EXPERIMENTAL STUDY OF THE EFFECT OF MIXING CHAMBER LENGTH AND DIFFUSER ANGLE ON THE PERFORMANCE OF DREDGING JET PUMP

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ABSTRACT

The jet pump generally needs a long throat to mix the driving and induced fluids and transfer the momentum of driving fluid to induced fluid. Simultaneously the energy losses occur when the fluids flow through the long throat happened due to the friction loss occurs inside of the throat wall. Therefore, it is known that the throat length largely affects the jet pump efficiency. In this study, experimental studies are performed for a typical single nozzle jet pump using water as driving fluid and sand as the induced fluid.

The aim of this study is to investigate the performance of dredging jet pump. 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 mixing chamber length and diffuser angles. In this study three different mixing chamber length to mixing chamber diameter ratio of 6.75, 7.25 and 7.86 are studied. And three different diffuser angles of 4°, 5.5° and 7° respectively with one suction nozzle of semi cone angle of 22°. Also one type of quartz sand was used with 0.152 mm mean particle size diameter and with a specific gravity of 2.65.

The effect of mixing chamber length and diffuser angles on the jet pump performance was also tested under different flow rates and motive pressures. Two different distance between the sand surface and suction pipe. Furthermore scouring nozzle system with two different scouring nozzle diameter of 6 mm and 8 mm. In all cases, it was found that the best efficiency for the jet pump is attained with mixing chamber length of 7.25 and diffuser angle of 5.5°, and the best values for these design parameters have been obtained from the experimental work.

Keywords: Jet pump, Dredging, Mixing chamber length, Diffuser angles, Scouring nozzle.

1. INTRODUCTION

The slurry jet pump and scouring nozzles system can be use in dredging of sites which are difficult to approach or needs handling of equipments and impossibility to reach with traditional methods such as intake of pumping stations, under bridges and concrete water channels. This system is suitable for sand, silt, sludge, mud and other organic materials.

The jet pump is a device, which performs its pumping action by the transfer of energy from a high velocity jet to one of low velocity. The pump consists mainly of a jet nozzle, a suction chamber, suction nozzle, a mixing chamber, and an outlet diffuser as schematically shown in Fig. 1. Even though its efficiency is low, the jet pump has some advantages, namely, the absence of moving mechanical parts, which eliminates the operational problems associated with bearing, seals, lubrication and the simplicity of its design, production, and test. For these reasons, the jet pump has a wide range of applications in different engineering branches. The primary velocity is provided by a high pressure stream of fluid directed through the nozzle. Because of the high velocity of the primary fluid, a low pressure in the suction chamber is created causing suction of the secondary fluid into the mixing chamber. Consequently, the turbulent mixing between the two streams (with two different velocities) occurs.

Jet pumps are also frequently used under conditions where the primary and secondary fluids are different. It is modified to be used for pumping water mixture containing solids to cover a wide range of applications in civil and industrial engineering. There are many investigations predicting the performance of slurry jet pump to cover the wide range of its applications. Zandi and Govateos **[1]**, Fish **[2]** and Mikhail et al **[3]** carried out experimental and theoretical work on water and slurry jet pumps to develop equations which may be used in designing a slurry jet pump. Siwiec et al **[4]** described a new design procedure for multi – jet pump that is used in dewatering and excavations in fine soils. Chamlong et al **[5]** presented a theoretical study for a centrally driven jet pumps for lifting solids. They concluded that, the performance of both solid handling jet pump and water jet pump are effected by nozzle–throat ratio and they found that, the maximum efficiency is attained when x/D = 0.5-0.6. Furthermore, Chamlong et al **[5]** developed a numerical prediction to find the optimum mixing throat length with respect to nozzle diameter. They concluded that, the optimum ratio of the mixing throat length to the nozzle diameter, (L_{mix}/D) is 2 - 3.5. El-Sibaie and El-Haggar **[6]** 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 **[7]** 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 **[8]** 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 **[9]** 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 **[10]** 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 **[11]** studied theoretically and experimentally the effects of some parameters on the performance of slurry jet pump using four different area ratios. Iran et al **[12]** 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. From the previous investigations, it is clear that the jet pump performance is extremely affected by pump design dimensions, especially when it is used in handling solids. In practice, the concentration of solids in water as a secondary stream affects the performance of the jet pump due to the presence of sand of an unexpected quantity and size. This unexpected mixture affects the design dimensions of the jet pump. Therefore, an experimental investigation for the dredging jet pump is presented to determine the effects of both mixing chamber length "L" and diffuser angle "θ_d" on the pump performance when pumping (sand-water) mixture. Furthermore, the research is directed also to study the effect of using two different scouring nozzle diameters on slurry jet pump performance and delivered sand concentration ration (C_{vd}) when using sand. Finally the two different heights between the sand surface and suction pipe of slurry jet pump are studied to show their effect on pump performance and delivered sand concentration ratio.

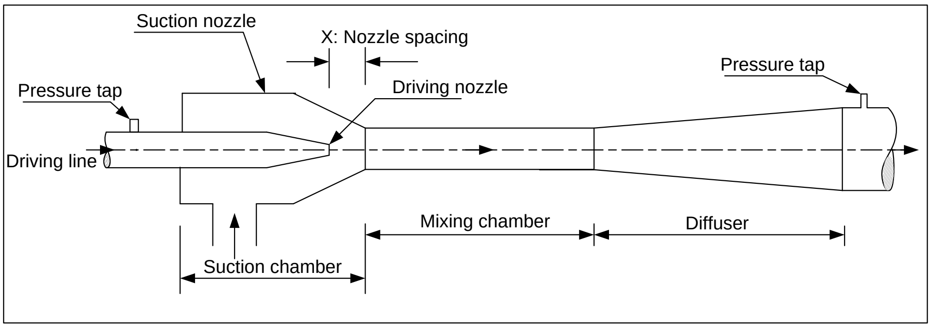


Fig. (1) Assembly of jet pump

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 mixing chamber length, three different nozzle angle configurations, one sand size with a specific gravity of 2.65, two different height between the sand surface and suction pipe namely, h_c= 5 cm and h_c= -10 cm (minus sign means the suction pipe is embedded on the sand bed) and two different scouring nozzle diameter.

In the current study the water sump is used as a pump intake with dimensions of 10 m long, 3 m width and 1 m depth. The sump is supplied with fresh water from water supply (1). The fresh water is pumped by driven centrifugal pump (3) from the water sump (2) to the driving nozzle via a 25.4 mm pipe inner diameter tube fitted with a ball valve to control the required pressure. Then discharging the water into the driving line where it is first passes through driving line ball valve (6), then it is divided into two branches. One of these branches passes through the bypass line (7), the other branch passes through the ultrasonic flow meter (8), then through the pressure transducer (14) and finally to the jet pump (9), where a low pressure region is created at the tip of this nozzle. This reduction in the pressure causes the suction fluid to flow in the direction of the driving jet. After that the total mixture passes through the mixing chamber and diffuser of jet pump. The mixture that leaves jet pump is then directed through pipe of 63.5 mm diameter to magnetic flow meter (18) and to delivery graded tank (20) of external dimensions of 500 x 500 x 600 mm.

In the scouring nozzles branch water flows from the centrifugal pump (4) to the scouring nozzle ball valve (10), then to the scouring nozzle pressure gage (11), finally to the scouring nozzles (12) as shown in Fig. (2). Water emanates from the holes of the scouring nozzle to fluidize layers of quartz sand bed (24) under it forming sand/water slurry. The slurry entrained by the jet pump (9) is then directed to delivery flow meter (18) and to graded tank (20) where discharge flow rate.

The jet pump combination parts are shown in Figs. (3-a and 3-b) three different mixing chamber length ratios of 6.75, 7.25 and 7.86 as shown in Fig. (3-a), and three different diffuser angle (θ_d) of 4°, 5.5° and 7°as shown in Fig. (3-b). In this paper the scouring nozzles system are use to optimize the hydraulic aspects of the system, including the plane of the scouring nozzles, the nozzle diameter, flow rate and pressure which enters the scouring nozzles system. Scouring nozzle injects fluid into sediment which helps the grains of sand to disintegrate and separate, this technology moves the sand to the jet pump. The scouring nozzles are used to disintegrate and separate the sand bed to increase the delivered solid concentration. The performance evaluation of scouring nozzles depend on the flow rate and total pressure through the scouring nozzles also the number of scouring nozzles and the distance between the scouring nozzle and the sand bed. In this study the changing of various parameters affecting the performance of the slurry jet pump is shown in Figs. (4 and 5).

2.2 Experimental procedure

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

1- Water temperature and atmospheric pressure in the laboratory are recorded.
2-The water sump 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 sand added to the flume until the sand layer reach to 200 mm, the sand thickness fixed along the experimental time, and then the water levels were first set to the required level. The height between the bottom of the suction pipe and the surface of the sand inside the flowing flume was set at 5 cm, and the scouring nozzle diameter of 6 mm.
4- Two centrifugal pumps were turned on, keeping the control-valve in the driving flow pump delivery side fully opened, and by means of control valves, the scouring nozzle pressure was fixed at one bar, this pressure fixed along the experimental time.
5- The driving flow 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 and the delivered sand concentration was calculated by take the sample of the mixture (sand-water) into the vessel sample and digital balance.
7-Steps (4) to (6) were repeated with different motive pressures 1.5, 2 and 2.5 bar.
8-Data was recorded for the test rig was emptied and new sets of experiments were carried out on the jet pump with the other mixing chamber lengths and diffuser angles.
9- The height between the suction pipe and sand surface was adjusted to -10 cm and steps from (4) to (8) were repeated.
10- The scouring nozzle diameter of 8 mm was arranged symmetry at left and right of the suction pipe and steps from (4) to (9) were repeated.

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

i- Flow ratio $M = \frac{Q_s \cdot \gamma_s}{Q_m \cdot \gamma_w}$, ii- Head ratio $N = \frac{(H_d .SG_d - H_s .SG_s)}{(H_m - H_d .SG_d)}$,

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

$\eta = \frac{[Q_s .\gamma_s .(H_d .SG_d - H_s .SG_s)]}{[Q_m .\gamma_w .(H_m - H_d .SG_d)]}$, $\eta = M.N$,

iv- Delivered sand concentration ratio $C_{vd} = \frac{\gamma_d - \gamma_w}{\gamma_{sa} - \gamma_w}$

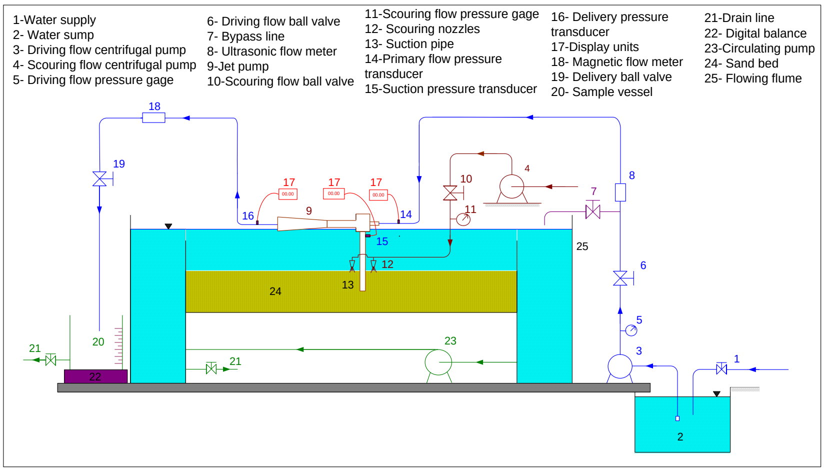
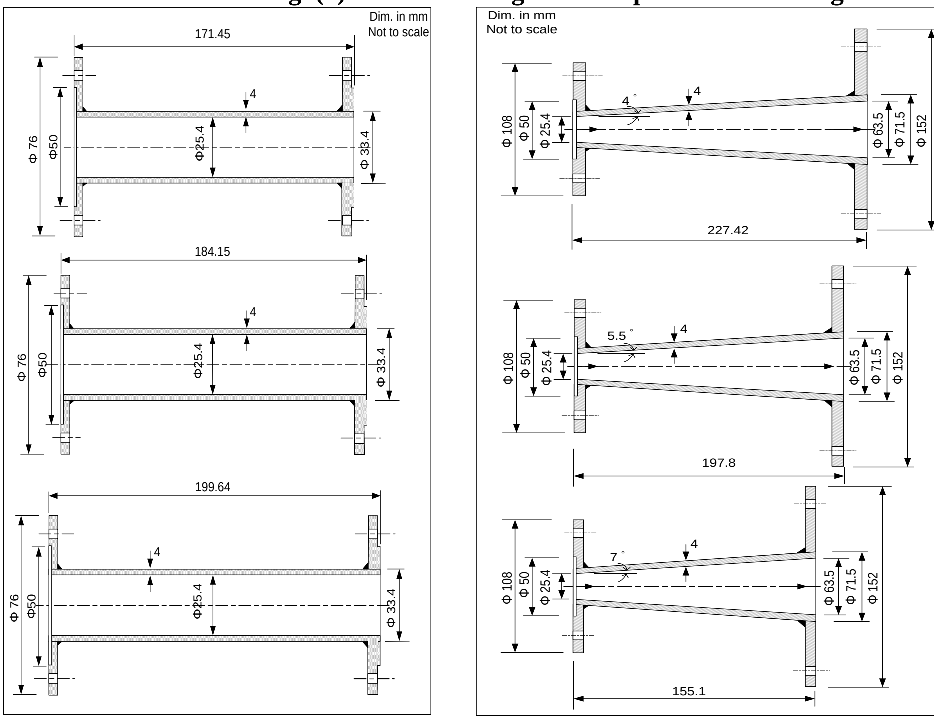


Fig. (2) Schematic diagram of experimental test rig



(a) Mixing chambers **(b) Diffusers**

Fig. (3) Jet pump different parts

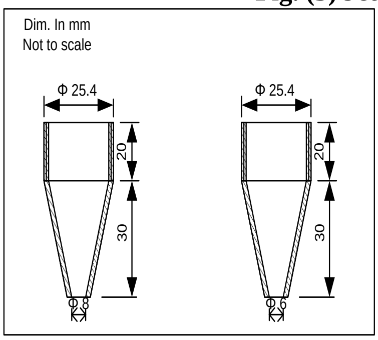


Fig. (4) Scouring nozzles used in the test rig

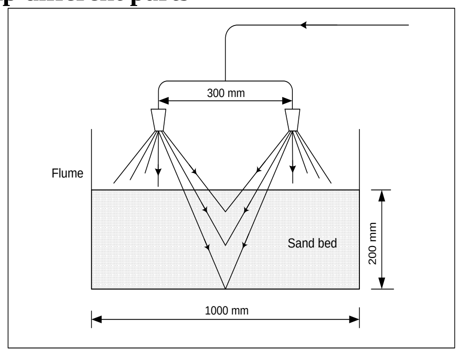


Fig. (5) Schematic diagram of the scouring nozzle system layout

3. RESULTS AND DISCUSSION

This part of experimental results is part of extended program studying the effect of different geometric variables on the slurry jet pump at different conditions.

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

In this study three mixing chamber lengths of 171.45, 184.15 and 199.64 mm with 25.4 mm were tested, having dimensionless mixing chamber length ratio (L) of 6.75, 7.25 and 7.86 respectively. Fig. (6) shows the results of the effect of changing mixing chamber length on performance of jet pump when pumping (sand-water) at scouring nozzle diameter of D_n=6 mm, these figure illustrate that the mixing chamber length of 7.25 has higher efficiency than that of other mixing chamber length. 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. Also the figure reveal that the value of highest efficiency point is strongly dependent on the height between the sand bed and the jet pump suction inlet distance (h_c).

Figure (7) illustrates the results of the effect of changing mixing chamber length on the delivered sand concentration for jet pump with the following configuration: diffuser angle θ_d= 7°, suction inlet distance of h_c= -10 cm and scouring nozzle diameter of D_n= 6 mm. Also, from Fig. (7) it is clear that the mixing chamber length of 7.86 D_{mix} gives higher delivered sand concentration than the other mixing chamber lengths.

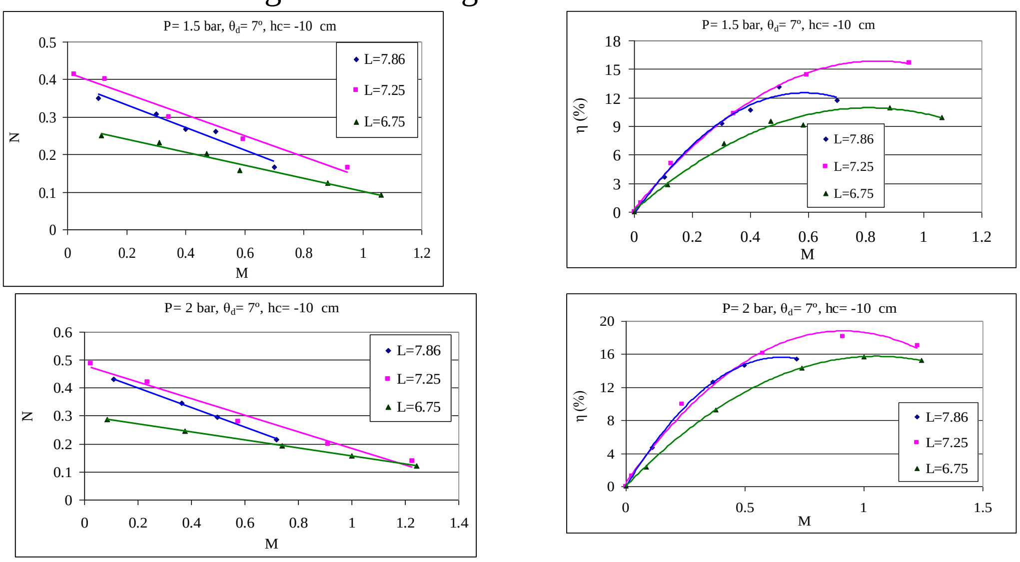


Fig.(6) Jet pump performance for different mixing chamber length ratio (L) at constant motive pressure, at diffuser angle, θ_d=7°

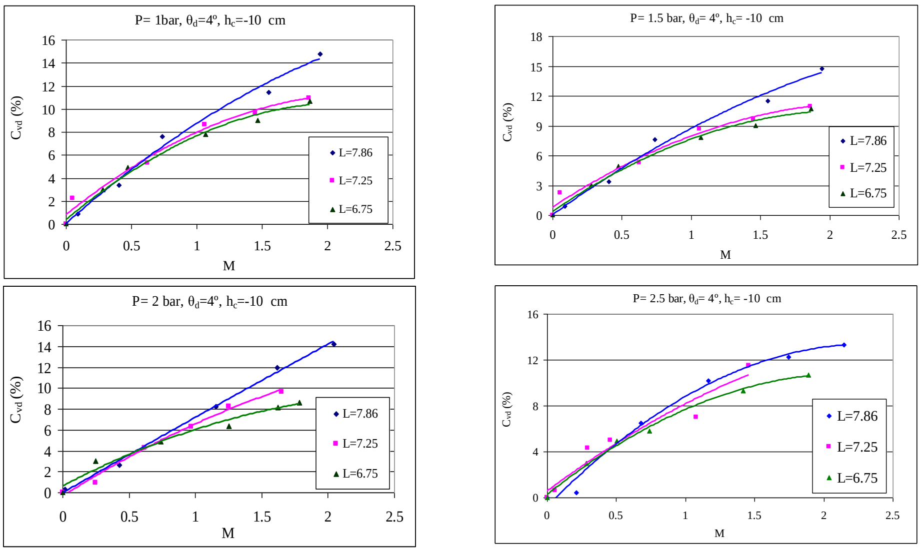


Fig.(7) Delivered sand concentration (C_{vd}) versus flow rate ratio (M) at different mixing chamber ratio

3.2 Effect of changing diffuser angle (θ_d) on slurry jet pump performance

Figure (8) shows the results of the effect of the different diffuser angles on slurry jet pump performance. 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. 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 the height between the sand bed and inlet suction $h_c= -10$ cm with scouring nozzles diameter of 6 mm for all tested driving pressure. For a given driving pressure 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.

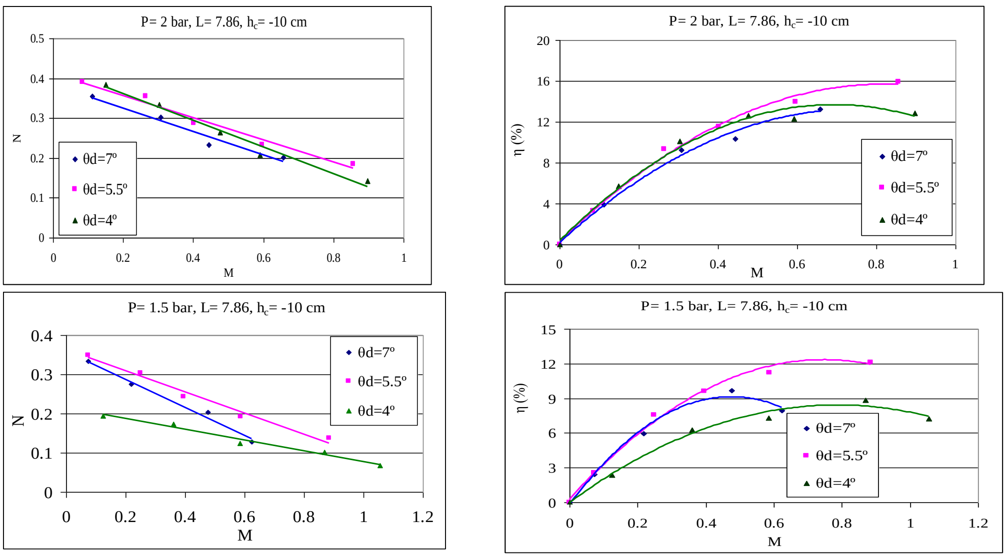


Fig.(8) Jet pump performance for different diffuser angle (θ_d) at constant motive pressure, at mixing chamber length ratio (L=7.86)

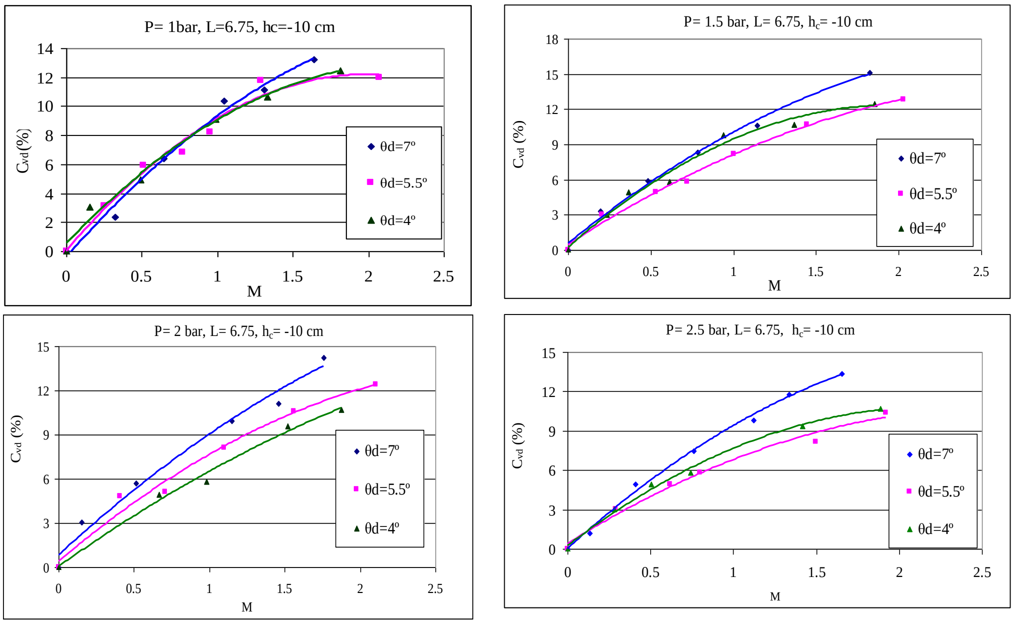


Fig.(9) Delivered sand concentration (C_{vd}) versus mass flow ratio (M) for different diffuser angle (θ_d)

On the contrary the lower diffuser angles the lower the delivery sand concentration as shown in Fig. (9). This may be because the lower diffuser angles the higher driving flow rate which dilutes the sand concentration at suction side. All experimental results show that the delivered sand concentration was higher with the height between the sand bed and jet pump suction inlet h_c= -10 cm and scouring nozzles diameters of 6 mm. This may be attributing to the way in which the suction flow enters the jet pump. Although, when the suction inlet is above the sand bed the amount of solids entrained in jet pump decreasing compared to when the suction inlet port is below the sand bed.

3.3 Effect of height between suction pipe and sand surface (h_c) on the performance of jet pump

In this work two vertical height between the sand bed and the inlet suction of slurry jet pump at h_c= 5 cm and h_c= -10 cm (minus sign means that the bottom of suction embedded under the sand surface) were tested. The experimental results are represented by curves in Fig. (10) at different driving pressure, different mixing chamber lengths, and different diffusers angles. From the set of curves shown in Fig. (10), the highest efficiency is obtained when jet pump was placed at the height between the sand bed and the inlet suction of slurry jet pump of h_c= -10 cm for all cases. This means that the height between the sand bed and the inlet suction of slurry jet pump of h_c= -10 cm sucked the amount of mixture more than that when the height between the sand bed and the inlet suction of slurry jet pump of h_c= 5 cm.

Figure (11) shows the relation between the delivered sand concentration versus the mass flow ratio at different height between the sand bed and the inlet suction of slurry jet pump. It is found that C_{vd} is very sensitive to h_c, the height between bottom of suction and sand surface. The experiment with h_c which changes gradually has been done. The results show that h_c takes negative value, which means that suction bottom was embedded into the sand surface, produces larger C_{vd}. All experimental results show that the delivered sand concentration was much higher with h_c= -10 cm than h_c = 5 cm. So, it is suggested that the suction of jet dredger should be embedded a little into the sand surface.

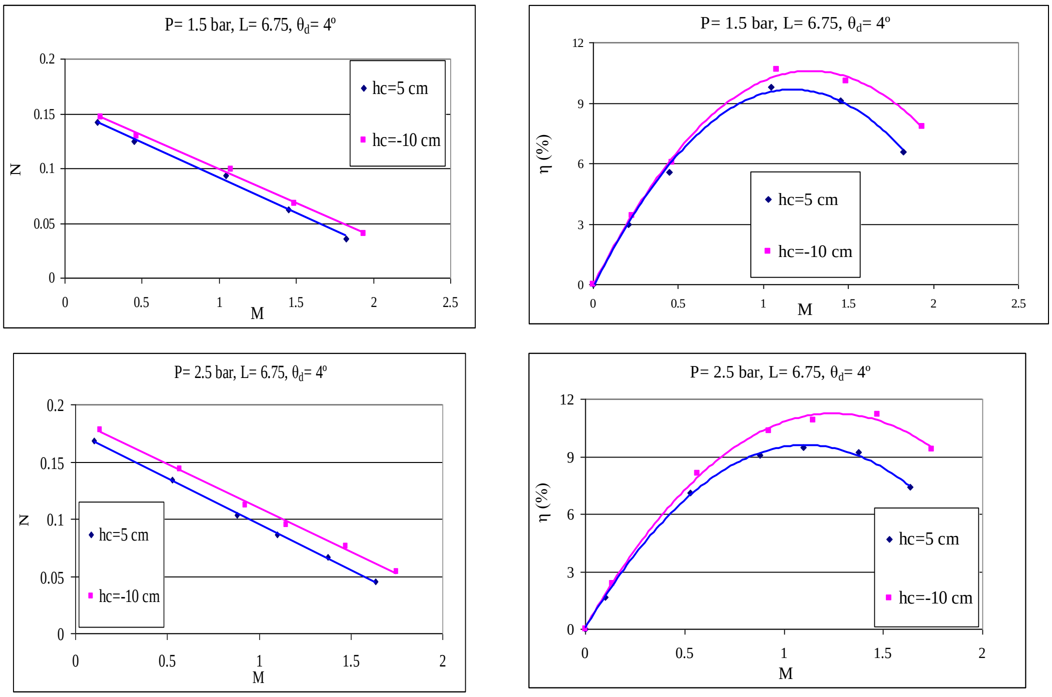


Fig.(10) Jet pump performance for different height between suction bottom and sand surface (h_c)at constant motive pressure, at mixing chamber ratio (L=6.75), diffuser angle (θ_d=4°).

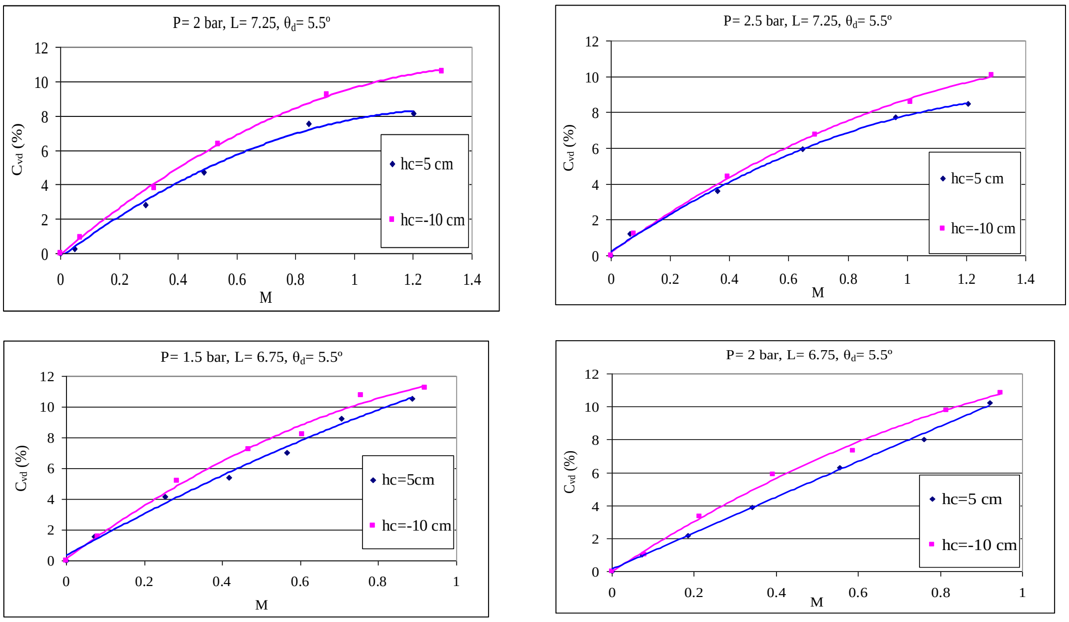


Fig.(11) Delivered sand concentration (C_{vd}) versus mass flow ratio (M) for different height between suction bottom and sand surface (h_c)

3.4 Effect of scouring nozzles diameters on the jet pump performance

Water from scouring nozzles impinges against the sand and stirs it up to high-concentration slurry near the suction of jet slurry pump. Then, the slurry is entrained by the jet slurry pump and delivered to collecting tank. Two Nozzles with diameter of 6 mm and 8 mm were fixed symmetrically at the left and right sides of suction pipe above the sand bed, the scouring nozzles input pressure are constant at one bar.

Figure (12) shows the results of the effect of different scouring nozzles diameters on slurry jet pump at different driving pressure, different mixing chamber lengths, different diffusers angles and different height between the sand bed and suction slurry jet pump. From the set of curves mentioned in this figure, the highest efficiency is obtained when the scouring nozzles diameter as D_n= 6 mm. All experimental results show that the slurry jet pump efficiency was higher with scouring nozzles diameters of 6 mm than with 8 mm this may be attributing to the scouring nozzles diameter of 8 mm generate vortexes more than that diameter of 6 mm and exist more eddy losses in the suction port, this vortexes decrease the amount of mixture (sand-water) passes thought the jet pump.

Figure (13) show the relation between the delivered sand concentrations versus the flow ratio at different scouring nozzle diameters. From this figure it is clear that the delivered sand concentration was higher with scouring nozzles diameter of 6 mm than with the scouring nozzles of 8 mm, this may due to the scouring nozzles diameter of 8 mm the sand under the suction will be flushed away from the inlet jet pump suction port.

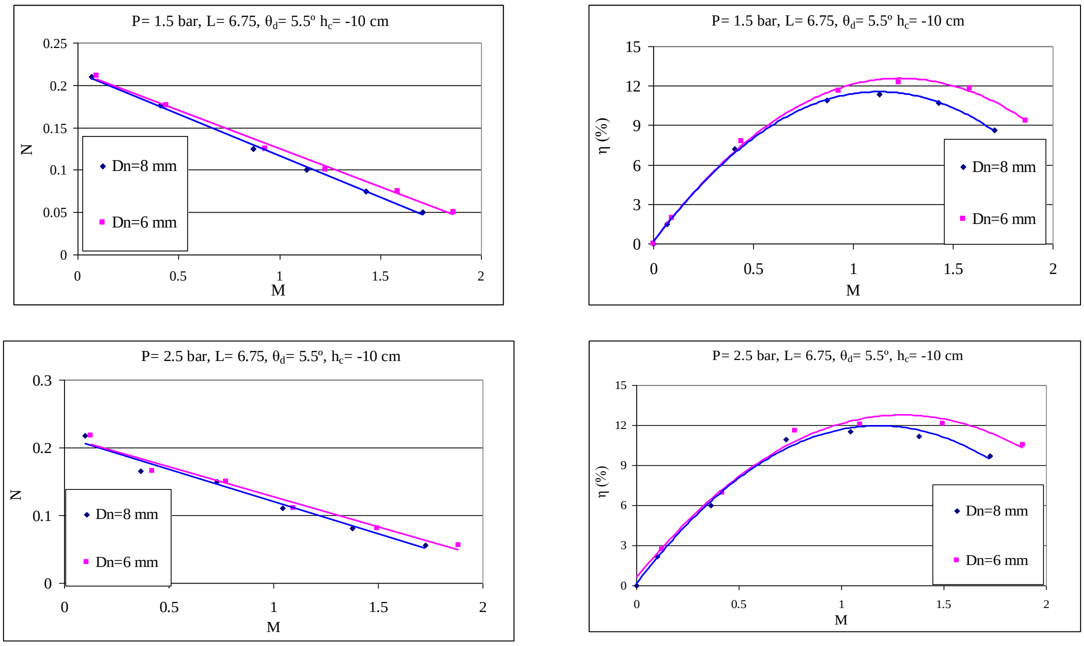


Fig.(12) Jet pump performance for different nozzle diameter (D_n) at mixing chamber ratio (L= 6.75), diffuser angle (θ_d= 5.5°) and the height between the sand bed and suction pipe (h_c= -10 cm)

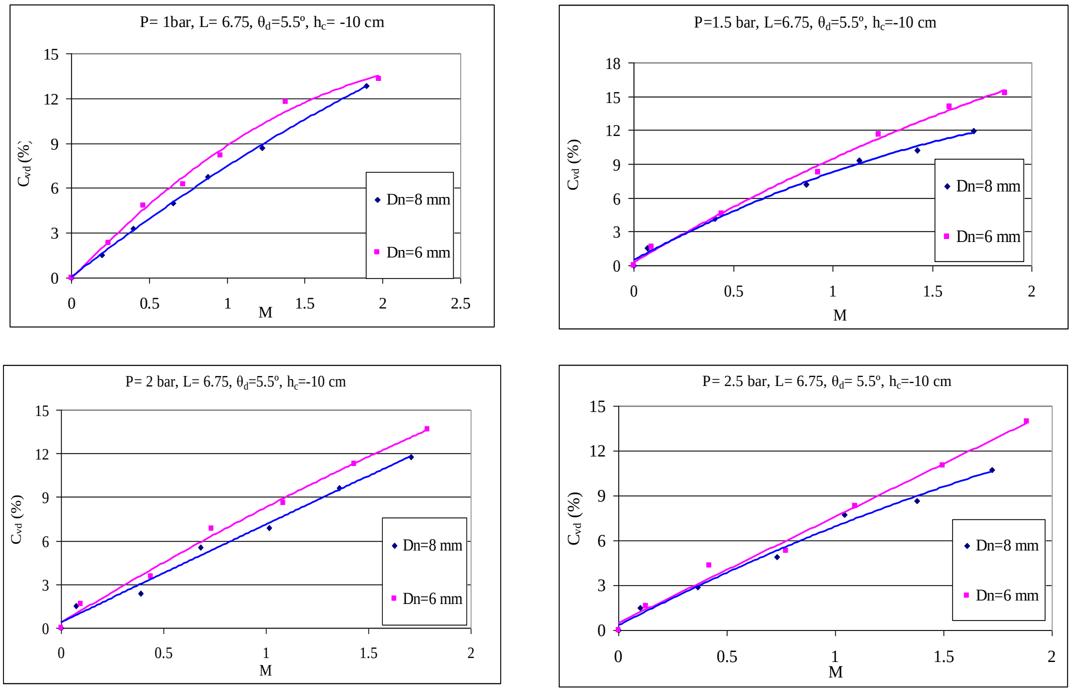


Fig.(13) Delivered sand concentration (C_{vd}) versus mass flow ratio (M) for different scouring nozzle diameter (D_n)

4. CONCLUSIONS

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

1- For all mixing chamber length and diffuser angle the height between the sand bed and the suction pipe of h_c= -10 cm attained a higher performance compared to that the result of h_c= 5 cm.

2- The jet pump mixing chamber length ratio of 7.25 gives the highest efficiency and the mixing chamber length ratio of 6.75 gives the minimum highest efficiency.

3- The jet pump diffuser angle of 5.5^{o} gives the highest efficiency and the diffuser angle of 4^{o} gives the minimum highest efficiency.

4- The scouring nozzles diameter of 6 mm arranged symmetry in the left and right of the suction pipe attained a higher efficiency compared to that results in the case of scouring nozzle diameter of 8 mm.

5- The highest efficiency achieved was corresponding to the following slurry jet pump parts configuration: the scouring nozzles diameter of 6 mm, the height between the sand surface and the suction pipe of -10 cm, mixing chamber length of 7.25, the diffuser angle of 5.5^{o} and the driving flow pressure of 2 bar.

6- A jet pump with mixing chamber length ratio of 7.86 gives the higher delivered sand concentration compared to jet pump with the mixing chamber length ratio of 6.75 and 7.25.

7- The diffuser angle of 7° gives the highest delivered sand concentration compared to the other diffuser angles of 4° and 5.5°.
8- The delivered volumetric concentration decreases by decreasing the driving pressure, the highest discharge volumetric concentration is obtained at a derived pressure of 1.5 bar.
9- The highest delivered sand concentration achieved for the considered jet pump was corresponding to the following slurry jet pump configuration: the height between the sand surface and the pipe suction is -10 cm, the scouring nozzle diameter of 6 mm, and derived pressure of 1.5 bar for all area ratios.

Nomenclature

A_J = Cross sectional area of the jet, (m^2)
A_{mix} = Cross sectional area of the mixing chamber, (m^2)
C_{vd} = Delivered sand concentration (%)
D = Nozzle (jet) diameter, (m)
D_{mix} = Mixing chamber diameter, (m)
D_n =Scouring nozzles diameter, (mm)
h_c =Distance between the sand bed and suction pipe, (cm)
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_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)
θ_d = Diffuser angle , (°)
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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