A REVIEW ON PERFORMANCE AND OPTIMIZATION OF RADIAL FLOW PUMP IMPELLER THROUGH CFD ANALYSIS

VISHAL N. KARANDE[1], ANIMESH V. PAWAR[2], RAHUL M. VISHWAKARMA[3], RUTUJA R. KHANZODE[4]

PROF. KRISHNA KUMAR YADAV[5]

[1-4]BE student, Dept. Mechanical engineering, ISB&M School of Technology, Pune
[5]Assistant Professor, Dept. Mechanical engineering, ISB&M School of technology, Pune

---

Abstract - These days due to ever increasing demand of improved performance, pump designers are being challenged to provide the machines which are more efficiently, quiet, and reliable with lower cost. It is very difficult and complex to analyze the hydraulic performance and characteristics of a centrifugal pump. Additionally, pump operation hugely depends on a large number of interdependent variables. This work aims to study the performance analysis of a centrifugal radial flow pump designed to deliver 0.0074 m3/s of water with a head of 30 m at a speed of 2870 rpm using ANSYS CFX (ver.14.0). The pump unit has been modeled using PTC Creo (ver. 2.0). In order to analyze the flow, Computation fluid dynamics (CFD) has been used. The performance of the pump was first determined using the existing number of the blades and then, the thickness of blades has been varied to analyze the pump's performance. The results show that for the optimized value, pump efficiency increased by 2 %.

Keyword: Centrifugal Pump, Computational fluid dynamics (CFD) Pump Performance, Pump Efficiency.

1. INTRODUCTION

Pumps are the most commonly encountered machines in day to day life. The common applications include building services, irrigation, water supplies and industrial plants. These add energy to water. A wide variety of centrifugal pump types have been constructed and used in many applications in industries and other technical sectors. However, their design and performance prediction process is still a difficult task, mainly due to the great number of free geometric parameters, the effect of which cannot be directly evaluated. This increases the cost of pump manufacturing. Simulation helps in reducing the cost of pump design. In the present work, pump is designed using design software CREO. Fluid analysis is done using computational fluid dynamics (CFD).

1.2 GENERAL: A different type of machinery has been developed to transfer liquids to higher locations, or forcing it against the resistance to flow of liquid. These machines which add energy to the fluid are called pumps. Therefore, pumps are very important in day to day life. Pumps have vital roles in irrigation, industries, water supply systems and fire extinguishing etc. centrifugal pumps suits in most of the working condition; these pumps have Moderate operating conditions and are most widely used. Pump consumes sufficient amounts of energy, which means high operating cost. That's why the design and manufacture attempt to make a pump of higher efficiencies for decreasing the operating cost. Pump design is done by using theoretical knowledge and the empirical relations that have been developed based on the experience.

1.3 PUMP: If the mechanical energy is converted into pressure energy by means of centrifugal force acting on the fluid, the hydraulic machine is called centrifugal pump. The centrifugal pump acts as a reverse of an inward radial flow reaction turbine. This means that the flow in centrifugal pump is in radial outward directions. The centrifugal pump works on the principle of forced vortex flow which means that when a certain mass of liquid is rotated by an external torque, the rise in pressure head of the rotating liquid takes place.

The following are the main parts of a centrifugal pump:

1. Casing
2. Impeller
3. Suction pipe with a foot valve and a strainer
4. Delivery pipe

Casing: It is an air tight passage surrounding the impeller.

Impeller: The rotating part of a centrifugal pump is called impeller. It consists of a series of curved vanes.

2. Losses in Centrifugal Pumps

Mainly there are three specific losses which can be separately calculated. These are

2.9.1Mechanical friction. Losses between the fixed and rotating parts in the bearings and gland and packing.

2.9.2Disc friction. Loss between the impeller surfaces and the fluid.

2.9.3 Leakage and recirculation Losses. The recirculation is along the clearance between the impeller and the casing due to the pressure difference between the hub and tip of the impeller. The various losses are indicating

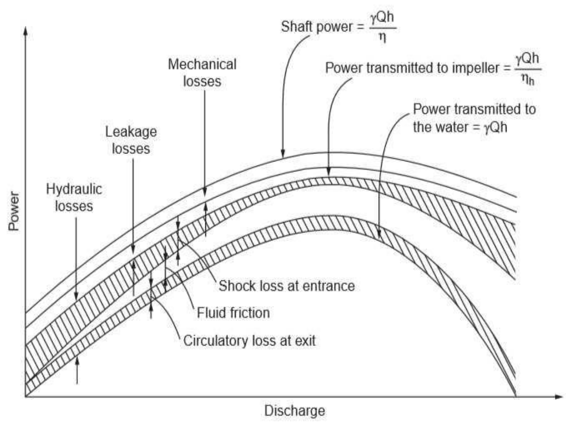


Fig 2.1 Losses in Pump

2.10 EFFICIEWNCY OF PUMP

In case of a centrifugal pump the power is transmitted from the shaft of the electric motor to the shaft of the pump and then to the impeller. From the impeller, the power is given to the water. Thus, power is decreasing from the shaft of the pump to the impeller and then to the water. The following are the important efficiencies of a centrifugal pump.

2.11 TYPES OF EFFICI ENCY OF PUMP

1. Manometric efficiency.
2. Mechanical efficiency.
3. Overall efficiency

2.11.1 MANOMETRIC EFFICIENCY

The ratio of manometric head to the head generated by impeller is known as manometric efficiency

$$\eta_{mano} = \frac{manometric\ head}{head\ genereted\ by\ impeller}$$

2.11.2 MECHANICAL EFFICIENCY

It is the ratio of power available at impeller power at the shaft of centrifugal pump is known as mechanical efficiency.

$$\eta_{m=}\frac{power\ at\ impeller}{power\ at\ shaft}$$

$$\eta_{m=}\frac{w}{g} = \frac{v_{w2*u_2}}{1000}$$

2.11.3 OVERALL EFFICIENCY

$$\eta_o = \frac{power\ output}{power\ input}$$

$$\eta_o = \frac{w}{1000} * \frac{H_m}{s.p.}$$

2.12 CHARACTERISTIC CURVE OF PUMP

Characteristic curves of centrifugal pumps are defined as those curves which are plotted from the results of a number of tests on the centrifugal pump these curves are necessary to predict the behavior and performance of the pump when the pump is working under different flow rate, head and speed. The following are the important characteristics curves of pumps.

1. Main characteristics curve
2. Operating Characteristics Curves
3. Constant efficiency curve

2.12.1 Main Characteristic Curve

The main characteristic of a centrifugal pump consists of a variation of head (manometric head,H_m), power and discharge with resprct to speed. For plotting curves of manometric head versus speed, discharge is kept constant.

For plotting curves of discharge versus speed, manometric head (H_m) is kept constant. And for plotting curves of power versus speed monomeric head and discharge is kept constant Fig 2.1 shows main characteristic curves of a pump.

For plotting the graph of (H_m) versus speed (N), the discharge is kept constant.

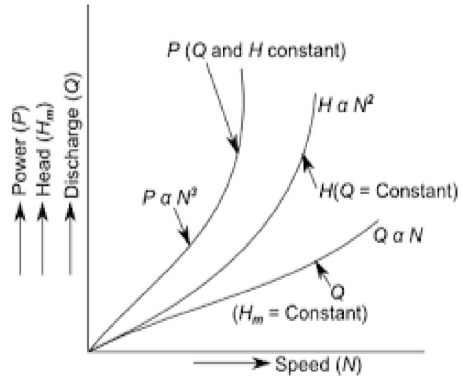


Fig: 2.2 Main Characteristics Curve

2.12.2 Operating Characteristics Curves.

If the speed is kept constant the variation of manometric head, power and efficiency with respect to discharge gives the operating characteristic of the pump. Fig 2.2 shown the operating characteristic curve of a pump.
The input power curve for the e pump shall pass through the origin. It will be slightly away from the origin on the Y-axis, as even at zero discharge some power is needed to overcome mechanical losses.

The head curve will have max imam value of head when discharge is zero.

The output power curve will s tart from origin as at Q = 0, output power (ρ *Q*g*H) will be zero.

The efficiency curve will start from origin at Q = 0, η = 0

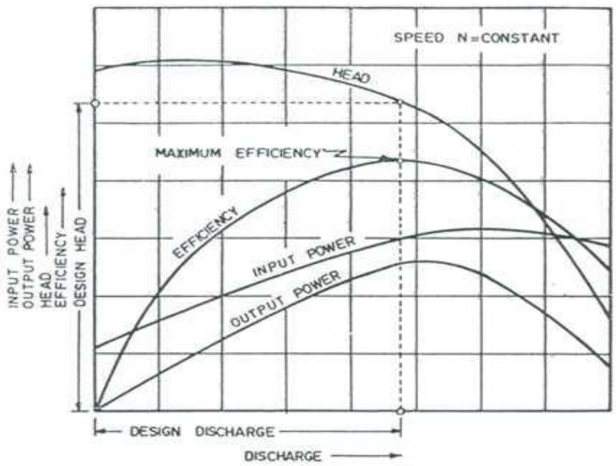


Fig 2.3 Operating Characteristic Curves

2.12.3 Constant efficiency curves.

1. For obtaining constant efficiency curve for a pump the head verse s discharge curve and efficiency verses discharge curve for different speed are used. Fig. 2.3(a) showed the head verses discharge curve for different speed. The efficiency verses discharge curve for the different speed is as shown in Fig. 2.3(c). By combining these curves (H~Q curves and 5~Q curves), constant efficiency curves are obtained as shown in Fig. 2.3(a).

2. for plotting the constant efficiency curves (also known as is efficiency curves), horizontal lines representing constant efficiency are drawn on the 5~Q curves. The points, at which these lines cut the efficiency curves at various speeds, are transferred to the corresponding H~Q curve. The points having the same efficiency are then joined by smooth curves. These smooth curves represent the Iso-efficiency curves

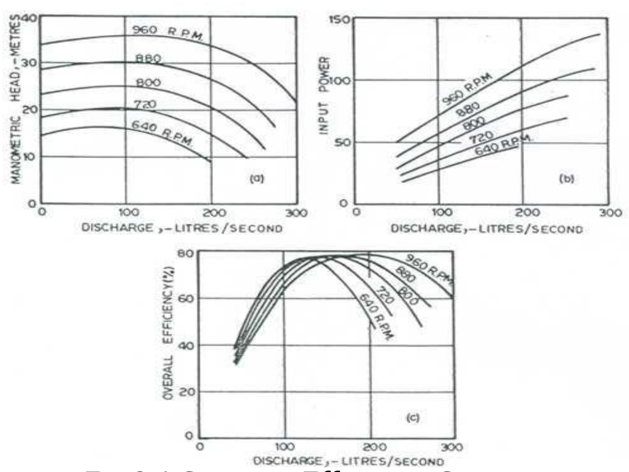
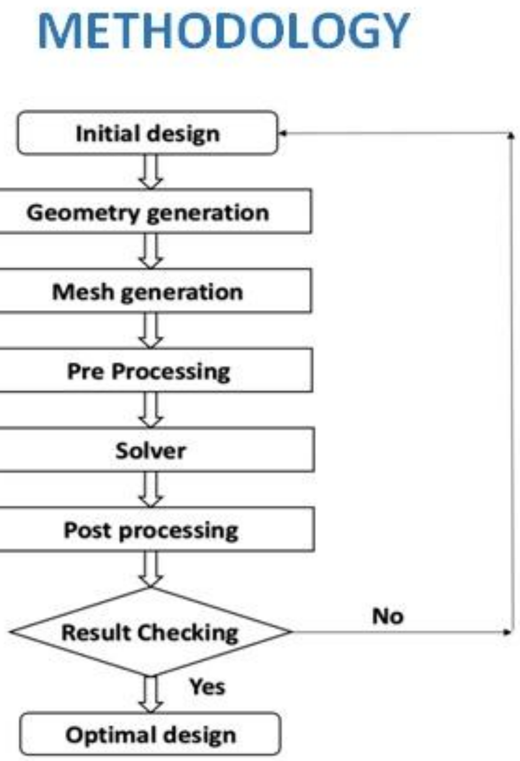


Fig 2.4 Constant Efficiency Curve

3. METHODOLOGY



4. Design of Pump & Impeller

4.1 DESIGN OF RADIAL IMPELLER

Parameters	Value
Specific speed	19.26
Power input to pump (kW)	3.4823
Shaft diameter (mm)	25.007
Outer diameter of impeller (mm)	171.9486
Inner diameter of impeller (mm)	66.1905
Impeller width at inlet (mm)	8.6267
Impeller width at outlet (mm)	5.0308
Blade angle at outlet	28.9375°
Inlet blade angle	22.9375°

4.2 CALCULATION OF VOLUTE CASING

- $Q=\frac{Q*\Phi}{360}$ in m^3/s
- $Q=\frac{0.0074*30}{360} = 0.000616 m^3/s$
- $A=\frac{Q}{c}$ in m^2

$A=\frac{0.0006146}{6.973} = 0.0000907\ m^2$

- $A = \frac{\pi}{4} * d^2$

$d= \sqrt{\frac{A*4}{\pi}} = \sqrt{\frac{0.0000907*4}{\pi}}$

d=0.01075 m

4.2.1 DESIGN OF VOLUTE CASING

Mean velocity in volute(m/s)	6.793
Axial gap between impeller outlet and casing inlet (mm)	22
Width of casing (mm)	8.5
Draft angle of casing	10

4.2.2 DESIGN OF VOLUTE CASING AT VARIOUS ANGLE

Angle in degree	$Q^*=Q^*\Phi/360$ (m3/s)	Area of various angles	Depth of various angles
	10^{-3}	10^{-4}	
30	0.616	0.907	0.0107
60	0.124	0.177	0.0474
90	0.185	0.265	0.0183
120	0.246	0.352	0.0211
150	0.308	0.441	0.0118
180	0.37	0.53	0.0129
210	0.431	0.618	0.0208
240	0.493	0.707	0.03
270	0.555	0.795	0.0318
300	0.616	0.883	0.0335
330	0.678	0.335	0.0351
360	0.74	0.106	0.0367

4.3 CALCULATION OF VANE PROFILE

- Relative Velocity at Inlet & outlet

$$W_1 = \frac{4.2071}{\sin(22.99)} = 10.7706\, m/s$$

$$W_2 = \frac{2.793}{\sin(28.99)} = 5.7628 m/s$$

- $C_m - C_{m1} = \frac{C_{m2} - C_{m1}}{R_2 - R_1}(R - R_1)$

W	R	C_m	**Sinβ=**$\frac{C_m}{W}$	**β**	**R*tanβ**	**B=**$\frac{1}{\text{R*tan}\beta}$	**Δa-ΔR=** $\frac{(B_n+B_{n-1})}{2}$	**Θ=**$\frac{180}{\Pi\sum\Delta a}$
10.7716	32.98	4.2071	0.3906	22.99	13.9923	0.07146	0	0
10.2990	37.98	4.0737	0.3983	23.47	16.4905	0.06064	0.3350	18.9362
9.8265	42.98	3.9403	0.4010	22.64	1808132	0.05315	0.6150	35.2369
9.3539	47.98	3.8069	0.4070	24.02	21.9821	0.04676	0.8647	49.5436
8.8814	52.98	3.6735	0.4136	23.43	24.0662	0.04155	1.0854	62.1888
8.4088	57.98	3.5401	0.4210	24.89	29.9011	0.03717	1.2822	73.4646
7.9363	62.98	3.4067	0.4293	25.42	29.9326	0.03340	1.4586	86.5716
7.4638	67.98	3.2733	0.4386	26.01	32.207	0.03014	1.6147	92.6701
6.9912	72.98	3.1399	0.4491	26.69	36.6819	0.02725	1.7608	100.8864
6.5187	77.98	3.0065	0.4612	27.47	40.5419	0.02466	1.8906	108.3234
6.04061	82.98	2.8731	0.4752	28.37	44.8110	0.02232	2.0081	115.0556
5.5735	87.98	2.7397	0.4916	29.44	49.6551	0.02014	2.1142	121.1376

5: RESULTS AND DISCUSSION

5.1 MESHING OF PUMP ASSEMBLY

The final mesh of the pump assembly was constructed using ANSYS. The corresponding model is shown in Fig.5. Meshing data with total number of elements and nodes are given in Table.

Table 5.1-: Mesh information of pump assembly

Total elements	Total nodes	TRI_3	TETRA_4	LINE_2
5850460	1170192	235802	5610460	8150

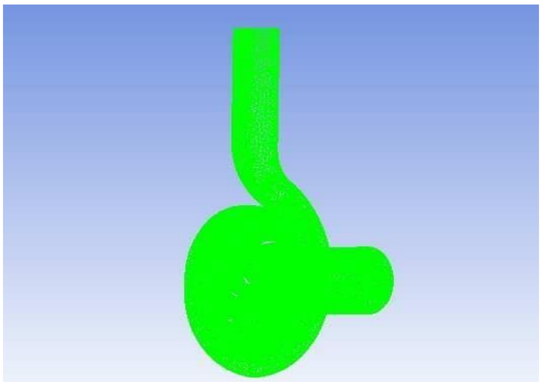


Fig 5.1 meshing of Designed pump.

5.1 BOUNDARY CONDITIONS

The numerical computation is based on steady-state condition with the following boundary conditions. Radial flow pump impeller domain is considered to be a rotating frame of reference with rotational speed of 2870 rpm, 1 atm. pressure at the inlet, and 0.0074 m^3/s discharges at the outlet. The working fluid is water at 25° C. k-ε turbulence model with turbulence intensity of 5% is used.

Velocity Stream Contour:

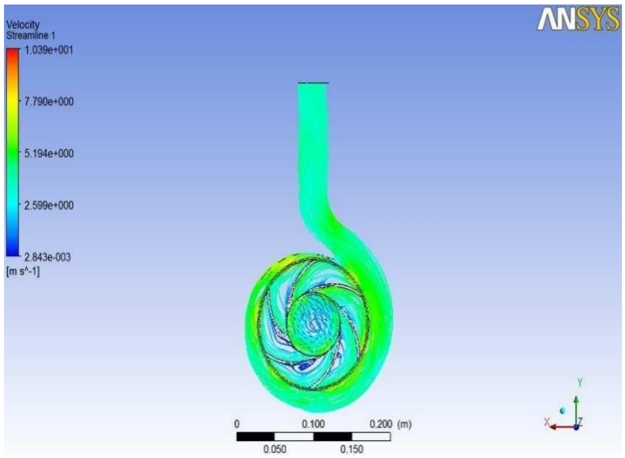


Fig-5.2: Velocity Stream Contour

Pressure Contour:

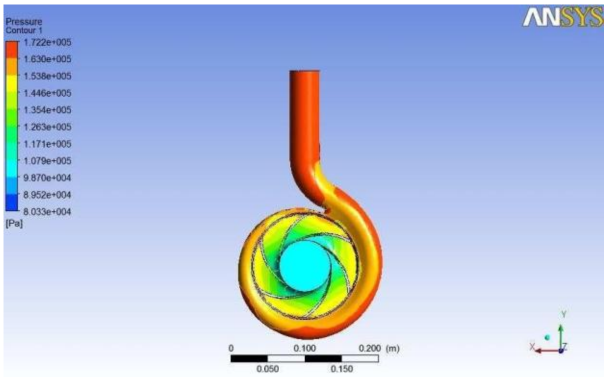


Fig-5.3: Pressure Contour

6. CONCLUSION

Based on the design and CFD analysis of radial flow impeller it can be concluded that the performance of radial flow pump, can be simulated by increasing no of blades. The optimum efficiency may be obtained for 8 numbers of blades. It may be observed that the efficiency of pump at optimum value increases by approximately 1.5 %.

REFERENCES

- Jude, Dorel Homentcovschib "Numerical analysis of the in viscid incompressible flow in two dimensional radial-flow pump impellers" (1983) https://doi.org/10.1016/S0955-7997(98)00052-6

- Gahlot, V.K., & Nyiri, A. (1993), Author's imperative to define shape & size of vanes
- J. S. choi, Discharge flow measurement of a centrifugal turbo machinery, journal of mechanical science & technology, 8(2) (1994) 152-160
- J. S. Anagnostopoulos, CFD Analysis and Design Effect in a Radial Pump Impeller", WSEAS transaction on fluid Mechanics, 7(1) (2006) 763-770.
- S. Kaewnai, M. Chamaoot and S. Wongwises, Predicting performance of radial flow type impeller of centrifugal pump using CFD, journal of Mechanical Science and Technology, 23(2009) 1620-1627.
- A. T. Oyelami, S. B. Adejuyigbe, M. A. Waheed, A. K. Ogunkoya, and D. Iliyas, Analysis of Radial-Flow Impeller of Different Configuration, The Pacific Journal of Science and Technology, 13(1) (2012)24-33.
- S. R. Shah, S. V. Jain, R. N. Patel, V. J. Lakhera, CFD for Centrifugal Pump: A review of the state of the art, procedia engineering, 51(2013)715-720
- V. N. Pavlechko & S. K. Protasov, On the problem of theoretical pressure of radial flow pump unit, journal of engineering Physics and Thermophysics,87(6)(2014)1513-1520
- J. H. Kim, H. C. Lee, S. Kim, J. Y. Yoon & Y. S. Choi, Design to improve the performance of a centrifugal pump using CFD, Journal of Mechanical Science & Technology, 29(1) (2015) 215-225
- M. A. Ismail, A. K. Othman and H. Zen, An Experience with simulation modeling of Radial Flow Pump" International journal of Emerging engineering research and technology,3(11)(2015)23-28.
- M. W. Heo, S. B. Ma, S. Shim, and Kwang-yong Kim, High-efficiency design optimization of a Centrifugal Pump. Journal of Mechanical Science and Technology, 30(9) (2016) 3917-3927.
- J. Pei, W. Wang, and S. Yuan, Multi-point Optimization on meridional shape of a centrifugal pump impeller for performance improvement, journal of Mechanical science And Technology,30(11)(2016)4949-4960
- M. G. Tan, X. H. HE, H. L. Liu, L. Dong, and X. F, Wu, Design and analysis of a radial diffuser a single stage centrifugal pump, Engineering Application of Computational Fluid Mechanics, 87(6)(2016)500-511.

BIOGRAPHIES

ANIMESH V PAWAR
BE student, Dept. Mechanical engineering, ISB&M School of technology, Pune.

VISHAL N KARANDE
BE student, Dept. Mechanical engineering, ISB&M School of technology, Pune.

RAHUL M. VISHWAKARMA
BE student, Dept. Mechanical engineering, ISB&M School of technology, Pune.

RUTUJA R. KHANZODE
BE student, Dept. Mechanical engineering, ISB&M School of technology, Pune.

PROF. KRISHNA KUMAR YADAV
Assistant Professor, Dept, Mechanical engineering, ISB&M School of technology, Pune.