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Design and Analysis of the Radial Flow Impeller of the Centrifugal Pump

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Abstract
Centrifugal pumps are widely used for pumping water over short to medium distances through a pipeline where moderate head and discharge are required. For optimum performance of the pump, the vanes should be properly designed. As there are very few papers that explain the radial type vane profile design procedure, it becomes very difficult for designers to design a vane, and they are forced to reverse engineer the vane profiles popularly available in the market. This project investigates the influence of the number of impeller blades on the performance of a centrifugal pump. Through a combination of design, computational fluid dynamics (CFD) simulations, and experimental validation, the study evaluates parameters such as pump efficiency, head, and flow rate characteristics for varying blade numbers. The results offer guidance on optimal blade design for specific applications and obtain maximum Efficiency.

Keywords: Pump, Impeller, Vane

I. Introduction

Hydraulic machines are categorized into turbines and pumps, playing a crucial role in energy conversion and fluid transportation. Turbines convert hydraulic energy into mechanical energy, while pumps convert mechanical energy into hydraulic energy. Pumps are classified into two main categories: Positive Displacement Pumps: These pumps draw in a fixed amount of fluid and then displace it to the delivery side, and Dynamic Pumps: These pumps use a rotating impeller to increase the energy level of the fluid. Centrifugal pumps are a type of dynamic pump that uses a rotating impeller to increase the energy level of the fluid. The pump consists of an impeller, casing, suction pipe, delivery pipe, foot valve, and strainer.

The working principle of centrifugal pumps involves the following steps. Priming: The pump is primed by filling the suction pipe, casing, and delivery pipe with water. Initial Rotation: The impeller is rotated by a motor, creating a strong suction at the eye. Speed Attainment: The delivery valve is opened, allowing liquid to enter the impeller vane and flow into the casing. Energy Development: The impeller's

action generates both pressure energy and velocity energy. Liquid Lift: The liquid is lifted through the delivery pipe to the required height. The casing is a critical component of the pump, and it comes in different types, including volute casing, vortex casing, and casing with guide blades. The impeller is a rotating component equipped with vanes or blades used in turbo machinery. The heads of a centrifugal pump include:

1. Suction head
2. Delivery head
3. Static head
4. Manometric head.

CAE tools are used to analyze the behavior of products, including pumps, and to simulate and study their expected behavior in various environments. CAE tools include finite element analysis (FEA), computational fluid dynamics (CFD), and other analysis software. CAE tools are used in various industries, including aerospace, automotive, civil engineering, and defense contracting. They are used to analyze and determine stress and deformation, heat transfer and thermal distribution, magnetic field distribution, fluid flow and dynamics, and other continuous field problems.

The volute's cross-sectional area increases from its initial point, encompassing 360 degrees around the impeller, and then expands to the final discharge opening. A distinctive feature of the volute design is the "tongue" or "cut-water," which is the wall separating the initial section from the discharge nozzle portion of the casing. This makes a major differences in the radial and tangential volutes.

II. General description of a centrifugal pump

A. *Centrifugal Pump*

Fig.1: Centrifugal pump

The centrifugal pump derives its name from the significant role of centrifugal action in its operation, which increases pressure within the rotor. A single-suction centrifugal pump, illustrated in Figure 1, features water entering the impeller from one side. This design results in a substantial axial hydraulic thrust force due to the unbalanced hydraulic pressure on the impeller, causing it to shift away from the suction side.

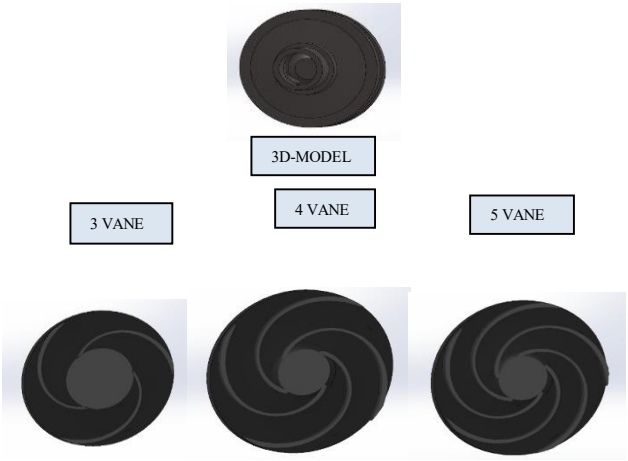
B. *Impeller*

Fig.2: Impeller

The radial flow impeller discharges the fluid radially at 90° to the shaft axis.

A Radial Flow Pump (also known as a centrifugal pump) is a velocity pump where a rotating impeller displaces varying amounts of water per rotation, depending on the speed of rotation, which throws water outwards at right angles to the shaft. The pump is useful for all phases of an emergency. Radial Flow Pumps function by forcing water towards the outer edge of a rotating impeller, where the discharge is captured by the pump casing and the kinetic energy is converted to pressure energy before leaving the pump. When this happens, a negative pressure zone is created at the inlet of the pump chamber, which in turn draws water into the pump. These pumps can be driven by electricity (grid or solar) or directly by diesel/petrol engines, and they can be situated at ground level (suction pumps) or submersible.

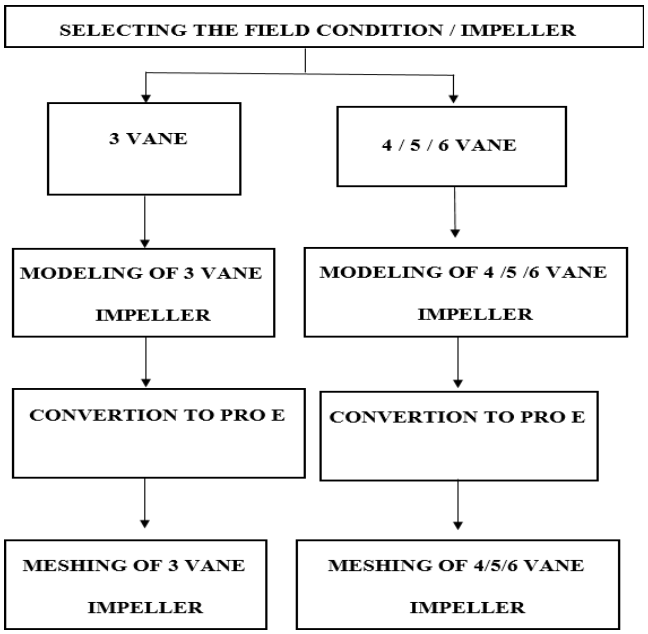
C. *Radial volute*



A closed impeller has vanes attached to a central hub with both sides shrouded. The closed design provides better efficiency and reduces wear and erosion. However, closed impellers are more difficult to balance and maintain.

III. METHODOLOGY

A. Method



B. *Modeling*

Fig.4 Radial Impeller 3D model

C. *Properties of Material*

The volute is made of cast iron. The definition of material properties has been declared in the "Property" module. The table shows the mechanical characteristics of the cast iron.

General Properties of Cast Iron FGS -400-15	Values
Young's module E	165000MPa
Poisson coefficient υ	0,3
Elastic limit	250MPa
Rupture strength	400MPa
Density	7200kg/m^3
Modulus of rigidity G	56GPa

TABLE I. PROPERTIES OF MATERIAL

D. *Meshing*

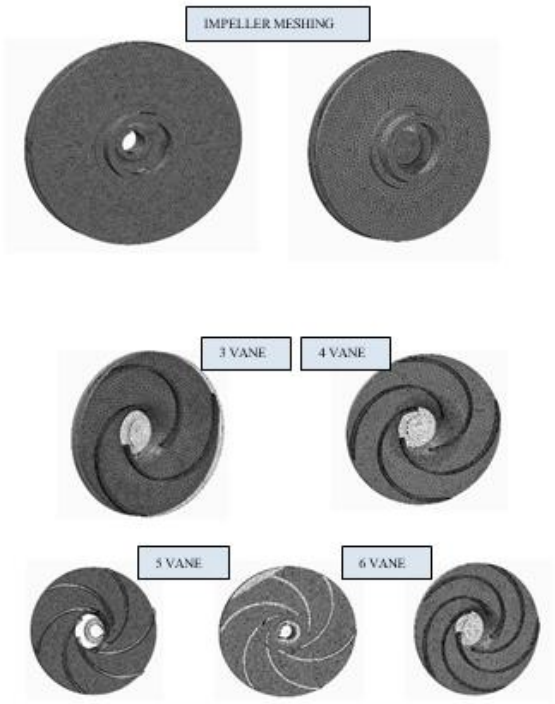


Fig.5 Meshing of a different vane impeller

The impeller was modeled with high geometric accuracy to reflect realistic blade profiles, and special attention was given to meshing this region due to its critical role in energy transfer. A fine mesh was

applied around the impeller blades to capture complex flow patterns, including blade-passing effects and pressure gradients. The blade surfaces were refined with several inflation layers to accurately resolve the boundary layer and minimize numerical errors in regions of high velocity and shear. The rotating zone was defined using a rotating reference frame, allowing accurate simulation of impeller motion and its interaction with the surrounding fluid. Mesh quality metrics such as skewness and aspect ratio were kept within acceptable limits to ensure simulation stability and reliability.

EXPERIMENTAL PARAMETERS

A. *Noload Reading*

OPENWELL – 1HP – 3VANE IMPELLER				
VOLATGE	CURRENT	SPEED	FERQ.	PF
180	2.81	2980	50.04	0.920
200	2.72	2984	50.07	0.979
220	3.44	2986	50.04	0.822

TABLE II. Noload Reading – 3 Vane

A. *Experimental Reading*

OPENWELL – 1HP – 3VANE IMPELLER		
HEAD (m)	DISCHARGE (lps)	OAE (%)
16.2	3.01	23.1
19	2.6	24.3
20.6	2.3	24.2
22.4	2.02	22.8
24.2	1.7	21.7
25.9	1.4	19.8
26.8	1.1	17
27.7	0.8	12.9
28.6	0.3	5.7
29.3	0	0

TABLE III. Experimental Reading – 3 Vane

B. *Graph Reading*

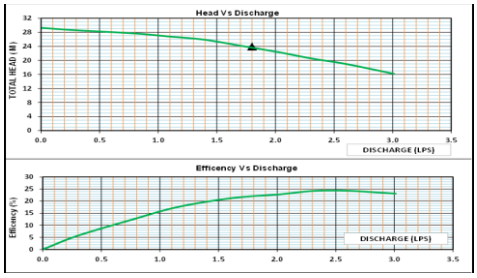


Fig.6 Comparison Graph

IV. RESULTS AND DISCUSSION

A. *Meshing the Impeller*

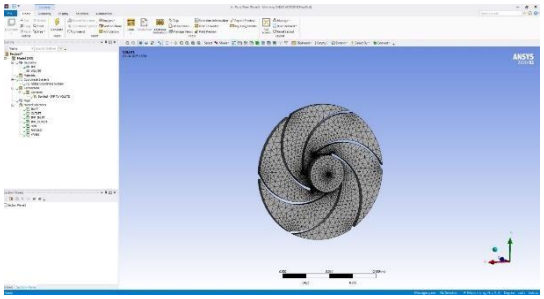


Fig.7 Impeller Meshing - Path

B. *Casing with Boundary condition*

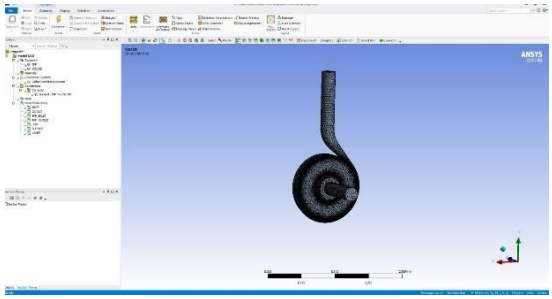


Fig.8 Casing with boundary condition

C. *Flow Iteration*

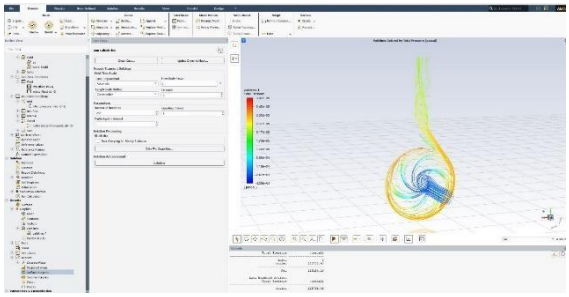


Fig.9 Casing with boundary condition

D. *Flow Iteration – Simulation*

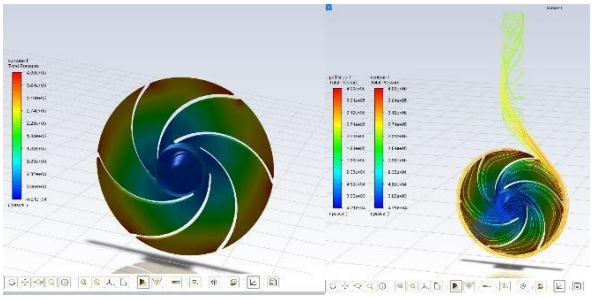


Fig.10 Flow Iteration – Simulation

E. *Comparative results of different blade Impeller*

COMPARTIVE RESULTS OF DIFFERENT IMPELLER BLADE					
4 VANE		5 VANE		6 VANE	
HEAD	OUTLET	HEAD	OUTLET	HEAD	OUTLET

16	3	16	3	20	3
24	2	24.5	2	24.8	2
26	1	26.5	1	28	1
28	0	28.2	0	29.5	0

TABLE IV. Different Impeller Blade

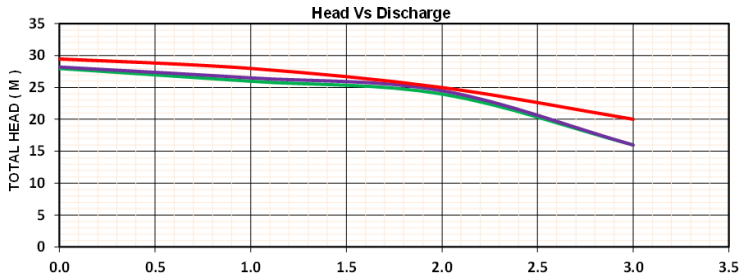


Fig.11 Different Blade Impeller – Head vs Discharge

A. *Experimental RPT final impeller*

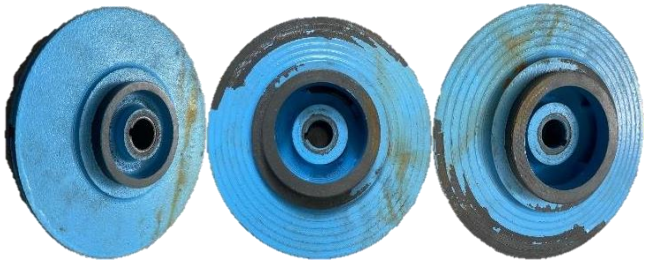


Fig.12 Experimental RPT Impeller – 6 Vane

G. *Final product of testing*

Fig.13 Final Product for testing – 6 Vane

H. *Final product of testing – No load Reading*

OPENWELL – 1HP				
Voltage	Current	Speed	Ferq.	PF
180	2.8	2984	50.01	0.930
200	2.7	2986	50.02	0.98
220	3.3	2990	50.04	0.81

TABLE V. Final product of testing – No load reading

I. *Final product of testing – Full load Reading*

OPENWELL – 1HP – 6 VANE IMPELLER		
Head (m)	Discharge (lps)	OAE (%)
16	3.3	23.0
18	3.1	24.32
19	3.0	25.1
22	2.5	27.16
24.5	2.1	28.0
25	2.0	27.49
26	1.8	26.01
27	1.5	22.1
28	1.0	15.89
29	0	0

TABLE VI. Final product of testing – Full load reading

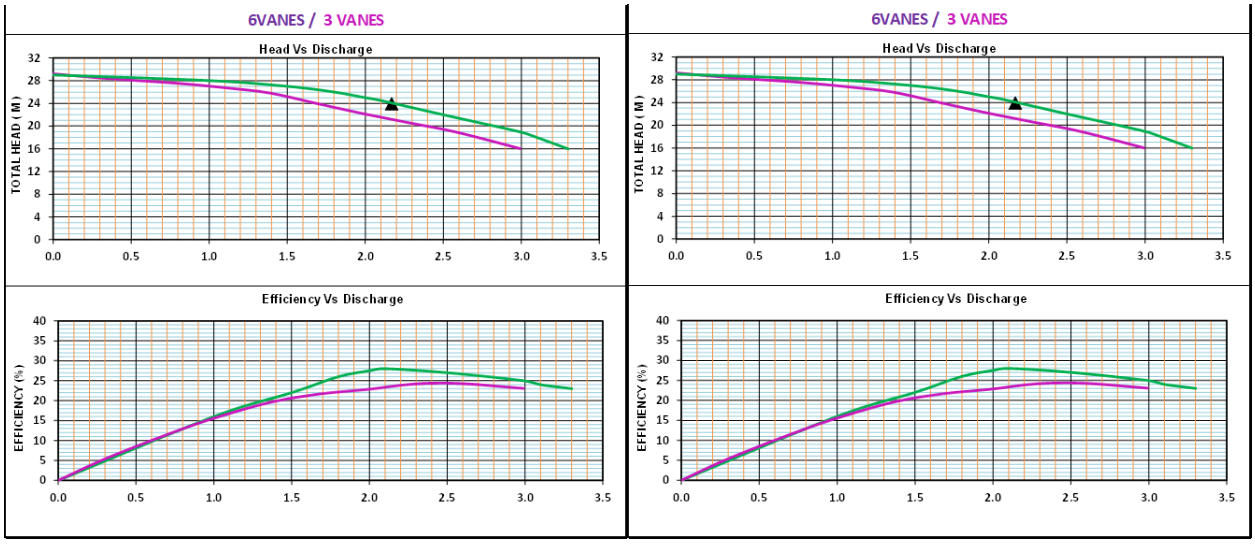


Fig.14 Final Product Comparison – 3 vs 6 vane.

CONCLUSION

This Project on impeller methodologies for centrifugal pumps has yielded significant insights into the number of vanes. Through an extensive literature review and complex design analysis, it has been demonstrated that 6 vanes impeller outperform 3 vane impeller when designed with the same parameters. The investigation into flow paths has further highlighted the advantages of 6 vane impeller, showcasing improved performance characteristics. The comparative analysis has conclusively shown that 6 vane impeller offers superior performance, making it the preferred choice for centrifugal pump applications.

The pump with a 3-vane impeller has a duty point of Head 24m, discharge 108 lpm with 24% in efficiency, and the Tangential volute pump has a Head 24m, discharge 126lpm with 27% efficiency. By comparing the 6 vane impeller over a 3 vane impeller, the discharge of a 6 vane impeller pump in 24m head will be 2.1lps. If the same pump operates with the 6-vane impeller for 2.5 hours a day will additionally deliver 2700 liters. For a year 9, 85,500 liters of water will be additionally delivered. This will save energy in additional star rating performance, also, if possible, time and resources.

Therefore, based on this research, it is recommended to adopt 6 vane impeller in centrifugal pump designs to optimize efficiency and overall performance in this particular case.

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