HYDRAULIC ANALYSIS OF MULTISTAGE VERTICAL TURBINE PUMP

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Abstract*—*Pumping is the process of adding energy to the fluid to move it from one point to another. The main task faced by an engineer while drawing a pump design is with meeting the ends with the economics and the hydraulic operating characteristics. A Borehole Shaft Driven Pump is a vertical turbine pump installed in a well with a pump shaft extended up to ground level and coupled at ground level to a motor or gear. Computational Fluid Dynamics (CFD) has been widely used in analysis of 3D complex fluid flows present inside the pump hydraulic passages. The hydraulic analysis of a Multistage Vertical pump is performed using AnsysCFX software. CFturbo software has been used to predict the initial design of multistage vertical pump. The overall goal of this work is to study the internal flow and performance parameters of a Multistage Vertical pump. While using single stage Vertical pump it is difficult to get high head although the structure become very massive. However, the objective to get higher head with appropriate efficiency can be achieved with multistage is better solution.

***Index Terms*—*Multistage, Vertical Pump, Computational Fluid Dynamics, CFD, Performance, Efficiency, Pump Characteristic curves*.**

I. INTRODUCTION

Pump is a machine which is required to lift liquid from low level to high level or to flow liquid from low pressure area to high pressure area and also as a debit booster in a piping network system. The Multistage Vertical pump is used for extraction of the underwater liquid to the ground by using mechanical energy motor output rotation to the hydraulic power of fluid. The Vertical pumps are used in many sectors like irrigation, chemical movement, marine services, power generation etc.

Vertical turbine pump is vertical axis centrifugal or mixed flow pump consisting of stages which accommodate rotating impellers and stationary bowls possessing guide blades. The word "Turbine" in the pump name is somewhat of a misnomer, as this type of pump has nothing to do with a turbine.

The Multistage Vertical pump performance can be analyzed by testing the physical model in test circuit. But performance testing requires laboratory setup and different types of measuring instruments, so it is the costlier affair. The use of CFD enables engineers to obtain solutions for problems with complex geometry and boundary conditions. Investigations of the internal flow structure are also performed with CFD tools in order to correct the design and obtain better performance characteristics from the designed pump.

The pump end consists of at least one rotating impeller that is attached to a shaft and directs the well water into a diffuser casing called a bowl. The water enters from the bottom of the pump called suction bell. From suction-bell water moves into the first stage impeller which raises the water's velocity. The diffuser bowl forms the outlet pressure and also it collects the flow from tip of one impeller and directs the fluid into the eye of next impeller located immediately above the bowl, and this process continues through all of the stages of the pump. The multistage pump has two or more Impeller and bowl assembly in series for getting high head with improved efficiency. Because of the wide variety of applications, pumps have several of shapes and sizes from very large to very small, from handling gas to handling liquid, from high pressure to low pressure, and from high volume to low volume [1].

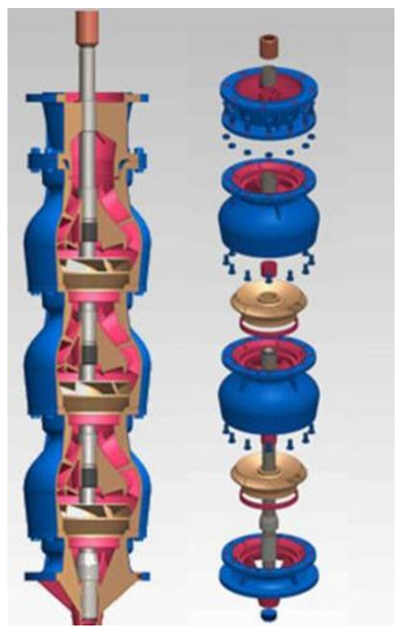

Figure 1 Multistage Vertical Pump

II. METHODOLOGY

The first step in strategy for analysis is to make Geometry Modeling. The fluid model of Vertical pump impeller with diffuser (bowl) is made in CFturbo 9. This fluid model is meshed using ICEM CFD. The CFD analysis is done using ANSYS 15.0. CFX-Pre 15.0 has been used to add the required boundary conditions applied to geometry which will be later solved using the CFX-Solver Manager 15.0.

Problem Specification

It is required to find the flow field of water through the Pump Impeller and Bowl of given model of the Multiple Vertical pump. The pump impeller is rotating at a speed of 1450 rpm, the required flow rate is $250m^3/hr$ and the required head is 15 m of water for each stage. The problem is to first analyze the head and find out the efficiency of the pump. Another objective of the

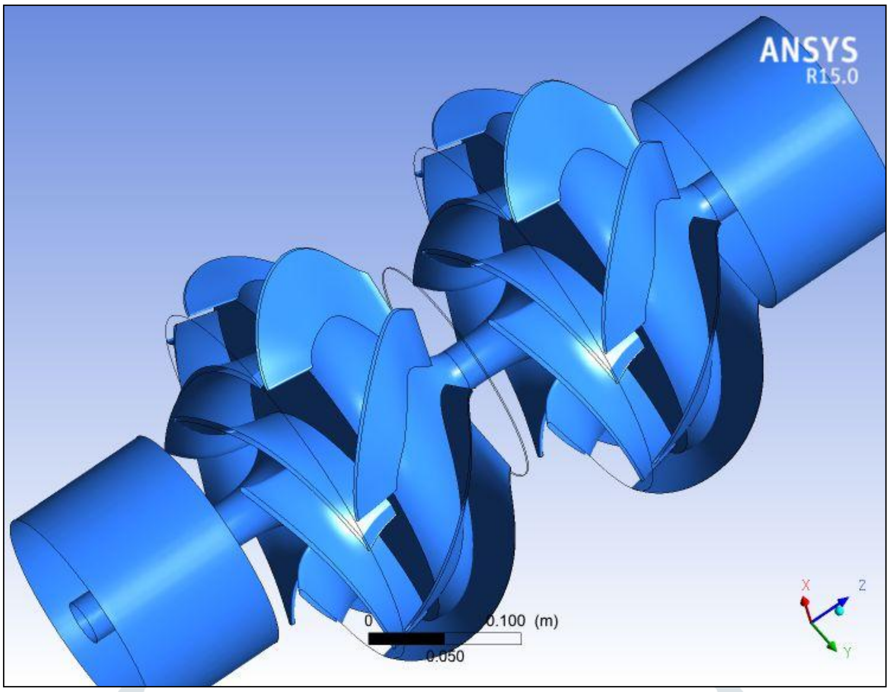

Figure 2 Blade Profile of Multistage Vertical Pump Impeller and Bowl

project includes the Performance analysis of Vertical Pump by varying the Outlet Width of Impeller and its effect on different performance variables like head, efficiency etc.[2]

Geometry of Multistage Vertical Pump

The geometry of multistage pump impeller and bowl assembly is created in CFturbo software and the major dimensions of the impeller as measured are given in Table T.1. 3D blade profiles of the Multi stage pump impeller and bowl are also depicted in **fig. 1** and **fig. 2**. **Figure 1** includes the cut section which gives the clear idea about solid walls and fluid flow passages related to multi stage vertical turbine pump.

As the flow of fluid around the impeller and bowl in two stages has to be analyzed it becomes necessary to perform analysis in fluid volume. The fluid volume of the multistage pump (Impeller and Bowl assembly) i.e. the volume of the fluid trapped between the impeller/bowl hub and shroud has been generated as it is in actual Multistage Vertical pump assembly. The performance of Multistage Vertical pump is analyzed for two stages in series by taking geometry of both the stages same. The impeller is having 6 blades in both the stages and bowl is having 8 blades in both the stages.

The water enters from the bottom of the pump called suction bell. From suction-bell water moves into the first stage impeller which raises the water's velocity. The diffuser bowl forms the outlet pressure casing also it collects the flow from tip of one impeller and directs the fluid into the eye of next impeller located immediately above the bowl, and this process continues through all of the stages of the pump.

Table 1 Dimensions of Vertical Pump

Sr. No	**Design Specifications**			
	Description	***Symbol***	***Value***	***Units***
1	Suction diameter	d1	162	mm
2	Impeller diameter	d2	248	mm
3	Hub diameter	dh	31.3	mm
4	Shaft diameter	ds	31.3	mm
5	Impeller outlet width	b2	32	mm
6	Bowl Average Diameter	db	260	mm

Generation of Mesh

The Meshing tool ICEM 15.0 is used to form the computational geometry zone and grids. Figure 2 shows the 3D geometry creations of two impellers (6 blades) and two diffusers (8 vanes). For Multistage Vertical pump having complex pump geometries, unstructured grid with tetrahedron mesh is used for grid generation in inside domain. Prism type mesh is used near the solid surfaces like Blades, Hub and Shroud walls. Prism type mesh efficiently captures boundary layer physics near the surface while maintaining the ease and automation of Tetra mesh. With Prism type mesh more elements perpendicular to the surface are constructed. **Figure 3** shows the appearance of tetrahedron grid generation of impeller and diffuser.

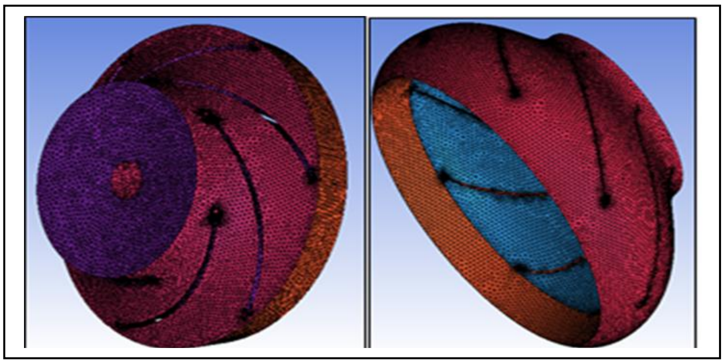

Figure 3 Meshed Geometry of Impeller and Bowl

The continuity equation for steady, fluid flow and the shear stress transport (SST) turbulence model was taken into consideration for present work.

Mathematical Modeling of the Problem

Mathematical Modeling of the problem includes the modeling of the physical problem. For fluid flow problems the governing partial differential equations are Continuity equations (1) and Nevier Stokes Reynolds Avg. Equations (2).[7]

$$\frac{\partial \rho}{\partial t}+\frac{\partial}{\partial x_i}(\rho u_i)=0 \qquad (1)$$

$$\frac{\partial \rho u_i}{\partial t}+\frac{\partial(\rho u_i u_j)}{\partial x_j}=-\frac{\partial \hat{p}'}{\partial x_i}+\frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)\right]-\frac{\partial}{\partial x_j}(\overline{\rho u_i u_j})+S_{Mi} \qquad (2)$$

III. Results and Discussion

Streamline

Table 2 Mesh Information

Sr. No	**Number of Stage**	**Mesh Data Information**		
		Domain	***Elements***	***Nodes***
1	1	Inflow	454363	77204
2		Impeller	4323955	773439
3		Bowl	2581316	837572
4	2	Impeller	4323955	773439
5		Bowl	2581316	837572
6		Outflow	446607	75804

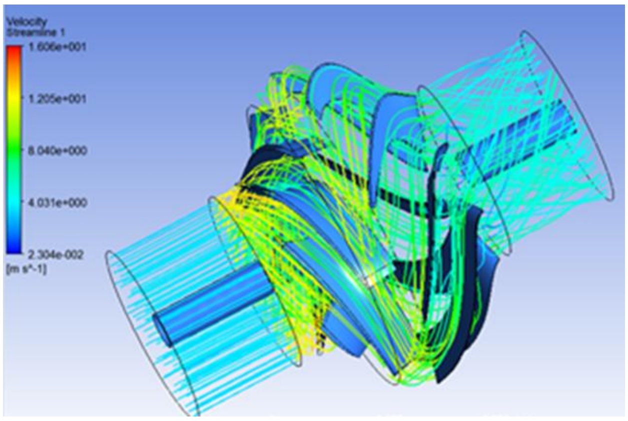

Figure 4 Velocity Stream Lines for Single Stage

Some representative computational results (steady state solutions) are shown in figures. Most information in these figures comes from the central positions in computational zones of impeller and diffuser. **Figure 4** shows the whole stream line of fluid in the Single stage Vertical Pump, which shows how the impeller imparts velocity to the fluid and the diffuser guides the fluid flow. **Figure 5** shows stream lines in multistage pump when two stages are installed in series for getting high head. The Velocity streamline helps to visualize the flow in actual condition which is very difficult to even predict by testing the pump practically in testing lab.

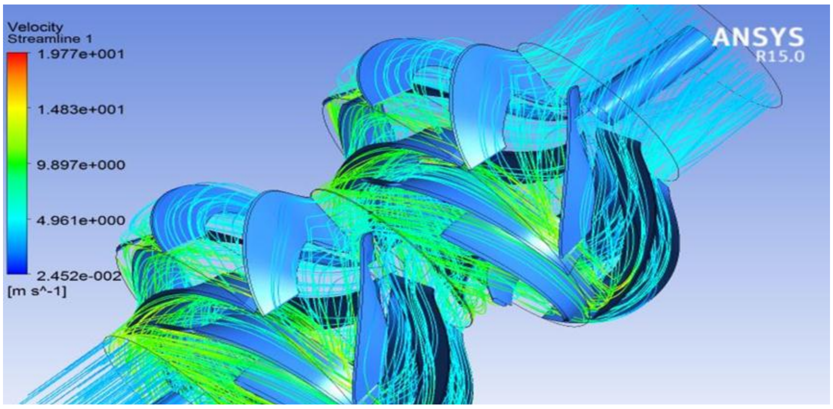

Figure 5 Velocity Stream Lines for Multistage

Static Pressure Contours

Figure 6 shows Static pressure contours along the blade surface of impeller and bow. This gives the idea of suction side and pressure side developed along the blade curvature.

It is clearly evident from the plots that enough suction pressure is created at the root of the impeller blades which is necessary for suction of fluid from inlet. In case of two stage pump the suction pressure created by the pump is larger as compare to the suction created by single stage pump to create the high head.

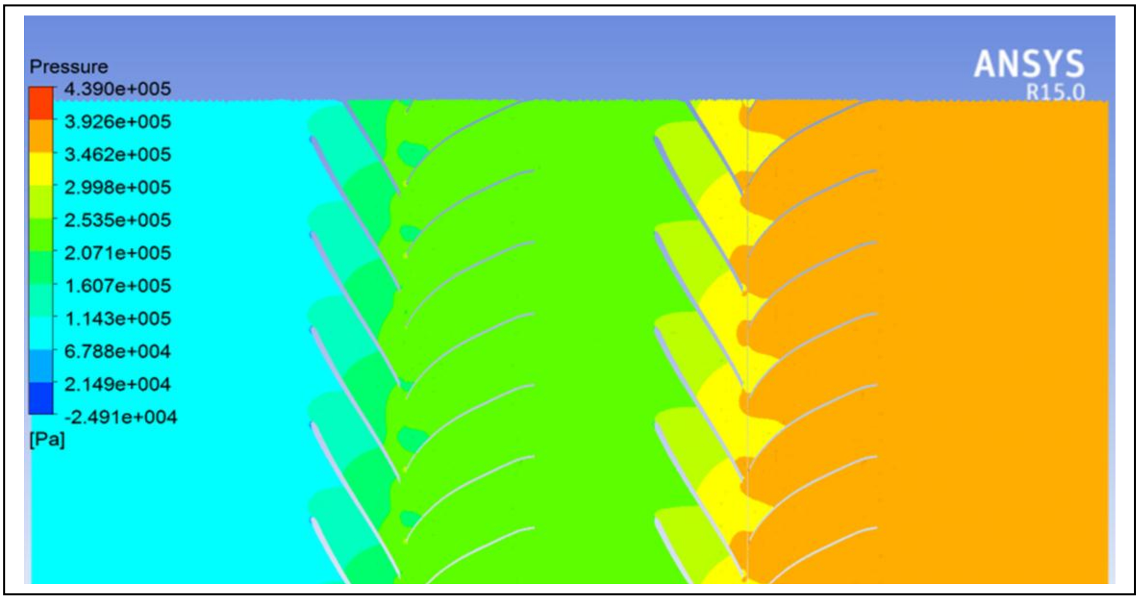

Figure 6 Static Pressure Contour in Blade-To-Blade View

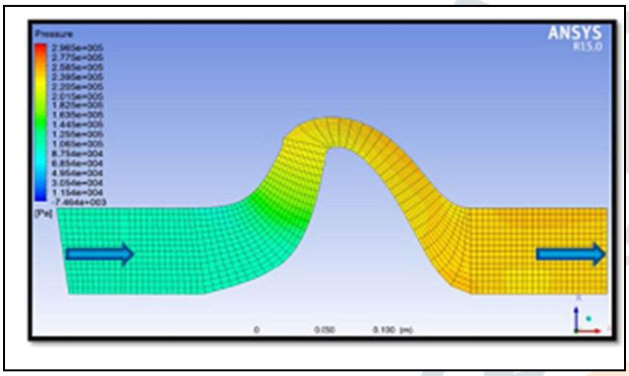

Figure 7 Pressure Contours in Meridional View

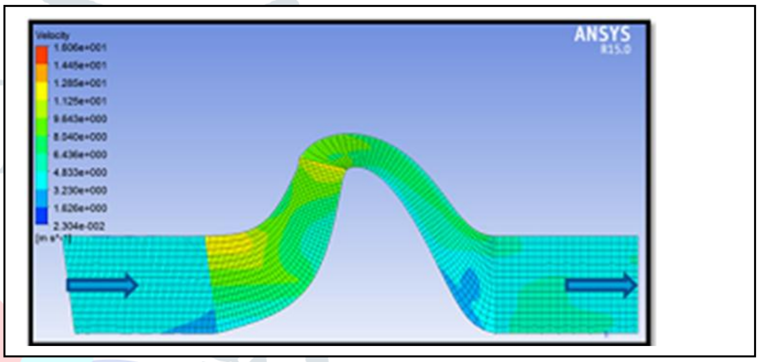

Figure 8 Velocity Contours in Meridional View

Pressure and Velocity Contours in Meridional region

Figure 7 and **Figure 8** show the plots of pressure and velocity contours for single stage Vertical pump in the space between the hub and shroud along the Meridional section of impeller and bowl as the fluid flows from impeller LE to its TE and then entering to bowl LE and exiting from its TE. **Figure 7** below clearly indicates negative to positive pressure change in flow direction. Besides, Meridional plane effectively defines the hub and shroud profile so that flow alignment is maintained.

Figure 9 and **Figure 10** show the plots of pressure and velocity contours for Multi stage Vertical pump along the Meridional section. The **Figure 9** indicates negative to positive pressure change in flow direction through inlet of first stage to exit of last stage in Multistage Vertical Pump. It indicates that in first stage of multistage vertical pump, water pressure is increasing while flowing through impeller to shroud. At the entry of second stage impeller pressure is increased by centrifugal action of rotating blades. The increase in water pressure is continued by enlarging area in second stage bowl so at the exit of multistage pump we have highest pressure higher as compare to pressure available at the exit of single stage pump. The velocity contour shown in **Fig. 8** and **Fig. 9** indicates that the velocity increase gradually from impeller inlet to outlet and become maximum at the impeller trailing edge. In bowl due to increase in flow area between blades, the velocity is gradually converting into pressure and hence velocity is decreasing from bowl blade leading edge to trailing edge.

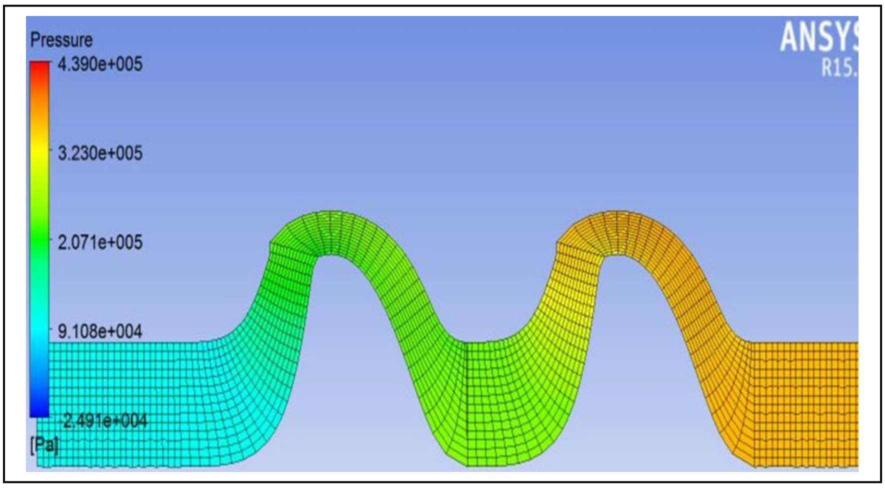

Figure 9 Pressure Contours along the Meridional Section for Multistage

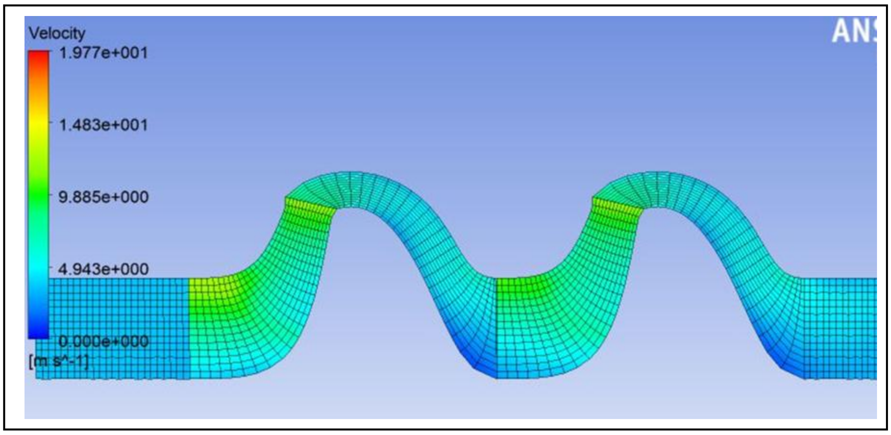

Figure 10 Velocity Contours along the Meridional Section for Multistage

Table 3 Calculation for Performance Parameters

Vertical Pump Type	**Performance Parameter**			
	Test	***Discharge (m3/s)***	***Head (m of water column)***	***Efficiency (%)***
Single Stage	1	150	17.7	74.31
	2	200	16.73	83
	3	250	14.98	86.26
	4	300	12.47	84.74
Multi Stage	1	150	32.05	77.22
	2	200	28	85.00
	3	250	26.64	87.66
	4	300	22	86.14

Power, Head and Efficiency Plots

The useful physical parameters are represented in table below which are calculated after CFD simulation. The significant variables of interest related to output of VT pump are calculated and plotted on XY charts to indicate the pump characteristics. These characteristics are useful in predicting the pump parameters for off-design conditions without calculating the actual results and assuming that the pump behaves linearly over the range of interest i.e. various losses and the assumptions hold true at the same points as well. Here, BEP is obtained at a flow rate of 250m^3/hr.

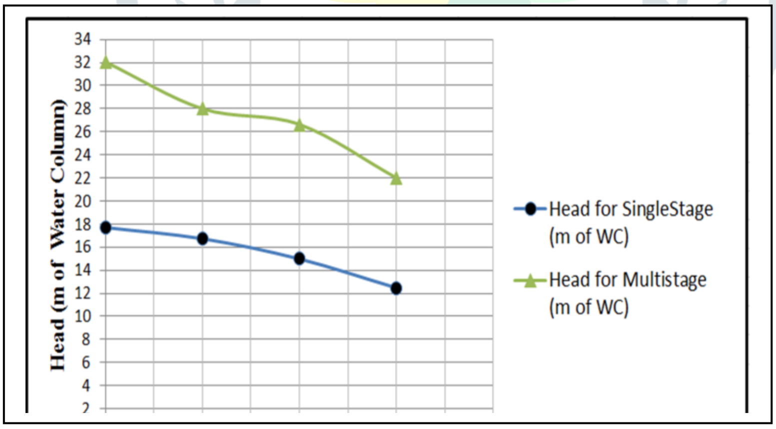

Figure 11 Pump Characteristic of Single stage and Multistage Vertical Pump

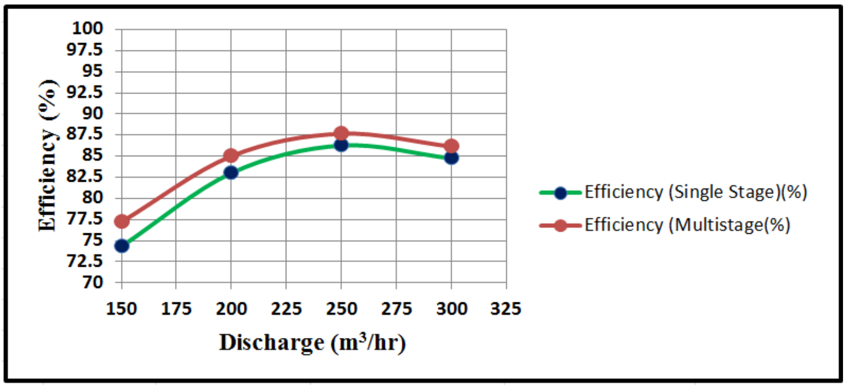

Figure 12 Discharge vs. Efficiency plot

IV. CONCLUSION

As flow rate is increased above BEP, efficiency decreases and hence, the parabolic nature of efficiency curve is observed. **Figure 11** shows the Pump characteristic curve having curves of Discharge vs. Total Head for single stage and multi stage vertical pump. Total Head goes on decreasing from 17.14m of water column to 12.47m of water column as the flow rate is increased from 150 m^3/hr. to 300 m^3/hr in case of single stage while it decreasing from 32.05 to 22m of water column in case of multi stage vertical pump. It shows the multistage pump is facilitating high head as compared to single stage pump. **Figure 11** suggests that as we shift from single stage to multi stage vertical pump the head almost become double for same discharge. This are typical characteristic curves followed by the centrifugal type pump and are observed here as well. The cavitation effect also analyzed for 120% discharge load in VT pump. The result shows, the cavitation is occurred in the small region near the impeller eye because of low pressure zone which is within acceptable limit. So the design is optimum as far as cavitation and flow separation loss are concern.

Figure 12 shows the graph of efficiency vs. discharge for single stage and multistage vertical pump. It shows that the multistage vertical pump is facilitating high efficiency as compared to single stage vertical pump for each discharge. Table 3 shows that at BEP the efficiency of single stage vertical pump is 86.26% and the efficiency of multistage vertical pump is 87.66%.

It is not always desirable to manufacture all types of impeller/bowl design and test them individually. An approximate flow field so generated gives a fair idea about the design of the impeller and its performance characteristics at different part and full load operating conditions. The design can be modified later depending upon the generated flow field and re-analyzed to check the improvements. The important feature of CFD is that it enables the designer to visualize the flow in actual condition and predict the regions of flow separation, region of cavitation along with quantitative values.

V. ACKNOWLEDGMENT

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