Performance Evaluation of Pressure head loads on Electrical Pump sets: an accurate measurement of the Pumping Efficiency

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Abstract: Experiment on performance evaluation of water lifting pump .The study was undertaken to determine the performance of submersible pump set of 15HP and mono-block centrifugal pump set of 5 HP 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, Water Horse Power 12.99 and input Horse Power 23.63, it was operating point of pump. 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 m to 52.16 m. While in Mono-block centrifugal 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 % at 16.58 m head. As more than 20 m head was not advisable, also under 0.7 m suction lift more than 17 m head may create cavitation. So, operating head may be adopted 17 m against this head maximum efficiency is 48 %, discharge 11.9 lps and 5.5 HP. Also compromise with slight possible cavitation at 20 m head 60 % efficiency can be achieved it was optimum operating point of mono block pump

Keywords: Suction lifts, Pump Efficiency, Francis formula, Submersible Pump, Mono Block Pump

1 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. Basis In such a situation a serious problem is created resulting in drying of shallow wells and increase in pumping head for deeper wells and tube wells. The Pumps are used in a wide range of industrial, Agriculture aspects and residential applications. Pumping equipment is extremely diverse, varying in type, size, and materials of construction. There have been significant new developments in the area of pumping equipment. They are used to transfer liquids from low-pressure to high pressure in this system, the liquid would move in the opposite direction because of the pressure difference. Centrifugal pumps are widely used for irrigation, water supply plants, stream power plants, sewage, oil refineries, chemical plants, hydraulic power service, food processing factories and mines. The pump efficiency with surfactant solutions was higher than that with tap water and increased with an increase in surfactant concentration by Ogata (2006).The aim of study to determine the pumping efficiency to develop characteristic curves of and its operating conditions.

2. Material 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. In the Saurashtra region farmers adopts submersible pumps for deep tube well operation up to 15 HP capacity and for open well Operation they prefer 5 HP mono block type centrifugal pump, so two different pumps were selected 1) 15 HP submersible pump 2) 5 HP centrifugal mono block pump. 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. 90^0 V- Notch is fitted in measuring tank for the measurement of discharge of pump under testing.

2.1. Overall Efficiency of Pump set: Overall Efficiency=Output horse power / Input horse power

Output horse power of water lifting pump= water horse power

$$WHP = Q \times H / 76 \qquad \ldots\ldots\ldots\ldots (1)$$

Where, Q= discharge (lps), H= Total Head (m)

2.2. 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.

2.3. 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.

Table 1: Specification of Submersible Pump.

HP	Volts	RPM	Head	Type	Size	Connection
15	200-400 V	2900	120 m	Radial throw	75 mm	Star/Delta starting

Table 2: Specification of Mono block Pump.

HP	Volts	RPM	Head	Type	Size	Connection
3.7-5.0	370 (+6%- 15%)	2880	20 m	Radial throw (MBP)	65 mm	Delta Type

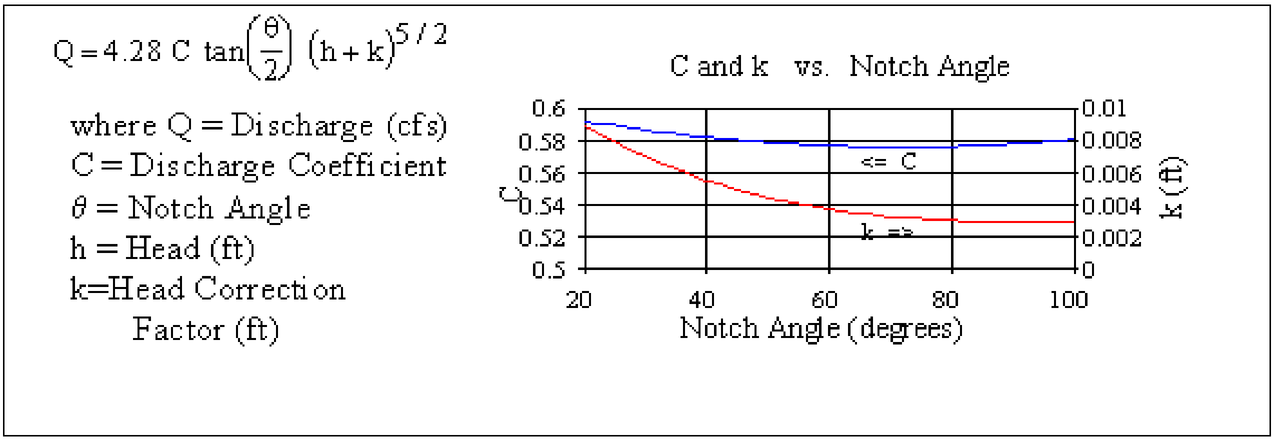

Fig. 1 from curve for 90^0 C = 0.53 and k = 0.003 ft for 90^0 notch

2.4. 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.

2.4.1. 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

2.4.1.1. 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

Where, Hv = velocity head, m V = velocity in pipe, m/s, g = gravity constant, m/s^2

Total head: Hd + Hs + ($Vd^2/2g + Vs^2/2g$) ... (5)

Where, Vd2/ 2g, Vs2/ 2g are the velocity heads

(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 ... (2)

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

Hd = hd + hfd …(3)

Velocity head (Hv): This is the pressure require to create the velocity of flow in pipe line.

Hv = V^2/ 2g …(4)

Where, Hv = velocity head, m V = velocity in pipe, m/s, g = gravity constant, m/s^2

on delivery side and suction side respectively.

2.4.1.2. The free surface of source of water supply is above the center line of the pump: Static suction head (hs) is difference between Centre line of pump and level of water at the source of pumping. Total suction head (Hts) is the sum of the static suction head (hs) minus all the friction losses in suction pipe (hfs)

Hts = hs – hfs … (6)

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

Hd = hd + hfd …(7)

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

H = Hd + Vd2/2g - Hts - Vs2/2g …(8)

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

H = Hd - Hts …(9)

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. … (10)

Where, Hs = Maximum practical suction lift,

Hf = friction loss in suction line, m, Ha = atmospheric pressure at the water surface, m (10.33 m at sea level)

es = saturated vapor pressure of water NPSH = Net positive suction head of pump, including losses at the impeller and velocity head, m

Fs = factor of safety, which is usually taken as 0.6m

2.4.2. Friction loss in straight pipe:

hf = 4 f l v^2 / 2 x g x d …(11)

Where, f = friction coefficient for pipe in fraction.

L = length of pipe, m

D = diameter of pipe, m

V = velocity in pipe, m/s

2.4.2.1. Friction losses in pipe fittings and pump accessories:

Head loss in strainer, hf = Ks V^2/2g … (12)

Head loss in foot valve, hf = Kf V^2/2g … (13)

Head loss in fittings = hff = 0.5 V^2/2g … (14)

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

Input horse power:

IHP = Water horse power / Pump efficiency x motor efficiency

= Electric energy (Watt) / 745 … (15)

In case of three phase input:

Electric energy input = √3 x Iav x Vav x cosφ… (16)

Where, Iav = Ir + Iy + Ib /3

Vav = Vry + Vrb + Vyb/3, Ir = Current in Red wire, Ampere

Iy= Current in yellow wire, Ampere,

Ib = Current in blue wire, Ampere

Vry = Voltage between red and yellow wire, volts

Vrb = Voltage between red and blue wire, volts

Vyb = Voltage between yellow and blue wire, volts

2.4.3. Pump Characteristic curves: Centrifugal pump have well defined operating properties which vary with the type of pump, manufacturer and model. These properties are expressed as characteristics curves. These curves are also known as performance curves, shows the inter relationship between capacity, head, power and efficiency of a pump at a given speed. Knowledge of the pump characteristics enables the selection of a pump which is best adapted to a particular set of conditions, thus obtaining high values efficiency at a low operating cost. The characteristics curve showed shown in Fig.13 Head capacity curve: Curve plotted head against discharge capacity, Efficiency Capacity curve: Curve plotted efficiency against discharge capacity, Input power capacity curve: Curve plotted Input power against discharge capacity

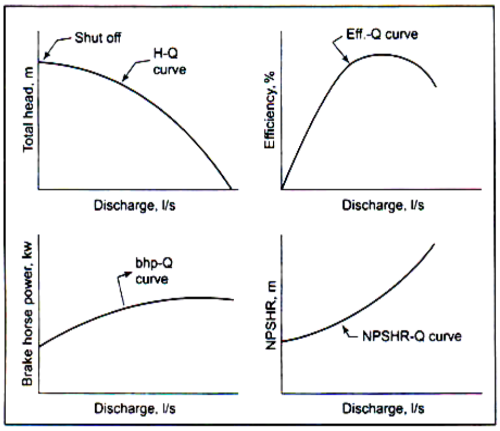

Fig. 2 Characteristics curves of pump

3. 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 minutes reading were determined in Table 3 and Table 4.

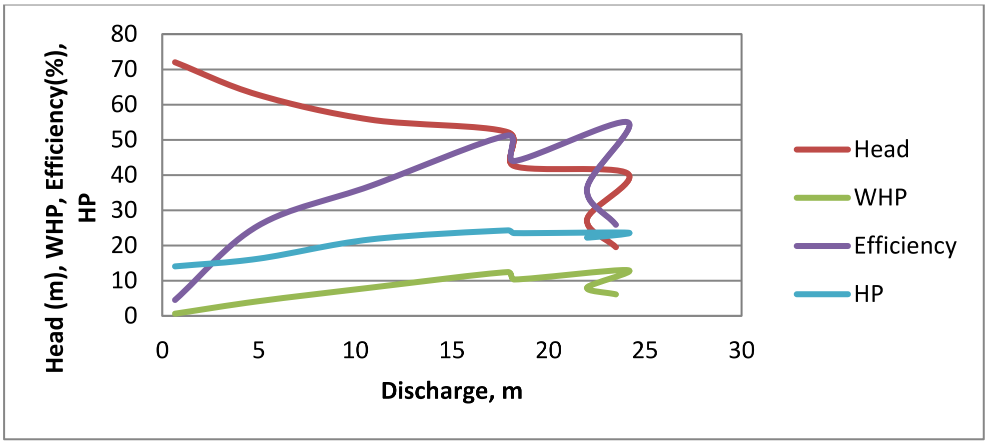

Fig. 3 Characteristic curve of submersible pump

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

Sr. No.	Discharge, lps	Area, Sq.m.	Velocity, m/s	Friction loss in straight pipe, m	Static head, m	Friction loss in fitting, m
1	23.492	0.004416	5.32	12.46	2	3.60
2	22.004	0.0044	5.00	11.01	2	3.18
3	24.104	0.004416	5.45	13.12	2	3.79
4	18.231	0.004416	4.12	7.50	2	2.17
5	17.894	0.004416	4.05	7.23	2	2.09
6	10.809	0.004416	2.44	2.63	2	0.76
7	4.9589	0.004416	1.12	0.55	2	0.16
8	0.662	0.01	0.14	0.01	2	0.01

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

Sr. No.	Pressure gauge, m	Velocity head, m/s	Total head, m	WHP	√3ivcosØ, HP	Efficiency, %
1	0	1.44	19.51	6.11	23.62	25.87
2	10	1.27	27.47	8.06	22.21	36.28
3	20	1.51	40.43	12.99	23.63	54.98
4	30	0.86	42.54	10.34	23.51	43.98
5	40	0.83	52.16	12.44	24.29	51.22
6	50	0.30	55.70	8.02	21.73	36.94
7	60	0.06	62.78	4.15	16.22	25.58
8	70	0.01	72.01	0.63	14.06	4.52

Efficiency of pump was found low while it increased as head reduced. But after cetain 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 efficieciency 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 variations 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 empting 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.

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	0	5.706	1.72	2.51	0.82	0.15
	5	5.242	1.58	2.12	0.7	0.12
	10	5.16	1.55	2.05	0.67	0.12
	15	4.023	1.21	1.25	0.41	0.074
0.7	0	11.854	3.57	10.86	3.58	0.65
	5	11.854	3.57	10.86	3.58	0.65
	10	11.001	3.31	9.35	3.08	0.56
	15	10.936	3.29	9.24	3.04	0.55
1.6	0	9.349	2.81	6.76	2.22	0.4
	5	9.349	2.81	6.76	2.22	0.4
	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	62.39	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

In Fig.4 Total head found maximum 18.02 m and minimum 4.78 m and Efficiencies were found 18.02 % to 6.28 %. Also Fig.5 it 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.6 total head found maximum 29.34 m and minimum 16.58 m and Efficiencies were found 75.10 % to 47.94 %.

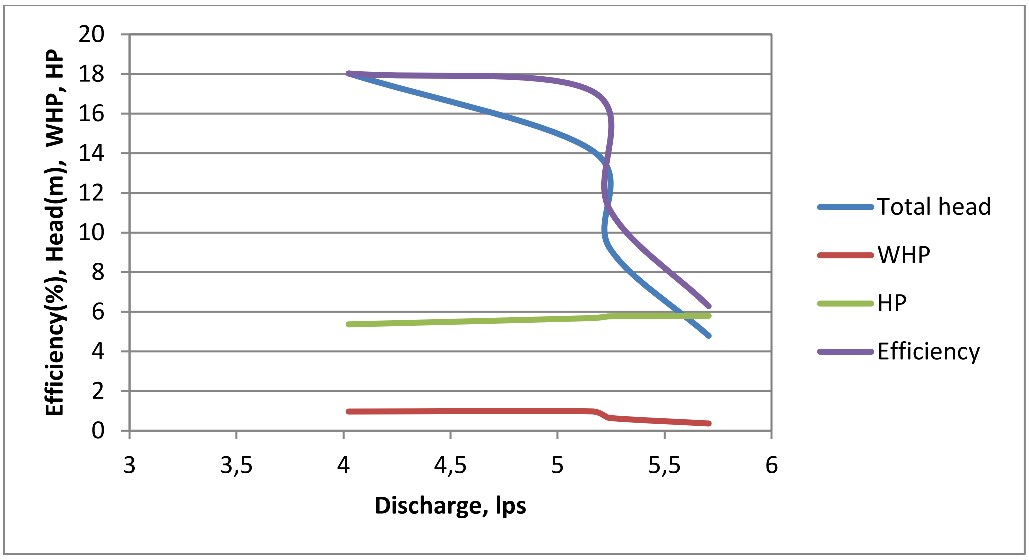

Fig. 4 Characteristic curve of mono block pump at 0.5 m suction lift

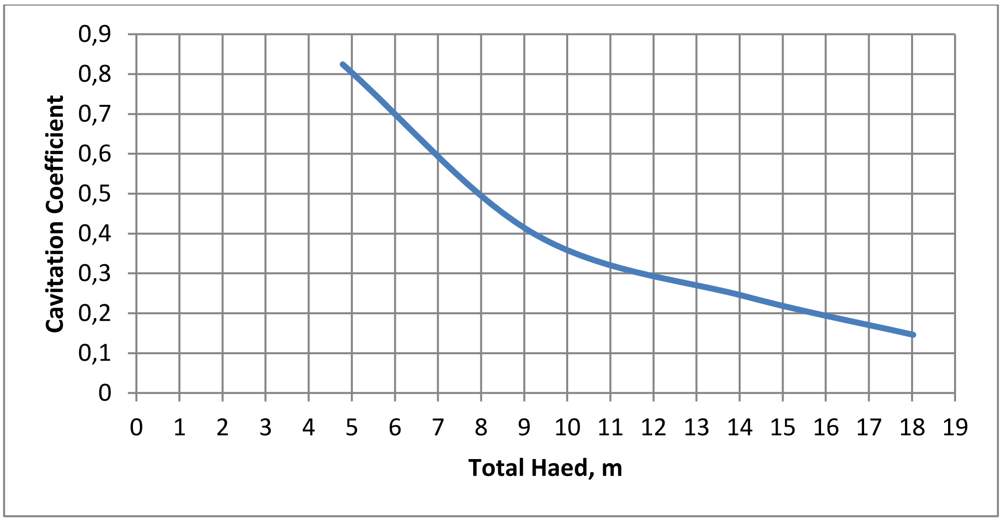

Fig.5 Plot of cavitation coefficient versus total head at 0.5 m suction lift

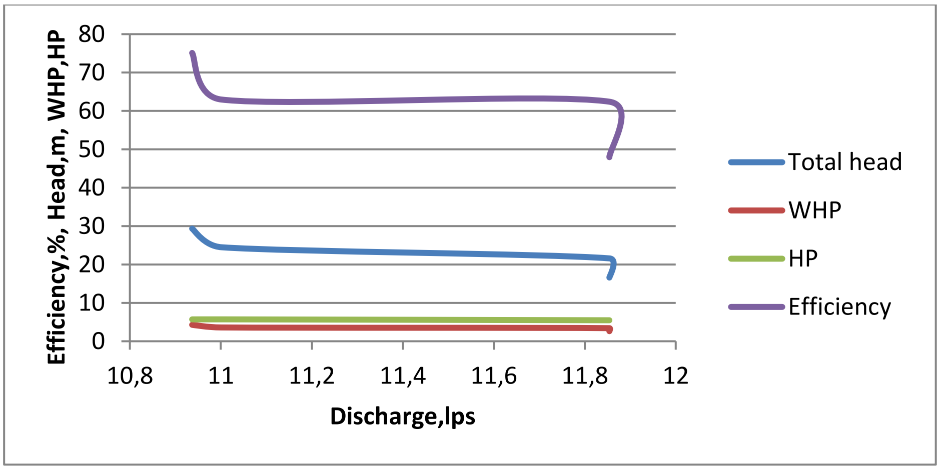

Fig.6 Characteristic curve of mono block pump at 0.7 m suction lift

It was observed from Fig.7 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.8 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.9 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.10 total head found maximum 23.68 m and minimum 11.78 m and Efficiencies were found 41.30 % to 33.77 %.

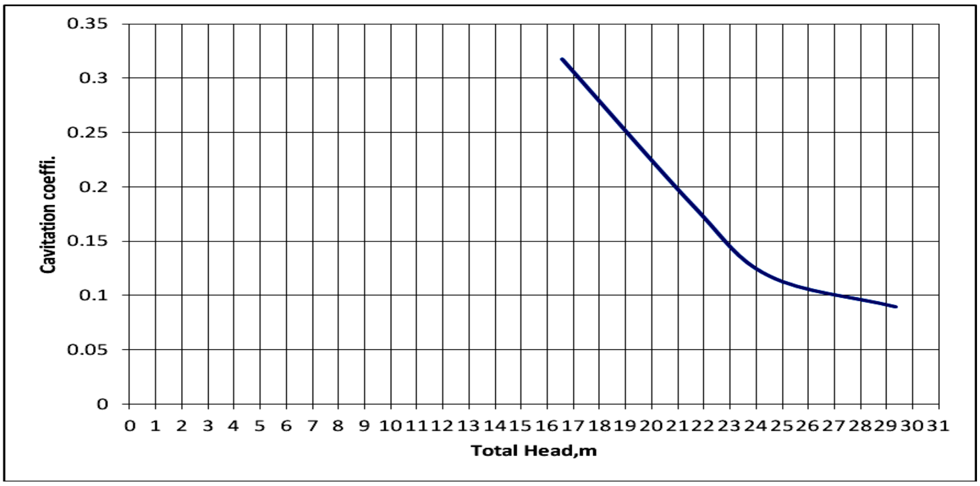

Fig.7 Plot of cavitation coefficient versus total head at 0.7 m suction lift

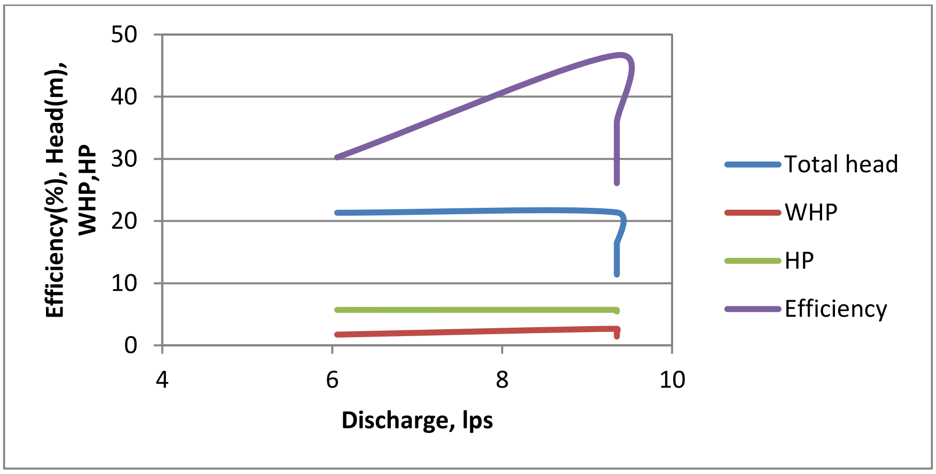

Fig.8 Characteristic curve of mono block pump at 1.6 m suction lift

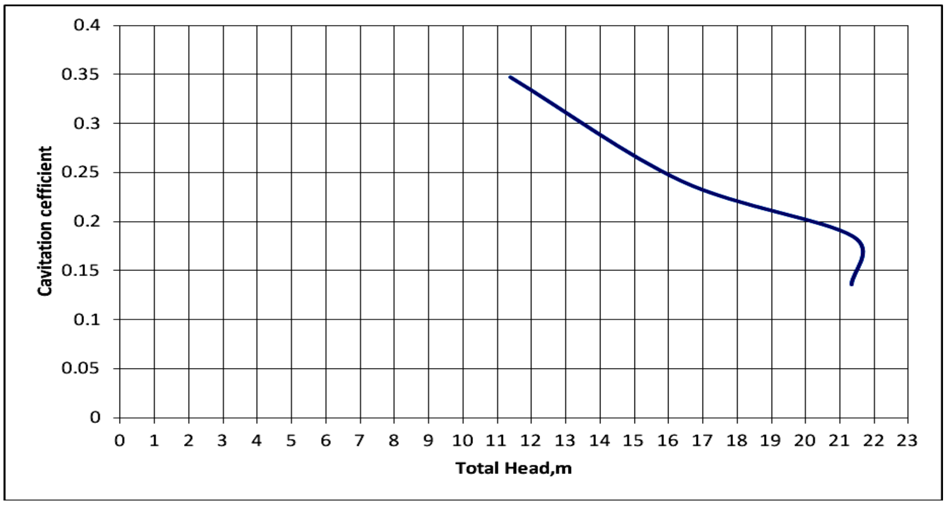

Fig.9 Plot of cavitation coefficient versus total head at 1.6 m suction lift

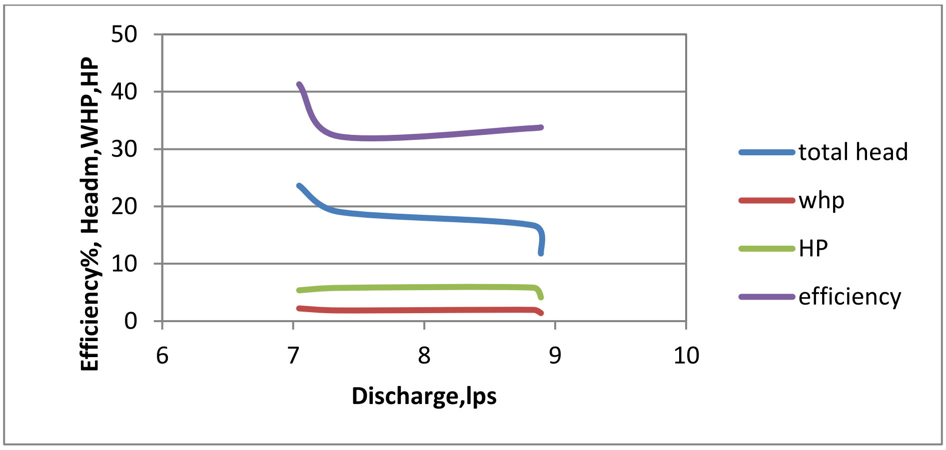

Fig. 10 Characteristic curve of mono block pump at 2.5 m suction lift

Fig.11 Plot of cavitation coefficient versus total head at 2.5 m suction lift

In Fig.11 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 charachtristic curves Fig. 4,6,8 and 10 static lift conditions maximum efficiency was recorded for 0.7 m static lift and at 29.34 m head 75.01 % under same static lift minimum efficiency was found 47.94 % at 1.6 m head

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4. Conclusions

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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