Numerical Flow Analysis of an Axial Flow Pump

Aung Kyaw Soe, Zin Ei Ei Win, Myat Myat Soe

Abstract— **This paper describes the detailed study of fluid flows in an axial pump that includes impeller and guide vanes. And the comparisons of flow simulations of the axial pump impeller with guide vanes and without guide vanes are carried out in this paper. In addition to this, the effect of number of guide blades on flow behaviours is analysed numerically. The computational results are performed by using one of CFD commercial software, Solidworks Flow Simulation. The input design data of the model pump are the flow rate of 0.2m3, head of 3m and the rotational speed of 1160 rpm. The outer and inner diameter of impeller is 0.3m and 0.15m respectively. . And the impeller with four blades is used in this paper. The guide blade number is varied to 5,7,9 with the same input data and other geometric parameters keep constant. In this study, the nature of velocities and pressures in an axial flow pump is analysed. The comparisons are averaged flow velocities, static pressure rise, dynamic pressure and total pressure.**

Index Terms— Axial pump, Flow Behaviours, Guide Vanes, Impeller.

I. INTRODUCTION

An axial-flow pump, or AFP, is a common type of pump that essentially consists of a propeller (an axial impeller) in a pipe. Axial flow pumps are most commonly used in industrial applications where large flow rates are handled at lower pumping head values. The blades of the axial flow pump are fixed radially to a central hub portion of the impeller through which fluid flows in the axial direction. Pipe-like casing is used in this pump instead of volute casing.

With the increasing application of an axial flow pump, the improvement of its efficiency continues to become more and more important. One of the most useful methods to in-crease its efficiency is the installation of a guide vane behind the pump impeller. The guide vanes can develop pump head by transforming kinetic energy of rotating flows to pressure energy [1].

The internal flow field of the axial flow pump is difficult to measure due to rotor-stator interaction. Thus, Computational Fluid Dynamics (CFD) has been an effective tool in studies on the internal flow field in hydromachinery (pumps and turbines). Therefore, the CFD simulations were used to investigate the flow conditions of an axial flow pump in this study.

II. SPECIFICATION OF AXIAL FLOW PUMP

The impeller numerically analyzed in this paper is modeled on the basic of the certain desired head and capacity at which the axial pump will operate most of the time. Using the following specification, the hydraulic design of impeller of an axial flow pump can be determined for irrigation system.

Pump Head	$H=3m$
Discharge or Flow Rate,	$Q = 0.2\ m^3/sec$
Rotational Speed,	$N = 1160$ rpm
Density of Water,	$\rho = 1000\ kg/m^3$
Acceleration of gravity,	$g = 9.81\ m/s^2$

A. Physical Model

The model axial pump for this analysis has a specific speed of 831 rpm and an impeller with four blades. The outer diameter of the impeller is 300mm. The hub diameter of 150mm and the hub ratio of 0.5 are used in this simulation. And the number of guide blades is seven. The guide vane spacing and the chord length of guide vanes are 67.31mm is 61.74mm respectively. The distance between the impeller and guide vane is 10mm.The computational domain is the flow passage from the inlet to the outlet regions. The designed model of impeller and guide vanes are shown in Figure 1 and Figure 2.

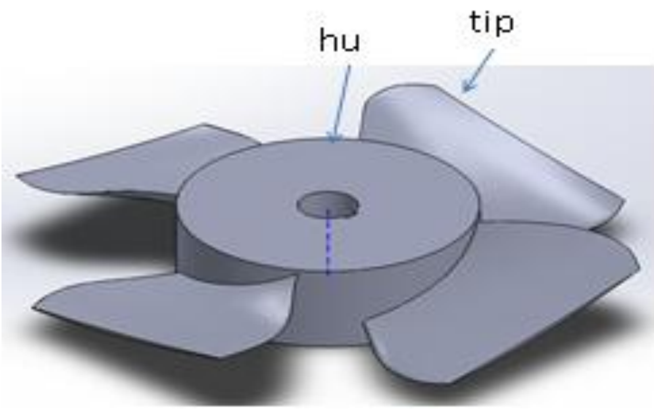


Fig.1 The isometric view of an axial pump impeller.

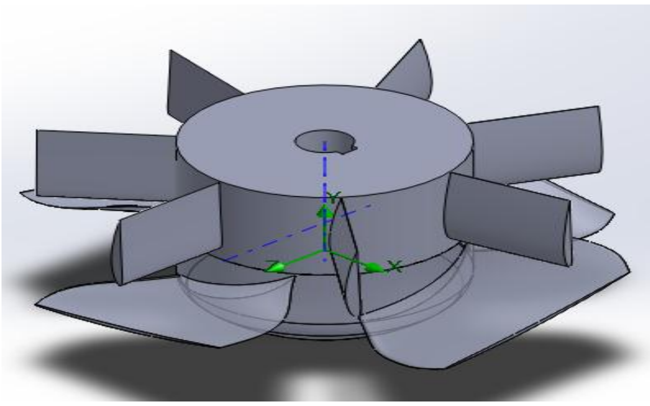


Fig.2 The isometric view of an axial pump impeller with guide vanes

Mr.Aung Kyaw Soe, Department of Mechanical Engineering, Mandalay Technological University, Myanmar.
Dr. Zin Ei Ei Win, Department of Mechanical Engineering, Mandalay Technological University, Myanmar.
Dr. Myat Myat Soe Department of Mechanical Engineering, Mandalay Technological University, Myanmar.

III. FLOW SIMULATINO OF AN AXIAL PUMP

Flow Simulation is a software fully integrated in SolidWorks for computing fluid (gas or liquid) flows inside and outside SolidWorks models, as well as heat transfer to (from, between, in) these models due to convection, radiation, and conduction with a proved computational fluid dynamics (CFD) technology. The software solves the governing equations over the computational mesh by using the finite volume (FV) method. The governing equations are Navier-Stokes equations for conservation of mass, momentum and energy in a fluid system. The following basic governing equations are used in Solidworks Flow Simulation [13]-[14]:

(i) Mass conservation equation is;

$$\frac{\partial p}{\partial t}+\frac{\partial}{\partial x_i}(\rho\rho_i)=0 \qquad \text{(i)}$$

(ii) Momentum conservation equation is described as;

$$\frac{\partial \rho u_i}{\partial t}+\frac{\partial}{\partial xj}(\rho\rho_i u_j)+\frac{\partial p}{\partial x_i}=\frac{\partial}{\partial x_j}\left(\tau_{ij}+\tau_{ij}^R\right)+S_i \qquad \text{(ii)}$$

(iii) Energy conservation is as follows:

$$\frac{\partial \rho H}{\partial t}+\frac{\partial \rho u_i H}{\partial x_i}=\frac{\partial}{\partial x_i}(u_j(\tau_{ij}+\tau_{ij}^R)+q_i)+ \qquad \text{(iii)}$$

$$\frac{\partial P}{\partial t}-\tau_{ij}^R\frac{\partial u_i}{\partial x_i}+\rho\varepsilon+S_i u_i+Q_H$$

Where,

u - Fluid velocity (m/s)

ρ - Fluid density (kg/m^3)

S_i - External force per unit mass from buoyancy

h - Thermal enthalpy (J/kg)

Q_H - Heat source per unit volume (W/m^3)

τ_{ij} - Viscous shear stress (Pa)

τ^R - Reynolds shear stress (Pa)

q_i - Diffusive heat flux (W)

H - $h+u^2/2$

To simulate the fluid flow, the inlet and outlet boundary conditions must be applied on the face and rotating reference frame and required goal parameters and goal type are specified as follows:

\

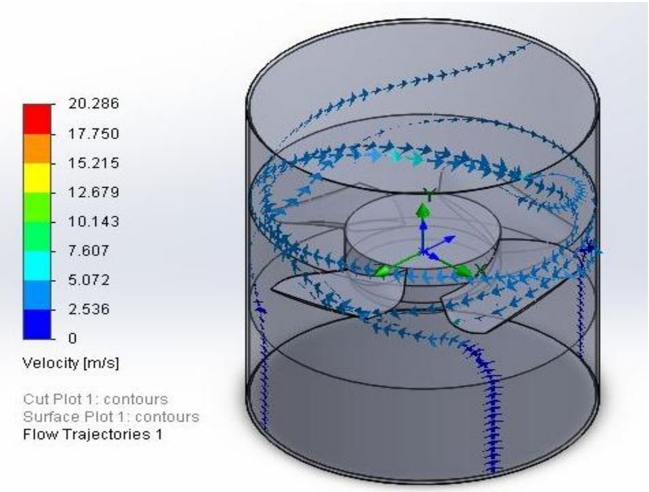
TABLE I CREATING A PROJECT FOR FLOW SIMULATION

Type	Specification
Analysis type	Internal: Exclude cavities without flow conditions
Unit System	SI
Fluid	Water
Axis of coordinate system	Y
Angular velocity	121.475 rad/sec
Wall condition	Adiabatic wall

TABLE II SPECIFYING THE BOUNDARY CONDITIONS

Inlet Boundary Condition	Inlet Volume Flow Rate of $0.2m^3/sec$	At the inner face of the lower cover
Outlet Boundary Condition	Outlet Static Pressure: (101325Pa)	At the inner face of the upper cover

IV. NUMERICAL RESULTS AND DISCUSSIONS



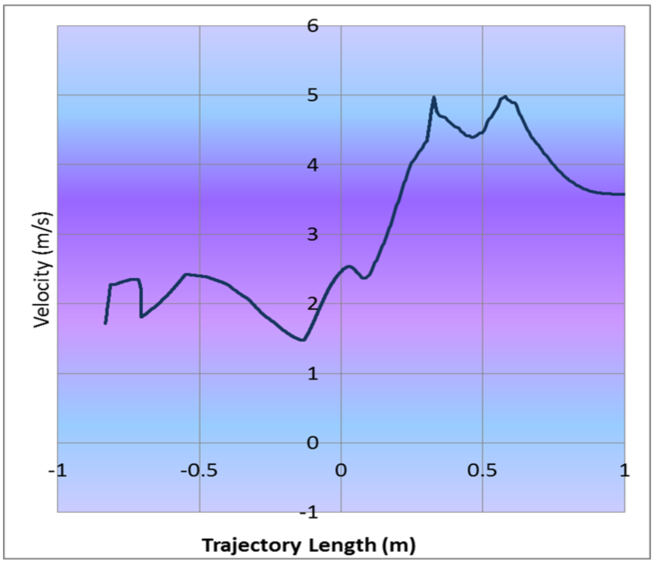
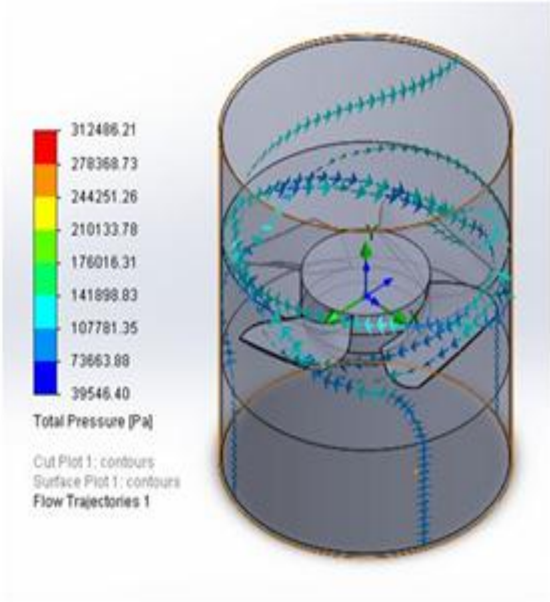


Fig.3 The velocity distribution of the axial pump impeller



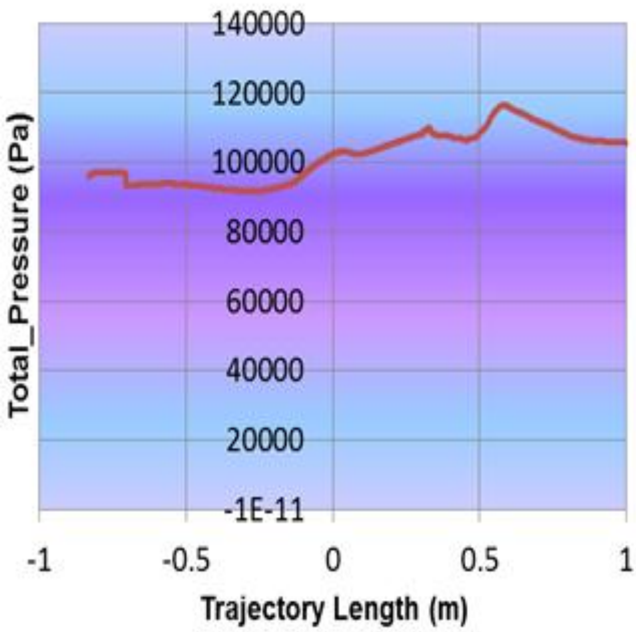
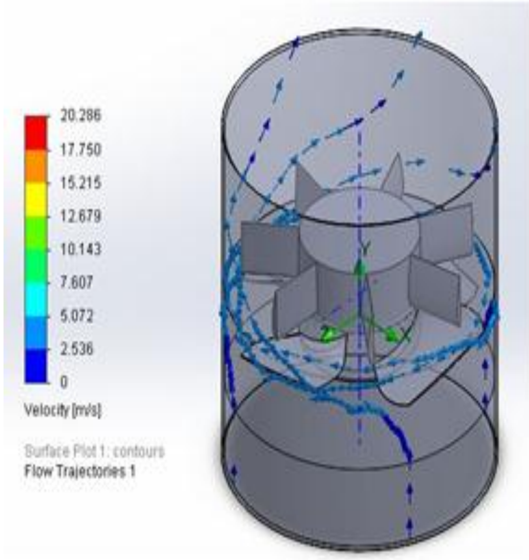


Fig.4 The pressure distribution of the axial pump impeller

Figure.3 shows the distribution of flow velocity from the inlet boundary to outlet boundary of the axial pump. At the inlet flow region, the variation in velocity is between 1 m/s and 2 m/s and the velocity near the entrance of the impeller is nearly 2.5 m/s**.** And then the velocity around the impeller has become higher significantly. Next, the flow velocity is about 5 m/s at the outlet flow region due to the impeller rotation. After that, the flow velocity has gradually decreased from 5 m/s to nearly 3.6 m/s at the outlet boundary.

According to the figure.4, the total pressure fluctuations around the impeller are displayed. The pressure distribution is larger than at the outlet of the flow region than at the inlet of the flow region because of the increased dynamic pressure. There are a lot of pressure fluctuations because of the structure of the blade profile.



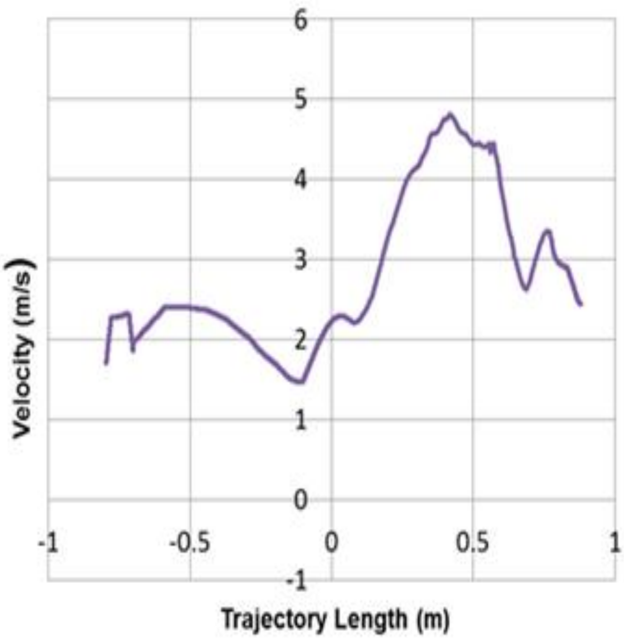
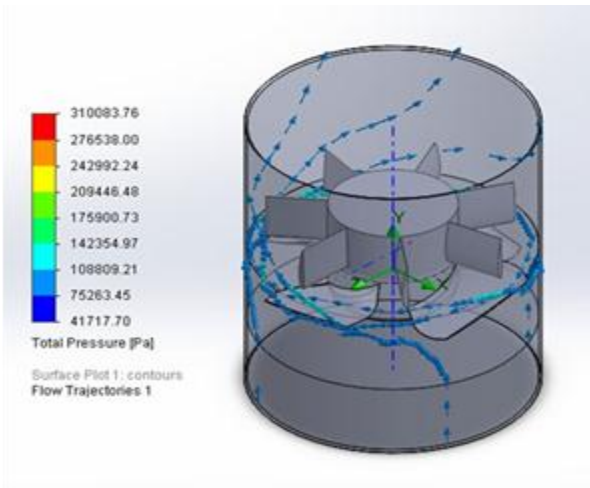


Fig.5 The velocity distribution of the axial pump impeller with guide vanes.



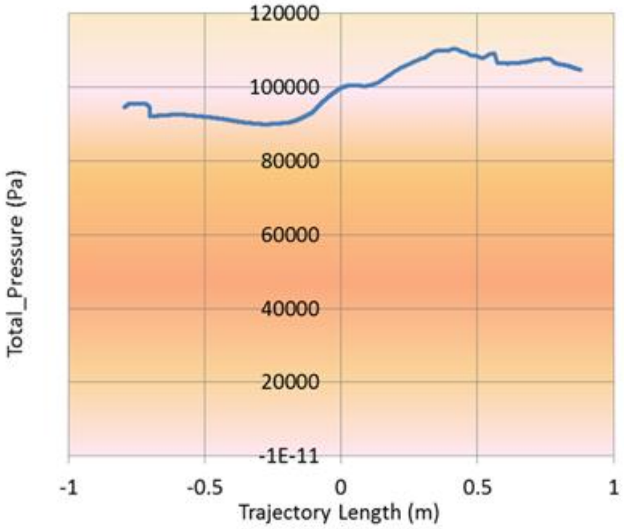


Fig.6 The pressure distribution of the axial pump impeller with guide vanes

The flow velocity distributions from the inlet boundary to outlet boundary of the axial pump are shown in figure.5. At the inlet flow region, the flow velocity is within in the range of 1 m/s to 2 m/s and the velocity near the entrance of the impeller is nearly 2.4 m/s. And the velocity around the impeller has increased significantly. The flow velocity is raised to about 4.8 m/at the outlet flow region of the runner. And then it has gradually decreased from 4.8 m/s to 2.8 m/s. After that, it has again risen to nearly 3.4 m/sec around the guide vanes. Finally, the flow velocity has slowly decreased at the outlet boundary of the pump.

Figure 6 shows the pressure fluctuations between the inlet boundary and outlet boundary of the axial pump. The velocity on the runner affects the total pressure. Therefore, the total pressure is higher at the inlet of the runner than at the outlet of that. And then, the static pressure values have increased at the outlet of the guide vanes in which the dynamic pressure values have decreased.

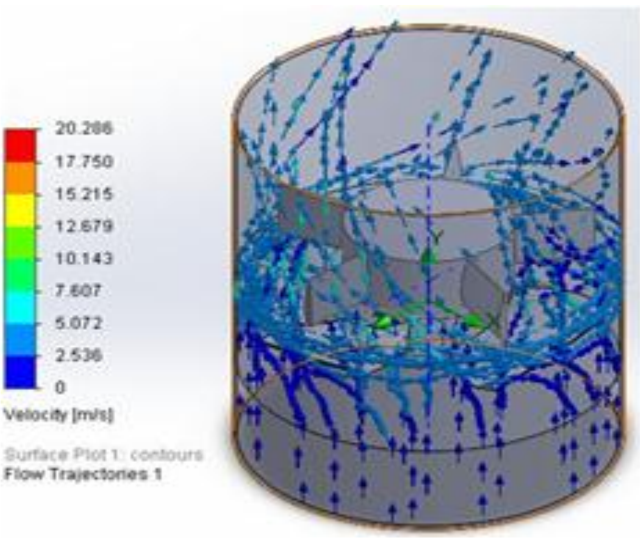


Fig.7.a The pressure distribution of the axial pump impeller with guide vanes , Z_2=5

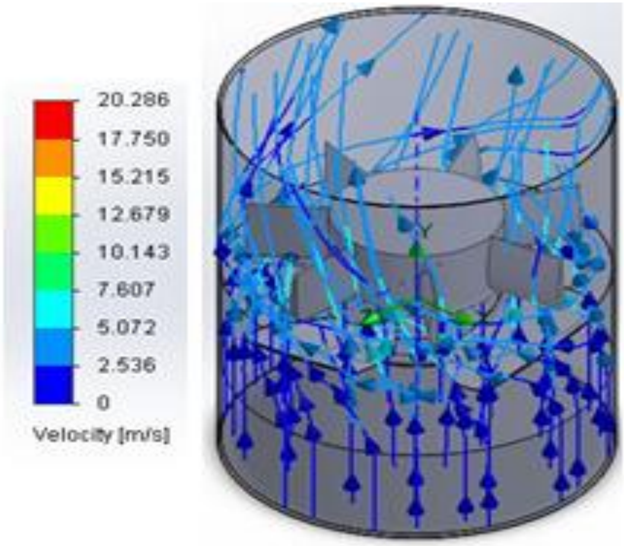


Fig.7.b The pressure distribution of the axial pump impeller with guide vanes , Z_2=7

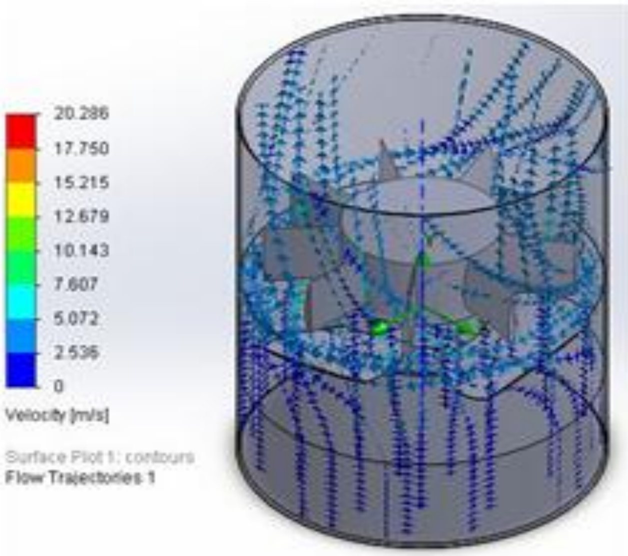


Fig.7.c The pressure distribution of the axial pump impeller with guide vanes , Z_2=9

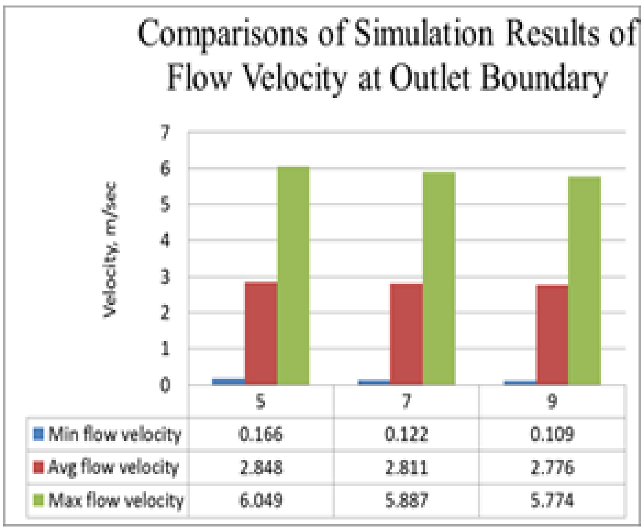


Fig.8. The flow velocity vs. the number of guide blades

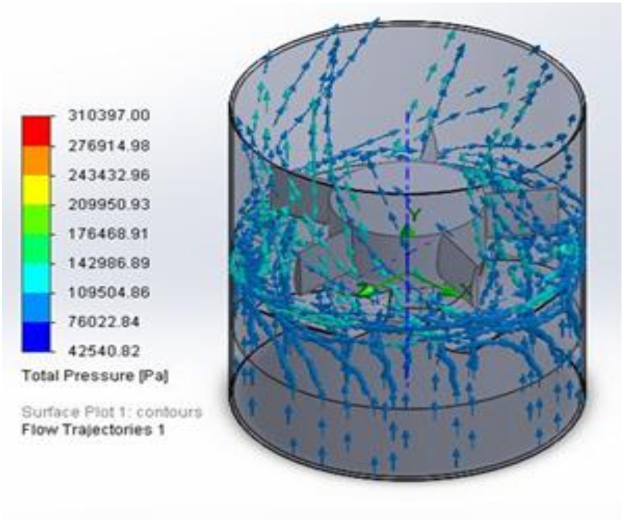


Fig.9.a The pressure distribution of the axial pump impeller with guide vanes , Z_2=5

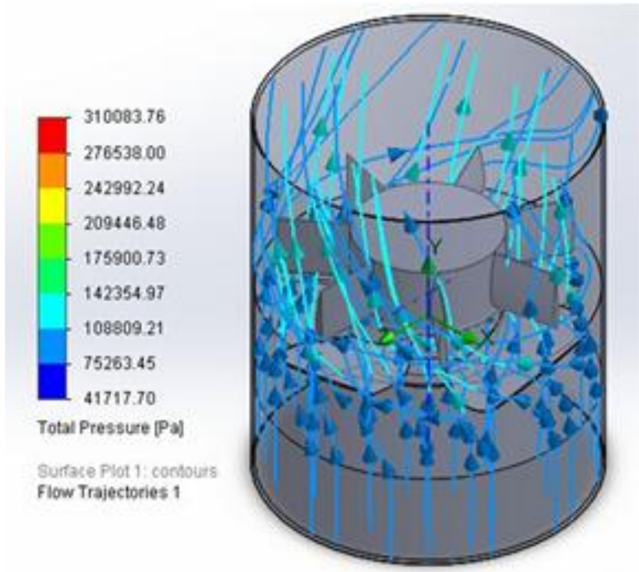


Fig.9.b The pressure distribution of the axial pump impeller with guide vanes , Z_2=7

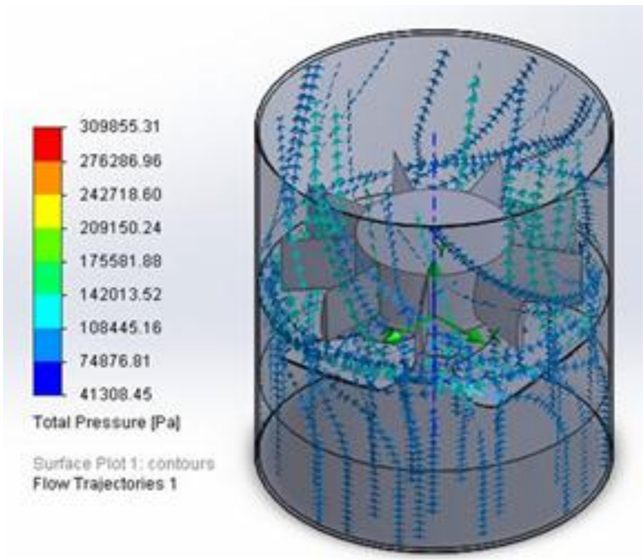
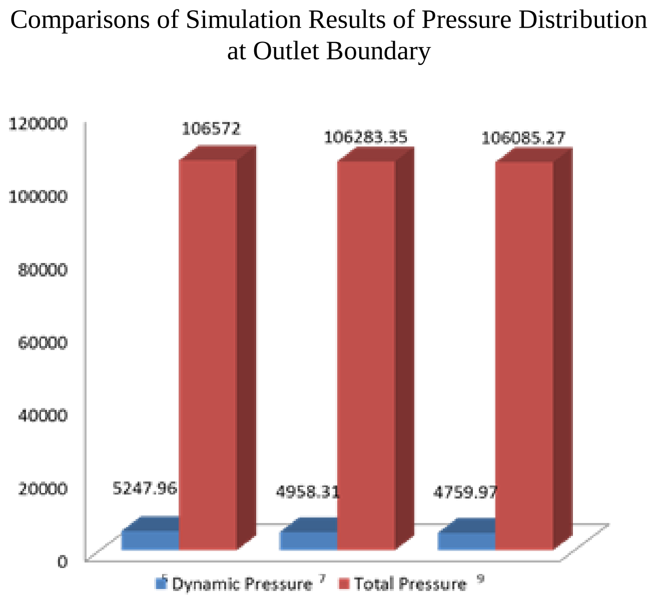


Fig.9.c The pressure distribution of the axial pump impeller with guide vanes , Z_2=9



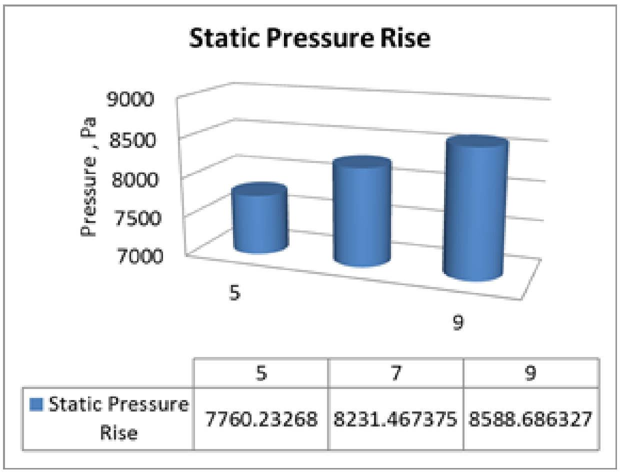


Fig.10. The pressure vs. The number of guide blades.

Based on the comparisons of flow simulation results changing number of guide blades, the averaged flow velocities have slightly decreased when the number of guide vanes is increased. The value of the averaged flow velocity is the largest at the axial pump with five number of guide blades.

According to the graphs of the pressure distribution, the values of the dynamic pressure and the total pressure have increased due to decreasing the number of guide blades. On the contrary, the values of static pressure rise have risen when the number of guide blades is increased.

V. CONCLUSION

In this study, the pressure and velocity, two main parameters of fluid flows, are studied in detail by using Flow Simulation in Solidworks. When the axial pump is installed with guide vanes, the static pressure rise which can get static head becomes higher than the condition without guide vanes. On the contrary, the flow rate is larger in only impeller than in the impeller with guide vanes. The difference between the axial flow pump with guide vanes and without guide vanes can be seen clearly with the aid of this numerical software. In addition to this, the effect of the various number of guide blades on the axial flow pump can be clearly studied with saving time and money because of the CFD commercial tool.

It can be seen that numerical results of this study is nearly the same with the theoretical concepts.

ACKNOWLEDGMENT

The present study was conducted under the Department of Mechanical Engineering, Mandalay Technological University, Myanmar. The author firstly would like to thank Dr.Tin San, Associate Professor and Head of Mechanical Engineering Department, Mandalay Technological University, for permission to do this paper. Moreover, the author is deeply gratitude to Dr. Myat Myat Soe, Associate Professor and Head of Fluid Mechanics Laboratory, Department of Mechanical Engineering, Mandalay Technological University, for her guidance and suggestions. Finally, the author wishes to express his deepest gratitude to Dr. Zin Ei Ei Win, Associate Professor, Department of Mechanical Engineering, Mandalay Technological University, for her supervision and encouragement.

REFERENCES

[1] Stepanoff, A.J. 1957. Centrifugal and Axial Flow Pumps, New York,John Wiley and Sons,
[2] Javur,M.M.; Investigations on Axial Flow Pumps and Fans, Ph.D. Thesis,1980. Dept. of Mech. Engg, Indian Institute of Technology, Bombay, India.
[3] Khin Mg Aye(Moscow), 2003. Axial Pumps
[4] Axial Flow and Mixed Flow Pump http://www.pump.flo.com.
[5] No Date. “Propeller Pumps”, July, 2006, http://www.pumps.org
[6] Anonymous, No Date. “ Lawrence Pump Inc. axial flow propeller pumps”, July, 2006. http://www.Lawrencepumps.com
[7] K.M.Srinivasan, Rotodynamicpump(centrifugal and axial pump)
[8] A Source Book for Industry, Hydraulic Institute, Improving Pump System
[9] Stephan Greets: Experimental and Numerical Study of an Axial Flow Pump, Ph.D Thesis, May 2006.
[10] Seppo A. Korpela, Principles of Turbomachinery,The Ohio State University.
[11] Helmut Jaberg, Hydraulic Aspect in Design and Operation of Axial Flow Pumps,Institute for Hydraulic Machinery, Graz, Austria.S.
[12] Jung, W. H. Jung, S. H. Baek, S. Kang, Shape Optimization of Impeller Blades for a Bidirectional Axial Flow Pump using Polynomial Surrogate Model, World Academy of Science, Engineering and Technology 66 2012..
[13] C. Pozrikidis, Fluid Dynamics: Theory, Computation, and Numerical Simulation, Second Edition
[14] Philip Marcus Babitz. “Thermo hydraulics Analysis of the University of Utah Triga Reactor of Higher Power Designs.”