SOLID-MATERIALS-HANDLING CENTRAL-TYPE JET PUMP

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ABSTRACT

An extensive program has been made to study the performance of solid-materials-handling central-type jet pump under various conditions such as: the change of suction inlet shape (90° elbow and straight connection); the area ratio (the area of driving nozzle to that of mixing chamber) of 0.217, 0.338 and 0.5; the dimensionless nozzle length (the ratio of the distance from the nozzle tip to the mixing chamber entrance with respect to the driving nozzle diameter) of 0.5, 1.0 and 2.0; the dimensionless mixing chamber length (the ratio of the mixing chamber length to its diameter) of 5.6, 7.0 and 7.25; the diffuser angle of 20°, 10° and 5°, and the sand grading. A computer program has been designed especially to predict the behavior of central-type jet pump under various conditions also, this program considered the phenomena of the two-phase flow. The present results obtained are compared with the previous researchers and agree well with them.

KEYWORDS: Solid-materials, sand, central-type, jet pump

NOMENCLATURE

A	area (m^2)
C_n	driving nozzle velocity coefficient (-)
C_s	suction nozzle velocity coefficient (-)
C_w	solid concentration ratio = $\dot{m}_{\acute{s}}/\dot{m}_s$ (-)
C_v	volumetric solid concentration ratio $Q_{\acute{s}}/Q_s$ (-)
D	mixing chamber diameter (m)
d	driving nozzle diameter (m)
f	friction factor (-)
g	gravitational acceleration = 9.81 (m^2/sec)
H	total pressure (Pa)
h	head loss (m)
k	loss factor (-)
L	mixing chamber length (m)
l	nozzle distance (m)
M	mass flow ratio = $\dot{m}_s/\dot{m}_n$ (-)
$\dot{m}$	mass flow rate (kg/sec)
N	head ratio $((H_3-H_2)\gamma_s/(H_1-H_3)\gamma_w)$ (-)
P	static pressure (pa)

Q flow rate (m^3/sec)
R the area ratio $=A_n/A_m$ (-)
R_{dif} the diffuser area ratio (-)
S relative density (-)
$T_{1,2,3}$ constants (-)
V velocity (m/sec)
$W^{\bullet}$ weight flow rate (N/sec)
X nozzle length ratio =l/d (-)
Z head (m)

Greek letters:

α semi cone angle of the driving nozzle (deg.)
β semi cone angle of the diffuser (deg.)
γ specific weight (N/m^3)
δ pressure ratio = $(H_3-H_2)/(H_1-H_3)$ (-)
η efficiency (-)
θ semi cone angle of the suction nozzle (deg.)
μ slip factor $=V_{\acute{s}}/V_s$ (-)
ρ density (kg/m^3)

Subscripts:

$_b$ bend
$_d$ delivery mixture at section 5
$_n$ driving nozzle
$_m$ mixing chamber
$_s$ suction nozzle
$_{\acute{s}}$ solids at suction
$_{d'}$ solids at delivery
$_{dif}$ diffuser
$_w$ water
$_{wd}$ water at delivery flow
$_{ws}$ water at suction flow
$_{1,2,3}$ at cross-sections 1,2,3

INTRODUCTION

The first use of the jet pump was in 1852 by James Thomson when he designed a jet pump to remove water from the pits of submerged water wheels. The theory of the pumping process was developed by Ranking in 1870 based on the continuity and the momentum equations. Since that time the jet pump had incorporated in many fields. At the beginning of the last century the American Engineers used the jet pump in water purification plants to transport slurry of water and sand. They designed a jet pump to transport the slurry to a distance of 630 ft through 4-inch diameter pipe and to a height of 30 ft. Up to 1945 no general work had been done until Gosline and O'Brien [5] published their leading work on the water jet pump. They developed a theoretical dimensionless equation and performed it with their experimental work. The principal aim of their work is to check the applicability of the momentum equation. The most important result of their work is the verification of the theoretical equation by experimental work. The agreement between theory and practice in their work the water jet pump is notably good. They also studied the effect of erosion on the jet pump performance and derived a formula for critical condition at which cavitation occurs.

Mueller [6] determined the optimum dimensions of the water jet pump so that the best efficiency may be obtained. He derived an analytical efficiency equation to define the pump behavior, which agrees well with experimental results. The effect of cavitation on the pump characteristic was also treated in his work. In order to maximize the efficiency and performance of the water jet pump he recommended that the driving and suction nozzles should have velocity coefficient of 0.95 or better. Best result was obtained when the nozzle distance is equal to driving nozzle diameter. The mixing chamber length of 7.15 times mixer diameter should be adopted if a diffuser with total included angle of 5° is used.

Reddy et al. [7] suggested that, to achieve maximum jet pump efficiency the following dimensions be recommended: the driving nozzle should have a semi cone angle of 8^o to 10^o and preferably be streamlined. If the jet pump has a fixed nozzle; the area ratio should be between 0.33 to 0.543. If the pump has an adjustable nozzle; the area ratio should be about 0.205 and the pump should be operated at a nozzle distance of one to two nozzle diameters. The mixing chamber length should be about 18 nozzle diameters. The diffuser should have a total angle of 5° and the suction nozzle should have a cone angle of 20° to 24°. A long radius bend with straight suction flow entry may be used. The pump material should be non-corrosive and smooth to get higher efficiencies than conventional mild steel pump.

Zandi and Govatos [9], and Govatos [1], presented a governing equation which may be used in designing a slurry jet pumps. Available data indicates the usefulness of the proposed governing equation. They suggested that much more data are needed to provide a basis for confidence when large projects are involved because their work was concerned by one type of jet pump (central-type), one dimension and one type of sand. They suggested for best performance the following: the loss factors must be kept to a minimum by streamlining all pump parts; multiple nozzles or drive jets in the form of an annulus should be avoided; the angle of entry of the drive jet into the mixing chamber should be zero; the mixing chamber length should be 7.25 times its diameter and the diffuser angle should be 5.5°.

During the same period, Fish [2], published his work on solid-handling jet pump. He presented analytical equation, which allows the performance characteristics of the solid handling jet pump to be calculated. He found a close agreement between the theoretically predicted test points and those obtained by experimentation. He showed that solids handling performance for a jet pump of diameter ratio 0.66 can be predicted with confidence and the efficiency is not impaired when solid material is entrained. A maximum efficiency of 40% was achieved with this particular design. He used two types of solid materials; the first being the low grade iron ore of specific gravity 2.7 and the other being cast steel shot of specific gravity 6.6.

Shaheen [3] investigated that the effect of some design parameters on slurry jet pump performance; namely the distance between the nozzle exit and the beginning of mixing chamber, the area ratio, the discharge volumetric concentration ratio and the solid specific gravity. He concluded that the best dimensionless distance for the slurry jet pump with area ratios of 0.34 and 0.473 are equal to 1.5 and 2 respectively for both the discharge volumetric concentrations of 3% and 8%. An increase in the discharge volumetric concentration in a range of 3% to 8% leaded to an increase in slurry jet pump efficiency. The selection of the jet pump area ratio is related to the required weight flow rate ratio for best efficiency. In his comparison between the previous works, he found a large discrepancy between the results of Fish [2] and Govatos [1], they considered that this happened due to the difference in the specific gravity of materials used or due to the difference in area ratio and nozzle distance.

The purpose of the present work is to find the optimum dimension of solid handling jet pump and the study of the effect of various parameters affecting the jet pump performance such as; the suction inlet shape; the area ratio; the nozzle distance; the mixing chamber length; the diffuser angle and the sand grading.

TECHNICAL CONCEPT OF JET PUMP

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 jet expands out of the driving nozzle, it creates a low-pressure area. 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.

The jet pump generally consists of: the driving nozzle which is the engine of the jet pump; the mixing chamber which is the heart of the pump; the diffuser it's not essential part of the pump and its existence depends on the application; the suction chamber which may be closed with suction inlet **Fig. (1-a)** or open when the pump is embedded and the suction flow is entrained around the whole periphery of the driving nozzle as shown in **Fig. (1-b).**

There are two configuration of the jet pump the first is the central-drive jet pump is shown in **Fig. (1-a)**, in which the driving fluid passing through the inner nozzle inside the pump and the secondary flow passing through the annular space surrounding the nozzle. The second is the annular drive jet pump **Fig. (2-a)**, in which the suction fluid passing through the inner tube of the pump and the driving flow passing through the outer annular space.

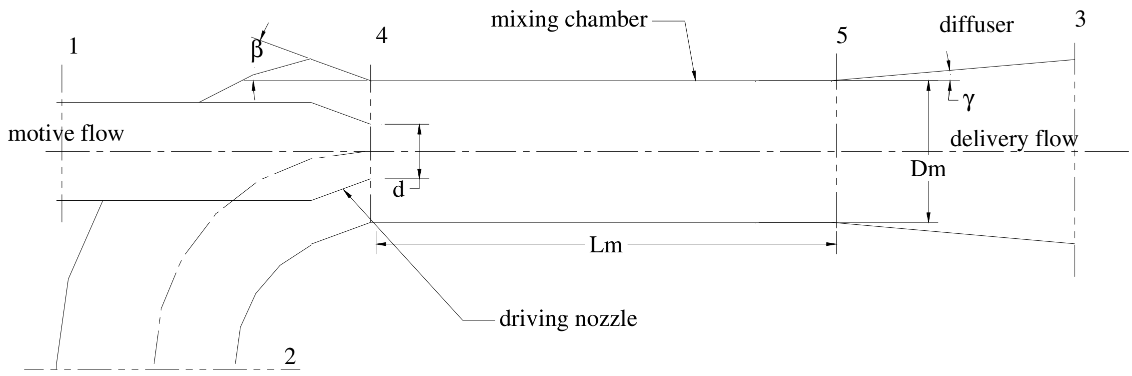
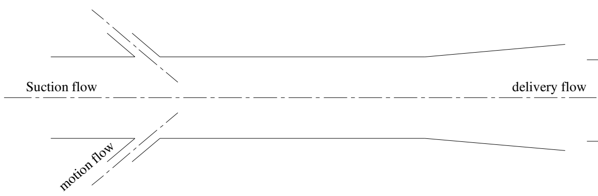


Fig. (1-a) Central drive jet pump with closed suction chamber

Fig. (1-b) A jet pump with open suction chamber

The jet pump can also be classified according to the number of driving nozzles as single nozzle or multi-nozzles (peripheral nozzles pump) as shown **Fig. (2-b)**. Also, it can be classified according to the driving and driven fluid, as liquid-liquid jet pump in which the driving fluid is liquid and the suction fluid is also liquid, on the same bases there are also liquid-gas; liquid-solid (slurry); gas-gas; gas-liquid and gas-solid jet pumps.



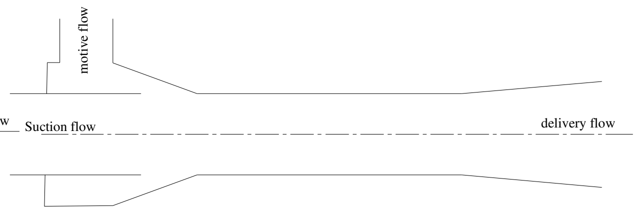


Fig. (2-b) Peripheral nozzle pump **Fig. (2-a) Annular jet pump**

The jet pump performances affected by some dimensionless parameters depending on the dimensions of the pump. The most important parameters are as follows:

$$\text{The area ratio } R = \frac{\text{The area of the driving nozzle}}{\text{The area of the mixing chamber}} \quad ,$$

$$\text{The nozzle distance ratio } X = \frac{\text{The distance between the tip of the driving nozzle to the beginning of the parallel part of mixing chamber}}{\text{The nozzle diameter}}$$

$$\text{and the mixing chamber length ratio } L = \frac{L_m \ \text{The length of the mixing chamber}}{D_m \ \text{The diameter of the mixing chamber}}$$

The performance of the jet pump can be described with respect to the following dimensionless factors:

$$\text{The flow ratio } M = \dot{m}_s/\dot{m}_n = \frac{\text{The mass flow rate of the suction fluid}}{\text{The mass flow rate of the driving fluid}}$$

$$\text{The pressure ratio } \delta = \frac{H_{delivery} - H_{suction}}{H_{driving} - H_{delivery}} = \frac{\text{Pressure increase in suction fluid}}{\text{Pressure decrease in driving fluid}}$$

and the efficiency of the jet pump $\eta = MN$.

The plot of the (M-N) curve indicates the behavior of the jet pump under various conditions. Although the jet pump efficiency relatively low compared by the centrifugal pump because of many losses of power involved in the mixing process besides friction in the diffuser and various parts of the pump, it has many applications in which the efficiency becomes of secondary importance.

THE THEORETICAL STUDY

The theory has been based on the application of the basic equations of fluid mechanics such as; continuity, momentum and energy equations. First there are some assumptions has been taken in consideration as:

- Incompressible one-dimensional flow.
- The suction and delivery flow are homogenous with relative density S_s and S_d, respectively.
- Particles have only kinetic energy.
- The mixing process is completed at the end of the mixing chamber.

From the geometry of the jet pump the following relations may be written as:

$A_d = A_n + A_s,\quad A_s/A_d = 1\text{-}R,\quad A_n/A_s = R/(1\text{-}R)$ (1)

The suction mass flow rate is composed of two components: the water phase $m^{\cdot}_{ws}$ and the solid phase $m^{\cdot}_{\acute{s}}$ i.e. $m^{\cdot}_s = m^{\cdot}_{ws} + m^{\cdot}_{\acute{s}}$ and also, $m^{\cdot}_d = m^{\cdot}_{wd} + m^{\cdot}_{d'}$ (2)

From the continuity equation $m^{\cdot}_d = m^{\cdot}_n + m^{\cdot}_s$ (3)

Let $C_{ws} = m^{\cdot}_{\acute{s}}/m^{\cdot}_n$ (the solids concentration ratio at suction), and (4)

$C_{wd} = m^{\cdot}_{d'}/m^{\cdot}_s$ (the solids concentration ratio at delivery),

$= C_{ws}m^{\cdot}/(1+m^{\cdot})$ (5)

From Govatos [1] the values of γ_s and γ_d are as follows:

$\gamma_s = C_{vs}\,(\gamma_{\acute{s}}\text{-}\gamma_w)\gamma_w,\qquad \gamma_d = \gamma_w\gamma_s(1+M)/(\gamma_s+M\gamma_w)$ (6)

And from the above relations we find the following:

$V_s/V_n= MR/(S_s(1\text{-}R)),$ (7)

$V_d/V_n= R\,(1+M)/S_d,$ (8)

$V_s/V_d = M\,(S_d/S_s)/(1\text{-}R)(1+M)$ (9)

$m^{\cdot}_n/A_d = R\rho_w V_n$ (10)

Then applying the energy equation between points 1&4, as shown in **Fig. (1-a)** we get:

$H_1 = P_1+ 0.5\rho_w V^2_n+ \gamma_w Z_1= P_4+ 0.5\rho_w V_n^2 + \gamma_w Z_4 + \gamma_w\,(h_1+h_2)$ (11)

As the datum coincide with the jet pump centerline then $Z_1=Z_3=Z_4=Z_5=0$ and H_1 becomes

$H_1=P_1+ 0.5\rho_w V^2_n =P_4+ 0.5\rho_w V_n^2 + \gamma_w\,(h_1+h_2)$ (12)

Again applying the energy equation between points 2&4

$H_2=P_2+ 0.5\rho_S V^2_2 + \gamma_S Z_1 =P_4+ 0.5\rho_S V_S^2 + \gamma_S\,(h_3+h_4)$ (13)

Then applying the energy equation between points 5&3

$H_5=P_5+ 0.5\rho_d V^2_d =P_3+ 0.5\rho_d V_3^2 + \gamma_d h_5 = H_3 + \gamma_d h_5$ (14)

Where h_1 is the head loss in the driving line before the driving nozzle

From Darcy's equation $h_1= (4f_1l_1/d_1)(V_1^2/2g)$ (15)

We will put all head loss in terms of $(V_n^2/2g)$ i.e. $h_I = k_I\,(V_n^2/2g)$ (16)

h_2 is the head loss in the driving nozzle expressed experimentally[6] as

$h_2= ((1/C_n^2)\text{-}1)\,(V_n^2/2g)$ then $k_2= (1/C_n^2)\text{-}1$ (17)

h_3 is the head loss in the suction nozzle expressed experimentally as

$h_3= ((1/C_s^2)\text{-}1)\,(V_s^2/2g)$ (18)

$$= ((1/C_s^2)-1)(V_s/V_n)^2(V_n^2/2g) \quad k_3 = ((1/C_s^2)-1)(V_s/V_n)^2 \tag{19}$$

From eq. (7) $k_3 = ((1/C_s^2)-1)(MR/(S_s(1-R))^2$ (20)

h_4 is the head loss in the suction bend expressed experimentally as

$$h_4 = k_b(V_2^2/2g) = k_b(A_s/A_2)^2(V_2/V_n)^2(V_n^2/2g) \tag{21}$$

$$k_4 = k_b(A_s/A_2)^2(MR/(S_s(1-R))^2 \tag{22}$$

h_5 is the head loss in the diffuser expressed experimentally as

$$h_5 = (1-\eta_{dif})(1-R_{dif})(V_5^2/2g) = (1-\eta_{dif})(1-R_{dif})(V_d/V_n)^2(V_n^2/2g) \tag{23}$$

where $V_5 = V_d$

$$k_5 = (1-\eta_{dif})(1-R_{dif}^2)(V_d/V_n)^2 = (1-\eta_{dif})(1-R_{dif}^2)(R(1+M)/S_d)^2 \tag{24}$$

h_6 is the head loss in the mixing chamber from section 4 to 5 and we can't apply Darcy's equation directly here because the mixing process marked by a rise in static pressure. This static pressure starts at section 1 and reaches its peak value then it starts to decrease so we must not increase mixing chamber length beyond this section.

According to Mueller [6] we will apply the modified Darcy's equation as follows

$$h_6 = (4f_6L/D)(V^2/2g) \qquad \text{where } V = 0.5(V_d^2+V_s^2)^{0.5} \tag{25}$$

and f_6 has the same value as the flowing fluid as water, then

$$V^2 = 0.25V_d^2(1+(V_s/V_d)^2) \text{ and } h_6 = (f_6L/D)(1+(V_s/V_d)^2)(V_d/V_n)^2(V_n^2/2g) \tag{26}$$

$$k_6 = (f_6L/D)(1+(MR/(S_s(1-R)))^2)(R(1+M)/S_d)^2 \tag{27}$$

by applying the momentum equation between points 4&5 shown in **Fig. (3).**

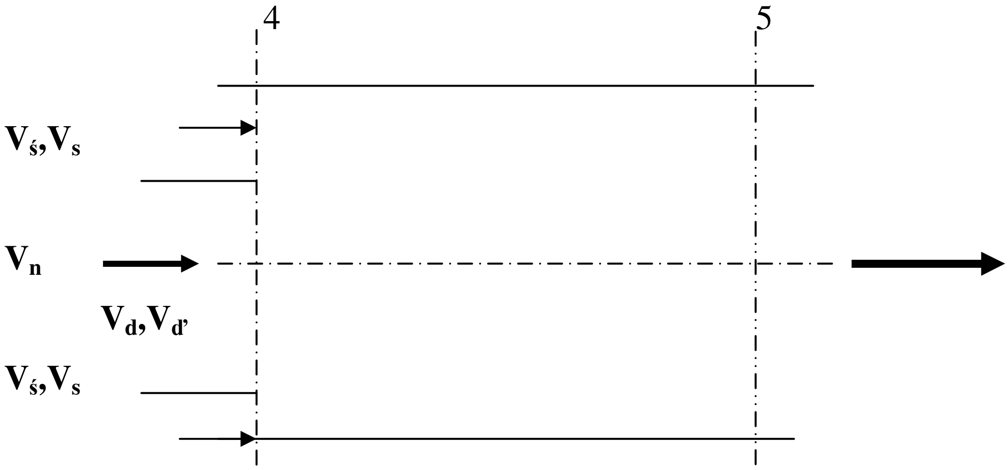


Fig. (3) Schematic diagram of the mixing chamber

$$P_4A_n + P_4A_s - P_5A_d - \gamma_d h_6 A_d = \dot{m}_{wd}V_d + \dot{m}_{d'}V_{d'} - \dot{m}_1V_n - \dot{m}_{ws}V_s - \dot{m}_{\acute{s}}V_{\acute{s}} \tag{28}$$

Where $\dot{m}_{\acute{s}} - \dot{m}_{d'}$, $\dot{m}_{wd} = \dot{m}_d - \dot{m}_{d'}$, $\dot{m}_{ws} = \dot{m}_s - \dot{m}_{\acute{s}}$, $V_{\acute{s}} = \mu_s V_{\acute{s}}$ and $V_{d'} = \mu_d V_d$ (29)

By rearranging the equation and getting $m^{\cdot}_n$ out of the parentheses we get:

$$(P_4-P_5) = (m^{\cdot}_n /A_d)[((1+M)-C_{ws}(1-\mu_d))V_d- V_n - (M- C_{ws} M(1-\mu_s))V_s]-\gamma_d h_6 \quad (30)$$

Refer to eqs. (7-10) and put h_6 from (26)

$$(P_4-P_5) =\rho RV_n [((1+M)-C_{ws}(1-\mu_d))V_d- V_n-(M-C_{ws}M(1-\mu_s))V_s]-\gamma_d k_6(V_n^2/2g)(31)$$

$$(P_4-P_5) = \rho RV_n [t_1V_d- V_n-t_2V_s]-\gamma_d k_6 (V_n^2/2g) \quad (32)$$

Where $t_1= (1+M)-C_{ws}(1-\mu_d)$, $t_2= M-C_{ws}M(1-\mu_s)$ (33)

Take V_n out of the parentheses & substitute from eqns (7) and (8) into eqn (32) we get

$$(P_4-P_5) = V_n^2/2g[2\gamma_w Rt_3 + \gamma_d k_6], \quad (34)$$

Where $t_3 = (R(1+M)/S_d)t_1-1-(MR/(S_s(1-R))t_2$

The efficiency of the jet pump can be defined as the power given to the suction fluid to the power given by the motive fluid.

The power given to the suction fluid is $Q_s(H_3-H_2)$ and (35)

The power given by the motive fluid is $Q_n(H_1-H_3)$ (36)

Then $\eta= Q_s(H_3-H_2)/ Q_n(H_1-H_3)$

$$=(Q_s\gamma_s /Q_n\gamma_w)(((H_3-H_2)/\gamma_s)/((H_1-H_3)/\gamma_w))=MN \quad (37)$$

Where $M= Q_s\gamma_s /Q_n\gamma_w$, and $N=((H_3-H_2)/\gamma_s)/((H_1-H_3)/\gamma_w)$ (38)

Let $\delta = (H_3-H_2)/(H_1-H_3) = (\gamma_s/\gamma_w)N$ (39)

Substitute from eqns (12), (13) and (14)in eq (39) we get:

$$\delta = \frac{(P_5+0.5\rho_d V^2{}_d-\gamma_d h_5)- (P_4+0.5\rho_S V_S^2+\gamma_S(h_3+h_4))}{(P_4+0.5\rho_w V_n^2+ +\gamma_w(h_1+h_2)) -(P_5+0.5\rho_d V^2{}_d-\gamma_d h_5)} \quad (40)$$

$$\delta = \frac{(P_5-P_4)+0.5(\rho_d V_d^2-\rho_s V_s^2)-\gamma_d h_5-\gamma_s(h_3+h_4)}{(P_4-P_5)+0.5(\rho_w V_n^2-\rho_d V_d^2)+\gamma_w(h_1+h_2)+\gamma_d h_5} \quad (41)$$

Substitute from eqn (34) in (41) we get and taking γ_s as a common part of the numerator & γ_w as a common part of the denominator

$$\delta = \frac{\gamma_s[-2Rt_3/S_s-(S_d/S_s)k_6+(S_d/S_s)(V_d/V_n)^2-(V_s/V_n)^2-(S_d/S_s)k_5-(k_3+k_4)]}{\gamma_w[2Rt_3-S_d k_6+1-S_d(V_d/V_n)^2 +k_1+k_2+S_d k_5]} \quad (42)$$

$$\delta = \gamma_s N/\gamma_w \tag{43}$$

And as

$$N = \frac{-2Rt_3/S_s-(S_d/S_s)k_6+(S_d/S_s)(V_d/V_n)^2-(V_s/V_n)^2-(S_d/S_s)k_5-(k_3+k_4)}{2Rt_3-S_dk_6+1-S_d(V_d/V_n)^2+k_1+k_2+S_dk_5} \tag{44}$$

Substitute from eqns (7) and (9), in eqn (44) we get

$$N= \frac{-2Rt_3/S_s+R^2(1+M)^2/S_s\, S_d-(MR/(S_s(1-R)))^2-(S_d/S_s)(k_5+k_6)-k_3-k_4}{2Rt_3+1-R^2(1+M)^2/\, S_d+S_d(k_5+k_6)+k_1-k_2} \tag{45}$$

Substitute from eqn (45) in eqn (37) we get

$$\eta = \frac{M[-2Rt_3/S_s+R^2(1+M)^2/S_s\, S_d-(MR/(S_s(1-R)))^2-(S_d/S_s)(k_5+k_6)-k_3-k_4]}{2Rt_3+1-R^2(1+M)^2/\, S_d+S_d(k_5+k_6)+k_1-k_2} \tag{46}$$

RESULTS AND DISCUSSION

A computer program had been made to evaluate the performance of the central jet pump, which had developed in the preceding section. The results obtained in the form of performance curves of (N versus M) and (η versus M) for different area ratio of 0.217, 0.338 and 0.5. Also for different suction volumetric concentration ratio (C_v) of 0.1, 0.2, 0.3and 0.4. A comparison of the present data and data from other researchers has been done, also during the current research.

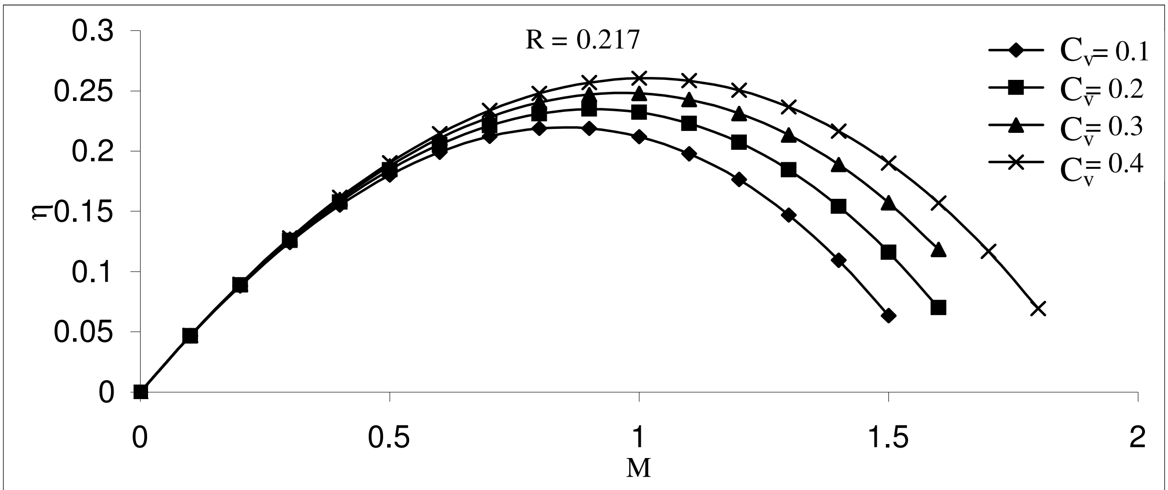


Fig. (4-a) Effect of C_v on slurry jet pump efficiency

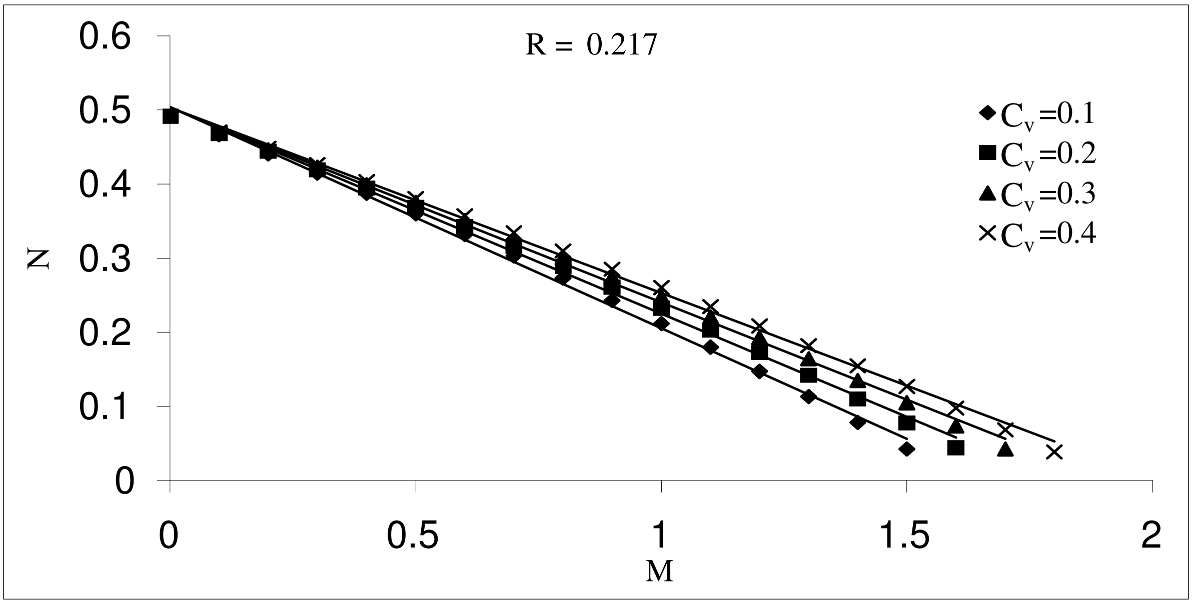


Fig. (4-b) Effect of C_v on slurry jet pump performance

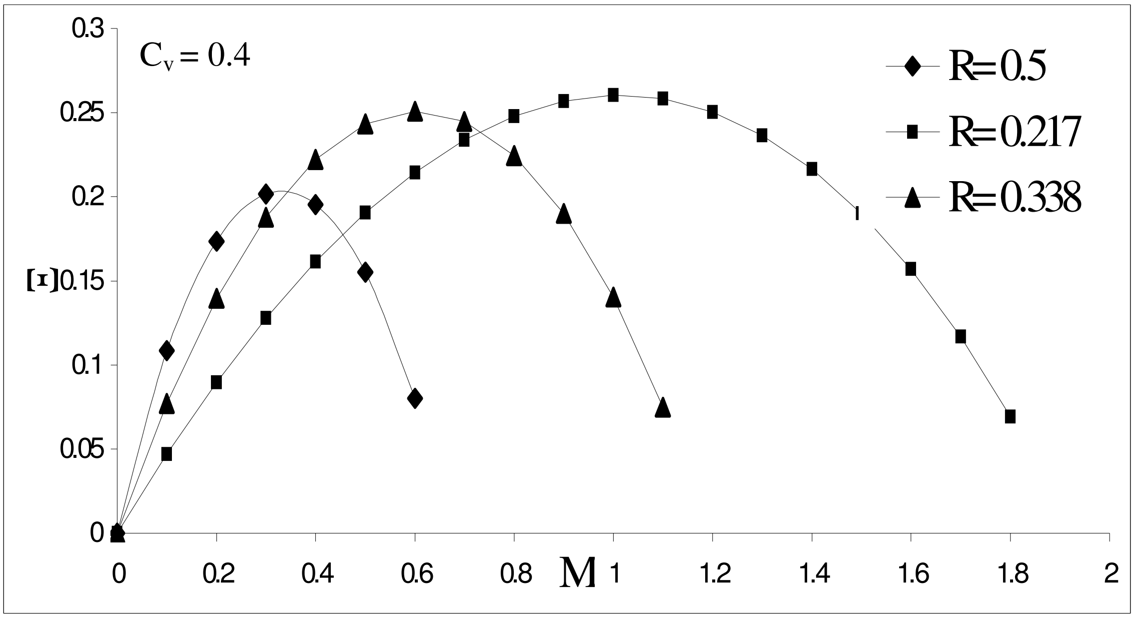


Fig. (5-a) Effect of area ratio R on slurry jet pump efficiency

Fig. (4-a) shows the relation between (M- η) of (R) = 0.217and for different C_v such as 0.1, 0.2, 0.3 and 0.4. It shows that the efficiency increases with the increase in C_v. For small M the curves almost identical, and it seems reasonable as the effect of C_v depends on the value of M. **Fig. (4-b)** shows (M-N)curves for the same data as **Fig. (4-a),** it indicates that (N) inversely proportional to (M) also show that as C_v increases (N) increases for the same (M) values. This agrees well with the results of Shaheen [3].

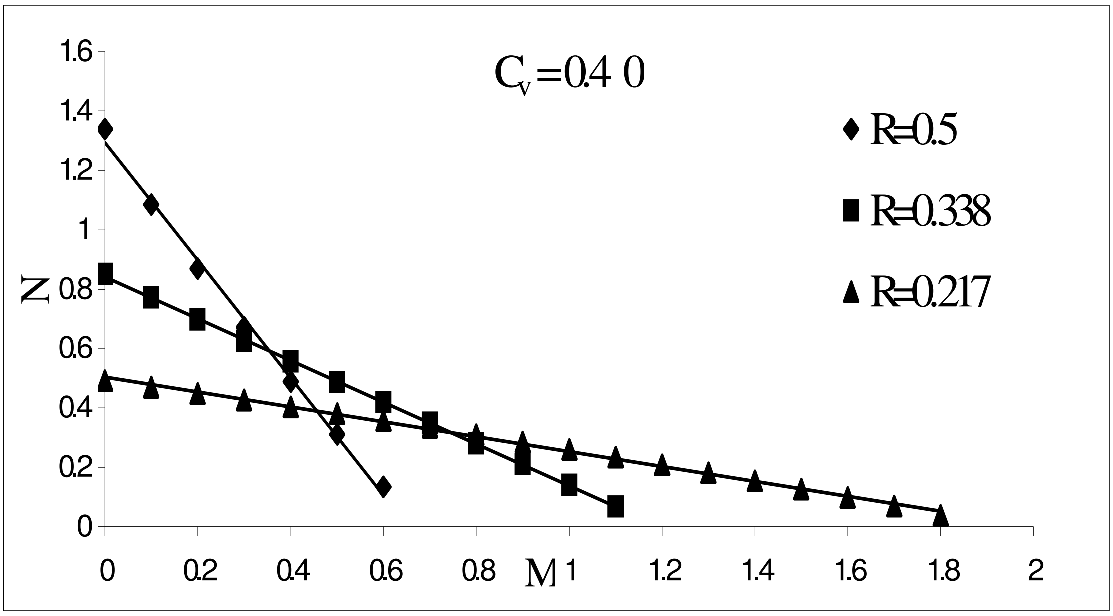


Fig. (5–b) Effect of area ratio R on slurry jet pump performance

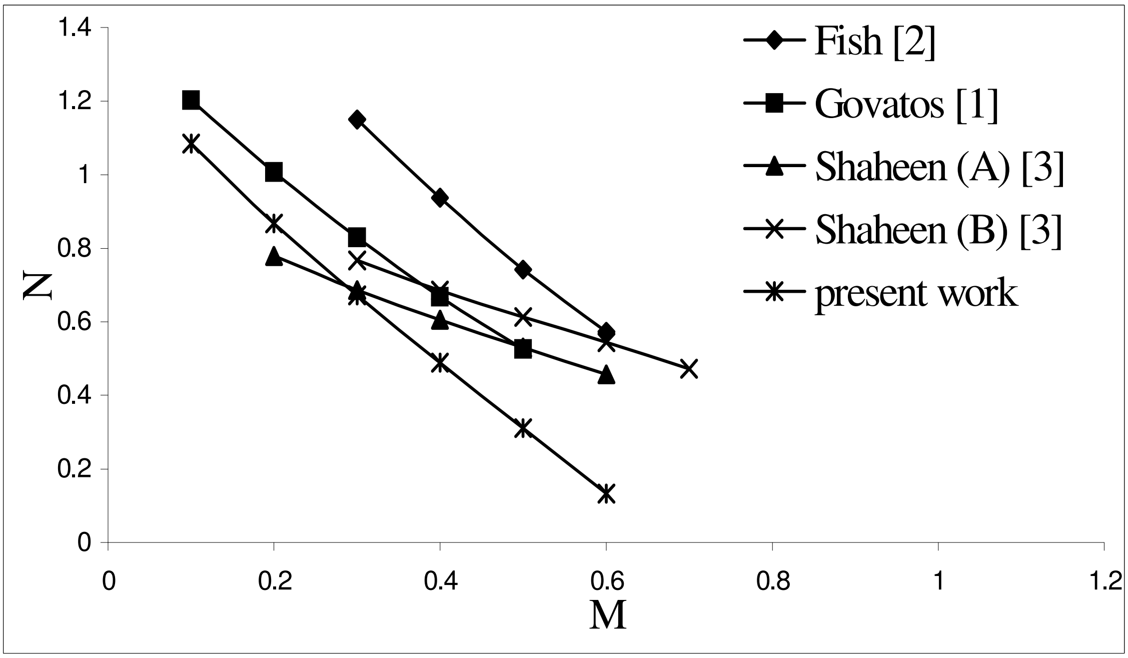


Fig. 6 Comparison between present calculated data with experimental data from Zandi and Govatos [9],Shaheen [3]and Fish [2].

Fig. (5-a) shows the (M- η) curves of C_v = 0.4 for different R= 0.217, 0.338 and 0.5. It shows that the lower the R the wider the curve, as (R) increases the value of (M) corresponding to maximum ηdecreases. **Fig.(5-b)** shows the (M-N) curves of C_v = 0.4 for different R. It shows that as R increases the slope of the curve increases. Also, it shows for the same (M), (N) increases with increase in R up to M = 0.33.

Fig. (6) compares the variation of the head ratio N versus the mass flow ratio M of the present results at R = 0.5 and C_v = 0.4 with the experimental results of other researches; Fish [2] with R = 0.444 and C_{vd} =0.4; Zandi and Govatos [9] with R = 0.5

and C_{vd} = 0.104; Shaheen [3] with R = 0.473 and for curve (A) with C_{vd} = 0.03 and for curve (B) with C_{vd} = 0.08. The higher values of Fish [2] data may be because he used cast steel shot with specific gravity of 6.6. The close of the data of the other research may attributed to utilization of the same solid specific gravity (sand of S=2.64) and the area ratio in the same range. The present work shows higher values than Shaheen [3] for the lower value of (M). This may be due to the higher suction volumetric concentration ratio used in the present work, however for higher values of Shaheen [3] work have higher values of (N) for the same (M). It may be due to the suction flow entrained in the suction chamber. In Shaheen [3] the suction flow enters under gravity while in the present work the suction flow enters against the gravity. For this reason, in the higher values of (M) increase the power required in sucking the suction flow which affects the pump efficiency.

CONCLUSION

The formula of jet pump efficiency agrees well with the experimental work of other researchers. Further experimental work is needed to insure the reliability of the equation. Thus the small deviation may be due to the different experimental conditions such as solid specific gravity, solid grading, suction concentration and the roughness of the materials used.

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