Experimental Analysis of Single Nozzle Jet Pump with varying Area ratio

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Abstract - Water is central to survival, without water human, plant and animal life would be impossible. Therefore supply of water has become one of the fundamental requirements of any society and the need to transfer water has generated the design of various forms of mechanical devices, which can be categorized as pumps. Jet pump is a device that performs its pumping action by the transfer of energy from a high velocity supply jet to one of low velocity suction flow. These two flows mix in the mixing tube and the kinetic energy of the combined flow is converted partially into the pressure energy in the diffuser. The optimization of the design of single hole nozzle jet pump with various area ratios and five different diameter mixing tubes. The area ratios chosen have been modified and the final area ratios used were R = 0.20, 0.28, 0.36, 0.43, 0.50, 0.546, 0.597, 0.655& 0.723.

Discharge ratio (M), Head ratio(N), Efficiency(η) were used to draw performance curves. Experiments were done for all other area ratios and specifications are given and the characteristics of jet pump were determined. In this M-N curves are fitted as a straight by the method of least squares. Efficiency generally increases with discharge ratio up to a maximum and then decreases.

Keywords: Area ratios, Mixing tube, Multi hole nozzle, Nozzle plate.

I. INTRODUCTION

The basic principle of jet pump is the transfer of energy and momentum from one stream of fluid to another through a process of turbulent mixing inside the mixing tube.

The high pressure primary driving stream enters the suction chamber through nozzle with a high velocity. The increase of velocity and the resulting reduction in pressure at the nozzle exit causes the secondary driven fluid to flow into the mixing chamber.

In the mixing chamber the transfer of momentum from the supply stream to secondary stream takes place. The mixed fluid then passes through the diffuser in which a portion of velocity energy is converted into pressure energy.

II. PERFORMANCE PARAMETERS

The performance of a jet pump depends on turbulent mixing of supply and suction fluids. The mixing process and hence the performance of the jet pump is largely influenced by the following geometric parameters.

1. Area ratio (R)
2. Distance between the nozzle exit and mixing tube entry (S)
3. Mixing tube length (D_L)
4. Primary nozzle geometry
5. Suction nozzle geometry
6. Diffuser geometry
7. Number and arrangement of holes in the nozzle.

The working of the jet pump depends on the efficient turbulent mixing. At the entry to the mixing tube the velocity of the primary stream and the velocity of the secondary stream are different and non-uniform. The mixing tube will play the role of eliminating or at least minimizing the difference in velocity and the non-uniform distribution before the combined flow leaves the mixing tube. The length of mixing tube and its diameter decide the effectiveness of the mixing tube. These dimensions have a direct bearing on the performance of the jet pump.

The mixing is very effective at high velocities. This is achieved by a smaller mixing tube diameter. This velocity energy is being converted to pressure energy to reduce the loss of energy during subsequent flow i.e. in the diffuser which is located at the exit of the mixing tube. The velocity distribution at the mixing tube entry depends on the primary nozzle and secondary nozzle geometry. All these parameters are having an influence on the jet pump performance.

2.1 Definition Of Various Terms

The following parameters have been used extensively for describing the jet pump characteristics since they were first suggested by Gosline and O'Brien [1934].

Area ratio (R)

It is the ratio of primary nozzle area to mixing tube throat area and is given by

$$R = \frac{A_n}{A_m} = \left(\frac{d_n}{d_m}\right)^2 \quad (1)$$

Where A_n = driving nozzle area

d_n = driving nozzle exit diameter

A_m = mixing tube throat area

d_m = mixing tube throat diameter

Discharge ratio (M)

It is the ratio between suction flow rate and primary flow rate of jet pump.

$$M = \frac{Q_2}{Q_1} \quad (2)$$

Where Q_1-Primary flow rate in m^3/s

Q_2-Suction flow rate in m^3/s

Head Ratio (N)

It is the ratio between net jet pump head and net driving head of the jet pump.

Jet pump supply head H_1 is given by

$$H_1 = \frac{p_1}{\gamma} + \frac{v_1^2}{2g} + z_1 \quad (3)$$

Where

P_1 = Supply pressure, kgf/cm^2

Z_1 = Level difference between pressure gauge and pressure tapping = 1.15m

$$v_1 = \frac{Q_1}{A_1} \quad (4)$$

Q_1 = Supply Discharge, m^3/s

A_1 = Cross sectional area of supply pipe, m^2 (D_1 = 0.053 m)

g = Acceleration due to gravity, m/s^2

Jet pump suction head H_2 is given by

$$H_2 = \frac{p_2}{\gamma} + \frac{v_2^2}{2g} + z_2 \quad (5)$$

Where

P_2 = Suction pressure, kgf/cm^2

Z_2 = Level difference between pressure gauge and pressure tapping = 0

Q_2 = Suction Discharge, m^3/s

A_2 = Cross sectional area of Suction pipe, m^2 (D_2 = 0.053 m)

g = Acceleration due to gravity, m/s^2

Jet pump delivery head H_3 is given by

$$H_3 = \frac{p_3}{\gamma} + \frac{v_3^2}{2g} + z_3 \quad (6)$$

Where

P_3 = Delivery pressure, kgf/cm^2

Z_3 = Level difference between pressure gauge and pressure tapping = 0

Q_3 = Delivery Discharge, m^3/s

A_3 = Cross sectional area of Delivery pipe, m^2 (D_3 = 0.069 m)

g = Acceleration due to gravity, m/s^2

Jet pump head ratio N is given by

$$N = \frac{H_3 - H_2}{H_1 - H_3} \quad (7)$$

Efficiency of jet pump (η)

It is defined as the ratio of energy increase of suction stream (output energy) to the energy decrease of driving stream (input energy).

$$\eta = \left(\frac{Q_2}{Q_1}\right) \times \left(\frac{H_3 - H_2}{H_1 - H_3}\right) \quad (8)$$

Therefore, Jet pump efficiency η is given by

$$\eta = M \text{ X } N \quad (9)$$

2.2 Jet Pump Analysis

The performance of any machine can be predicted by means of theoretical investigations with proper assumptions, which will make the mathematical treatment of the analysis easy. These theoretical investigations may not predict the behavior truly along the complete course of action because of some assumptions but it estimates the effectiveness of the machine up to the required accuracy needed for design purposes.

III. PERFORMANCE CHARACTERISTICS

The performance of a jet pump is graphically represented by

a. Head ratio (N) as a function of Discharge ratio (M)

b. Efficiency (η) as a function of Discharge ratio (M)

The graphical representation of the efficiency and head ratio w.r.t. the discharge ratio is called the performance characteristics of the jet pump. Typical performance characteristics of a jet pump are shown in Fig.1. The graph indicates that as the discharge ratio increases the head ratio decreases.

The slope of the head ratio vs discharge ratio curve depends on the area ratio of the jet pump. In case of efficiency vs discharge ratio, the efficiency curve increases till a maximum and then it decreases.

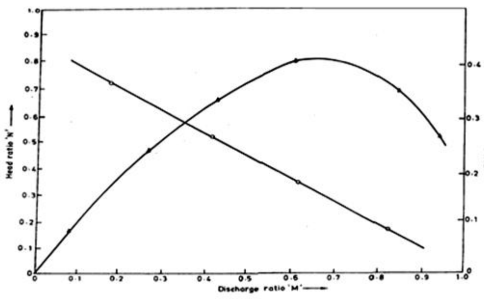

Fig.1. Performance characteristic of a jet pump

3.1 Mixing Tube Design

The jet pump assembly available in the hydroturbomachines laboratory has facilities to change the various components of the jet pump. Different area ratios have to be achieved since it is the parameter of interest in this project work. Effect of change of area ratio on jet pump performance is to be obtained experimentally using different diameter mixing tubes. The design of mixing tube should match with the existing suction nozzle and diffuser. The procedure of finalizing the dimensions of the suction nozzle, mixing tube and diffuser is discussed in detail in the following sections.

3.2 Existing Jet Pump Details

The major dimensions of the existing jet pump for an area ratio of 0.282 are

Primary nozzle diameter (d_n)= 17 mm

Mixing tube diameter (d_m) = 32 mm

Mixing tube length (l_m)= 140 mm

Diffuser length (l_d) = 210 mm

Diffuser angle (β)= 10^o

Suction nozzle angle = 50^o

Spacing between the primary nozzle exit and the mixing tube entrance S = 17 mm

This jet pump was kept as reference. It was decided to use 9 different area ratios from 0.200 to 0.723.

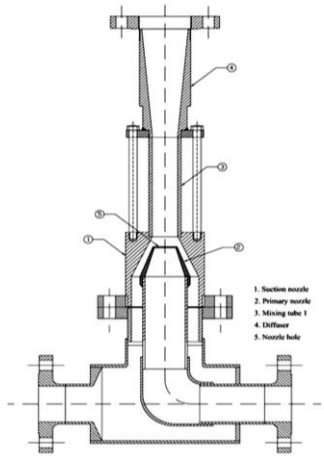

Fig.2.Cross Sectional view of the Jet Pump

3.3 Design Considerations

The dimensions of the existing jet pump assembly were kept in view during the design of new components. For each of the area ratio, different parameters like diameter and length of mixing tube, length of diffuser and the spacing between the primary nozzle exit to mixing tube entrance were calculated.

In the study of the effect of area ratio on the performance of jet pump, the annular area available between suction and primary nozzle should be the same for each of area ratio. To fulfill this criterion, a proper spacing between the nozzle exit to the mixing tube entrance to be found out.

It may be noted that for these carry, mixing tube length and diffuser length are varying. When expressed non dimensionally mixing tube length as a ratio of mixing tube diameter from smaller area ratio (R<0.20) pump requires optimum mixing length of 7 to 10 times the diameter. For higher area ratio (R = 0.200 to 0.723) pumps, mixing tube length of 3 to 5 times the diameter may be sufficient. In this present work 'l_m' is taken as $4.5d_m$(approximately).

This results in l_d/l_m also varying as different mixing tubes used. The selection of diffuser cone angle (β) was based on the work of Mueller (1964) who concluded that a diffuser angle of 10° yields the best efficiency. In this present work 'β' is taken as 10° and length of diffuser is calculated using diffuser cone angle, mixing tube diameter & delivery pipe diameter.

Table 1 Finalized dimensions for different area ratios

Diameter of Mixing tube (dm) mm	Area Ratio (R)	Length of Mixing tube (lm)mm	Length of Diffuser (ld)mm	lm /dm	ld /dm
38.0	0.200	170.0	173.0	4.47	4.55
32.0	0.282	140.0	207.7	4.37	6.56
28.2	0.363	129.5	229.0	4.59	8.12
25.9	0.431	120.0	242.0	4.63	9.34
24.0	0.502	110.0	253.0	4.58	10.54

23.0	0.546	103.2	258.7	4.48	11.25
22.0	0.597	99.4	264.4	4.52	12.02
21.0	0.655	94.6	274.2	4.50	13.05
20.0	0.723	89.8	275.9	4.49	13.79

IV. EXPERIMENTAL PROCEDURE

4.1 Performance Tests

Once venting is completed, readings were taken to determine the performance of jet pump. It should be ensured that the valves 2, 3, 6, 7, 10 and 11 should be kept open and 3-way valves in position 2 when readings are being taken.

Several sets of experiments are performed on the setup by varying the diameter of the mixing tube and gasket. Special code is given for each experiment as mentioned in Appendix-B.

In the observation table, the supply discharge readings in U-tube mercury – water manometer, the delivery discharge readings in single column mercury – water manometer, the supply and delivery side static pressures from pressure gauges $P_{1\ BBB}$and P_{3BBBB}, and the suction side pressure reading in U tube mercury – water manometer were noted .

After taking the first set of readings with V1, V2, and V3 in full open position, the delivery valve V3 was partly closed keeping primary valve V1 and suction valve V2 in full open position. For various discharge valve (V3) openings, the readings were noted.

From the observed readings, supply discharge (Q1), Delivery discharge (Q3), Supply side static pressure (PB1BB$_{BBB}$), Delivery side static pressure (P3), Suction side static pressure (PB2BB$_{BBB}$), from the reading head calculated. From these values discharge ratio (M), Head ratio (N), efficiency (η) were found out and the performance curves of the jet pump were plotted. A set of sample readings & calculations are given in Appendix C along with error analysis.

V. ERROR ANALYSIS

The accuracies of the measuring instruments used

are given below:

1. Orifice meter ---- 2% = ± 0.02
2. Pressure gauges ---- 0.6% of full scale value
3. Single column manometer ---- ± 1 mm (mc-wc)
4. U - tube manometer ---- ± 2 mm (mc-wc)
5. Vernier Calipers ---- ± 0.02 mm

The values given above refer to the reading inaccuracies, as far as the manometer is concerned, practically there is no additional error in the measurement of pressure with the manometers since the venting of the connecting tubes was done prior to taking the readings and the lines are full of water.

Because of the inaccuracies of the instruments used, the calculated value may also have a deviation. The percentage deviation can be computed as the square root of the sum of the squares of the errors caused by inaccuracies in the instruments.

The efficiency is computed from head ratio and discharge ratio values. Hence the error will be the square root of sum of the squares of the individual errors. The numerical values given below correspond to the best efficiency point of Table B.1. This calculation is done at best efficiency point since the experimental results were compared only at that point.

VI. RESULTS AND CONCLUSION

Experimental results were obtained with water (water to water) as the working fluid.

6.1 Performance Characteristics

The Discharge Ratio (M), Head Ratio (N), and Efficiency (η) were used to draw the performance curves.

The experiment was conducted first with the existing jet pump of area ratio 0.282. Same experiment was done again to check the repeatability.

Experiments were done for all other area ratios and specifications as given in the Table 1 and the characteristics of the jet pump were determined. It may be mentioned here that a simple gasket of 3 mm was used while fixing the mixing tube in order to obtain the spacing between primary nozzle exit to mixing tube entrances indicated in table 1. The performance characteristic curves for jet pump of area ratio (R) = 0.200, 0.282, 0.363, 0.431, 0.502, 0.546, 0.597, 0.655 & 0.723 are given in the Fig. 1 & 2. In these figures, results of two trials are shown. It may be seen that the repeatability of experimental results is good. In this plot M-N curves are fitted as a straight line by the method of least squares. Efficiency of the jet pump is the product of M and N. Hence values of M and N are calculated from the fitted curve M-N. Efficiency generally increases with discharge ratio up to a maximum and then it decreases. If of area ratio (R) = 0.200 is considered it may be observed that the range of discharge ratio is from 0.2 to 0.63 and head ratio is from 0.15 to 0.33.

As the area ratio is increased further, it may be observed that the head ratio at discharge ratio is equal to 0 increases to expect for the area ratios of 0.597 & 0.723. The range of discharge ratio for which readings could be obtained was between 0.15 and 0.7 in most of the cases due to the limitations of the test rig.

In order to make a comparison these curves are plotted on a common grid and the results are shown in Fig 3 & 4

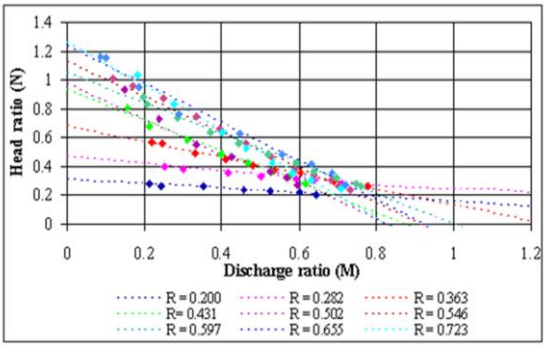

Fig. 3. Performance characteristic curve head ratio(N) vs discharge ratio(M) for various area ratios

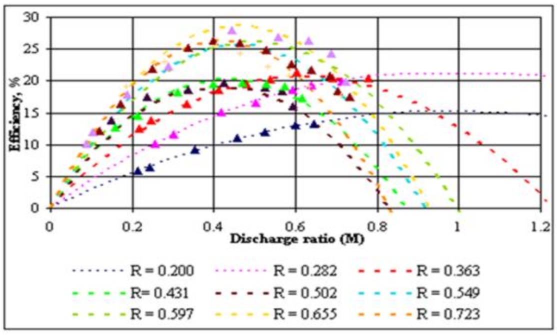

Fig.4. Performance characteristic curve efficiency vs discharge ratio (M) for various area ratios

The value of slope of M vs N line, M and N at the maximum efficiency (M_{bep}, N_{bep}) & η_{max} as a function of R are extracted and given in Table 6.1.

The slope is decreasing from -0.1557 to -1.5255 as increase the area ratio 0.200 to 0.723, except the area ratio is 0.597

Here an area ratio is increasing slope increases except for R = 0.597. M_{bep} decreases from 1 to 0.4 for area ratio from 0.200 to 0.546. At an area ratio of 0.597 M_{bep} was 0.48 & it decreases to 0.4 for an area ratio of 0.723. The maximum efficiency is increasing up to 0.655 area ratio then decreasing. Fig 5 shows a plot of the variation of M_{bep} , N_{bep} and η_{max} with R. It may be seen that generally M_{bep} decreases with increase of area ratio, while Nbep & η_{max} increase.

Is increasing an area ratio is increasing except for the case of are a ratio 0.416 & 0.530.

Table 2 Values of M_{bep}, N_{bep} & η_{max}

R	Slope	M_{bep}	N_{bep}	η_{max}
0.200	-0.1557	1.00	0.152	15.15
0.282	-0.2182	0.90	0.233	20.97
0.361	-0.5482	0.80	0.247	22.61
0.431	-1.0721	0.45	0.451	21.00
0.502	-1.1569	0.4	0.416	21.20
0.546	-1.3078	0.40	0.530	26.28
0.597	-1.0532	0.48	0.481	26.11
0.655	-1.3373	0.45	0.544	28.70
0.723	-1.5255	0.4	0.656	26.24

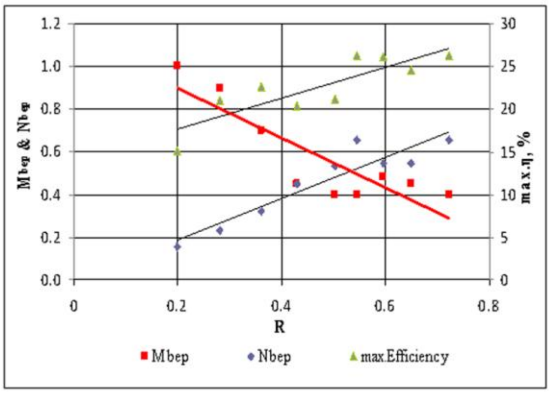

Fig.5. Variation of M_{bep}, N_{bep} & η_{max}

The variation in the N_{bep}, M_{bep} and maximum efficiency with R are compared with available literature and are shown in Fig 1 to Fig 2.

For comparison the available results obtained by Mueller (1964), Reddy and Subir Kar (1968), Cunningham (1970), Nilavalagan (1985) and Anilkumar (2009) are used.

The trends obtained from the present experiments are similar to those obtained by Mueller (1964), Reddy and Subir Kar (1968), Cunningham et al (1970) and Nilavalagan (1985) for the variation of M_{bep} & N_{bep} with area ratio.

As far as the variation of maximum efficiency is concerned, the trend agrees with the results of Mueller (1964) & Reddy and Subir Kar (1968).

In these cases maximum efficiency increases with area ratio. The results of other two investigators shown as optimum value of area ratio where η_{max} is the highest.

The tend of efficiency increases as increase the area ratio this obtained by Anilkumar (2009).

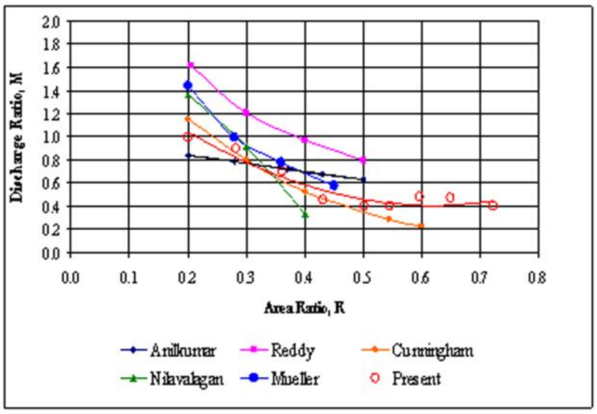

Fig.6. Relationship of M_{bep} with Area Ratio

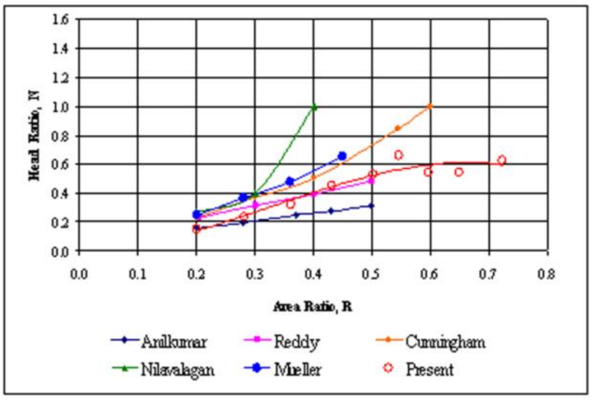

Fig.7. Relationship of N_{bep} with Area Ratio

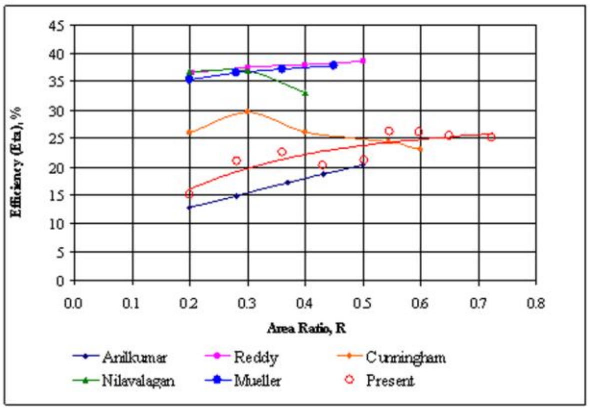

Fig .8.Relationship of Maximum Efficiency with Area Ratio

VII. DESCRIPTION OF REFERENCES

Sudevan (1978) studied the mixing characteristics of the multi-hole nozzle jet pump (with holes from one to six in the jet pump constant throat area) and optimized the mixing tube length on the basis of static pressure variation along the length of the mixing tube.

Ramesh Babu (1981) designed and fabricated the jet pump with a single hole nozzle for five different area ratios. He conducted experiments for one nozzle.

Ramakrishna Pai (1986) optimized the mixing tube length on the basis of best efficiency for three area ratios at constant nozzle set back.

Anil Kumar (2009) conducted experiments to study the characteristics of a water jet pump at various area ratios based on the change of mixing tube area. Within the range of experiments conducted by varying spacing between primary nozzle exit to mixing tube entrance, for the five area ratios, a conclusion about best distance could not be arrived at.

Jagadeshwar (2011) conducted experiments for various multi-hole nozzles configuration with various PCD for 2, 3, 4, 5 and 6 holes arrangements having the different area ratio of 0.2 to 0.5. Jet pump with multi-hole nozzle having holes at lower PCD and lower mixing tube diameter gives high efficiency i.e., area ratio increases maximum efficiency also increases.

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