A CENTRAL-TYPE JET PUMP MODEL FOR WHEAT GRAINS REMOVING FROM WATER CHANNELS

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ABSTRACT

The aims of this research were (i) to design a central-type jet pump model to remove wheat grains from water channels and (ii) to establish a test-rig for jet pump model performance test. Experiments were performed using wheat grains and water.

The experiments deals with the performance and choice of suitable nozzle distance ratio and area ratio (area of motive flow nozzle to area of mixing chamber) for a central-type jet pump model with the following parameter: 7.25 mixing chamber length ratio (length of mixing chamber to mixing chamber diameter), diffuser angle of 5.5° and wheat concentration ratio from 5% to 35%. The experimental rig was constructed such a way it can be changing the driving nozzle diameter and the distance between the nozzles to throat. 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 R= 0.155, 0.25 and 0.4). The effect of nozzle to throat spacing to nozzle diameter ratio "X" with values of 1, 1.5 and 2, on the jet pump performance was also tested under different flow rates and motive pressures.

From the experimental work, the beast and suitable nozzle distance ratio and area ratio are obtained. The effect of wheat concentration on jet pump efficiency was also measured. The research proved the ability to use a central-type jet pump model successfully for the first time for wheat grains removing from water channels up to 35%.

The results allow prediction of how a similar practical unit behaves in order to remove the wheat grains from the bottom of water channels.

Keywords: Jet pump, area ratio, nozzle distance ratio, wheat grains, water channels.

1. INTRODUCTION

The jet pump is being used in many fields for different purposes because of its simple construction and easy operation. Jet pumps have been used frequently in deep pumping, booster pumping, dredging, tail water suppressors, as a recirculation device in atomic reactors, remove oils from water channels and in many other systems [1 and 2]. The operating principle of a jet pump is based on the transfer of momentum and kinetic energy from a high-velocity primary fluid to pump a secondary (or suction) fluid from a low pressure to a high pressure [3]. The main components of a jet pump are shown in Fig.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.

If the jet pump has a driving line in the center and a suction line on the outside it is called a "central jet pump" type. In contrast to this, there is another type of jet pump which has suction line in the center and annular driving jet on the outside it is called "annular jet pump" type. Shimizu et al [4] investigated experimentally the relation between configuration and performance of the annular type jet pump and compared it with that of the central jet pump. They studied also the effect of swirl component in the driving jet, and compared it with the result without swirl component.

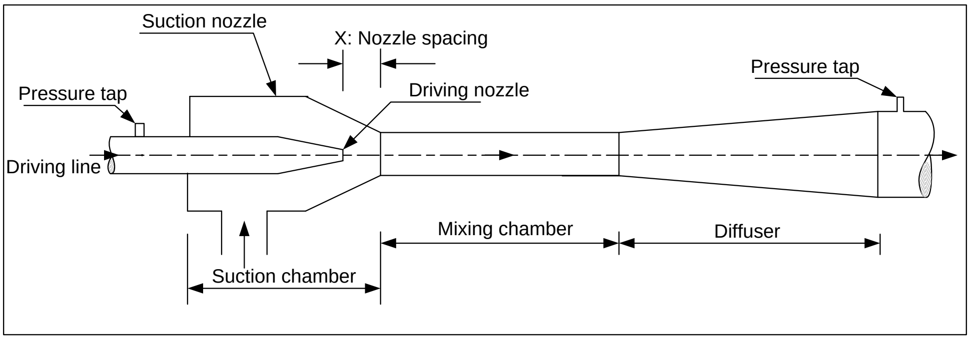


Figure (1) Assembly of jet pump

Zandi and Govatos [5] 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 [6] 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 [7] extended his previous work with Zandi [5] where the performance equations for slurry jet pump have been developed. Richardson [8] carried out full-scale laboratory tests on a center drive water and slurry jet pump. El-Sibaie and El-Haggar [9] 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 [10] 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-Sawaf et al [11] 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 [12] 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 [13] studied theoretically and experimentally the effects of some parameters on the performance of slurry jet pump using four different area ratios. Iran et al [14] 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 ratio 0.35 are the most efficient. Jet pumps are also frequently used under conditions where the primary and secondary fluids are different. Cunningham [15] 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 [16] 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. The jet pump can be used in many applications such as refrigeration systems Aphornratana and Eames [17] studied the effect of primary nozzle exit position on system performance by using an ejector with movable primary nozzle. It was found that the nozzle exit position could be adjusted in order to maximize the system performance when the operating conditions were difference from the design point. S.He et al [18] presented briefly describes ejector including fundamental principle, flowing and mixing mechanism and the method of model establishment. Then various models consisting of ideal assumptions, governing equations, auxiliary conditions, solution methods and main results are presented. The models can be classified into two main categories: (i) steady thermodynamic models which can be further subdivided into single-phase flow model and two-phase flow model and (ii) dynamic models which are also subdivided according to the flowing phases considered. They concluded that the dynamic models have higher prediction precision and give more information compared with the steady thermodynamic models. In addition, the simplified empirical and semi-empirical models based on measured data are briefly discussed. This review is useful for understanding the evolution process and the current status of the mathematical models on ejector and highlighting the key aspects of model improvement such as the mixing mechanism, the capture of the shock wave, etc. J. Fan et al [19] studied the optimization of jet pump design using computational fluid dynamics analysis. They design initial jet pump using an analytical approach and its efficiency was improved using an efficient and accurate computational fluid dynamics model of the compressible turbulent flow in the pump. They concluded that this prediction agreed well with corresponding experimental data. Parametric studies were performed to determine the influence of the pump's geometry on its performance and the high fidelity CFD solutions were used to build surrogate models of the pump's behavior using the moving least squares method. Global optimization was carried out using the surrogates. This approach resulted in pump efficiency increasing from 29% to 33% and enabled the energy requirements of the pump to be reduced by over 20%.

The aim of this work was to experimentally investigate the effects of area ratio and the distance between the driving nozzle and the beginning of mixing chamber on the performance of a central-type jet pump remove the wheat grains from the water channels.

2. STATEMENT OF THE PROBLEM

The Nile River and its branches spans from Aswan in south to Mediterranean Sea in north. There is river transport processes occurred. Sometimes is required to transport Petroleum products such as diesel, etc. and some of the crystals and phosphate as well as vegetables, fruit and some grain such as wheat and corn, etc.

In this paper the researcher deals with access to the best design of the jet pump (central type jet pump) to removing wheat from the water channels. In case of exposure to drowning in the bottom as a result of wrong or non-transport security.

3. TEST RIG DESCRIPTION AND EXPERIMENTAL PROCEDURE

3.1 Experimental Test Rig

It was specially designed and constructed for this research work. Figure (2) shows the experimental test rig used. 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), (of ± 2% accuracy), then through the pressure transducer (14), (of ± 1.4% accuracy) and finally to the jet pump (9), where a low pressure area 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), (of ± 2.5% accuracy) and to delivery graded tank (20) of external dimensions of 500 x 500 x 1000 mm.

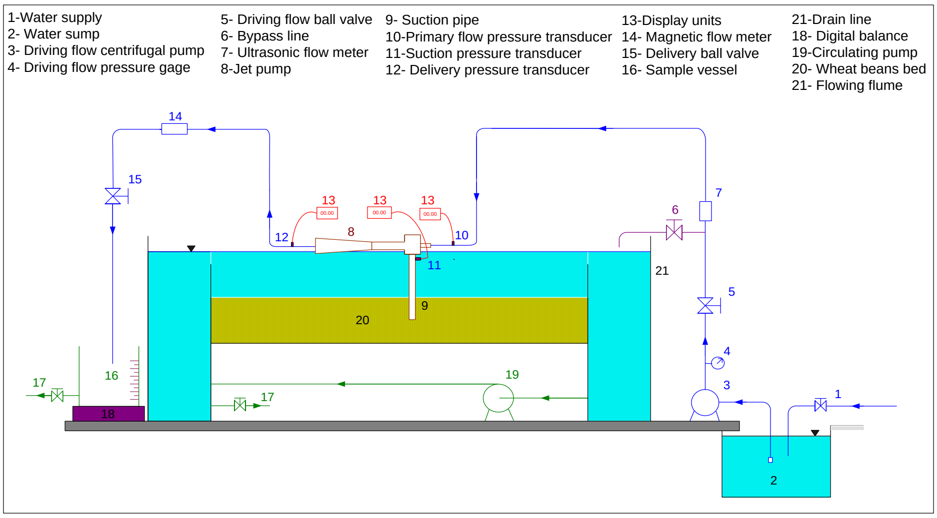


Figure (2) Schematic diagram of experimental test rig

The jet pump (8) shown in Figure (3) is made of steel, and it has three branches, motive, suction and discharge. The motive branch of 1" inch nominal diameter galvanized pipe and flanged to a driving chamber of 63.5 mm diameter and 80 mm long. The diffuser has an angle equal to, $\theta_d=5.5^{\circ}$ and is 197.8 mm long (L_d) with 63.5 mm outlet diameter. The suction branch of 38 mm diameter and 130 mm long. The discharge branch of 63.5 mm diameter and flanged. The geometry of the inlet device is completely free from constrains which apply to centrifugal or other pumps, so that wheat can be induced into the system at high concentration and with greatly reduced or no risk blockage. The assembly, together with a means of adjusting the area ratio of driving nozzles is mounted by flanges. Figure (4) shows different driving nozzle diameter of 10 mm, 12.7 mm and 16 mm, i.e. three different area ratios, R=0.155, 0.25 and 0.4 respectively.

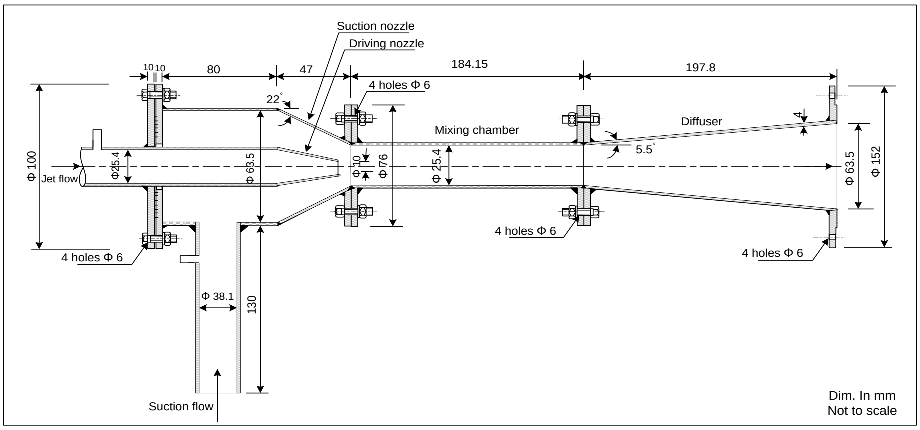


Figure (3) Central type jet pump for wheat beans removal

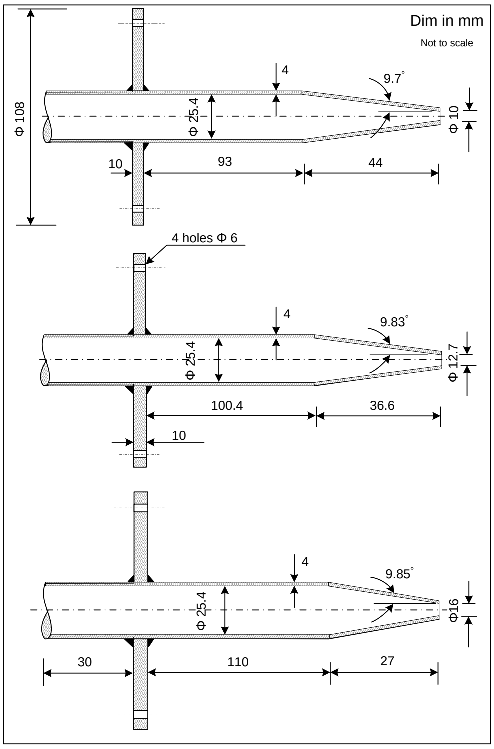


Figure (4) Driving nozzles

3.2 Experimental Procedure

The centrifugal pump is switched on to fill the test loop with the clear water. After a steady state condition is reached for a drive pressure of 10 m H_2O, a specified amount of wheat beans is supplied to the main tank and the readings of the different measuring instruments were recorded. A sample of the discharge mixture flow was collected in a graded tank and balanced by using digital balance to determine the discharge concentration. Then, the jet pump drive pressure is partially changed. Subsequently, different readings of the measuring instruments were recorded and a new sample is taken to determine the corresponding discharge volume flow rate. The preceding steps were repeated every time the jet pump drive pressure valve was partially changed. The other test drive pressure was 15 m, 20 m, and 25 m H_2O respectively.

The area ratio of 0.155, 0.25 and 0.4 were tested under the same working conditions of the motive flow rate, drive head, suction head, delivery head and four distances between the motive flow nozzle exit and the begging of the mixing chamber was test at 1, 1.5 and 2 diameter of driving nozzle. The mixing chamber length ratio was fixed on an optimum mixing chamber length ratio of, L=6.75. The same have been done for the diffuser angle, i.e., the diffuser angle was fixed on an optimum diffuser angle of, θ_d=5.5°.

3.3 Theoretical Basis

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

(a) Flow ratio, $M = \dfrac{Q_s.\gamma_s}{Q_m.\gamma_w}$

(b) Head ratio, $N = \dfrac{(H_d.SG_d - H_s.SG_s)}{(H_m - H_d.SG_d)}$

(c) Jet pump efficiency, η =the ratio of the total energy increase of suction flow to the total energy increase of driving flow as,

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

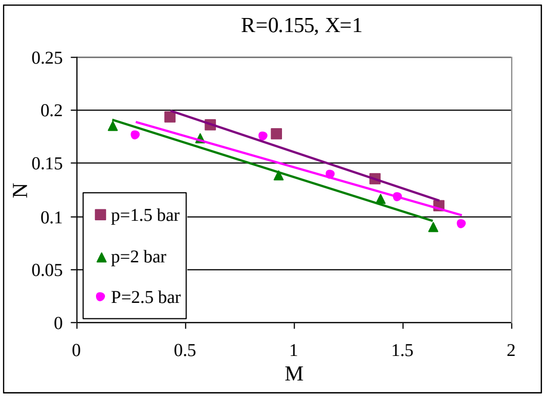
(d) The wheat concentration in the induced flow is calculated by the ratio,

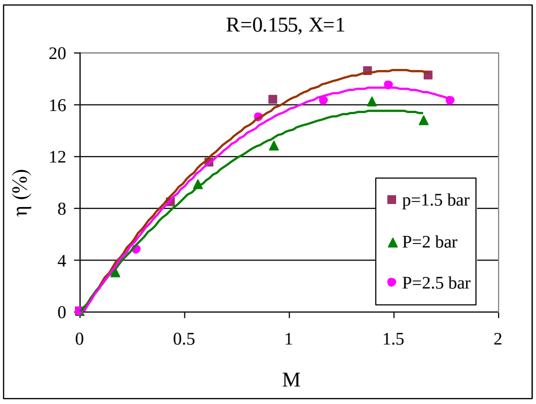
$$C_{vd} = \frac{\gamma_d - \gamma_w}{\gamma_{wh} - \gamma_w}$$

4. THE TEST RESULTS

Main object of the testes is to establish the minimum size of a model unit which is capable of handling the wheat grains from the water channels and that has been proved successfully during the tests. Through the actual test program the design and operating parameters for a practical unit were studied. The results obtained for three area ratios, R=0.155, 0.25 and 0.4 are presented in Figs. (5, 7 and 9) respectively. Each figure consists of graphs of N versus M, and η versus M for several values of X. Figures (6, 8 and 10) show the effect of area ratio on maximum efficiency. These data are cross-plotted from Figs. (5, 7 and 9).

In figures (5, 7 and 9) the maximum efficiency occurred at driving pressure of 1 bar for area ratio of 0.25 and 0.4 while the optimum efficiency occurred at driving pressure of 1.5 bar for area ratio of 0.155, the driving pressure of 1 bar not achieved with area ratio of 0.155 because the small cross section area of this nozzle. A comparison of the area ratio in Figs. (6, 8 and 10) show that the optimum nozzle distance ratio “X”, is close to X=1.5 since the maximum efficiency is higher than the other two driving nozzle distance.





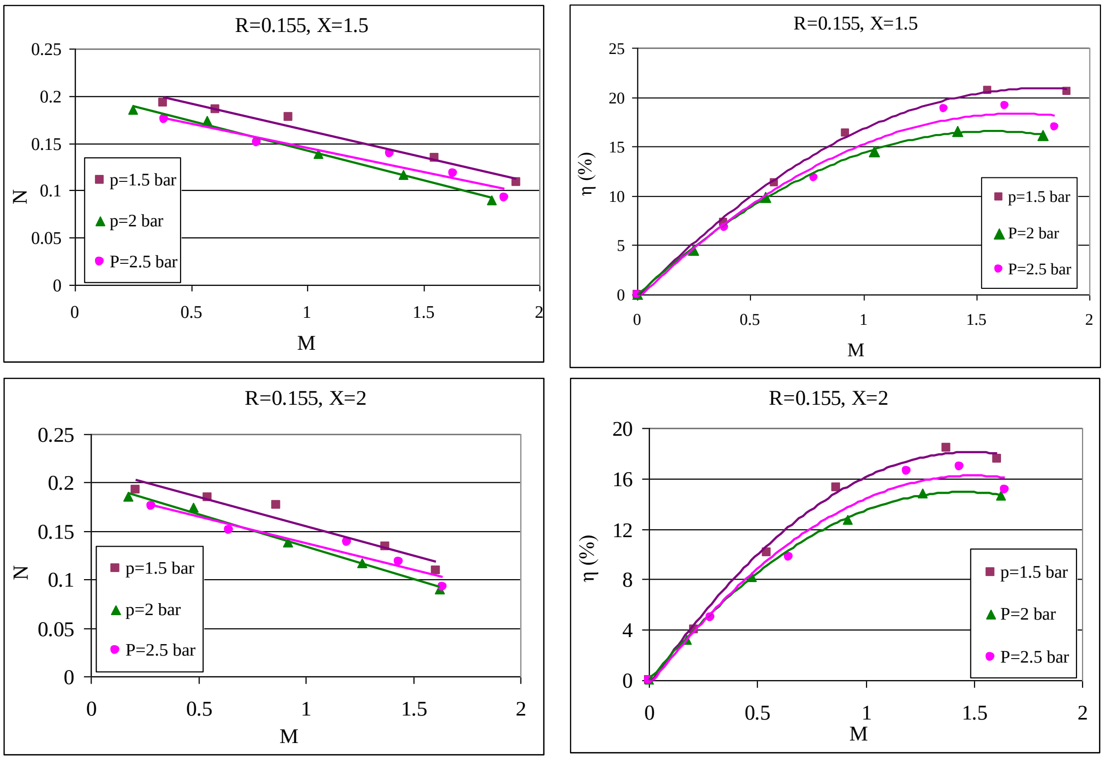


Figure (5) jet pump performance for different driving pressure at area ratio, R=0.155

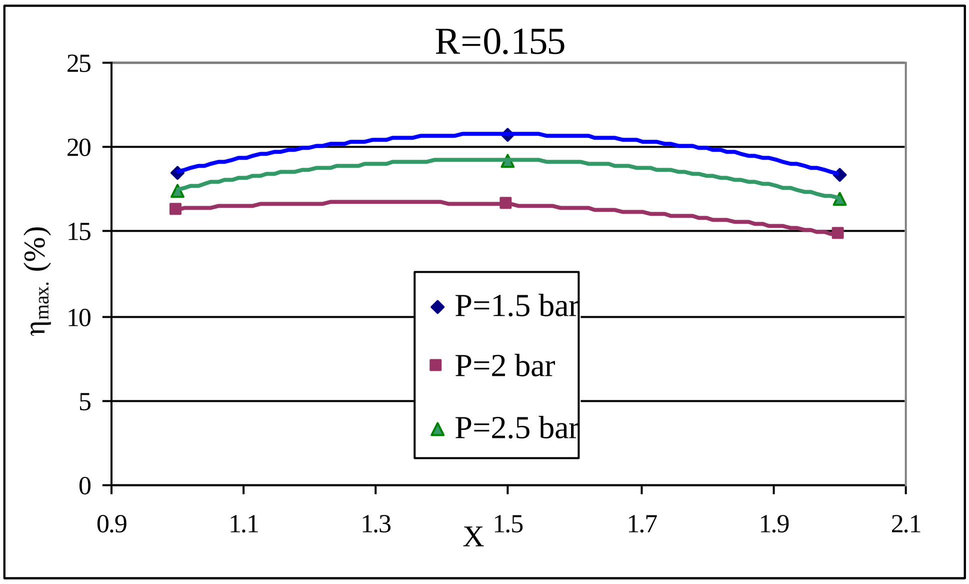


Figure (6) Maximum efficiency versus nozzle distance ratio at different driving pressure for area ratio R=0.155

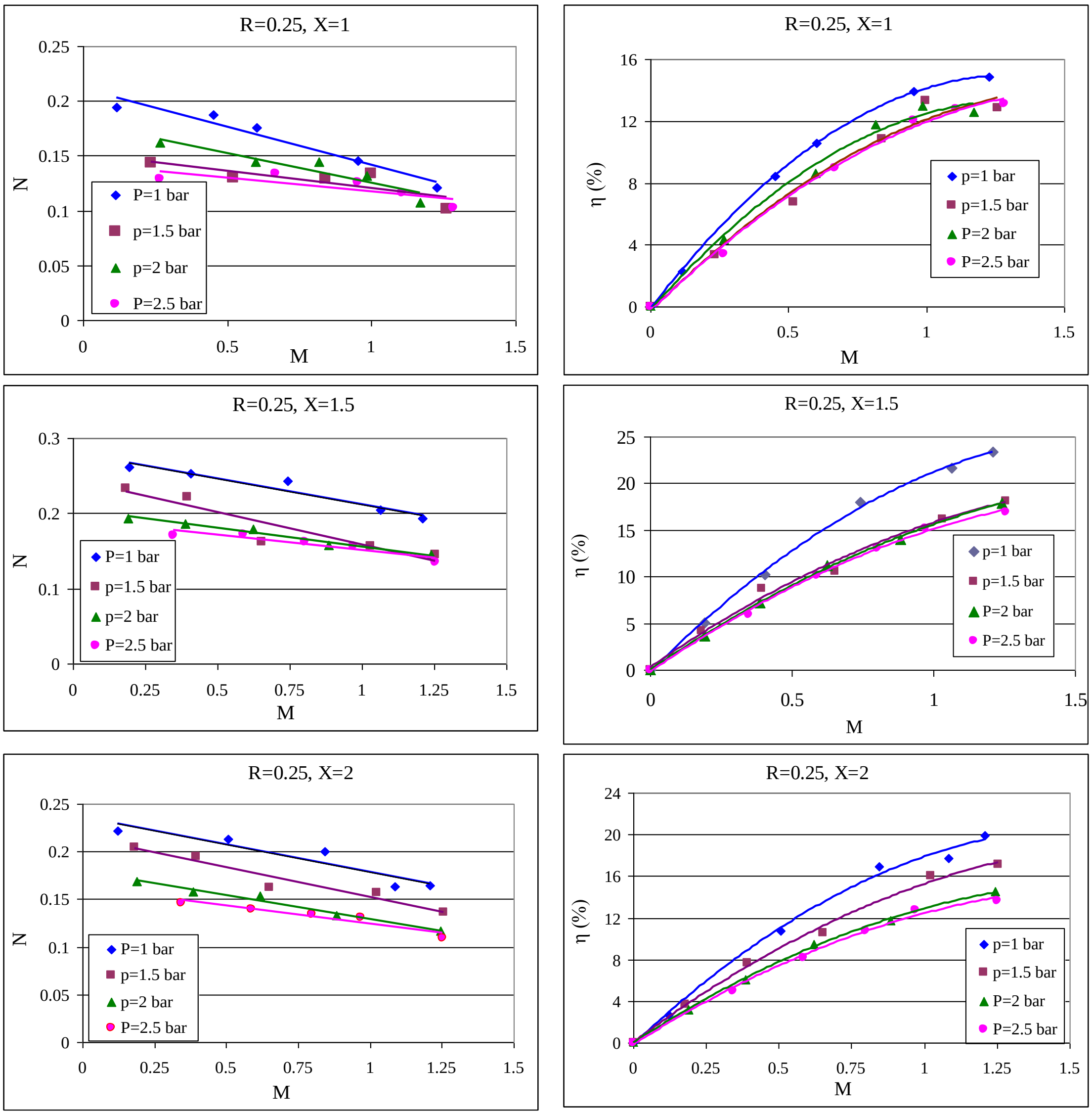


Figure (7) jet pump performance for different driving pressure at area ratio, R=0.25

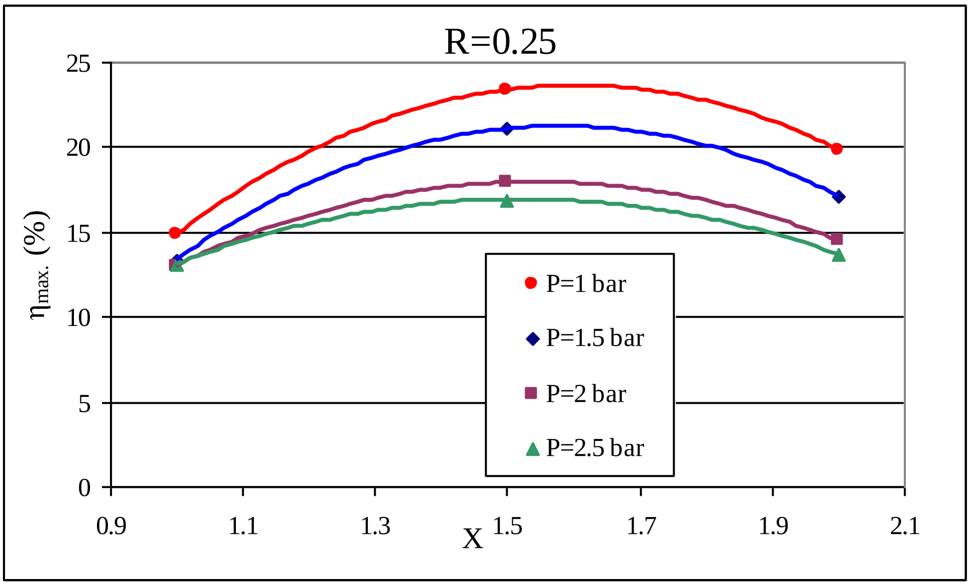


Figure (8) Maximum efficiency versus nozzle distance ratio at different driving pressure for area ratio R=0.25

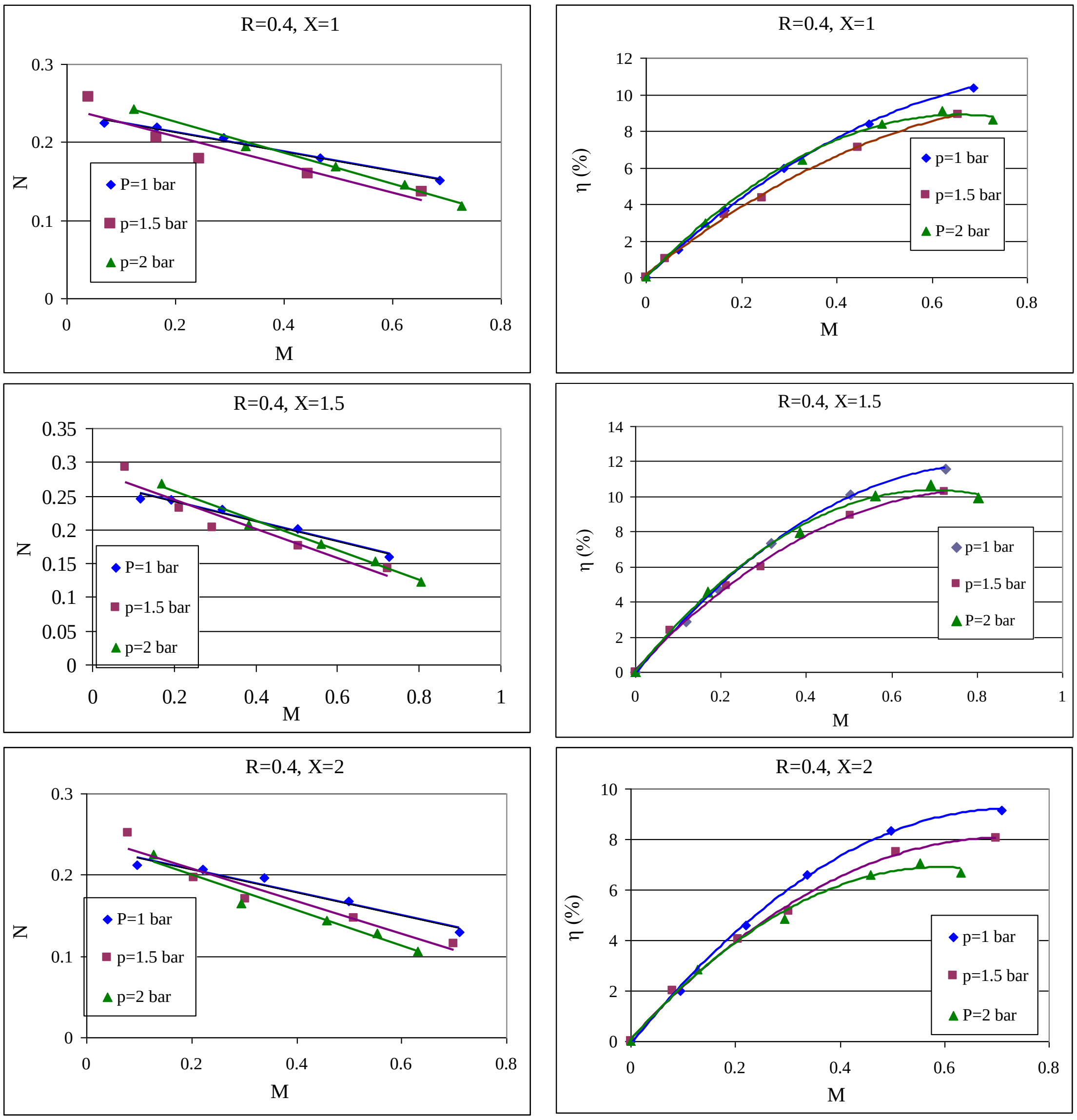


Figure (9) jet pump performance for different driving pressure at area ratio, R=0.4

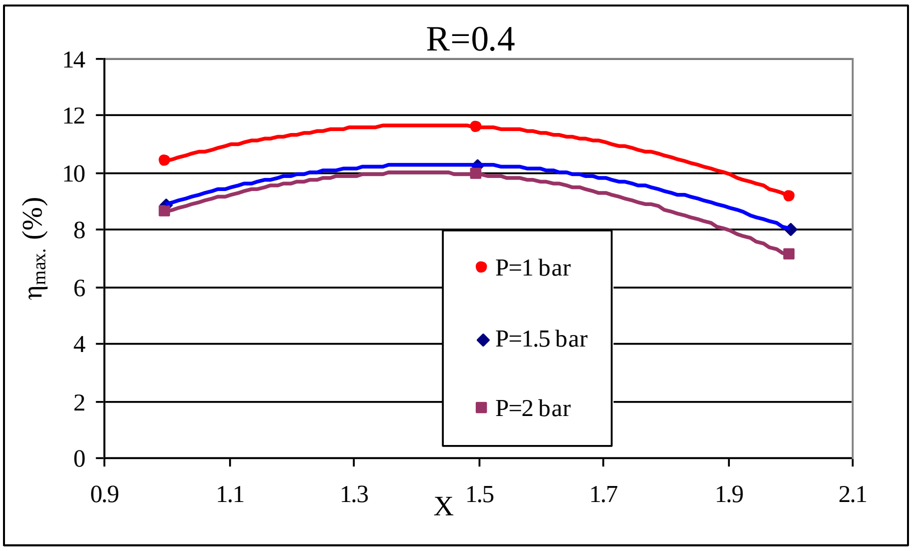


Figure (10) Maximum efficiency versus nozzle distance ratio at different driving pressure for area ratio R=0.4

Figure (11) shows the effect of changing area ratio (R) on the performance of jet pump. From this figure it is illustrate that the area ratio has remarkable effect on the jet pump performance. It is clear from this figure for the same jet pump combination parts that, the efficiency increase with increasing the mass flow rate ratio. The highest values of efficiency and head ratio are for area ratio of 0.155 at X= 1.5 as shown in Fig. (11). It is also clear that the area ratio of 0.25 gives the best performance compared to area ratio 0.4 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 0.4 for the same conditions. On the contrary, the experimental tests reveal that, the higher area ratio gives the lower delivery concentration. This may be because the higher area ratio the higher driving flow rate that dilutes the wheat beans concentration at suction side.

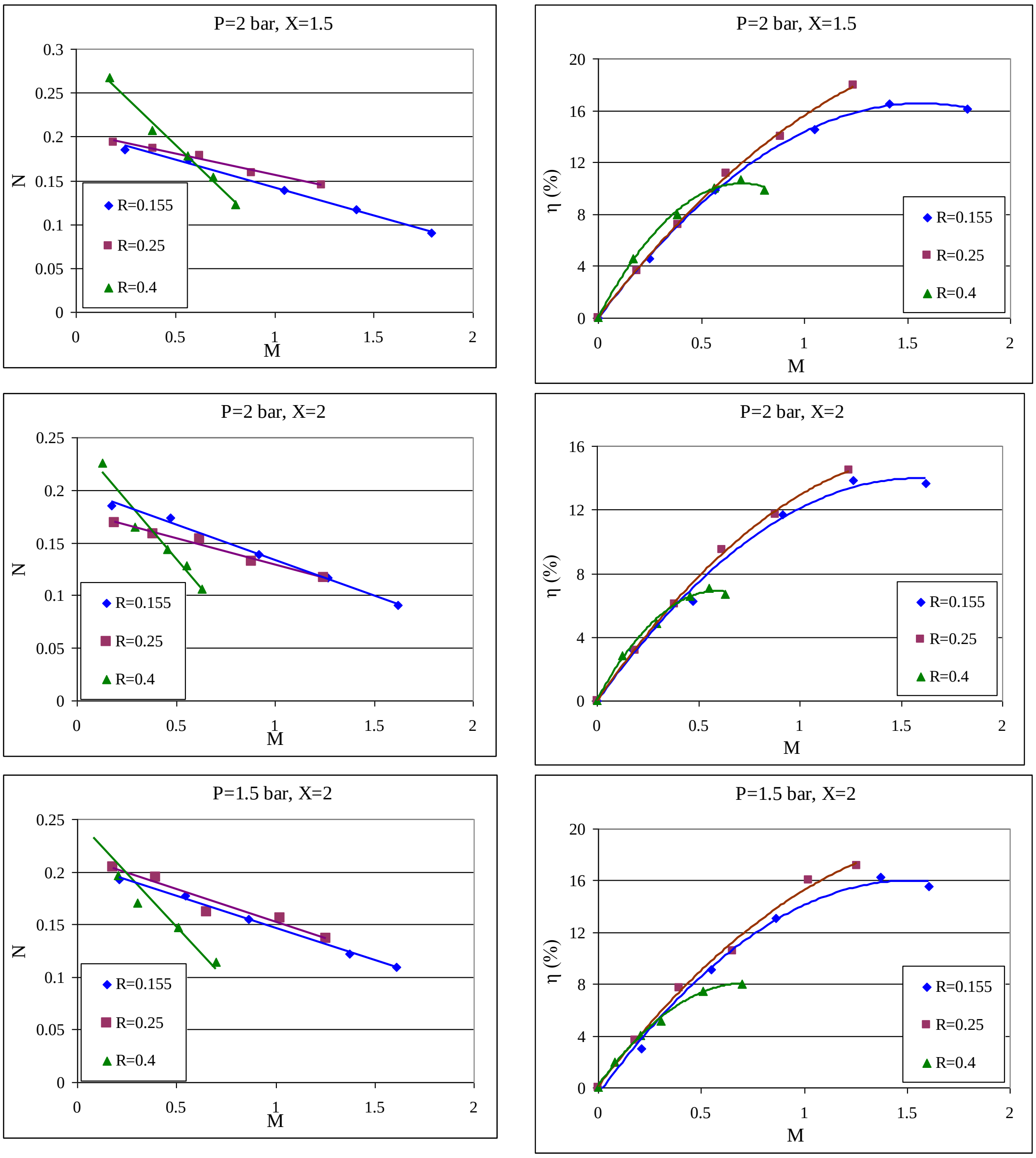


Figure (11) jet pump performance for different area ratio and different nozzle distance

Figure (12) shows the relation between the delivered wheat beans concentration ratios (C_{vd}) with mass flow ratio (M), it is clear from these figure that the higher delivered wheat beans concentration at area ratio R= 0.155, with the distance between the driving nozzle and the beginning of mixing chamber to the driving nozzle diameter X=1.5 at the same mass flow ratio.

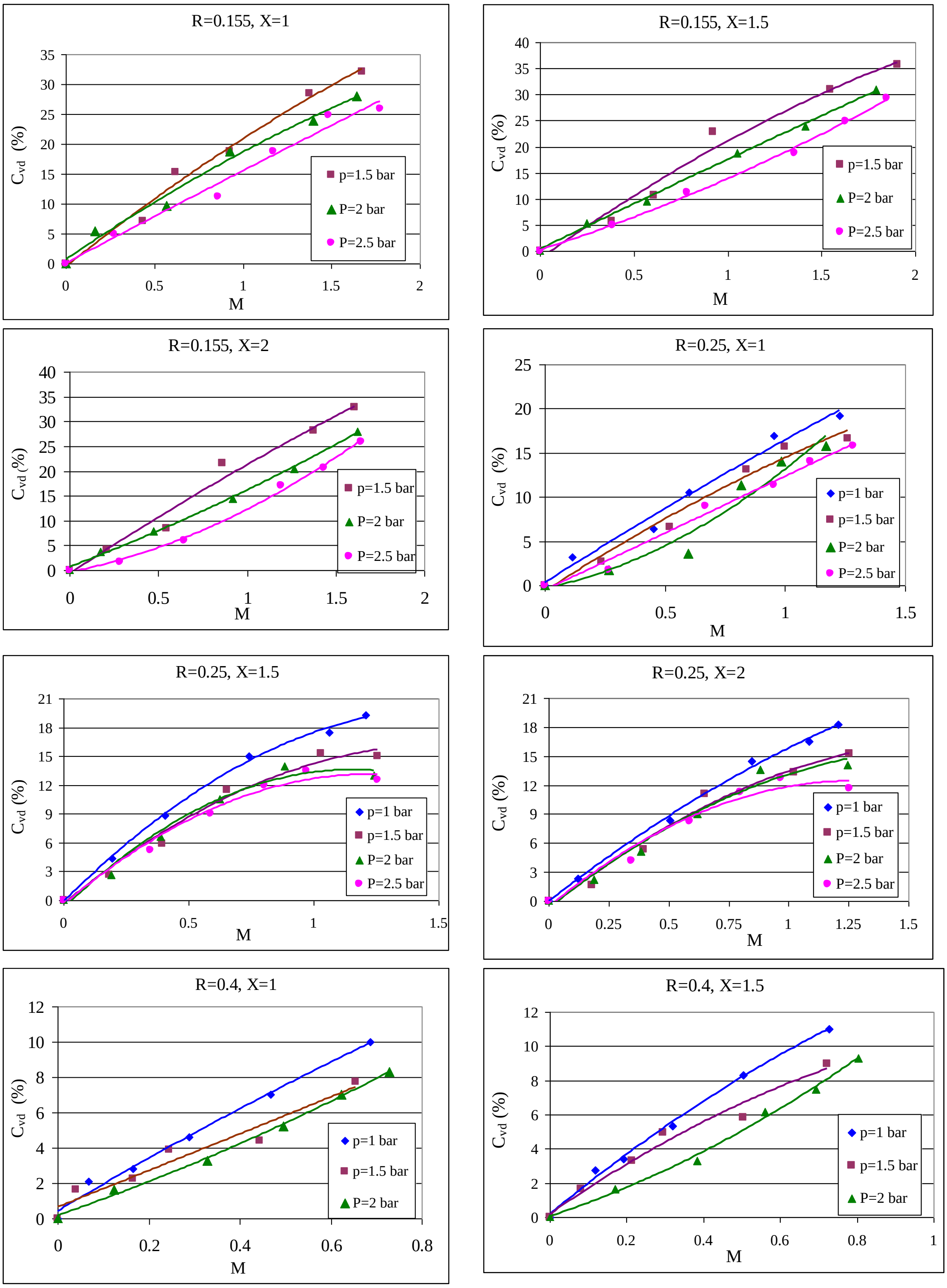


Figure (12) Delivered wheat concentration versus mass flow ratio at different driving pressure

5. CONCLUSIONS

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

1. The area ratio of 0.25 gives the maximum highest efficiency and area ratio of 0.4 gives the minimum highest efficiency.
2. The driving pressure of 1 bar gives the maximum efficiency in case of R=0.25 and 0.4 but at R=0.155 the driving pressure of 1.5 bar gives the maximum efficiency.
3. The jet pump with area ratio of 0.155 gives the maximum highest delivered wheat grains concentration while the jet pump with area ratio of 0.4 gives the minimum delivered concentration.
4. The distance between the driving nozzles to the beginning of mixing chamber to driving nozzle diameter ratio "X" of 1.5 gives the maximum efficiency for all tested cases.
5. The driving pressure of 1 bar gives the maximum delivered concentration in case of R=0.25 and 0.4 but at R=0.155 the driving pressure of 1.5 bar gives the maximum delivered concentration.

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 wheat concentration (%)
D = Nozzle (jet) diameter, (m)
D_{mix} = Mixing chamber diameter, (m)
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)
P_s = Suction Pressure, (Pa)
N = Head ratio, (-)
M = Flow ratio, (-)
M_p = Primary flow rate, (kg/s)
M_s = Secondary flow rate, (kg/s)
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 (x/D)
x =Nozzle-to-throat spacing (distance between the nozzle exit and the beginning of the mixing chamber),(-)
θ_d = Diffuser angle , ($^\circ$)
ρ =Density, (kg/m^3)
γ = Specific weight, (N/m^3)
η =Pump efficiency = M x N

Subscripts

d = Discharge
i = Nozzle tip
mix = Mixing chamber
m = Motive
s =Suction
wh = Wheat beans
w = Water

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