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Design and CFD Analysis of Liquid Ring Vacuum Pump

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Abstract: *- A Liquid ring vacuum pump is the mostly used vacuum producing device in industry. The Liquid ring vacuum pump is a specific form of rotary positive displacement pump utilizing liquid as the principle element in gas compression. The present paper describes an improvement in the performance of vacuum pump impeller; Computational Fluid Dynamics (CFD) analysis is one of the advance CAE tools used in the pump industry. From the result of CFD analysis, the velocity and pressure in the outlet of the impeller is predicted. The Optimum inlet and outlet angle of impeller and also blade thickness are calculated for existing impeller by using empirical relations. Modelling of the pump unit has been done using PTC Creo2.0 software. By changing the inlet angle, outlet angle and the blade thickness of the impeller the higher effect on performance is improved. The standard k-Ɛ turbulence model was chosen for turbulence model.*

Keywords: *Vacuum pump, Computational fluid dynamics (CFD) analysis, Overall efficiency, Impeller, ANSYS CFX.*

I. INTRODUCTION

A pump is a mechanical device that moves fluids (liquid or gases), or sometimes slurries, by mechanical action. A vacuum pump is a device for creating, improving and/or maintaining a vacuum [1, 2]Mechanical vacuum pumps works by the process of positive gas displacement, that is, during operation the pump periodically creates increasing and decreasing volumes to remove gases from the system, and exhaust them to the atmosphere [5]. Two basically distinct categories may be considered gas transfer pumps and entrapment or capture pumps [4]. Different types of vacuum pumps are Liquid ring (water ring), rotary vane, rotary piston, dry vacuum pumps, vacuum boosters etc [3]. Pumps are classified in number of the ways according to their purpose, specifications, design, environment etc.

A liquid ring vacuum pump is a very versatile machine. It can handle “wet” loads and has no metal-to-metal contact. It also acts like a direct contact condenser; it can absorb the heat generated by the compression, friction and condensation of the incoming gas; and it will absorb and wash out any contaminants entrained in the gas. In spite of this versatility, however sizing and selection of the most economical system still requires full information concerning not only what fluids it will handle, but how it will be operated.

II. Working principle of WRVP

The major component of the liquid ring vacuum pump is a multi-bladed rotating assembly positioned eccentrically in a cylindrical casing (see figure). This assembly is driven by an external source, normally an electric motor. Service liquid (usually water) is introduced into the pump. As the impeller rotates, centrifugal force creates a liquid ring which is concentric to the casing. At the inlet, the area between the impeller blades increases in size, drawing gas in. As the impeller continues to rotate toward the discharge, the impeller bucket area decreases in size, compressing the gas. The gas, along with the liquid from the pump, is discharged through the outlet nozzle. In addition to being the compressing medium, the liquid ring vacuum pump performs two other important functions: 1) It absorbs the heat generated by compression, friction, and condensation of the incoming vapour. 2) It absorbs and washes out any process contaminants entrained in the gas.

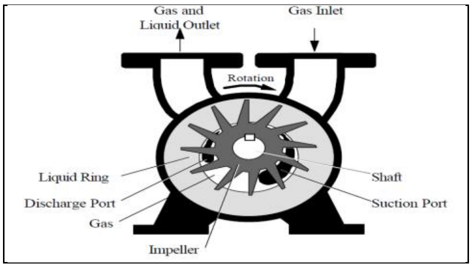

Figure1. Water ring vacuum pump

Water Ring Vacuum Pump Features

a) Reliable simple design which involves only one rotating part, which is not subject to much wear
b) Can handle condensable vapours or even slugs of liquid in entrained in the gas stram without damage to pump or affecting pump performance.
c) Produces a steady non-pulsating gas flow when it is used as either a vacuum pump or compressor.
d) Resistance to contaminants entering with the gas stream these will be diluted and washed through the pump by the seal liquid.

The information needed to accurately size a water ring vacuum pump (LRVP) includes:

- Inlet pressure, usually expressed in mm of Hg
- Inlet temperature
- Mass flow rate, usually expressed in LB/hr and the molecular weight of fluid components
- Vapour pressure data for each fluid components
- Seal fluid data, if other than water: specific gravity, specific heat, viscosity, thermal conductivity, molecular weight and vapour pressure data.
- Temperature of the seal fluid or cooling water
- Discharge pressure.

III. Modelling of existing vacuum pump impeller

Impeller layout is designed in order to meet the hydraulic characteristics of the pump to be designed. Impeller is the important part of the vacuum pump as it displace the water and force it to form water ring as a result of which air is trapped between the cavity of formed between two successive blade and drawing further rotation vacuum is created in pump as the expansion of trapped air takes place. Pump efficiency is more dependent on impeller of pump. The main design parameters of the impeller of this water ring vacuum pump are: No. Of blades 12, Rotational speed of impellers 2880 rpm, Flow rate is 10m^3 /hr, width of impeller is 26mm and outlet blade angle is 52° and inlet angle is 15°.

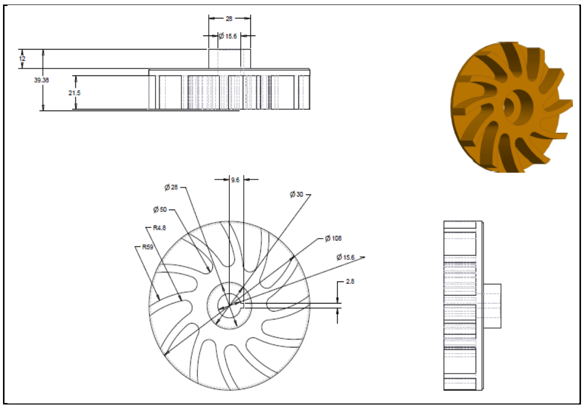

Fig.2 existing impeller model

In order to study the effect of various parameters and for the ease of operation the existing pump components have been re modelled using the CREO 2.0 software. The design specification of impeller is shown below table.

Table 1 : Design Specification of Impeller

Diameter of shaft	108 mm
Inlet angle	15^0
Outlet angle	52^0
Thickness of blade	5 mm
Diameter of motor	16 mm

IV. CFD Analysis and Meshing of WRVP

Computational Fluid dynamics (CFD) uses numerical methods to solve the fundamental nonlinear differential equations that describes fluid flow (the Navier- strokes and allied equations), for predefined geometries and boundary conditions. The result is a wealth of the predictions for flow velocity, temperature, density, and chemical concentrations for any region where flow occurs. CFD analysis begins with a mathematical model of a physical problem, conservation of matter, momentum, and energy must be satisfied throughout the region of interest. CFD applies numerical methods (called discretization) to develop approximations of the governing equations of fluid mechanical in the fluid region of interest. The solution is post processed to extract quantities of interest (e.g. lift, drag, torque, heat transfer, separation, pressure loss, etc).

Meshing of water ring vacuum pump: The geometry and the mesh of a twelve bladed pump impeller domain is generated using ANSYS work bench. An unstructured mesh with tetrahedral cells is used for the zones of impeller and cavity of WRVP as shown in figure. A total of 469681 elements are generated for the cavity of water ring vacuum pump. Mesh statistics are presented in Table.

Table.2 Mesh statics are presented

No. Of Nodes	104035
No. Of Elements	469681
Meshing type	3D
Type of Element	Tetrahedral

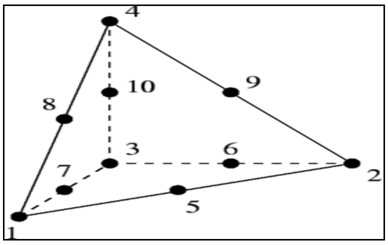

Fig. 3 Meshing Type

Once the pump geometry has been specified and a mesh has been created automatically, where the flow equations need to be solved

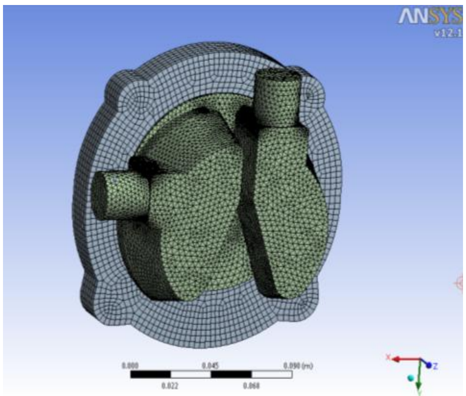

Fig.4 Meshed model of WRVP cavity

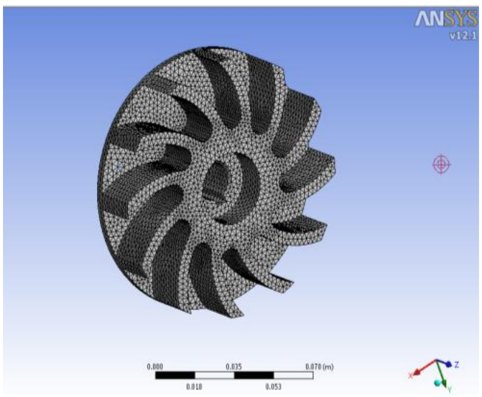

Fig.5 Meshed model of Impeller

V. Analysis Setup and Result

Design points for a parametric study can be specified using the required duty of the pump in the setup steps.

Input Material: Material is also assigned to the parts of the pump as Casing and Impeller: cast iron, Hydraulic Region: Water, Rotating part: Impeller.

Boundary condition: Here boundary condition at inlet mass flow rate is 2.7 $kg.s^{-1}$ at outlet atmospheric pressure is 1.045 bar and rotational speed is 2880 rpm.

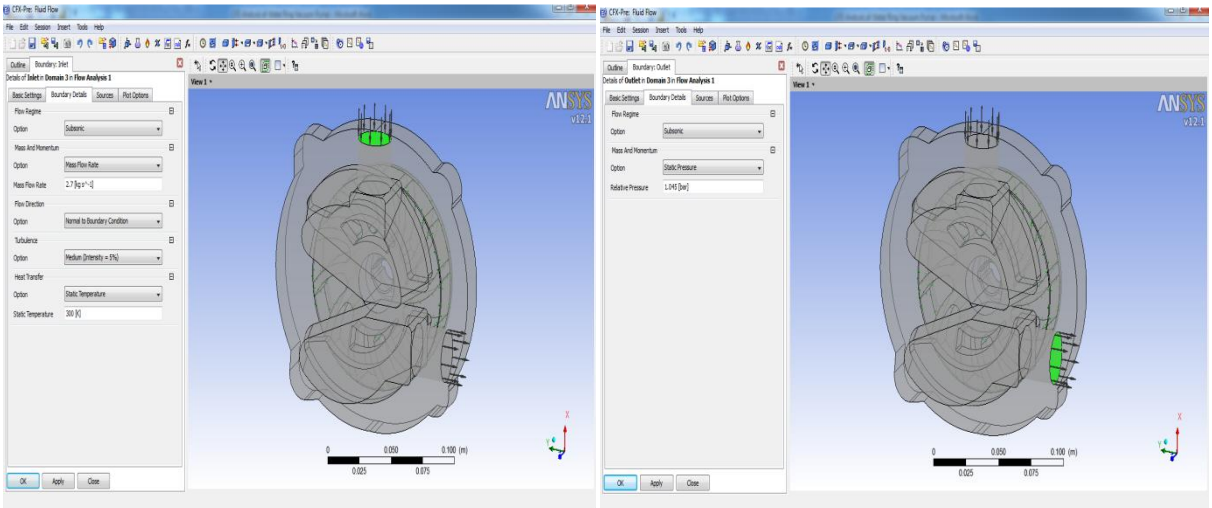

Fig. 6 Boundary condition of Inlet and Outlet

In this CFD analysis we can see different pressure contours generated are as shown below fig. And we can see result obtained using CFD analysis.

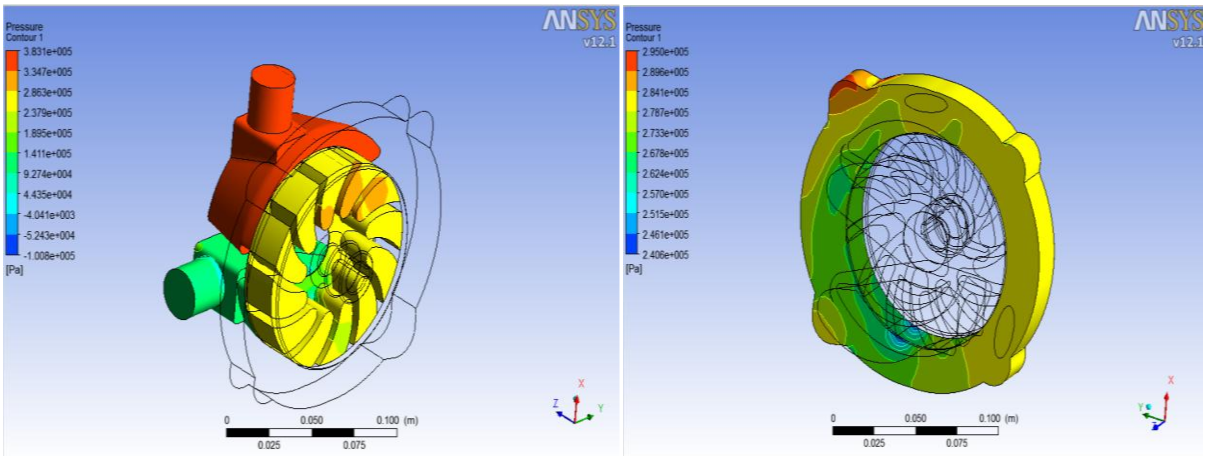

Fig. 7 Pressure Contour in WRVP and Pressure Contour

Here by using CFD analysis of existing vacuum pump get result in terms of vacuum pressure which is shown in fig below. That at inlet of WRVP get generated vacuum pressure is 6.134 e^4 Pa which means that 460.087 mm of Hg in terms of vacuum.

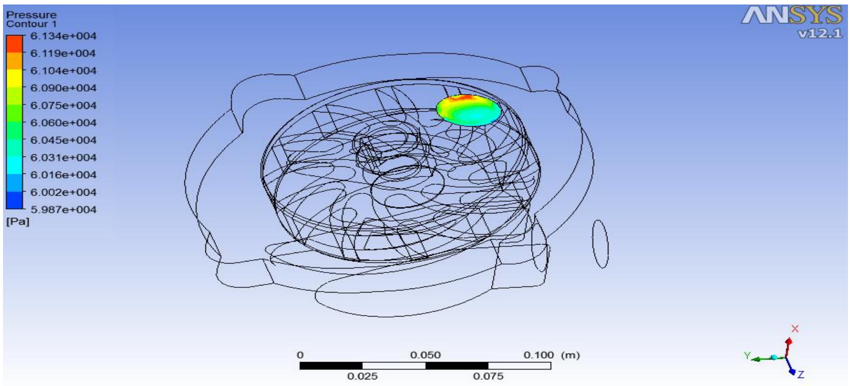

Fig. 8 Generated vacuum at inlet

Table.3 validation of experimental results with CFD analysis results

	Experimental Results	CFD analysis results	% Deviation
Original existing case	450 mm of Hg	460.087 mm of Hg	2.241%

Experiment is carried out and same case when analyzed using software the result obtained is almost satisfying. This proves the accuracy of CFD and experimental approaches. Here by experimental and CFD analysis result has 2.241% deviation which is very low and negligible, which difference is shown in above table. So for the further analysis to improve performance of the pump we can use CFD analysis.

VI. Optimization of Result

Existing impeller data,

Thickness: 5 mm

Inlet angle: 15^0

Outlet angle: 52^0

Optimization for Thickness of blade, inlet angle and outlet angle

In existing impeller thickness of impeller is 5 mm, and modifying thickness of existing impeller using empirical relation and CFD analysis result shown below.

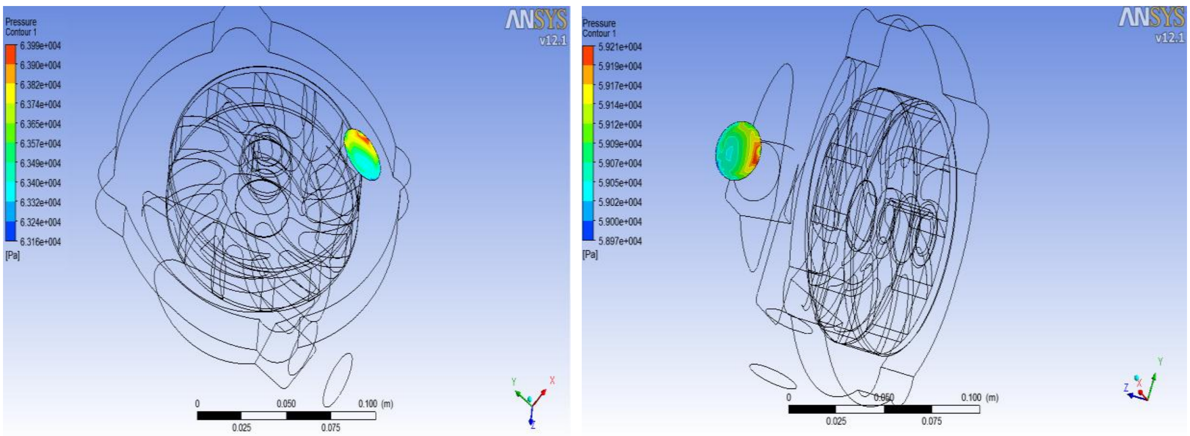

Fig. 9 1 mm increase and decrease thickness generated vacuum at inlet

Table. 4 comparison of vacuum of three impeller

Sr no.	Thickness (mm)	Generated vacuum (mm of Hg)
1	6	480
2	5	460
3	4	444

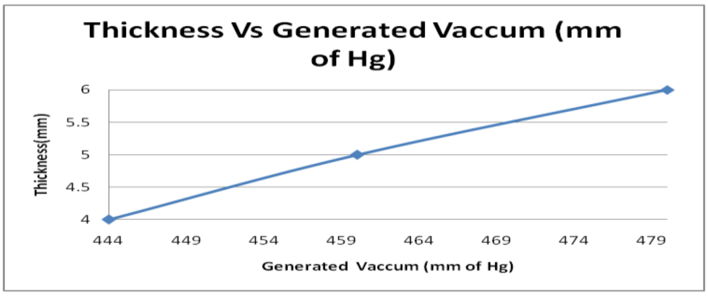

Fig.10 Graph of thickness Vs generated vacuum

In existing impeller inlet angle existing impeller is 15^0 and modified inlet angle also based on empirical relation and its CFD analysis result shown below.

Table.5 Comparison of five impeller

Sr no.	Inlet angle (degree)	Generated vacuum (mm of Hg)
1	18	462.86
2	17	470
3	16	464.21
4	15	460
5	13	459.30

Table gives comparision of five different value of inlet angle and vacuum generated by them also shown in graph below.

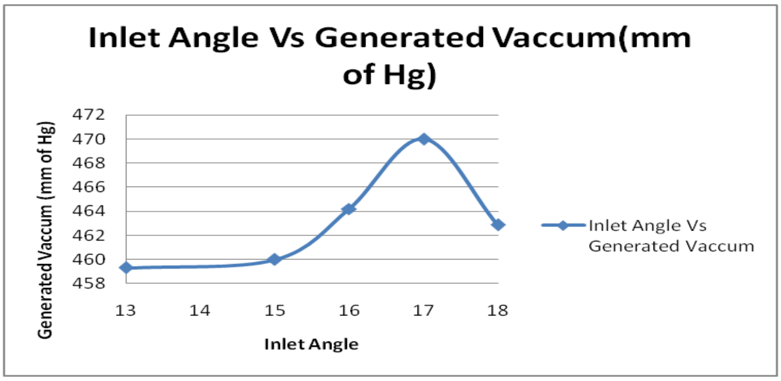

Fig.11 Graph of inlet angle Vs generated vacuum

In existing impeller outlet angle existing impeller is 52^0 and modified inlet angle also based on empirical relation and its CFD analysis result shown below.

Table. 6 Comparison of six impeller

Sr no.	Outlet angle (degree)	Generated vacuum (mm of Hg)
1	54	450.86
2	52	460
3	51	472.01
4	50	481
5	49	485.88
6	48	458.21

Table gives comparision of six different value of outlet angle and vacuum generated by them also shown in graph below.

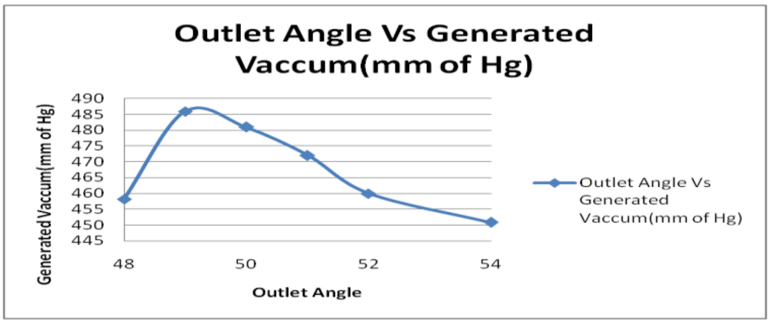

Fig.12 Graph of outlet angle Vs generated vacuum

Result

Table. 7 comparison of all modified impeller WRVP

Sr no.	Modified impeller	Thickness	Inlet angle	Outlet angle	result
1	Existing	5	15	52	460
2	Impeller-1	4	15	52	444
3	Impeller-2	6	15	52	480
4	Impeller-3	5	13	52	459.30
5	Impeller-4	5	16	52	464.21
6	Impeller-5	5	17	52	470
7	Impeller-6	5	18	52	462.86
8	Impeller-7	5	15	48	458.21
9	Impeller-8	5	15	49	485.88
10	Impeller-9	5	15	50	481
11	Impeller-10	5	15	51	472.01
12	Impeller-11	5	15	54	450.86

We can see that after all CFD analysis of all new modified impeller WRVP get highest vacuum pressure of highest value at impeller-8 and its result is 485.88mm of Hg which gives improved result of WRVP than existing WRVP and also lowest value is 444mm of hg which is given when thickness of blade is decreased with 1mm in impeller-1 which is shown in above table and finally get improved performance Water Ring vacuum pump using CFD analysis.

VII. Conclusion

A water ring vacuum pump which is used for purpose of creating vacuum. In WRVP all parts of that pump are very important for performance of pump and also affect directly to the performance of vacuum pump. But most critical part of pump is impeller and impeller is heart of pump and its function needed very properly to get higher performance. In WRVP it is very difficult task to find out fault and improve design of pump by experimental and also very costly to improve performance. So introduced CFD analysis which very friendly software to finding fault and for improve design of vacuum pump. CFD analysis of existing vacuum pump and for design improvement using CFD analysis, also validation of CFD result of existing vacuum pump with experimental results take place.

WRVP in which impeller is most critical part so choose it for modification in its design and to get higher effect in performance. we have seen that changes in inlet angle and outlet angle of impeller and also blade thickness based on empirical relation and also these three parameters are critical parameters of impeller and they are very important parameters to improve performance so these three parameters are modified in existing impeller and all these modified impellers are used in existing pump model and took place CFD analysis of all those pumps. After CFD analysis of those all modified impeller pumps getting different results in terms of vacuum. In existing Vacuum pump generated vacuum is 460 mm of Hg, in existing impeller model thickness of blade is 5 mm, 15˚ inlet angle and 52˚ outlet angle. But when modification in outlet angle of impeller and angle is 49˚, in that model After CFD analysis generated vacuum pressure is 485.88 mm of hg vacuum. So result is improved in terms of vacuum using CFD analysis of water ring vacuum pump.

VIII. Future scope

We see in this project work CFD analysis of vacuum pump and modified part of vacuum pump to improve result is impeller. In impeller many critical parameters exist which are directly affected to result of vacuum pump. They are inlet angle, outlet angle, blade thickness, blade height, blade curvature radius, impeller diameter. We can work on modifying blade curvature, impeller diameter, and blade height. Also eccentricity is main parameters of pump and after changing in diameter also changes eccentricity, which is affected very much to the performance of pump.

In water ring vacuum pump many parts existing and performance of pump depends on all parts. Main parts of WRVP are:

- Casing
- Cover
- Control Disc
- Impeller

All these parts have their own function in WRVP. Here we modified impeller parameters to improve result but also can modify all other parts based on empirical relation or other literature to improve performance of WRVP. After modifying other parts and their CFD analysis, can achieve desired vacuum level. So all these work on WRVP will help in more performance improvement of water ring vacuum pump.

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