Performance evaluation of pressure head loads and pumping efficiency on electrical pump sets

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ABSTRACT

The study was undertaken to determine the performance of submersible pump and mono-block centrifugal pump to develop characteristic curves of and its operating conditions. The results revealed that submersible pump the maximum all over pump set efficiency was found 54.98 % at working head 40.43 m, discharge equal to 24.10 lps, WHP 12.99 and input HP 23.63, it was operating point of pump. More than 50 % efficiency can be achieved with discharge capacity varied between 24.10 to 17.89 lps. While Mono-block pump testing was done for suction lifts 0.5 m, 0.7 m, 1.6 m and 2.5m, the maximum efficiency was found 75.10 % at 0.7 m suction lift and at 29.34 m head under same static lift minimum efficiency was found 47.94 .So, operating head may be adopted 17 m against this head maximum efficiency is 48 %, discharge 11.9 lps and 5.5 HP.

Key words: Francis formula, Mono Block Pump, Pump efficiency, Submersible pump, Suction lifts.

INTRODUCTION

The simultaneous development of groundwater especially through dug wells and shallow tube wells will lower water table and continuous increased withdrawals from groundwater reservoir in excess of replicable recharge may result in regular lowering of water table. Dogra et al. (1988) tested that Static head ranged from 2.8 cm to 3.8 cm with speed ranging from 850 rpm. to 1100 rpm. diameter ratio-discharge relationship followed a parabolic curve. In general, maximum efficiency was obtained in the case of diameter ratio of 1.12 and vane twist of 12°. In the case of straight vane impeller, maximum efficiency was observed at diameter ratio of 1.07. Further no appreciable change in pump efficiency as observed while operating in the range of 900 to 1100 rpm. Guruswamy and Michael (2001) observed that the developed pump was tested at different speeds ranging from 600 r.p.m. to 1350 r.p.m. the maximum efficiency of 34.52 % of the test pump could be attained at 1040 r.p.m. operating speed at low head (less than 2.10 meters) operating conditions. The pump discharge of the test pump decreased as the head of the pump was increased for all speeds tested. The brake horse power requirement of the test pump was increased gradually as the head of the pump was decreased for all speeds tested also Reddy et al. (2001) stated that the well water utilization was maximum (67 %) in the category of larger farmers and minimum (27 %). Ogata et al. (2006) stated that the pump efficiency with surfactant solutions was higher than that with tap water and increased with an increase in surfactant concentration. The value of maximum flow rate also increases. The total pump head increased with an increase in concentration, and shaft power decreased with a decrease in the impeller rotating speed.

MATERIALS AND METHODS

The Experiment work was carried out at pump testing laboratory Department of Soil and Water Engineering, CTAE, JAU, Junagadh during 2012, having pump testing facilities as per IS standard. A 15 HP submersible pump having operating capacity of 2900 rpm and another 5 HP mono block type centrifugal pump, having 2880 rpm capacity, so two different pumps were selected. The discharge was measured with 90° V-notch and Francis formula. Water horse power as output was estimated based on total head and measured discharge. The electric input horse power was measured using digital electrical penal board.

Overall efficiency of pump set: Overall Efficiency=Output horse power / Input horse power

Output horse power of water lifting pump= water horse power

\[ \text{WHP} = \frac{Q \times H}{76} \]

Where, \( Q \) = discharge (lps), \( H \) = total head (m)

Measurement of discharge: Different measurement method has been experimented but among all of them Francis Formula (V-notch Formula) gives actual results for pumping efficiency.

Francis formula: Francis Formula have become somewhat standardized. ISO (1980), ASTM (1993), and USBR (1997) all suggest using the Kindsvater-Shen equation, which is presented below from USBR (1997) for Q in cfs and heights in ft units. All of the references show similar curves for C and k vs. angle, but none of them provide equations for the curves. To produce automated calculations, LMNO Engineering used a curve fitting program to obtain the equations which best fit the C and k curves. Fig.1 shows equations. Pump specification is given in Table.1 and Table 2.
Estimation of total head: Total head in which all the heads over pump must be work out properly and summation of all heads is called total working head.

Practically there should be two situations in pumping:
1) The free surface of source of water supply is below the center line of the pump
2) The free surface of source of water supply is above the center line of the pump

The free surface of source of water supply is below the center line of the pump: Total suction lift is the sum of the static lift (Hss) and the losses due to friction in the suction pipe and fitting, including the entrance losses at the inlet to the suction pipe (hfs)

\[ Hs = hss + hfs \]

Delivery head (Hd): It is the sum of the static delivery head and friction losses in the delivery pipe (hfd)

\[ Hd = hd + hfd \]

Total head (H) is define as sum of the delivery head and velocity head minus the total suction head

\[ H = Hd + Vd^2/2g - Hts - Vs^2/2g \]

In case of delivery and suction pipe of same diameter, total head

\[ H = Hd - Hts \]

Maximum suction lift: Maximum suction lift is limited by four factors, Atmospheric pressure, vapor pressure, head loss due to friction and net positive suction head of pump itself

\[ Hs = Ha – Hf – es -NPSH - Fs \]

Where, Hs = maximum practical suction lift, m.

\[ Hf = \text{friction losses in suction line, m} \]

\[ Ha = \text{atmospheric pressure at the water surface, m (10.33 m at sea level)} \]

\[ es = \text{saturated vapor pressure of water, m.} \]

\[ \text{NPSH = Net positive suction head of pump, including losses at the impeller and velocity head, m} \]

\[ Fs = \text{factor of safety, which is usually taken as 0.6m} \]

Friction loss in straight pipe: The friction loss equation can be determined by Darcy-Weisbach. Its general form can be derived analytically for laminar flow, and can be used for any fluid:

\[ h_f = \frac{fLV^2}{D2g} \]

Where, \( f \) = Darcy friction factor.

\( L \) = length of pipe, m

\( D \) = diameter of pipe, m

\( V \) = velocity in pipe, m/s

Friction losses in pipe fittings and pump accessories:
Head loss in strainer, \( h_f = KsV^2/2g \)

Head loss in foot valve, \( h_f = KfV^2/2g \)

Head loss in fittings =, \( h_f = 0.5 V^2/2g \)

Where, Value of Ks usually taken = 0.95 and Kf = 0.8, V is velocity of flow through fitting, m/s

Input horse power
\( \text{IHP} = \text{Water horse power / Pump efficiency x motor efficiency} \)

= Electric energy (Watt)/ 745

In case of three phase input

\[ \text{Electric energy input} = \sqrt{3} \times Iav \times Vav \times \cos \phi \]
Where, \( I_{av} = \frac{I_r + I_y + I_b}{3} \)
\( V_{av} = \frac{V_{ry} + V_{rb} + V_{yb}}{3}, \)
\( I_r = \) Current in red wire, Ampere
\( I_y = \) Current in yellow wire, Ampere,
\( I_b = \) Current in blue wire, Ampere
\( V_{ry} = \) Voltage between red and yellow wire, volts
\( V_{rb} = \) Voltage between red and blue wire, volts
\( V_{yb} = \) Voltage between yellow and blue wire, volts

**Cavitation coefficient:** Cavitation is qualified through the cavitation coefficient
\[ \sigma = \frac{H_{av}}{H} \]
Where, \( H_{av} = \) Net positive head at critical point, m.
\( H = \) Total head.

The maintenance of a \( \sigma \) value is greater than 0.2 results in the successful operation of the centrifugal pump. This critical limit of \( \sigma \) refers to a safe suction lift, which is nearly 4.5 to 5 m for most pumps.

**RESULTS AND DISCUSSION**

Pumping tests were conducted under laboratory condition and the observations like head over v-notch, pressure gauge reading, vacuum gauge reading, static head, input currents in all three phases, input voltages in all three phases, power factor and dimensions of pipe and fittings were recorded and data analyzed to characteristic of pump set and results are presented as follows.

**Submersible pump:** Submersible pump set was tested by adjusting different pressure head with gate valve and pressure gauge. The pressure heads were changed by closing and opening valve. For any fixed pressure head one hour testing was carried out and data at 0, 15, 30 and 60 minutes were collected. The average values of all this four reading were determined in Table 3 and Table 4.

**Table 3:** Efficiency of submersible pump under different operating heads.

| Discharge, lps | Area, Sq.m. | Velocity, m/s | Friction loss in straight pipe, m | Static head, m | Friction loss in fitting, m |
|----------------|-------------|---------------|-----------------------------------|----------------|-----------------------------|
| 23.492         | 0.004416    | 5.32          | 12.46                             | 2              | 3.60                        |
| 22.004         | 0.0044      | 5.00          | 11.01                             | 2              | 3.18                        |
| 24.104         | 0.004416    | 5.45          | 13.12                             | 2              | 3.79                        |
| 18.231         | 0.004416    | 4.12          | 7.50                              | 2              | 2.17                        |
| 17.894         | 0.004416    | 4.05          | 7.23                              | 2              | 2.09                        |
| 10.809         | 0.004416    | 2.44          | 2.63                              | 2              | 0.76                        |
| 4.9589         | 0.004416    | 1.12          | 0.55                              | 2              | 0.16                        |
| 0.662          | 0.01        | 0.14          | 0.01                              | 2              | 0.01                        |

**Table 4:** Efficiency of submersible pump under different operating heads.

| Pressure gauge, m | Velocity head, m/s | Total head, m | WHP | \( \sqrt{3ivcos\theta} \), HP | Efficiency, % |
|------------------|-------------------|---------------|-----|-----------------------------|---------------|
| 0                | 1.44              | 19.51         | 6.11| 23.62                       | 25.87         |
| 10               | 1.27              | 27.47         | 8.06| 22.21                       | 36.28         |
| 20               | 1.51              | 40.43         | 12.99| 23.63                       | 54.98         |
| 30               | 0.86              | 42.54         | 10.34| 23.51                       | 43.98         |
| 40               | 0.83              | 52.16         | 12.44| 24.29                       | 51.22         |
| 50               | 0.30              | 55.70         | 8.02 | 21.73                       | 36.94         |
| 60               | 0.06              | 62.78         | 4.15 | 16.22                       | 25.58         |
| 70               | 0.01              | 72.01         | 0.63 | 14.06                       | 4.52          |

From the Fig. 2 the submersible pump was tested keeping maximum 70 m head so, including other heads total maximum head was 72.01 m and while testing minimum pressure gauage reading was kept zero under this condition minimum head was 19.51 m between this maximum and minimum range of head the characteristics was observed. More than 72.01 m head discharge was drastically reduced so, more than that head pump operation to achieve require discharge is difficult.

![Fig 2: Characteristic curve of submersible pump](image1)

![Fig 3: Characteristic curve of mono block pump at 0.5 m suction lift](image2)
Efficiency of pump was found low while it increased as head reduced. But after certain limit of reduction in head efficiency again start falling. This behaviour of pump required to decide operating range of pump. The all over pump set efficiency was found 54.98% maximum at working head 40.43 m, discharge equal to 24.10 lps, WHP 12.99 and input HP 23.63 and it may be called operating point of pump for highest efficiency. The curves more than 50% efficiency can be achieved with discharge capacity variation between 24.10 to 17.89 lps at total head variation between 40.43 to 52.16 m.

**Mono-block centrifugal pump:** While testing of mono block pump, the variation in static lift also playing important role for the cavitation point of view. Therefore Mono block centrifugal pump set was tested as per following two conditions, 1) under different pressure heads by adjusting pressure heads with gate valve and pressure gauge. 2) Under different suction lifts by emptying sump to particular water level below center line of pump for all adjusted pressure heads as per (a). For any fixed pressure head one hour testing was carried out and data at 0, 15, 30 and 60 minutes were collected. The average values of all this four reading were determined in Table 5 and Table 6.

In Fig. 3 Total head found maximum 18.02 m and minimum 4.78 m and Efficiencies were found 18.02% to 6.28%. Also in Fig. 4 it was observed that less than 11.5 m total head cavitation coefficient found more than 0.3 when suction lift was 0.5 m. So, more than 11.5 m total heads may create cavitation problem in pump. And in Fig. 5 total head found maximum 29.34 m and minimum 16.58 m and efficiencies were found 75.10% to 47.94%.

### Table 5: Efficiency of mono block pump under different operating pressure heads at 0.5 m, 0.7 m, 1.6 m and 2.5 m suction lift.

| Pressure head, m | Pressure ,m. | Discharge, lps. | Velocity, m/s | Friction loss at straight pipes. | Friction loss at fittings | Velocity head |
|-----------------|--------------|-----------------|---------------|---------------------------------|--------------------------|---------------|
| 0               | 5            | 5.706           | 1.72          | 2.51                            | 0.82                     | 0.15          |
| 0.5             | 10           | 5.242           | 1.58          | 2.12                            | 0.7                      | 0.12          |
| 15              | 4.023        | 1.21            | 1.25          | 0.41                            | 0.074                    |
| 0               | 11.854       | 3.57            | 10.86         | 3.58                            | 0.65                     |
| 5               | 11.854       | 3.57            | 10.86         | 3.58                            | 0.65                     |
| 0.7             | 10           | 11.001          | 3.31          | 9.35                            | 3.08                     | 0.56          |
| 15              | 10.936       | 3.29            | 9.24          | 3.04                            | 0.55                     |
| 0               | 9.349        | 2.81            | 6.76          | 2.22                            | 0.4                      |
| 5               | 9.349        | 2.81            | 6.76          | 2.22                            | 0.4                      |
| 1.6             | 10           | 9.349           | 2.81          | 6.76                            | 2.22                     | 0.4           |
| 15              | 6.058        | 1.82            | 2.83          | 0.93                            | 0.17                     |
| 0               | 8.891        | 2.68            | 6.11          | 2.01                            | 0.36                     |
| 5               | 8.834        | 2.66            | 6.03          | 1.98                            | 0.36                     |
| 2.5             | 10           | 7.343           | 2.21          | 4.16                            | 1.37                     | 0.24          |
|                | 15           | 7.044           | 2.12          | 3.83                            | 1.26                     | 0.22          |

### Table 6: Efficiency of mono block pump under different operating pressure heads at 0.5 m, 0.7 m, 1.6 m and 2.5 m suction lift.

| Pressure head, m | Pressure ,m. | Total head | WHP | √3ivcosØ | Efficiency, % | Cavitation coefficient |
|-----------------|--------------|------------|-----|----------|---------------|------------------------|
| 0.5             | 0            | 4.78       | 0.36| 5.79     | 6.28          | 0.824328               |
| 5               | 9.24         | 0.64       | 5.77| 11.19    | 0.398611      |
| 10              | 14.15        | 0.97       | 5.68| 17.13    | 0.241751      |
| 15              | 18.02        | 0.96       | 5.36| 18.02    | 0.145959      |
| 0.7             | 0            | 16.58      | 2.62| 5.46     | 47.94         | 0.317276               |
| 5               | 21.58        | 3.41       | 5.46| 62.93    | 0.182845      |
| 10              | 24.49        | 3.59       | 5.7 | 62.96    | 0.118183      |
| 15              | 29.34        | 4.27       | 5.69| 75.10    | 0.089685      |
| 1.6             | 0            | 11.37      | 1.41| 5.43     | 26.08         | 0.34693               |
| 5               | 16.37        | 2.04       | 5.7 | 35.76    | 0.241016      |
| 10              | 21.37        | 2.66       | 5.7 | 46.68    | 0.184646      |
| 15              | 21.33        | 1.72       | 5.69| 30.24    | 0.135686      |
| 2.5             | 0            | 11.78      | 1.39| 4.13     | 33.77         | 0.312638               |
| 5               | 16.67        | 1.96       | 5.83| 33.64    | 0.197247      |
| 10              | 19.08        | 1.86       | 5.79| 32.23    | 0.179263      |
| 15              | 23.68        | 2.21       | 5.37| 41.3     | 0.1114        |
It was observed from Fig. 6 that for less than 17 m total head cavitation coefficient found more than 0.3 when suction lift was 0.7 m. So, more than 17 m total heads may create cavitation in pump. Fig. 7 determined that total head was found maximum 21.37 m and minimum 11.37 m and Efficiencies were found 46.68 % to 26.08 %. Fig. 8 shows that for less than 12.5 m total head cavitation coefficient found more than 0.3 when suction lift was 1.6 m. So, more than 12.5 m total heads may create cavitation in pump. And in Fig. 9 total head found maximum 23.68 m and minimum 11.78 m and Efficiencies were found 41.30 % to 33.77 %.

In Fig. 10 less than 12.25 m total head cavitation coefficient found more than 0.3 when suction lift was 2.5 m. So, more than 12.25 m total heads may create cavitation in pump. From the characteristic curves Fig. 5, 7, 9.

**Operating condition if mono block pump:** Static lift conditions maximum efficiency was recorded for 0.7 m static lift and at 29.34 m head 75.10 % under same static lift minimum efficiency was found 47.94 % at 1.6 m head. But more than 20 m head is not advisable also under 0.7 m static lift more than 17 m head may create cavitation. So, Oprerating head may be adopted 17 m against this head, maximum efficiency is possible 48% with discharge 11.9 lps at 5 HP. Also compromise with slight cavitation at 20 m head 60% efficiency can be achieved and it may be called operating point of the mono block pump.
CONCLUSION

Under the experiment it was found that the submersible pump efficiency varied according to increase in pressure while velocity head decrease at a certain point and over total head the efficiency drop drastically. So, the suggested pressure for submersible pump is 20m. Also in mono block pump under different operating pressure heads at 0.5 m, 0.7 m, 1.6 m and 2.5 m suction lift. The suggested suction lifts for maximum efficiency at 0.7m. And the water horse power and pump efficiency was found increased according to pressure.

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Fig 10: Plot of cavitation coefficient versus total head at 2.5 m suction lift.