PERFORMANCE OF A CENTRAL-TYPE JET PUMP
II- EXPERIMENTAL STUDY ON WATER FLOW

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ABSTRACT

This paper deals with the effect of changing some design parameters on the performance of central-type jet pump when handling water. The parameters tested such as the area ratio between driving nozzle and mixing chamber, the distance between the driving nozzle exit and the beginning of the mixing chamber, the suction inlet shape, the suction nozzle semi cone angle and the mixing chamber length.

A test rig has been designed to test the jet pump various parts using different dimensions and shapes, in order to reach the best combinations set of jet pump parts, which give the best performance.

A FORTRAN computer program had been designed based on previously derived formula and theoretical loss factors for all parts of the jet pump, except that the loss factors for suction inlets which are evaluated experimentally. The experimental results are compared with the computer program and the previous research results and the comparison indicates a good agreement between them.

KEYWORDS: Water, Central-Type, Jet Pump

1- INTRODUCTION

The jet pump is a pump without moving parts, since it can increase the pressure or the velocity or both of a fluid. Its pumping action depends on fluid energy exchange, where a high-pressure fluid called driving or primary flow coming from a centrifugal pump or other sources are changing its pressure energy into kinetic energy via the driving nozzle. When the fluid expands out of the driving nozzle, it creates a low-pressure area around the driving nozzle exit. This fall in pressure inducing the suction flow (secondary flow), then the two streams mixes in the mixing chamber where a process of momentum transfer between the two streams occurs which accelerates the secondary flow and decelerates the primary flow composing the combined flow. A diffuser follows the mixing chamber to convert the kinetic energy of the mixture into pressure energy [1, 2 & 3].

Although the jet pump has a limited efficiency range but it is used in situations where the efficiency was of second importance. Also the jet pump has many advantages over other types of pumps, it has simple construction and can be constructed from wide range of materials, it needs minimum man labor and is suitable for adverse environments, hence it has been used in many applications [1, 2, 3 & 4].

Gosline and O'Brien [5] reported that the jet pump has been known for the first time when James Thomson in 1852 used it to remove water from the pits of submerged water wheels. The theory of the pumping process was developed by Ranking in 1870 based on continuity and momentum equations. Furthermore they [5] developed a theoretical dimensionless efficiency equation. Also, they performed experimental work in order to check the validity of the derived equation.

Mueller [6] determined experimentally the optimum dimensions of the water jet pump so that the best efficiency may be obtained. Also, he derived an analytical efficiency equation to define the pump behavior. The calculated results agree with experimental results. The effect of cavitation on the pump characteristic was also treated in his work.

Shedid et al [7] developed a method capable of calculating the pump intake pressure and bottom hole flowing pressure using the hydraulic jet pump performance data.

Djebedjian et al [8] employed jet pump in order to power a vapor compression system for the production of desalinated water. They predicted that optimum efficiency of approximately 10 % at diffuser area ratio of about 2 can be obtained. Based on their results it is evident that suction pressure at diffuser exit would improve efficiency.

The present paper is directed to evaluate the results obtained from a study of central-type jet pump performance. The study is divided into two main parts. The first part was to drive a formula that could predict the jet pump performance, under various conditions using basic fluid mechanics equations (continuity, momentum and energy equations) [9 & 10]. The other part of the study was to perform a set of experiments, for two purposes. The first purpose was to check the validity of the derived equation which predicts jet pump performance. The other purpose was to examine some of alternatives of jet pump parts, in order to reach the best combinations set of jet pump parts, which give the best performance, when handling water and slurry [9].

A FORTRAN computer program had been designed based on the derived formula and theoretical loss factors for all parts of the jet pump except that for suction inlets which are evaluated experimentally. The experimental results are compared with the computer program and the previous research results [9].

The present paper summarizes the results of experiments on water jet pump to estimate the combination parts which give the maximum efficiency among a set of combinations. Also, to compare the experimental results with the computer program results as well as the results of other researchers.

2- EXPERIMENTAL TEST RIG

A schematic diagram of the experimental test rig is shown in **Figs. (1** & 2**)**. The test rig is consists of; flowing flume; centrifugal pumps; jet pump; rotameter; elbow flow meter; pressure transducer; digital indicator and piping system.

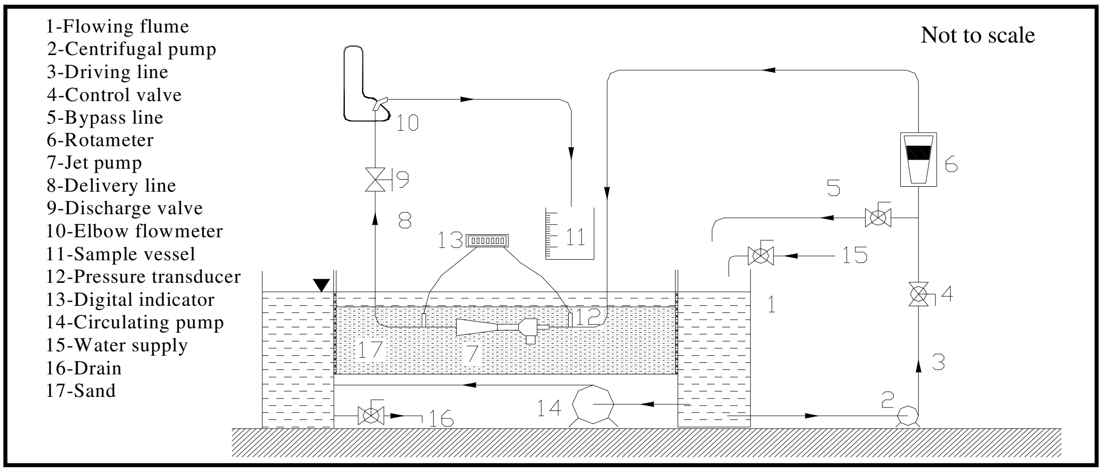


Fig. (1) Schematic diagram of the experimental test rig

Fig. (2) Photo of the experimental test rig

The centrifugal pump (2) draws water form the flume (1), discharging the water into the driving line where it is first passes through control valve (4), then it is divided into two branches. One of these branches passes through the bypass line (5). The other branch passes through the rotameter (6), then through the pressure sensor (12) and finally to the jet pump (7). In the jet pump the driving flow combines with the secondary flow, to make the delivery flow, which is discharged to the discharge line, where it passes to the pressure sensor, then passes through the elbow flow meter (10), and finally, it discharged to the flume again. In the case of slurry measurements, elbow flow meter is replaced by the sample vessel (11). The flowing flume (1) has the following dimensions: length, width and depth of working section were 10 m, 0.3 m and 0.5 m respectively. Flume maximum positive bed slope is fixed on 1 to 40. The water in the flume is circulated by means of circulating centrifugal pump (14), but it was not used during experiments. There were four centrifugal pumps (2), arranged in two sets, each set consists of two centrifugal pumps connected in series, the two sets are connected in parallel. Each of the centrifugal pumps has 1.104 kW electric motors, delivering 9.6 m^3/hr at 33.5 meter head of water. The flow rotameter (6) has a span of reading from one to 10 m^3/hr. The elbow flow meter (10) is composed of standard 90^o elbow connected with inverted U-tube manometer.

The pressure transducer (12) shown to the right hand side in **Fig. (2)**, has a span of readings from -1 to 3 bar and the output signal from 4 to 20 mA. The digital indicator (13) also, shown in **Fig. (2)** is used to convert the output signal of the pressure transducer into digital reading. The indicator has four-digits monitor. The piping system consists of two parts: the driving line (3) which consists of one-inch nominal size galvanized pipe and the delivery line (8), which consists of two-inch nominal size galvanized pipe.

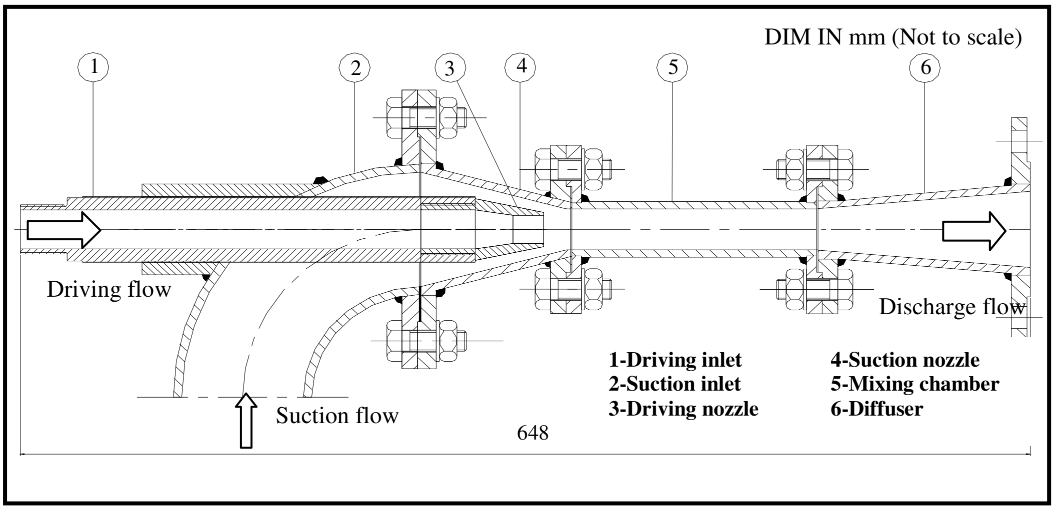
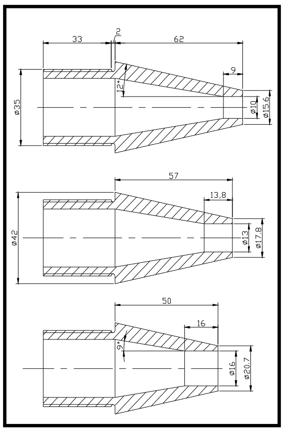
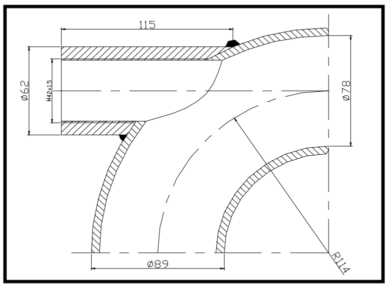


Fig. (3) Sectional elevation of the jet pump

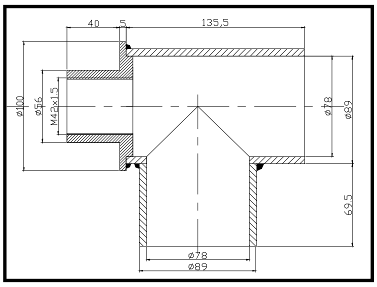
The jet pump combination parts illustrated in **Fig. (4)** are as follows: three different driving nozzles with 10, 13 and 16 mm exit nozzle as shown in **Fig. (4-a)** with 28 mm mixing chamber diameter which give area ratios of 0.1276, 0.2156 and 0.3265; three nozzle distance ratios of 1.0, 1.5 and 2.0; two suction chamber shapes, the first, bend suction chamber and the other, straight suction chamber as shown in **Fig. (4-b)**; two suction nozzles, the first, with semi cone angle of 15^o and the other, with semi cone angle of 20^o as shown in **Fig. (4-c)** and two mixing chamber length ratios of 7.86 and 6.75 as shown in **Fig. (4-d)**.



(a) Driving nozzles

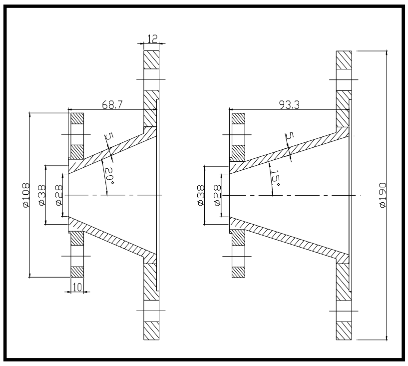


Bend suction inlet

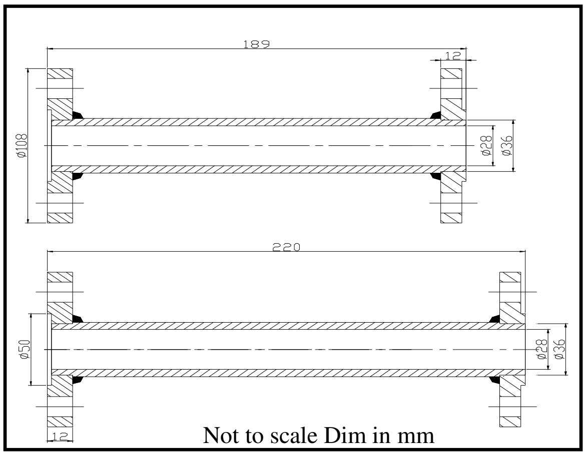


Straight suction inlet

(b) Suction inlet shapes



(c) Suction nozzles



(d) Mixing chambers

Fig. (4) Jet pump different parts

The test rig has been designed specially to test the performance of jet pump using various parts, in order to reach the best combination parts of jet pump, which give the best performance. This paper deals with the performance of central-type jet pump when handling water only due to the limited paper space. In future the performance of the same jet pump when handling solids will be published.

4- RESULTS AND DISCUSSION

4-1 Effect of Changing Nozzle Distance (X)

In order to investigate the effect of changing the position of the driving nozzle with respect to the mixing chamber entrance on the efficiency and the head ratio; three nozzle positions i.e. three nozzle distance ratios (X) of 1.0, 1.5 and 2.0 are tested and their results are shown in **Fig. (5)**, consequently these results covered three area ratios ranging from 0.1276 to 0.3265. The experimental results plotted in this figure represent water jet pump having the following specifications: straight suction inlet; mixing chamber length ratio of 7.86 and 20^{o} semi cone angle suction nozzle. The results are grouped into two sets. The first set (i) presents the efficiency (η) versus mass flow ratio (M). The second set (ii) presents the head ratio (N) versus mass flow ratio (M).

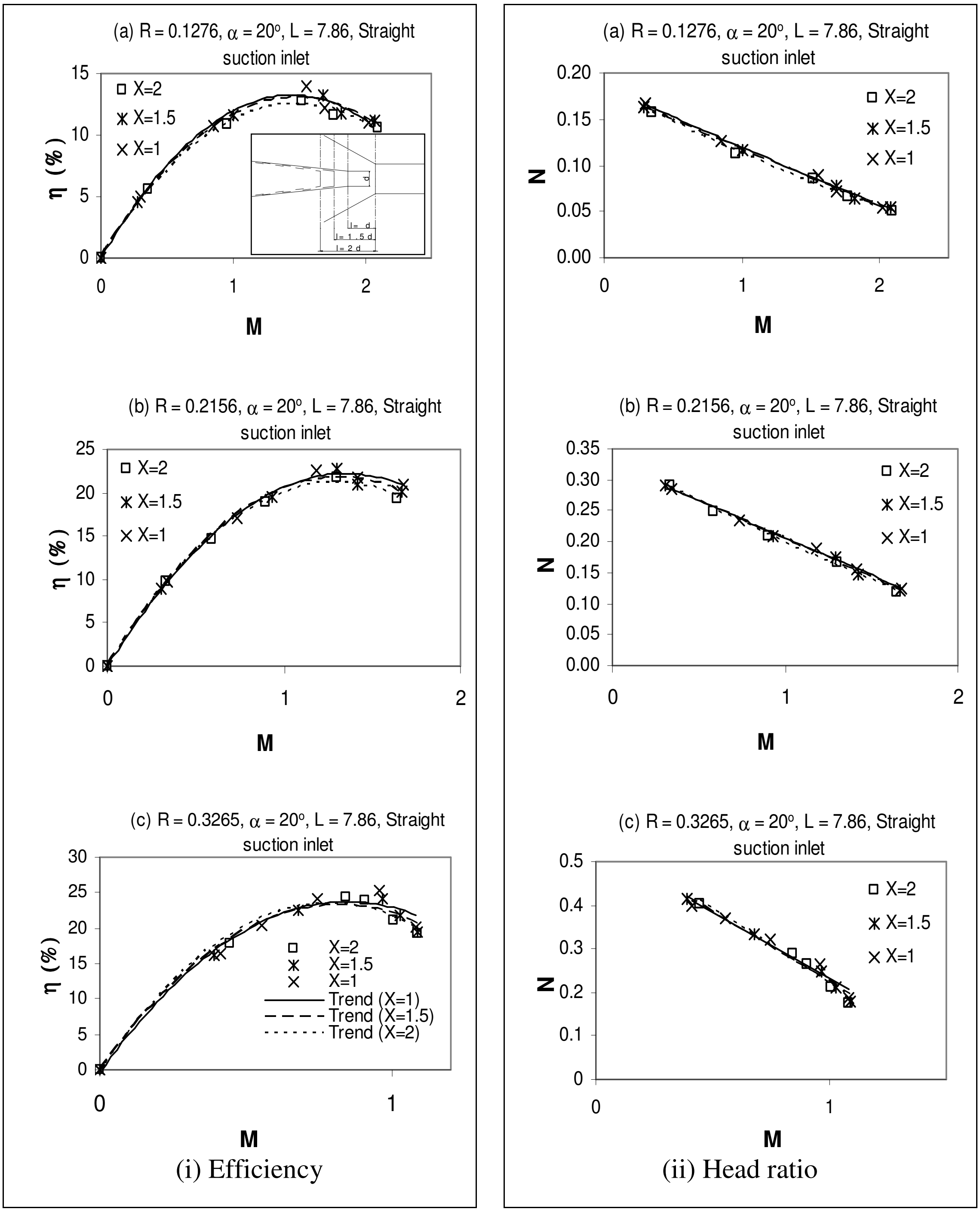


Fig. (5) Water jet pump performance curves for different nozzle distance ratios by using straight suction inlet

It is clear from the first set of curves (i) that, the nozzle distance ratio which gives the highest efficiency values are varied with the area ratio. Such as for area ratios of 0.1276 and 0.2156, the nozzle distance ratios which give the highest efficiencies are dependent on jet pump combination parts. For the given conditions on **Fig. (5)**, the highest efficiency values are occurred at nozzle distance ratios of 1.0 and 1.5 respectively as shown from **Fig. (5 a & b)**. But for area ratio of 0.3265, the nozzle distance ratio of 1.0 gives the highest efficiency point in comparison with the other tested cases as shown from **Fig. (5 c)**. Also, the highest efficiency was occurred at area ratio 0.3265 as shown in **Fig. (5 c)** in comparison with other area ratios, shown in **Fig. (5 a & b)**. The relation between the head ratio and the mass flow ratio are depicted on the second set of curves (ii) shown in **Fig. (5).** It is clear from the figure that, as the mass flow ratio increases the head ratio is decreased, this agrees with the trend of similar curves of other researchers' results [2 & 4].

4-2 Effect of Changing Area Ratio (R)

Figure (6) shows the experimental results of the effect of changing the area ratio on the performance of water jet pump having the following specifications: bend suction inlet; mixing chamber length ratio of 7.86 and 15^{o} semi cone angle suction nozzle. It is clear from the figure that increasing the area ratio the efficiency and the head ratio are increased too. The efficiency increases also with the increase of the mass flow ratio until the efficiency reaches it beak value then it decreases with the increase of mass flow ratio as shown from the first set of curves (i). While the highest values of efficiency and head ratio are for area ratio of 0.3265 at X = 1.0 as shown in **Fig. (6 a)**.

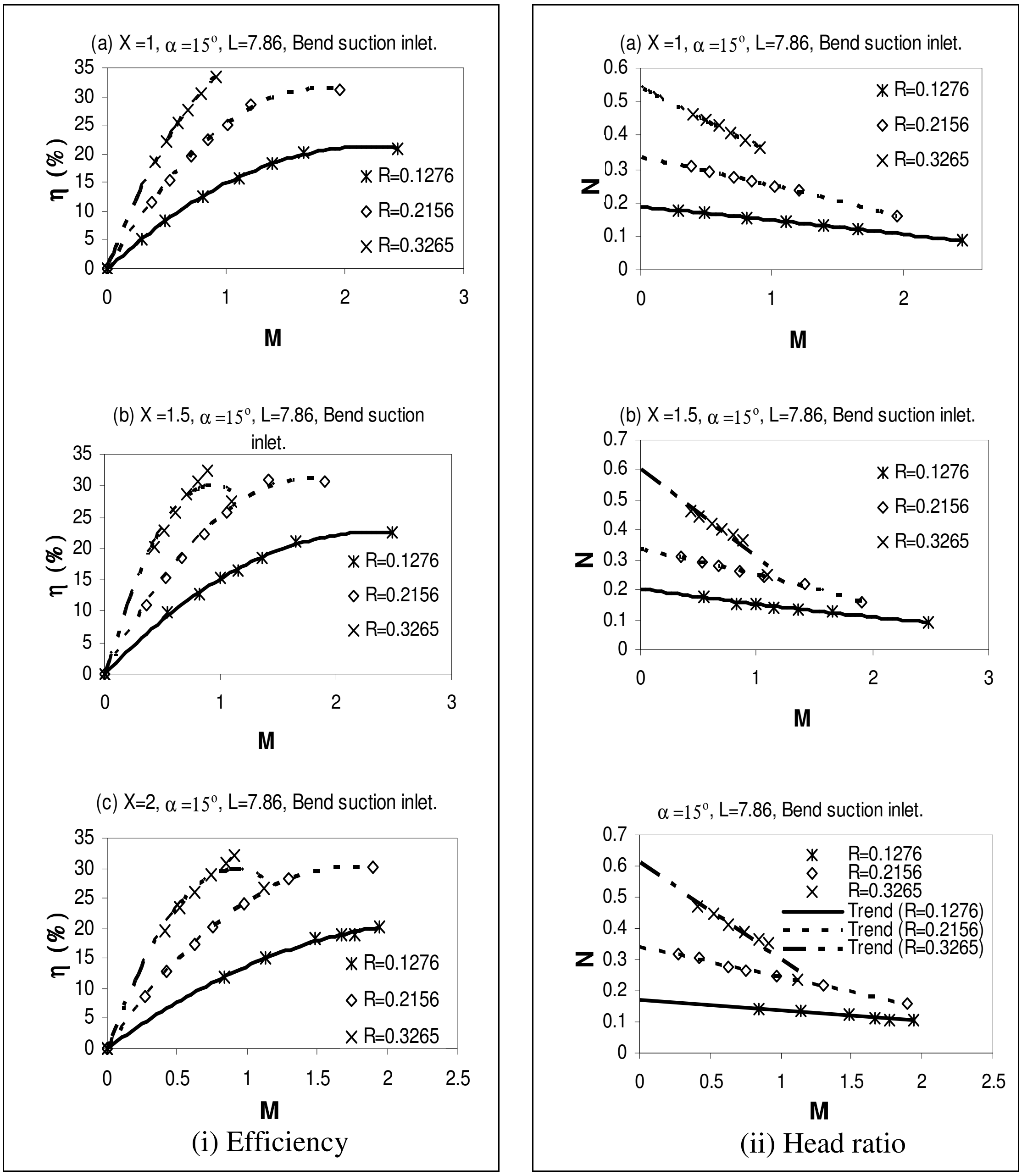


Fig. (6) Water jet pump performance curves for different area ratios by using bend suction inlet

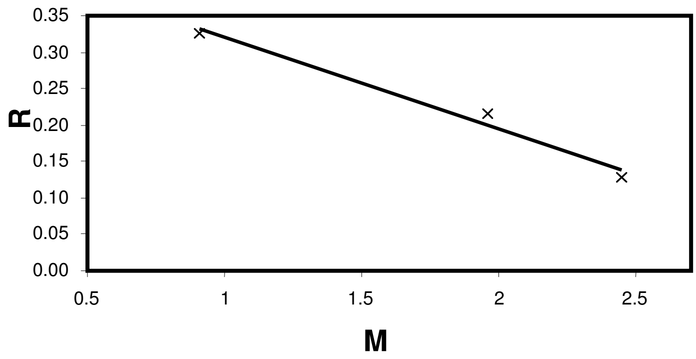


Fig. (7) Area ratio (R) versus mass flow ratio (M) for highest efficiency points of water jet pump

4-3 Effect of Changing Suction Inlet Shape

Figure (8) shows the performance curves of water jet pump with different suction inlet shapes for area ratio 0.3265, nozzle distance ratio of 2.0 and mixing chamber length ratio of 7.86 and 6.75 using suction nozzle with semi cone angles of 15^o and 20^o.

This figure indicates the results of experimental work which proves that for mixing chamber length ratio of 7.86; the bend suction inlet had better values of efficiency and head ratio than that of straight suction inlet, especially with a suction nozzle of 15^o semi cone angle as shown in **Fig. (8 a & b)**. But with 20^o semi cone angle suction nozzle the difference was relatively small between both suction inlet shapes. For the mixing chamber length ratio of 6.75; the straight suction inlet shows small higher values than that for the bend suction inlet as shown in **Fig. (8 c & d)**. Generally the difference between the points of the two suction inlets is small when the suction nozzle semi cone angle was 20^o as shown in **Fig. (8 b & d)**.

4-4 Effect of Changing Suction Nozzle Semi Cone Angle

Figure (9) shows the results of the effect of changing suction nozzle semi cone angle for the water jet pump of the following configuration: area ratio of 0.1276, nozzle distance ratio of 1.0 and mixing chamber length ratio 7.86 and 6.75 using both straight suction inlet and bend suction inlet. It is clear from the first set (i) of this figure that the suction nozzle with a semi cone angle of 15^o had better efficiency than that of suction nozzle with a semi cone angle of 20^o. The figure also, declares that the difference between the jet pump efficiencies and head ratios of the two suction nozzles was small using straight suction inlet than that using bend suction inlet as shown from **Fig. (9 a & b)** and **Fig. (9 c & d)**. In addition the difference between the jet pump efficiencies of the two suction nozzles was smaller using 6.75 mixing chamber length ratio than that using 7.86 mixing chamber length ratio as shown from **Fig. (9 a & c)** and **Fig. (9 b & d),** respectively.

This better efficiency of suction nozzle with a semi cone angle of 15^o compared with the efficiency of suction nozzle with a semi cone angle of 20^o may be because the head loss through the suction nozzle with a semi cone angle of 15^o is less than the head loss through the suction nozzle with a semi cone angle of 20^o.

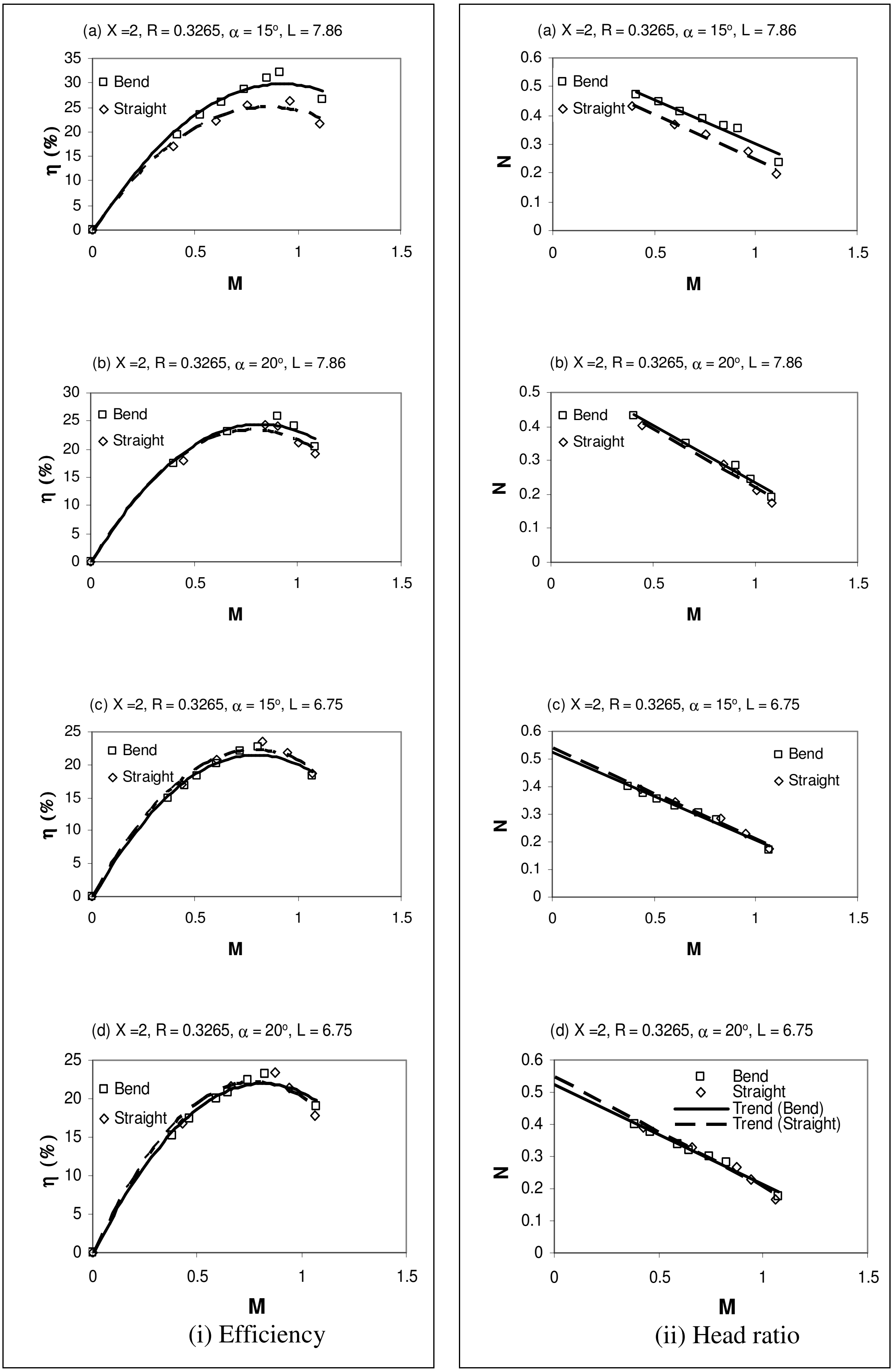


Fig. (8) Water jet pump performance curves for different suction inlet shapes by using nozzle distance ratio (X) = 2

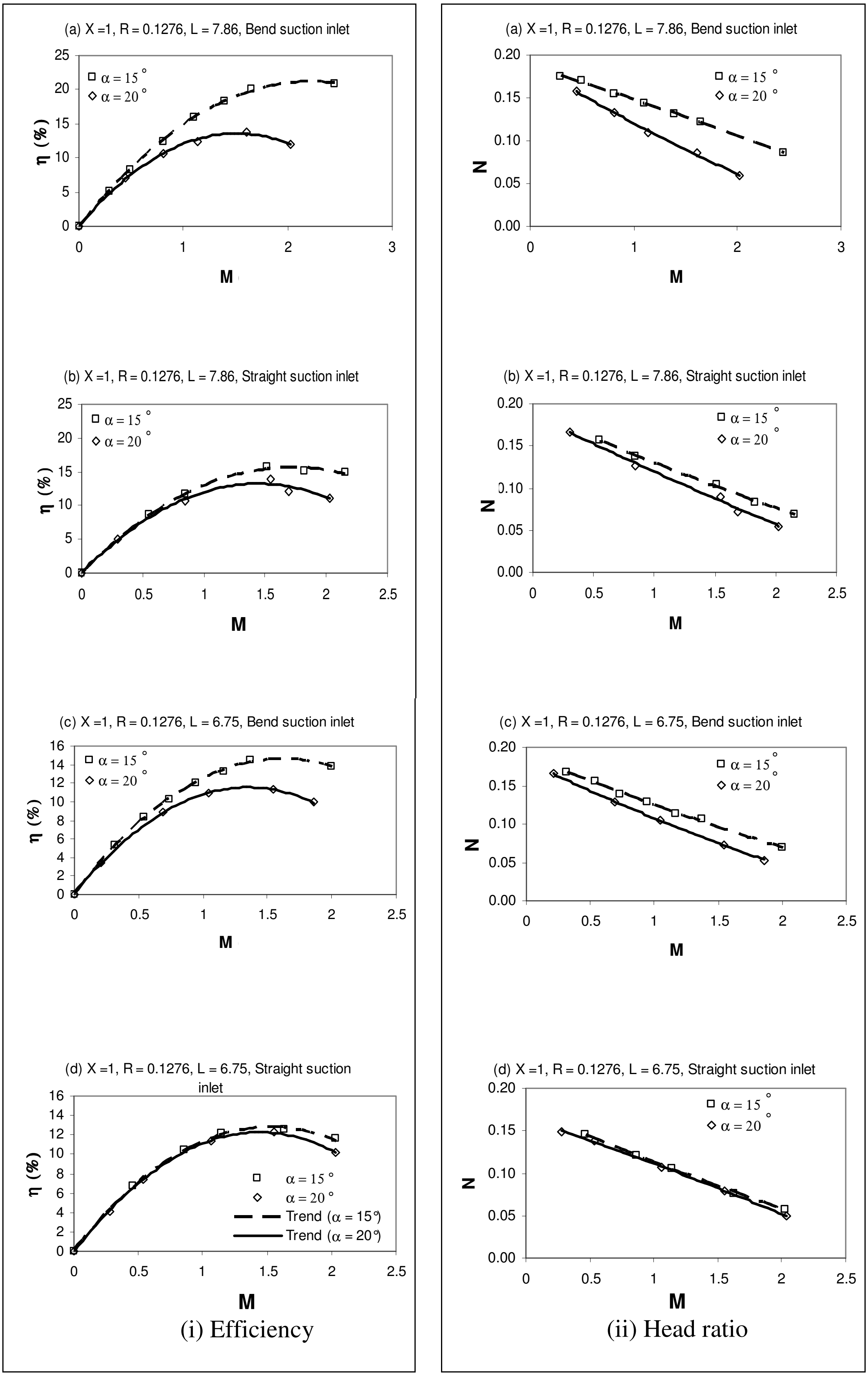


Fig. (9) Water jet pump performance curves for different suction nozzle semi cone angles

4-5 Effect of Changing Mixing Chamber Length

Figure (10) shows the results of the effect of changing mixing chamber length on the performance of water jet pump for the following configuration: area ratio of 0.3265, nozzle distance ratio of 2.0 and suction nozzle semi cone angles 15^o and 20^o for both bend suction inlet and straight suction inlet. It is clear from this figure that the mixing chamber length of $7.86d_m$ had proven superiority over $6.75d_m$ mixing chamber length for all experimental runs. The difference of water jet pump efficiency and head ratio using the two mixing chamber lengths was smaller using straight suction inlet rather than that using bend suction inlet as shown in **Fig. (10 a & b)** and **Fig. (10 c & d),** respectively.

The figure also, declares that the difference in jet pump efficiency values using the two mixing chamber lengths was smaller using 20^o semi cone angle suction nozzle rather than that with 15^o semi cone angle suction nozzle as shown from **Fig. (10 a & c)** and **Fig. (10 b & d)**, respectively. The superiority in the performance of $7.86d_m$ mixing chamber length over $6.75d_m$ may attribute to that, the $7.86d_m$ mixing chamber length provide a suitable environment to the mixing process to be completed. This means that, the suction fluid extracts more power from the driving fluid.

5- THEORETICAL PREDICTION OF JET PUMP PERFORMANCE

The results of the computer program are compared with the experimental results. This program based on equations (1 & 2) [9 & 10]. All loss factors were calculated theoretically, except suction inlets loss factors were evaluated experimentally, because of the complicated geometry of different suction inlets. The efficiency of water jet pump is given by the following equations [9 & 10]:

$$N = \frac{(-2RT_3 / S_s) - (S_d / S_s)(K_6 + K_5 - (R(1+M)/S_d)^2) - (K_3 + K_4 + (MR/(S_s(1-R)))^2)}{1 + K_1 + K_2 - S_d K_5 - S_s(K_3 + K_4 + (MR/(S_s(1-R)))^2)} \qquad (1)$$

$$\eta = M.N \qquad (2)$$

Figure (11) shows the performance curves of water jet pump for both experimental and calculated results for the configurations mentioned on the figure. It shows how the calculated results are close to experimental results. It is clear from **Fig. (11)** that there is a good agreement between the calculated results and the experimental results, which means that the equation described the jet pump performance fairly good.

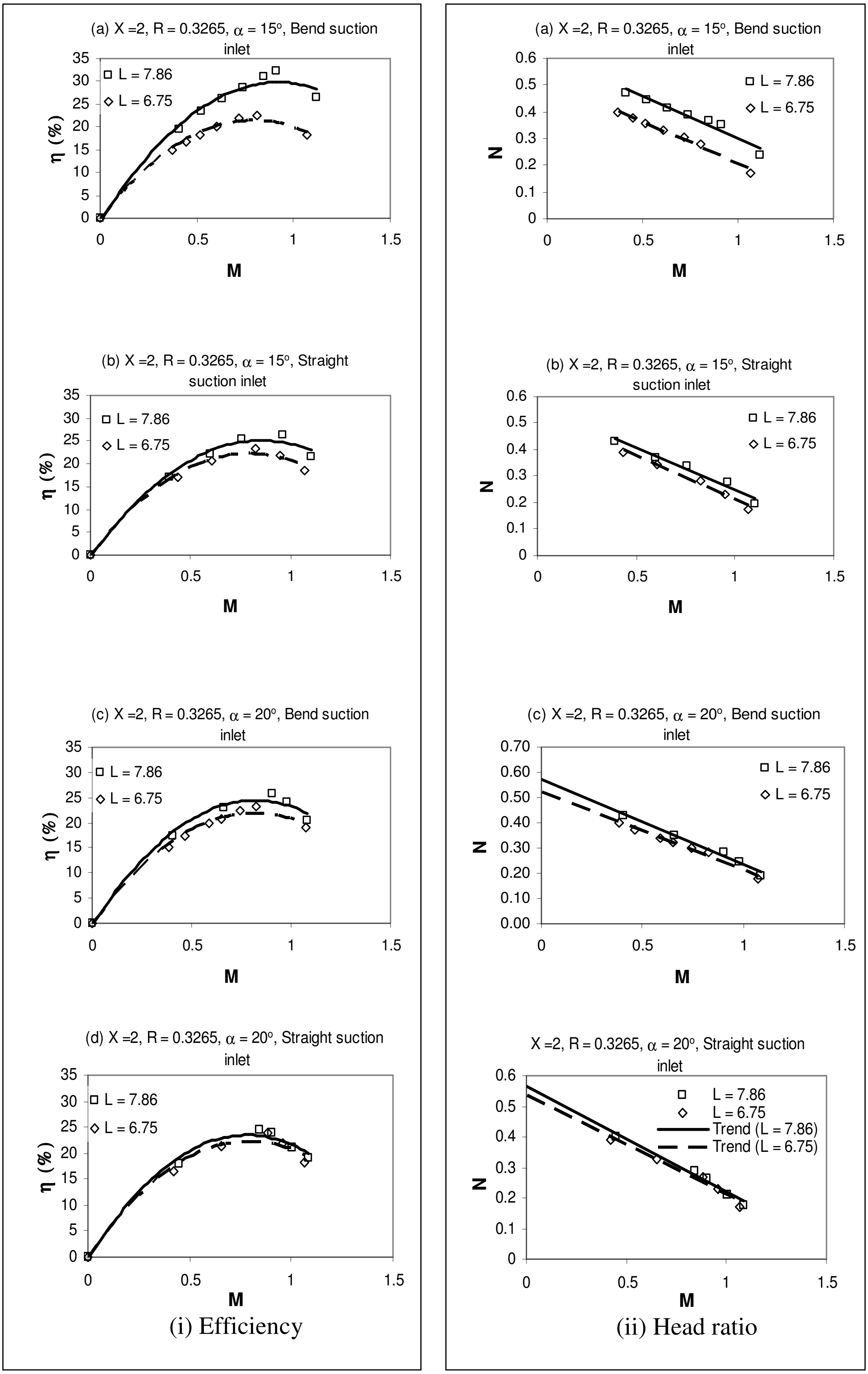


Fig. (10) Water jet pump performance curves for different mixing chamber lengths

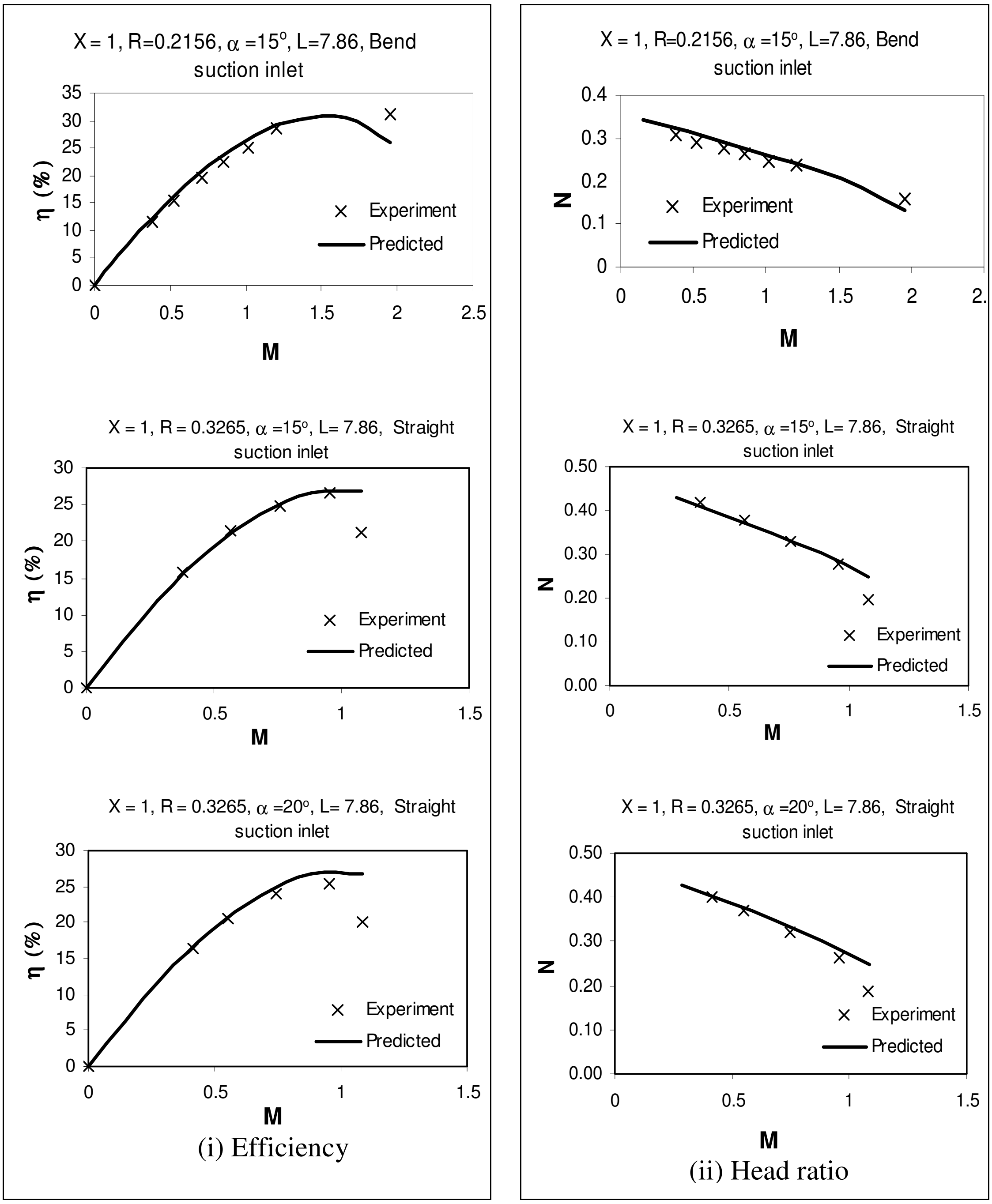


Fig. (11) Water jet pump performance curves for experimental and calculated results

6- COMPARISON BETWEEN PRESENT AND OTHER RESEARCHERS RESULTS

Figures (12 & 13) show a comparison between the water jet pump performance obtained from the present experimental results (area ratio of 0.3265 and nozzle distance ratio of 1.0) and some of the available previous experimental results [5, 11 & 12]. These are Gosline and O'Brien [7] (area ratio of 0.326 and nozzle distance ratio of

1.0), Zandi and Govatos [11] (area ratio of 0.338 and nozzle distance ratio of 1.0) and Shaheen [12] (area ratio of 0.34 and nozzle distance ratio of 1.0). The comparison purpose is just to give an indication to the results trend. It is clear from **Fig. (12)** that the present work curve has mild slope than the other curves. This means that the maximum efficiency point occurred at higher values of mass flow ratio as illustrated in **Fig. (12).** Also, means that the jet pump is capable to work at wide span of mass flow ratios. **Fig. (13)** illustrates that, for law value of mass flow ratio (M < 0.9) the present work has lower efficiency values compared with the others. But the present work has higher efficiency values compared with the others at higher mass flow ratios (M > 0.9). It may be attributed to that the present jet pump was embedded which means that it was working under positive suction head. On the other hand, it may be attributed to the large scale model used in the present work rather than small models used by the others. Shaheen's work [12] have higher efficiency values at low mass flow ratio compared by the others, it may be because the special arrangement of his jet pump, as the suction fluid enters the jet pump under gravity force.

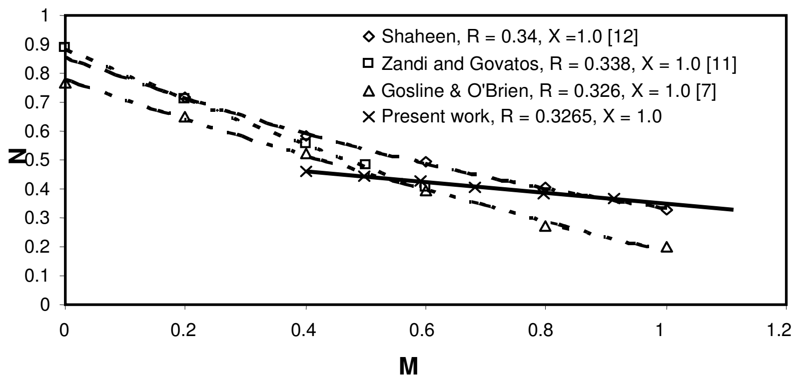


Fig. (12) Head ratio (N) versus mass flow ratio (M) curve; Comparison between present and other researchers' results

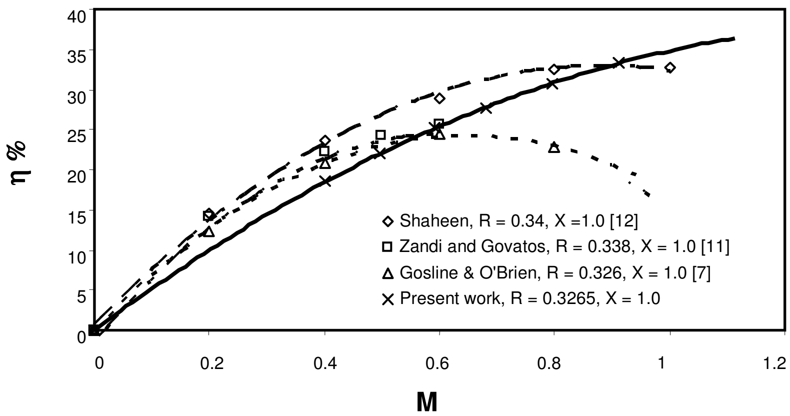


Fig. (13) Efficiency (η) versus mass flow ratio (M) curve; Comparison between present and other researchers' results

7- CONCLUSIONS

1. The nozzle distance ratios of 1.0, 1.0 and 1.5 gives the highest efficiency values for jet pump of the following area ratios of 0.3265, 0.2156 and 0.1276 respectively. However, the variation of the nozzle distance ratio from 1.0 to 2.0 has a small influence on jet pump efficiency.
2. The area ratio of 0.3265 gives the best efficiency while the area ratio of 0.1276 gives the worst efficiency. The highest efficiency of 33.38% was achieved at area ratio of 0.3265, 31.19% at area ratio of 0.2156 and 22.49% at area ratio of 0.1276, respectively.
3. The suction nozzle with a semi cone angle of 15^o had better efficiency than that of suction nozzle with a semi cone angle of 20^o, for all area ratios tested.
4. The mixing chamber length of $7.86d_m$ had proven superiority over 6.75 d_m mixing chamber length for all experiments done.
5. The highest efficiency achieved was corresponding to the following jet pump combination parts: bend suction inlet; mixing chamber with length ratio of 7.85, suction nozzle semi cone angle of 15^o and nozzle distance ratio of 1.0 for all area ratios tested, except that of 0.1276 area ratio which gives highest efficiency for a nozzle distance ratio of 1.5.

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NOMENCLATURE

d	Driving nozzle diameter	(m)
d_m	Mixing chamber diameter	(m)
H_1	Driving head	(m)
H_d	Delivery head	(m)
H_s	Suction head	(m)
K_1	Loss factor in driving inlet	(-)
K_2	Loss factor in driving nozzle	(-)
K_3	Loss factor in suction nozzle	(-)
K_4	Loss factor in suction inlet	(-)
K_5	Loss factor in diffuser	(-)
K_6	Loss factor in mixing chamber	(-)
l	Nozzle to mixing chamber spacing	(m)
L	Mixing chamber length ratio = L_m / d_m	(-)
L_m	Mixing chamber length	(m)
M	Mass flow ratio = $\dot{m}_s / \dot{m}_n$	(-)
$\dot{m}_n$	Driving mass flow rate	(m^3/s)
$\dot{m}_s$	Suction mass flow rate	(m^3/s)
N	Head ratio = $H_d - H_s / H_1 - H_d$	(-)
R	Area ratio = d^2 / d_m^2	(-)
S_d	Delivered specific density	(-)
S_s	Suction specific density	(-)
T_3	constant	(-)
X	Nozzle distance ratio = l/d	(-)
α	Suction nozzle semi cone angle	(°)
η	Efficiency = M.N	(%)