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Performance Study of Designed Single Suction Centrifugal Pump by Increasing Face Width at the Speed of Impeller

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Abstract*- This paper presents the performance of single-suction centrifugal pump use in irrigation and agriculture. The mentioned parameters are the designer of centrifugal pump with face width 12 mm. This paper focus mainly on the performance of centrifugal pump for 18 mm face width variation only as the existing designed with 12 mm face width. This paper is not doing the design and calculation for 18 mm face width. Type of pump is single stage centrifugal pump with closed impeller and 12 mm face width impeller can develop a head of 20 m and deliver 0.015 m^3/s of water at 1800 rpm. This impeller has 99 mm inlet diameter, 226 mm outlet diameter, 20° inlet vane angle and 23° outlet vane angle. The number of vanes is 6 and input shaft power is 6 hp. The inlet width and outlet width are 26 mm and 18 mm respectively. The discharge diameter is 80 mm to operate the designed head and capacity. The performance study of 12 mm face width impeller and 18 mm face width impeller are also presented at constant speed. According to observations, theoretical head is about 15 m and experimental head is 11.24 m, by mean of flow rate in theoretically about 57% and actually 50% maximum at 25.17 L/sec capacity. In this study, the performance of 18 mm face width pump is more efficient than 12 mm face width pump at speed 1450 rpm.

Keywords- Head, Flow Rate, Speed, Efficiency, Face Width.

I. INTRODUCTION

A pump is a mechanical device for moving a fluid from a lower to a higher location or from a lower to a higher pressure area. Mechanical energy will be given to the pump and it later converted into hydraulic energy of fluid. Pumps produce negative pressure at the pressure at the inlet so that the atmospheric pressure pushes the fluid towards the pump.

The fluid coming into the pump is pushed towards the outlet mechanically where positive pressure is generated. Pumps are classified in number of the ways based on their purpose, specifications, design, environment etc. The fluid enters the pump impeller along or near to the rotating axis and is accelerated by the impeller, flowing radially outward or axially into a diffuser or volute chamber, from where it exits into the downstream piping system. Centrifugal pumps are typically used for large discharge through smaller heads.

The centrifugal pump is the most used pump type in the world. The principle is simple, well-described and thoroughly tested, and the pump is robust, effective and relatively inexpensive to produce. There is a wide range of variations based on the principle of the centrifugal pump and consisting

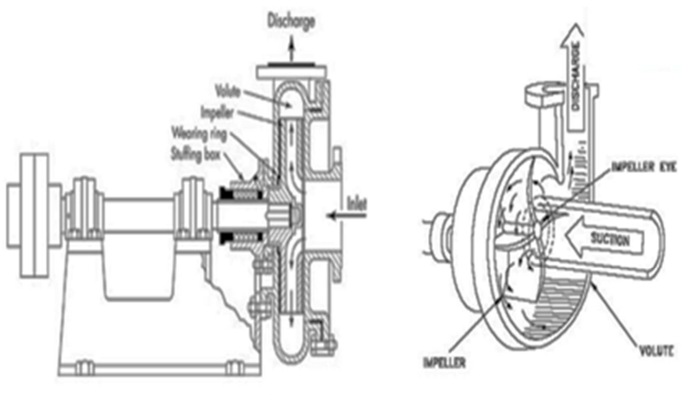


Fig 1.Single Suction Centrifugal Pump [9]

II. DESIGN OF CENTRIFUGAL PUMP

The centrifugal pump is analyzed by using a single- stage end suction centrifugal pump. The two main components of centrifugal pump are impeller and casing. The impeller is a rotating component and the casing is a stationary component.

Impeller is designed on the basic of design flow rate, pump head and pump specific speed. In a centrifugal pump, the liquid is forced by atmospheric or other pressure into a set of rotating vanes. A centrifugal pump consists of a set of rotation vanes enclosed within a housing or casing that is used to impart energy to a fluid through centrifugal force.

When the overall design of pump is considered, the shape of an impeller is the most important for optimum efficiency. Impeller design should be in such a way that, losses must be as low as possible. The design of a pump's impeller can be divided into two parts. The first is the selection of proper velocities and vane angles needed to obtain the desired performance with the best possible efficiency. The second is the layout of the impeller for the selected angles and areas.[8]

The specifications of pump that will be designed are:

Pump head,	H	= 20 m
Discharge,	Q	= 0.9 m^3/min
	Q_s	= (Q/60) m^3/s = 0.015m^3/s
Rotational Speed, n		= 1800 rpm
Density of water, ρ		= 1000 kg/m^3

A. *Design of impeller*

Specific speed is an essential criterion to determine the impeller shapes. It is mathematically expressed as

$$n_s = \frac{n \times \sqrt{Q}}{H^{3/4}} \tag{1}$$

In this design, calculated value of specific speed based on required head and capacity is 180 rpm and it is within the range of low specific speed pump that is greater than 80 and less than 600. So, end-suction type single stage centrifugal pump with closed impeller is chosen.

Input power of centrifugal pump can be determined by following equation.

$$L = \frac{\rho Q_s g H}{\eta} \tag{2}$$

For charge condition of the pump work, maximum shaft power or rated output of an electric motor L_r (kW) is decided by using Equation (4).

$$L_r = \frac{(1+F_a)\times L}{\eta_{tr}\times 1000} \tag{3}$$

Where, Fa is the allowance factor, and 0.1~ 0.4 for an electric motor and larger than 0.2 for engines. And then, ηtr is the transmission efficiency, and 1.0 for direct coupling and 0.9 ~ 0.95 for belt drive.

The shaft diameter at hub section of impeller is

$$d_s = \sqrt[3]{\frac{16\,T}{\pi\,\tau}} \tag{4}$$

Where, T is the torsional moment and it can be estimated by

$$T = \frac{60\,L_r}{2\,\pi\,n} \tag{5}$$

Allowable shear stress of material of shaft, τ is 24.5 MPa because the main shaft is made of S30C. The estimated shaft diameter will be increased because it is difficult to predict the bending moment at this time.

The hub diameter, Dh is usually taken from 1.5 to 2.0 times of the shaft diameter and the hub length, Lh is from 1.0 times to 2.0 times of the shaft diameter.

The diameter of impeller eye, D_o is calculated by

$$D_o = \sqrt{\frac{4Q_s'}{\pi V_{mo}} + D_h^2} \tag{6}$$

For a fluid flowing through the rotating impeller, u is the tangential velocity, V is the absolute velocity and v is the relative velocity of a fluid particle to impeller rotation. The angle between V and u is α and the angle between v and u is β and it is the angle made by tangent to the impeller vane and a line in the direction of motion of the vane. The tangential component and radial component of absolute velocity V are V_u and V_r respectively.[8]

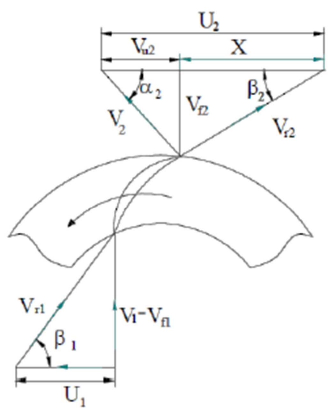


Fig. 2 Velocity triangle at inlet and outlet of a centrifugal pump[10]

The parameters K_u (speed constant), K_{m1}, K_{m2}, and D_1/D_2 are obtained on the value of specific speed in Fig A2.

The outlet diameter D_2,

$$D_2 = \frac{u_2 \times 60}{\pi \times n} \tag{7}$$

Where, the peripheral velocity at impeller outlet is

$$u_2 = K_u\sqrt{2gH} \quad (8)$$

The peripheral velocity at the inlet is also expressed by

$$u_1 = \frac{\pi D_1 n}{60} \quad (9)$$

And then, flow velocities at the inlet and outlet are

$$V_{r1} = K_{m1}\sqrt{2gH} \text{ and } V_{r2} = K_{m2}\sqrt{2gH} \quad (10)$$

If the incoming flow has no pre-rotation, the blade angle β_1(deg) is given by

$$\beta_1 = \tan^{-1}[\frac{K_{b1}V_{r1}}{u_1}] \approx \tan^{-1}[\frac{V_{r1}}{u_1}] + (0\sim6) \quad (11)$$

Where, K_{b1} = 1.1~1.25

The amount of outlet angle $\beta_2$usually has between 15° and 35°. So, the vane outlet angle is assumed that β_2= 23° in this design. From the velocity triangles, inlet and outlet relative velocities are

$$v_1 = \frac{u_1}{\cos\beta_1} \text{ and } v_2 = \frac{V_{r2}}{\sin\beta_2} \quad (12)$$

The virtual tangential component V_{u2} of V_2 is

$$V_{u2} = u_2 - \frac{V_{r2}}{\tan\beta_2} \quad (13)$$

For radial-type impellers, the slip factor, η_∞ varies between 0.65 and 0.75and it is assumed that η_∞ = 0.7 average. Thus, the actual tangential component V'_{u2} of V'_2 is

$$V'_{u2} = V_{u2}\eta_\infty \quad (14)$$

Thus, the actual outlet is found by

$$\tan\alpha'_2 = \frac{V_{r2}}{V'_{u2}} \quad (15)$$

The absolute outlet velocity from outlet velocity diagram is

$$V'_2 = \sqrt{V_{r2}^2 + V'^2_{u2}} \quad (16)$$

The number of blades, Z is decided by using the Plfeiderer formula.

$$Z \approx 6.5\frac{D_2 + D_1}{D_2 - D_1}\sin[\frac{\beta_1 + \beta_2}{2}] \quad (17)$$

In this design, blade thickness and shroud thickness are taken as 2.5 mm and 3.0 mm respectively for $D_2$is greater than 200 mm.

The inlet passage width b_1 and outlet passage width b_2 are calculated by

$$b_1 = [\frac{Q'_s}{\pi D_1 V_{r1}}][\frac{\pi D_1}{\pi D_1 - S_1 Z}] \text{ and}$$

$$b_2 = [\frac{Q'_s}{\pi D_2 V_{r2}}][\frac{\pi D_2}{\pi D_2 - S_2 Z}] \quad (18)$$

Where, S_1 is (δ_1/sin β_1), S_2 is (δ_2/sin β_2), and $\delta_1$and δ_2 are blade thicknesses near the leading edge and trailing edge respectively. Moreover, S_2 can also be determined by the following relationship equation.

$$\frac{\pi D_1}{(\pi D_1 - S_1 Z)} = \frac{\pi D_2}{(\pi D_2 - S_2 Z)} \quad (19)$$

III. DESIGNED RESULTS OF CENTRIFUGAL PUMP

A. *Calculated Results*

The following results table is both impeller and casing design of centrifugal pump for face width 12 mm are clearly expressed in Table I.

Table I. Calculated Results of single-suction Centrifugal Pump Design

No	Descriptions	Symbols	Results
1	Input Power	L	6hp
2	Shaft diameter	d_s	34 mm
3	Hub diameter	D_h	51 mm
4	Hub length	L_h	68 mm
5	Impeller eye diameter	D_o	95 mm
6	Impeller inlet diameter	D_1	97 mm
7	Impeller outlet diameter	D_2	226 mm
8	Inlet angle of impeller blade	β_1	20°
9	Outlet angle of impeller blade	β_2	23°
10	Impeller passage width at inlet	b_1	26 mm
11	Impeller passage width at outlet	b_2	12mm
12	Number of impeller blades	Z	6 blades
13	Base width of volute casing at D_2	b_3	24 mm
14	Volute tongue angle	$\Phi°_t$	15.51°
15	Discharge nozzle diameter	D_d	264 mm

But this paper describes the performance of centrifugal pump on face width 18 mm with simulation pictures and experimental results table with efficiency and head based on capacity.

B. Design of volute casing

Design of volute casing is calculated depending on the D_2 and the basis of constant average flow velocity in volute casing. The volute casing increases proportionally in size from cut water to the discharge nozzle. In rear velocities distribution, across volute section is not uniform. Volute angle is read from volute constant chart shown in Fig. A3 and in this design, the volute angle, α_v is 8° based on n_s value.[8]

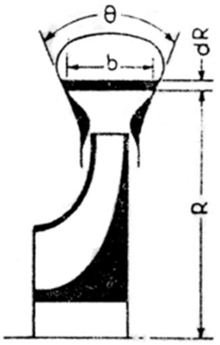


Fig. 3 Section through Volute Casing [4]

The width of the volute at any point may be calculated from

$$b = b_3 + 2x \times \tan(\theta/2) \qquad (20)$$

Where, x is the distance between any radius R and impeller outside radius R_2. The volute is designed by determining the angle Φ° measured from and assumed radial line by tabular integration of Equation (27).

$$\Phi^\circ = \frac{360\, R_2 V'_{u2}}{Q} \int_{R_2}^{R_\Phi} \frac{b\,dR}{R} = \frac{360 R_2 V'_{u2}}{Q} \sum_{R_2}^{R_\Phi} b \frac{\Delta R}{R} \qquad (21)$$

The tongue angle of volute casing is determined by

$$\Phi_t^\circ = \frac{132 \ \log_{10} \ R_t/R_2}{\tan \ \alpha'_2} \qquad (22)$$

Volute wall thickness is chosen according to suction pipe diameter and it is taken as 6 mm since the suction pipe diameter is within 100 and 150 mm in this design.

IV. DESCRIPTION OF EXPERIMENTAL SET UP

The description of experimental set up is single suction centrifugal pump with coupling a 18 hp diesel engine. It consists of main components such as impeller, volute casing, gate valve, discharge pressure gauge, suction pressure gauge, suction pipe, 200 gallons fiber tank and Supply Lake. Also Tachometer and stop watch need for measurement in observation.

Fig. 4 Face width 18 mm Impeller and 12 mm Impeller

Fig. 5 Description of Study on Experimental Test

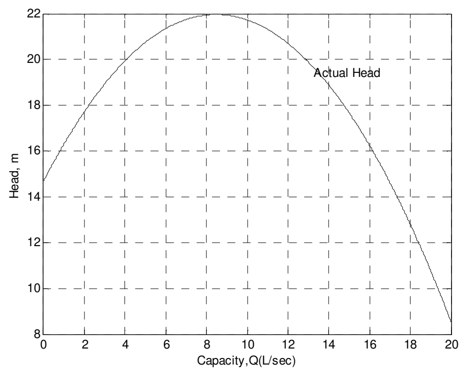


Fig. 8 Performance Characteristic Curves of Actual Head and

Efficiency on Capacity in designed Speed

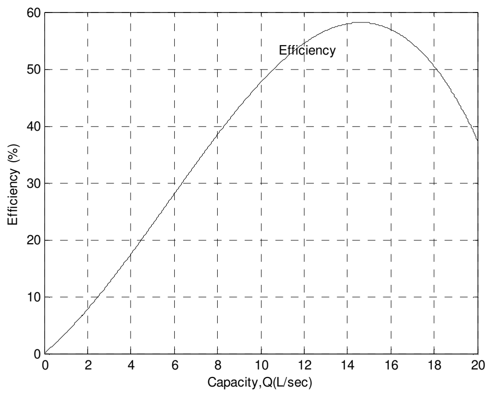


Fig. 6 Performance Characteristic Curves of Actual Head and Efficiency on Capacity in Testing Speed

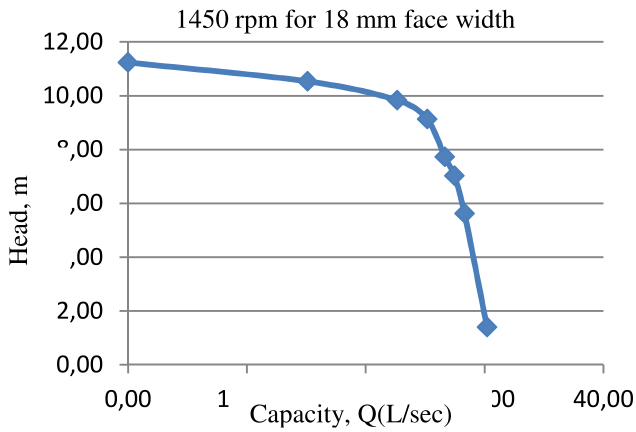
V. Performance Results At Constant Speed Of Impeller

Table II. . Experimental Results in Eight Points Gate Opening at 18 mm

Sr. No	Gate Opening	Deliver Pressure (psi)	Head (m)	Time (Sec)	Q (Lit/ sec)	Efficiency (%)
1	Fully Opened	2	1.40	30	30.20	9%
2	6/7	8	5.62	32	28.32	35%
3	5/7	10	7.02	33	27.46	42%
4	4/7	11	7.73	34	26.65	45%
5	3/7	13	9.13	36	25.17	50%
6	2/7	14	9.83	40	22.65	49%
7	1/7	15	10.54	60	15.10	35%
8	Fully Closed	16	11.24	0	0.00	0%

Table III. Experimental Results In Eight Points Gate Opening At 12 Mm

Sr. No	Gate Opening	Discharge Pressure (psi)	Head (m)	Time (Sec)	Q (Lit/ sec)	Efficiency (%)
1	Fully Opened	2	1.18	39.3	23.06	6
2	6/7	3	2.06	39.6	22.88	10
3	5/7	3.5	3.97	41.7	21.73	19
4	4/7	5	5.07	42.9	21.12	23
5	3/7	5.2	5.85	44.2	20.17	27
6	2/7	6.5	10.7	46.6	19.45	46
7	1/7	9	11.67	52.9	17.13	44
8	Fully Closed	12	12.7	0	0	0



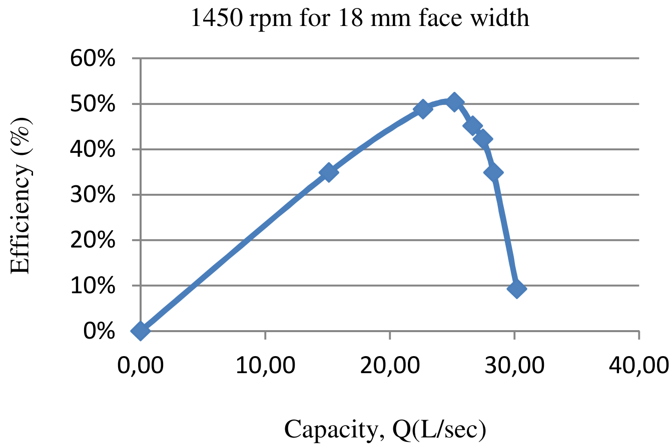
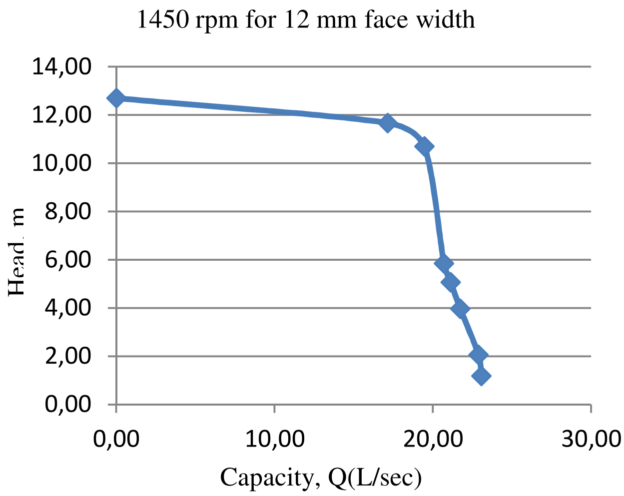


Fig.7 Performance Characteristic Curves of Head and Efficiency on Capacity in Constant speed



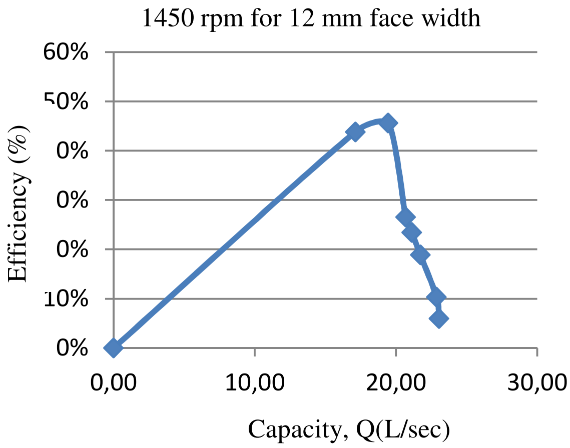


Fig.8 Performance Characteristic Curves of Head and Efficiency on Capacity in Constant Speed

V. Conclusion

This paper presents the performance of centrifugal pump is intended to use in agricultural application. This research is worked as a research of department of mechanical engineering in Technological University (Mandalay). In this work, the centrifugal pump is designed and calculated for 12 mm face width at 1800 rpm, 0.9 m^3/min capacity and 20 m head. As this design parameters, the pump impeller was casting with 18 mm face width and testing at 1450 rpm. According to observations, the 12 mm face width impeller can fulfill the requirements of water pumping system at 1800 rpm for irrigation. In this experimental, the performance efficiency of pump for 18 mm face width is more efficient than 12 mm face width at almost every operating point at 1450 rpm. Therefore if this pump use in an application, 18 mm face width impeller should be selected in the same design and parameters at 1450 rpm for available head is not different.

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[10] E.C. Bacharoudis*,1, AE.Filios2, MD.Mentzos1and D,p. Margaris1 Parametric Study of a Centrifugal Pump Impeller by Varying the Outlet `Blade Angle