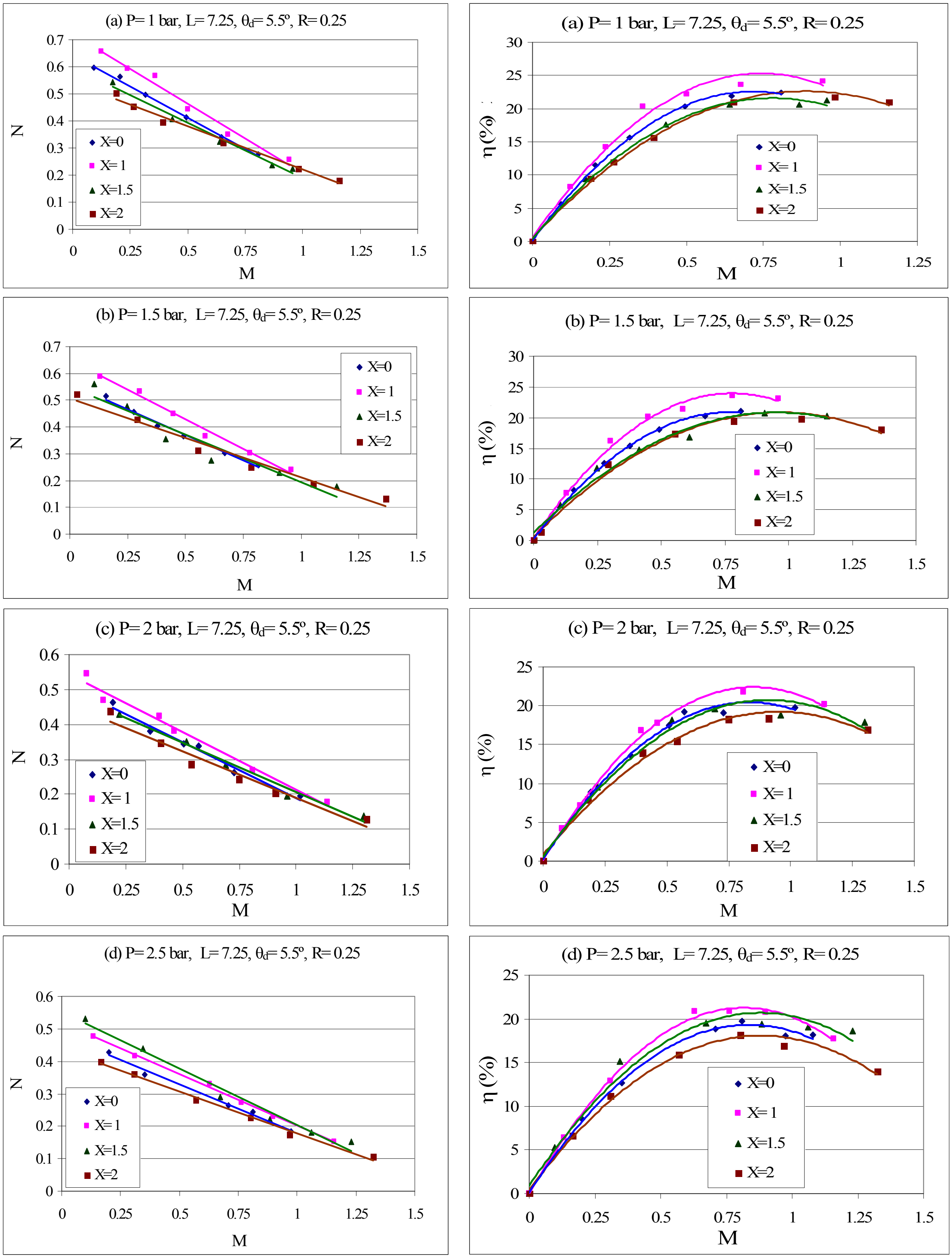
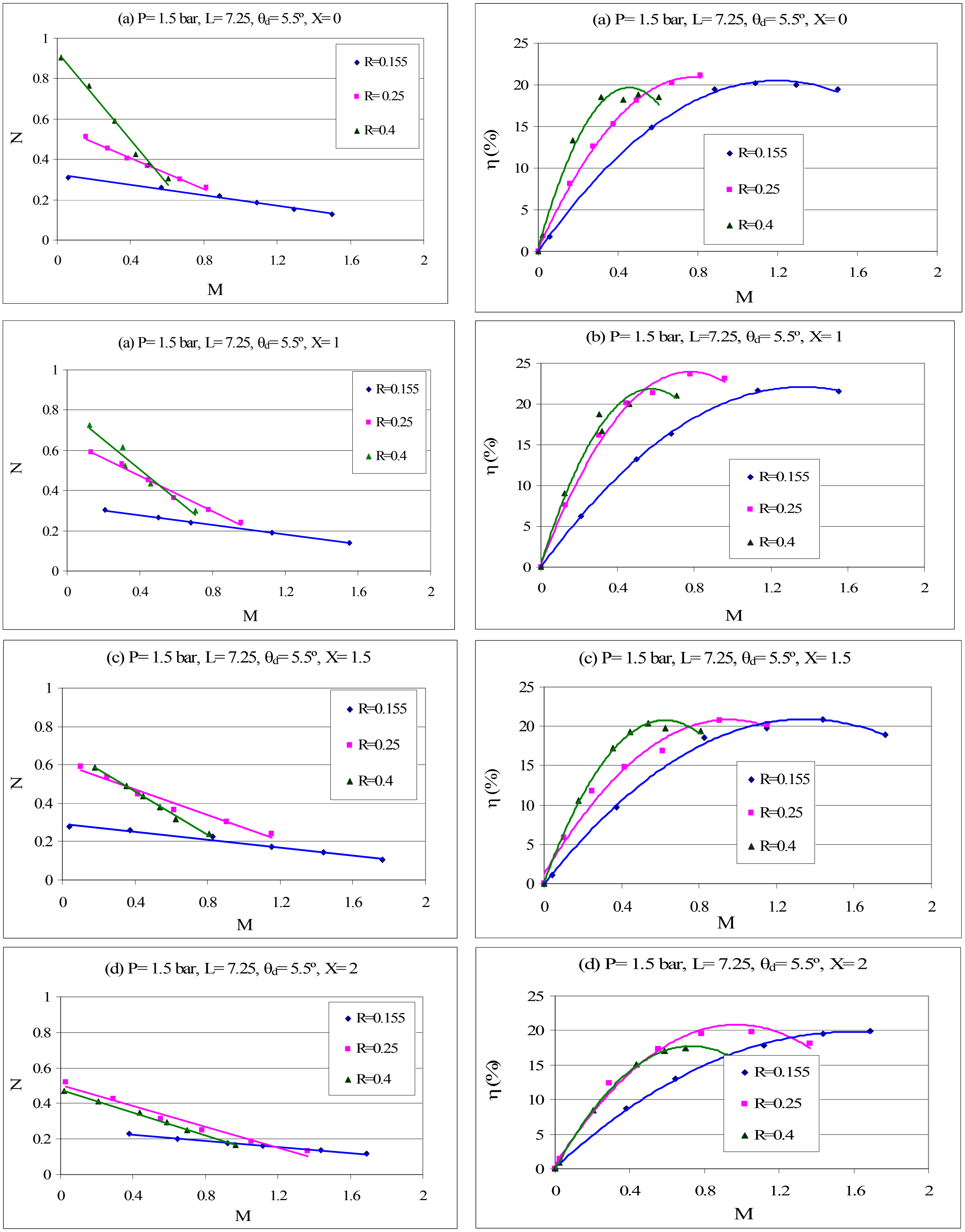


Fig.(6) Jet pump performance for different a specific nozzle distance (X) at constant motive pressure, when pumping water at constant area ratio (R=0.25) for θ_d=5.5° and mixing chamber ratio (L =7.25)
(a) P=1 bar, (b) P=1.5 bar, (c) P=2 bar, (d) P=2.5 bar


(a) P= 1.5 bar, L= 7.25, θ_d= 5.5º, X= 0

(a) P= 1.5 bar, L= 7.25, θ_d= 5.5º, X= 0

(a) P= 1.5 bar, L= 7.25, θ_d= 5.5º, X= 1

(b) P= 1.5 bar, L=7.25, θ_d= 5.5º, X= 1

(c) P= 1.5 bar, L= 7.25, θ_d= 5.5º, X= 1.5

(c) P= 1.5 bar, L= 7.25, θ_d= 5.5º, X= 1.5

(d) P= 1.5 bar, L= 7.25, θ_d= 5.5º, X= 2

(d) P= 1.5 bar, L= 7.25, θ_d= 5.5º, X= 2

Fig.(7) Jet pump performance for different area ratio (R) at constant motive pressure, when pumping water at θ_d=5.5° and mixing chamber ratio (L =7.25)
(a) X=0, (b) X=1, (c) X=1.5, (d) X=2

3.3 Effect of changing mixing chamber length (L_{mix}) on jet pump performance

The mixing chamber is the most important design element of the jet pump. The main fluid enters through the driving nozzle and secondary fluid enters through the suction nozzle. The secondary fluid encircles the main jet and mixing takes place. This mixing of two streams is accompanied by a rise in static pressure. In this study three mixing chamber lengths of 171.45, 184.15 and 199.64 mm were tested, having dimensionless mixing chamber length ratio (L) of 6.75, 7.25 and 7.86 D_{mix} respectively.

Figure (8) shows the results of the effect of changing mixing chamber length (L_{mix}) on the performance of water jet pump for the following configuration: area ratio of 0.155 and diffuser angle $\theta_d = 4^{\circ}$. It is clear from this figure that the mixing chamber length of 7.25 D_{mix} had proven superiority over 6.75 and 7.86 D_{mix} mixing chamber length for all experiments done. The difference in jet pump efficiency using the three different diffuser angles is shown in Figure (8). The superiority in the performance of 7.25 D_{mix} mixing chamber length provides a suitable environment to the mixing process to be completed. This means that, the suction fluid extracts more power from the driving fluid. The performance of jet pump having longer mixing length was penalized by friction losses in the mixing chamber. Also the shorter mixing chamber length resulted in continuation of mixing into diffuser with associated performance loss.

3.4 Effect of changing Diffuser angle (θ_d) on jet pump performance

The diffuser is a gradually diverging passage which converts the kinetic energy of the mixed stream to potential energy. In this study three diffuser lengths (L_d) of 227.42, 197.8 and 155.15 mm were tested, the inlet diameter and outlet diameters of the diffusers are 25.4 and 63.5 mm respectively, having diffuser angles (θ_d) of 4°, 5.5° and 7° respectively.

Figure (9) shows the results of the effect of changing diffuser angle (θ_d) on the performance of water jet pump for the flowing configuration: area ratio of 0.155 and mixing chamber ratio L=7.86 at motive pressure of 2 bar and "X"=2. It is clear from this figure that the diffuser angle of $\theta_d=5.5^{\circ}$ have a maximum efficiency rather than that of $\theta_d=4^{\circ}$ and $\theta_d=7^{\circ}$ at nozzle-to-throat spacing to nozzle diameter ratio “X” = 1 for all tested driving pressure and area ratio. For a given area ratio as the angle increases to $\theta_d=7^{\circ}$ the losses due to separation increases but as the angle decreases to $\theta_d=4^{\circ}$ the length of the diffuser increases and correspondingly the friction loss increases.

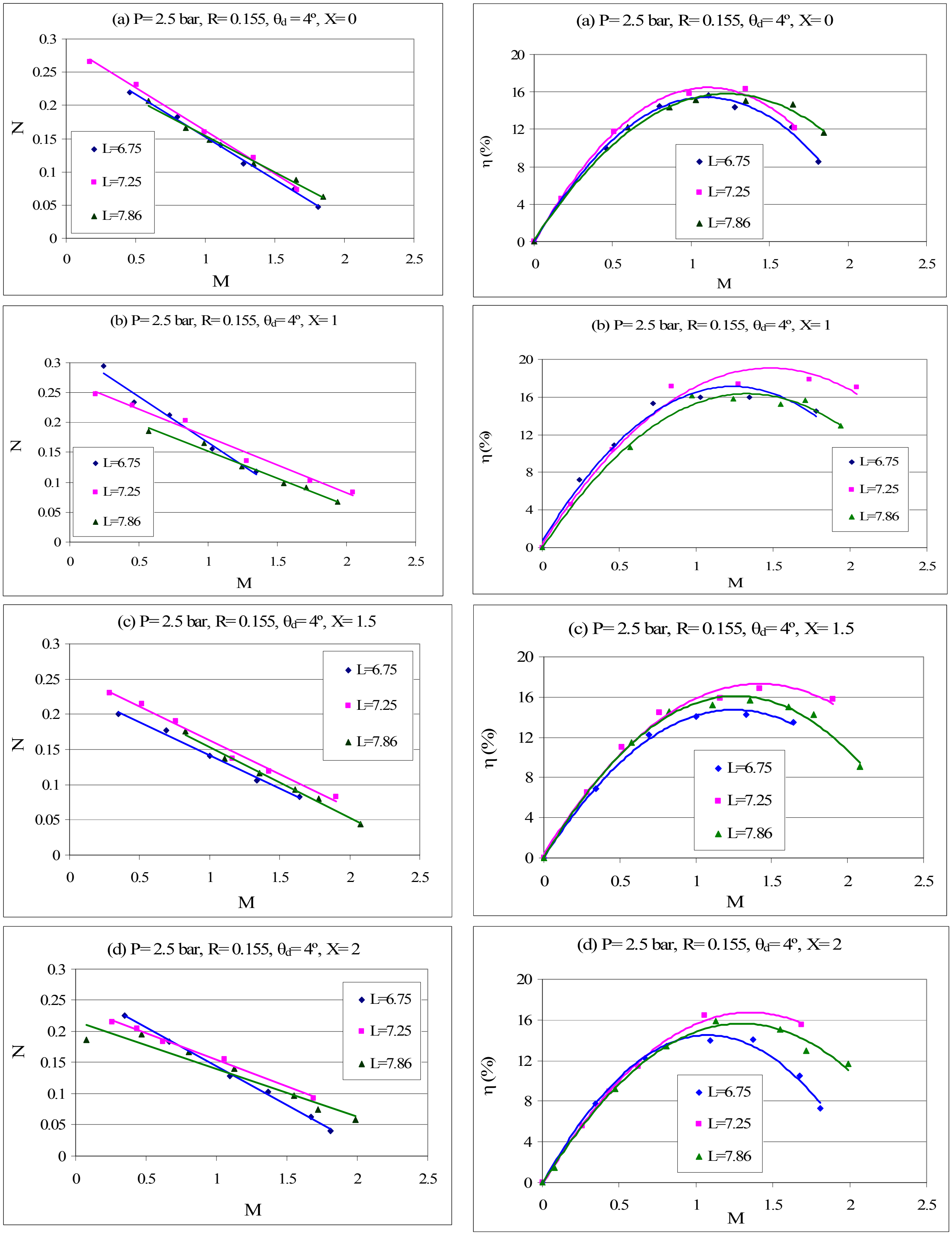


Fig.(8) Jet pump performance for different mixing chamber ratio (L) at constant motive pressure, when pumping water at θ_d=4° and area ratio (R=0.155)
(a) X=0, (b) X=1, (c) X=1.5, (d) X=2

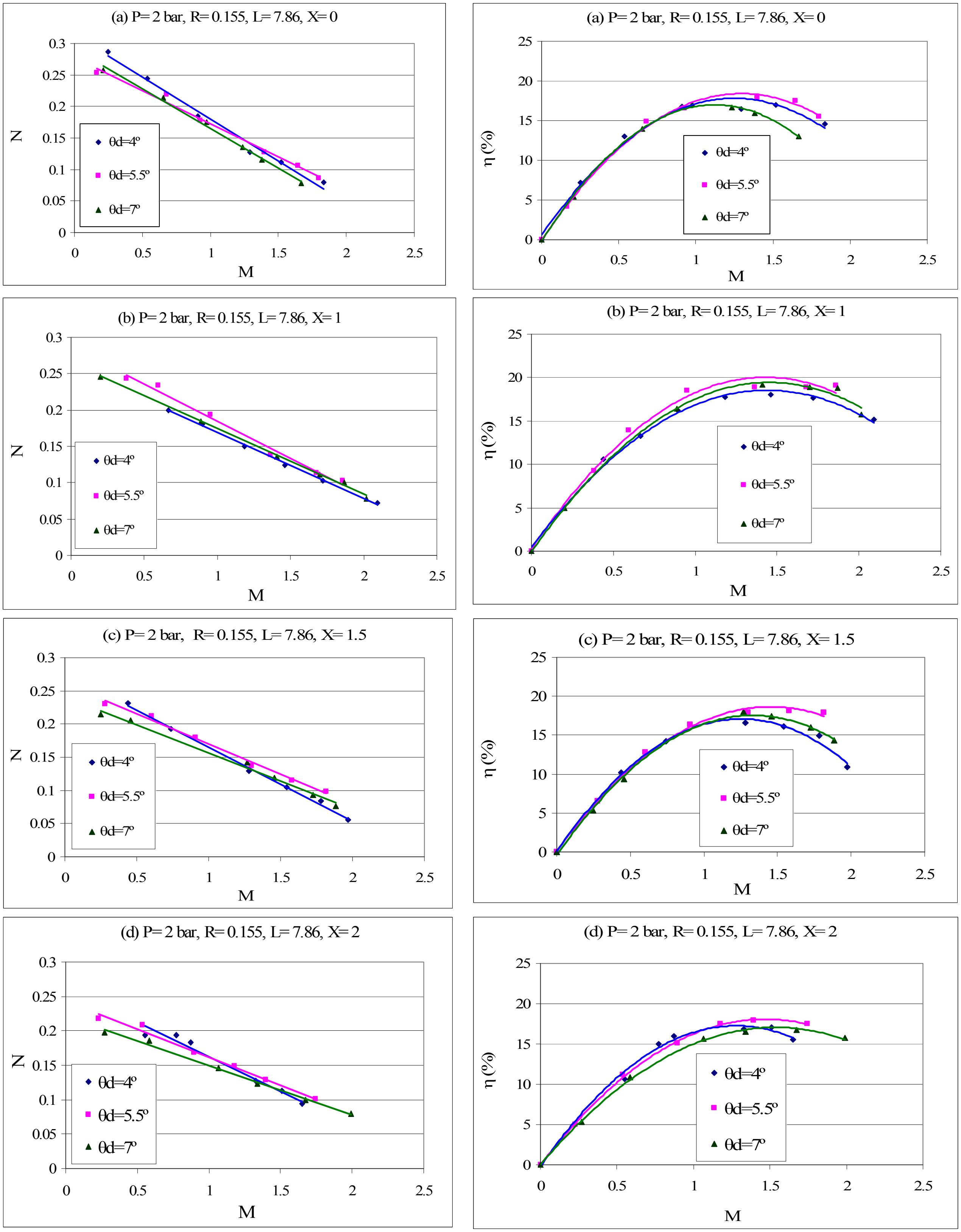


Fig.(9) Jet pump performance for different diffuser angle (θ_d) at constant motive pressure, when pumping water at mixing chamber ratio (L=7.86) and area ratio (R=0.155)
(a) X=0, (b) X=1, (c) X=1.5, (d) X=2

4. CONCLUSIONS

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

- The net jet pump head and the head ratio decrease with increasing suction capacity.
- Increasing driving jet pressure increases the net jet pump head and decreases the head ratio.
- Increasing flow ratio and decreasing driving pressure will increase the efficiency of the jet pump to a maximum value and then decreases again.
- The optimum value for nozzle-to-throat spacing to nozzle diameter ratio “X” for pumping water is about 1.
- The optimum value for motive fluid pressure at nozzle-to-throat spacing to nozzle diameter ratio “X” of 1 is about 1 bar when lifting water.
- The area ratio of 0.25 gives the maximum highest efficiency and the area ratio of 0.155 gives a lowest efficiency.
- The mixing chamber length of 7.25 D_{mix} had proven superiority over the other two mixing chamber length of 6.75 and 7.86 D_{mix} for all mentioned experiments.
- The diffuser angle of $\theta_d=5.5^{\circ}$ had better efficiency than that the other two diffuser angle of $\theta_d=4^{\circ}$ and $\theta_d=7^{\circ}$, for all test area ratio.
- The highest efficiency achieved was corresponding to the following jet pump specifications: motive fluid driving pressure of one bar, area ratio of 0.25, nozzle-to-throat spacing to nozzle diameter ratio “X” equal one for all area ratio tested, mixing chamber length 7.25 D_{mix}, and diffuser angle $\theta_d=5.5^{\circ}$.

Nomenclature

A_J = Cross sectional area of the jet, (m^2)
A_{mix} = Cross sectional area of the mixing chamber, (m^2)
D = Nozzle (jet) diameter, (m)
D_{mix} = Mixing chamber diameter, (m)
l =Nozzle-to-throat spacing (distance between the nozzle exit and the beginning of the mixing chamber),(-)
L =Mixing chamber length to mixing chamber diameter ratio (L_{mix}/D_{mix})
L_{mix} = Length of the mixing chamber, (m)
L_d = Diffuser length, (m)
P = Total pressure = P_d - P_s
P_m = Motive pressure, (Pa)
P_d = Discharge Pressure, (Pa)
N = Head ratio, (-)
P_s = Suction Pressure, (Pa)
M = Flow ratio, (-)

R = Area ratio = A_j/A_{mix} , (area of nozzle to area of mixing chamber)
X = Ratio of nozzle-to-throat spacing to nozzle diameter (l/D)
θ_d = Diffuser angle , $(^\circ)$
γ = Specific weight, (N/m^3)
η =pump efficiency = M x N

Subscripts

d = discharge
j = nozzle tip
mix = mixing chamber
m = motive
s =suction

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