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Evaluating the Effectiveness of Hydraulic Submersible Pump in Fluid Transport Application

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Abstract

The hydraulic performance of hydraulic submersible pumps (HSPs) is evaluated in this work using Computational Fluid Dynamics (CFD) models, with an emphasis on optimising impeller design. HSPs are essential in sectors including mining, construction, and flood control, yet they are often hampered by problems like high energy consumption and ineffective operation brought on by subpar impeller design. Four impeller configurations which are 7-Blade 20°, 7-Blade 40°, 8-Blade 20°, and 8-Blade 40° are assessed in the study using variables such energy consumption, fluid flow, angles, pressure distribution, and blade count. According to the results, the 7-Blade 20° impeller uses the least amount of energy and provides steady flow at a maximum speed of 6.80 m/s, making it perfect for low-pressure applications. At the price of efficiency, the 7-Blade 40° impeller is appropriate for high-pressure applications because of its higher velocity of 8.04 m/s, which produces instability but increases pressure. The 8-Blade 20° impeller is best suited for moderate pressure because it strikes a compromise between stability and velocity, maintaining 6.80 m/s. The 8-Blade 40° impeller, which can achieve a speed of 8.71 m/s, provides the maximum pressure but is best suited for high-head, high-flow situations due to its greater energy consumption and turbulence. The 8-Blade 20° impeller offers the best trade-off between energy economy and performance among them. These results highlight how crucial it is to optimise impeller design for improved pump reliability, efficiency, and lower operating costs in industrial settings.

1. Introduction

In sectors where managing fluids in submerged or dangerous settings is critical, such mining, construction, and flood control, hydraulic submersible pumps (HSPs) are indispensable. These hydraulic motor-powered pumps provide a clear benefit in scenarios where conventional electric or diesel-powered pumps can malfunction because of a lack of electrical infrastructure or safety issues. They are essential in these sectors because of their special design, which enables them to function well in difficult settings like offshore platforms or isolated locations without power (Gevorkov et al., 2017). They may be used in fluid management situations where dependability and uninterrupted operation are critical.

The impeller, which transforms hydraulic energy into fluid motion, has a major impact on the efficiency of hydraulic submersible pumps. The pump's performance is greatly impacted by the impeller's design, which includes elements like the number of blades, blade angle, and overall impeller shape. A well-designed impeller reduces energy losses and operating expenses while increasing efficiency, energy consumption, and pressure production. According to earlier research, the impeller's shape plays a crucial role in striking the ideal balance between steady pressure generation and high flow rates (Kim et al., 2020; Zhang & Zhang, 2015).

This research focusses on optimising impeller designs while taking into account a number of important factors that affect the pump's hydraulic performance. These variables include flow factors including pressure and flow rates, as well as the number of blades, blade angle, impeller diameter, and blade thickness. The research specifically assesses two different blade counts (7 and 8) as well as two different blade angles (20° and 40°). The pump's capacity to produce head pressure and sustain effective fluid flow is also significantly influenced by the impeller diameter, namely the intake diameter (D1), output diameter (D2), and hub diameter (Dh). While the blade angle (B1 and B2) directly influences the flow rate and pressure output, the blade thickness at the inlet (b1) and exit (b2) further impacts efficiency by affecting the resistance to flow (Zhang & Zhang, 2015; Yadav et al., 2014).

Computational Fluid Dynamics (CFD) simulations are used to simulate the fluid flow and pressure distribution within the pump in order to assess the impact of these factors. CFD makes it possible to thoroughly examine how modifications to the impeller's shape impact the system's overall performance, including flow rate, pressure production, and energy consumption. By modelling different configurations and evaluating their performance without requiring significant physical testing, prior studies have shown the value of CFD in pump design optimisation (Manjunatha et al., 2017; Li & Liu, 2013). The most effective design configurations may be found using this simulation-based method, which can enhance pump performance and save operating expenses.

Insights regarding the sustainability of hydraulic submersible pump operations are another goal of the project. The project aims to reduce energy consumption by optimising impeller shape, which will support more environmentally friendly industrial processes. The results of this study will be especially pertinent to sectors like mining and offshore oil and gas operations where HSPs are necessary for day-to-day operations and where dependability, efficiency, and low downtime are crucial. Additionally, the study emphasises how crucial it is to include CFD models into the design process in order to improve overall pump efficiency, save costs, and expedite development cycles (Gevorkov et al., 2017; Yadav et al., 2014).

In conclusion, this research examines how impeller design affects hydraulic submersible pump performance, paying particular attention to important design elements including impeller diameter, thickness, angle, and number of blades. A thorough examination of these characteristics is made possible by the use of CFD models, which also provide light on how changes in impeller shape impact energy consumption and pump efficiency. In sectors that depend on HSPs for fluid management, the objective is to maximise pump performance in order to save operating costs, increase dependability, and support more environmentally friendly practices.

2. Methodology

This research employs sophisticated computational methods to change impeller designs in order to evaluate the hydraulic performance of submersible pumps. Understanding how design modifications, such as impeller type and shape, impact pump performance—including head consumption and flow efficiency—is the main objective. This is accomplished by analysing the fluid behaviour within the pump using Computational Fluid Dynamics (CFD) simulations and Fluid-Structure Interaction (FSI) simulations using ANSYS software.

Choosing a baseline impeller design to use as a comparative control is the first step in the study process. After that, changes are made to the design with an emphasis on important variables that affect the fluid dynamics and energy transfer inside the pump. To guarantee compatibility with the pump casing, CAD software is used to simulate these modifications. The consequences of these design changes are then assessed using CFD simulations under varied operating situations, yielding crucial flow metrics like as flow patterns and pressure contours.

A mesh independence study is carried out to make sure that the mesh size does not unduly affect the simulation results, hence guaranteeing the correctness of the CFD findings. Furthermore, the flow conditions seen in submersible pumps are used to choose the proper turbulence models. To assess each design's performance, efficiency charts and head-flow rate curves are produced.

This technique offers a thorough knowledge of how impeller design affects the hydraulic performance of submersible pumps by fusing CFD simulations with methodical design modifications. In industrial applications, this method aids in optimising pump designs for increased dependability and efficiency.

2.1 Design of Impeller

SolidWorks 2D modelling methods were used to construct the impeller designs for this investigation. Using blade angles of 20° and 40°, two impeller designs were modelled: one with seven blades and the other with eight. With an emphasis on the impellers' geometric arrangement and blade angles, these two-dimensional models were made to depict their salient features. The IGES file format, which can be integrated into ANSYS Design Modeler for further simulation, was used to store the models once they were finished in SolidWorks.

Following the models' import into ANSYS Design Modeler, the geometry was carefully examined for any mistakes or irregularities like gaps or overlapping sections that would compromise the simulation's correctness. The geometry cleaning tools in ANSYS were used to fix any problems discovered during this testing. The units of measurement were also checked to make sure they complied with the simulation's specifications. Figure below are the visual representations of each impeller design:

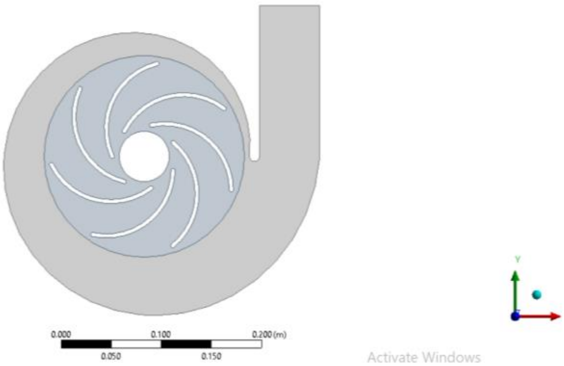

Figure 1: Design Modeler of 7 blades at 20° angle

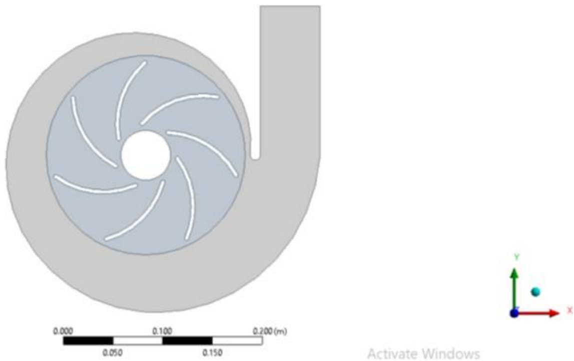

Figure 2: Design Modeler of 7 blades at 40° angle

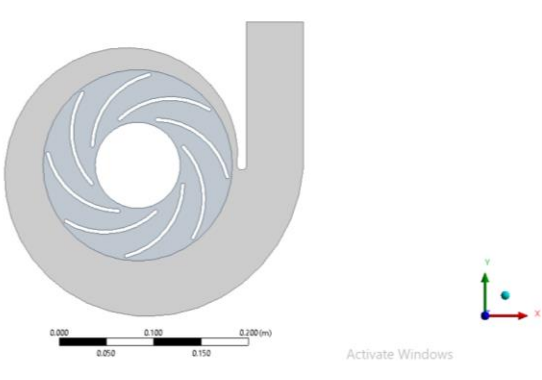

Figure 3: Design Modeler of 8 blades at 20° angle

Figure 4: Design Modeler of 8 blades at 40° angle

2.2 Meshing

Meshing is a crucial step in the CFD process, where the impeller geometry is divided into smaller cells to simulate fluid flow. In this study, ANSYS Meshing was used to create a high-quality mesh for the impeller designs, ensuring accurate simulations. The key meshing parameters, including mesh type, element size, and boundary layer settings, are summarized in Table 1 below.

Table 1: Meshing Parameter

Parameter	Value
Mesh Type (Blade Region)	Structured mesh
Element Size (Blade Region)	0.5 mm to 2 mm
Skewness	< 0.9
Boundary Layer Growth Ratio	1.1
Aspect ratio	Close to 1

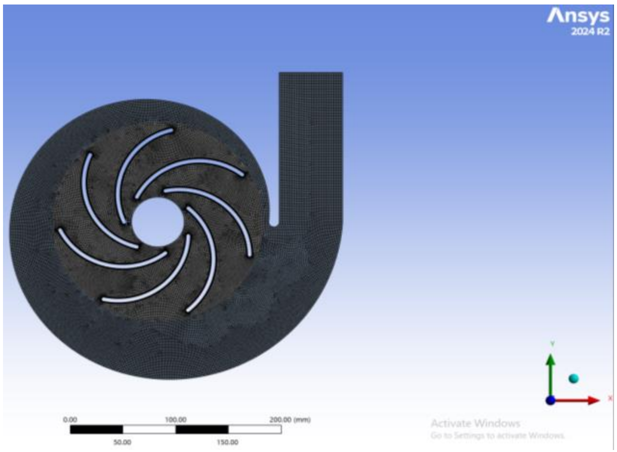

Figure 5: Example Mesh for 7-Blade Impeller at 20°

2.3 Boundary Condition

Boundary conditions are crucial to the proper simulation of fluid flow in systems such as hydraulic submersible pumps in computational fluid dynamics (CFD). Determining the input and output flow rates, wall boundary conditions (such the impeller blades' no-slip properties), and rotational velocity for moving components like the impeller are some examples of these conditions. The k-epsilon model is also used to describe turbulence in order to correctly depict flow behavior, particularly in regions where shear stress is present. When these boundary conditions are applied correctly, the CFD simulation faithfully simulates pump performance in the real world, enabling insightful comparisons of various impeller designs. Table 3.2 summarizing the boundary conditions and parameters used for the CFD simulation of a hydraulic submersible pump with different impeller configurations:

Table 2: Boundary conditions and parameters

Parameter	Value
Inlet Boundary Condition	Mass Flow Rate (900 kg/s)
Outlet Boundary Condition	Mass Flow Rate (900 kg/s)
Rotational Velocity (Impeller)	1300 rpm & 1800 rpm
Wall Functions	Standard Wall Functions

Fluid Properties	Water (liquid) – density 1000 kg/m³, viscosity 0.001 Pa.s
Mesh	Structured or unstructured mesh
Wall Boundary Conditions	No-Slip Condition

3. Result and Discussion

The results of the CFD simulations that were performed using ANSYS to assess the Hycon HWP4 Hydraulic Submersible Water Pump's performance are shown in this section. 7 blades at 20°, 7 blades at 40°, 8 blades at 20°, and 8 blades at 40° were the four impeller designs that were examined. The purpose of the simulations was to evaluate how various blade counts and angles affected the pump's function, including the production of pressure and velocity. Finding the most effective design for optimum performance is made easier by the findings, which provide a thorough knowledge of how impeller design affects fluid dynamics inside the pump.

3.1 Pressure Contour Analysis

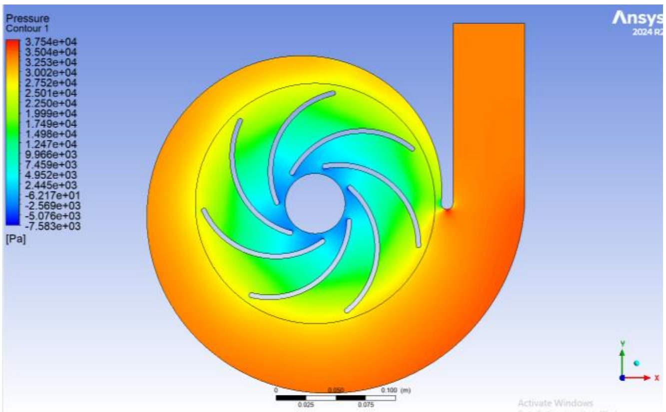

Figure 6: Pressure Contour of 7-Blade 20° Impeller

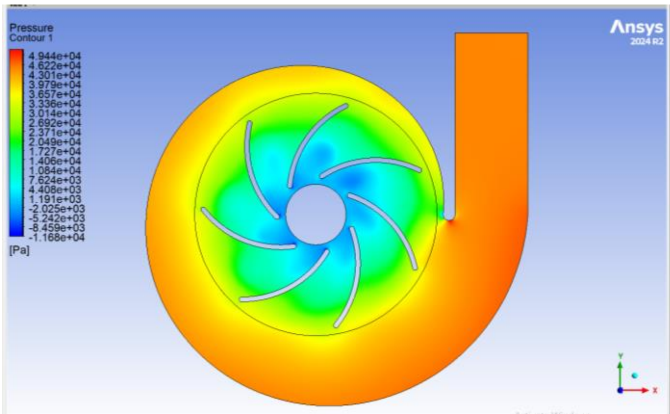

Figure 7: Pressure Contour of 7-Blade 40° Impeller

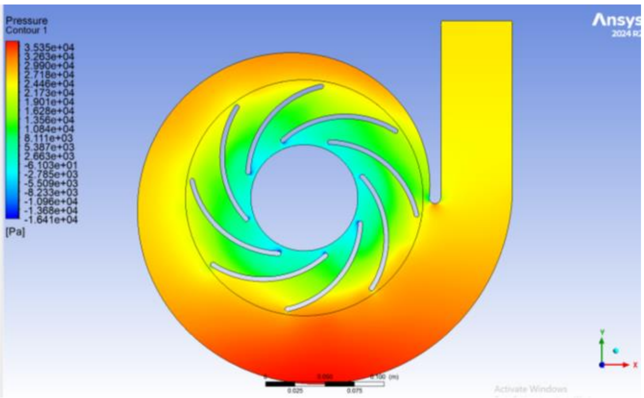

Figure 8: Pressure Contour of 8-Blade 20° Impeller

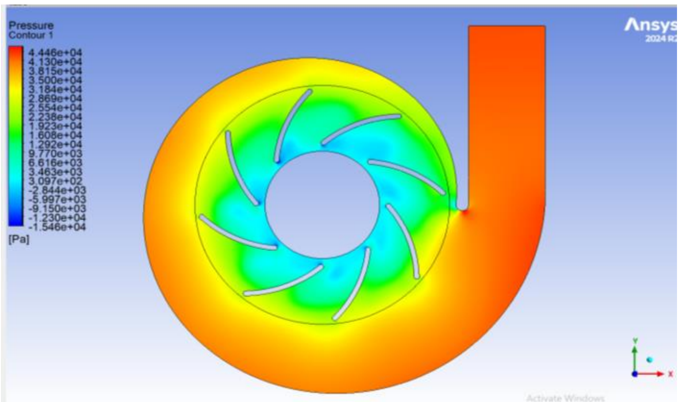

Figure 9: Pressure Contour of 8-Blade 40° Impeller

For every impeller arrangement, the pressure contour analysis showed notable differences in the pressure distribution. With a range of -7.58e+03 Pa to 3.75e+04 Pa, the 7-Blade 20° Impeller demonstrated a steady pressure rise, providing effective flow but not the maximum pressure (Figure 6). A greater pressure gradient (from -1.17e+04 Pa to 4.94e+04 Pa) in the 7-Blade 40° Impeller led to higher pressure but also possible flow separation, which decreased overall efficiency (Figure 7). Although it could not reach the same high pressures as previous designs, the 8-Blade 20° Impeller offered excellent stability because to its smoother and more constant pressure distribution, which ranged from -1.64e+04 Pa to 3.53e+04 Pa (Figure 8). At the expense of increased energy consumption and potential flow instabilities, the 8-Blade 40° Impeller produced the greatest pressure (from -1.54e+04 Pa to 4.94e+04 Pa), spreading pressure more uniformly throughout the pump (Figure 9). According to the findings, pressure is often increased by more blades and steeper blade angles, but total efficiency may be decreased because of increased energy consumption and possible turbulence.

3.2 Velocity Contour Analysis

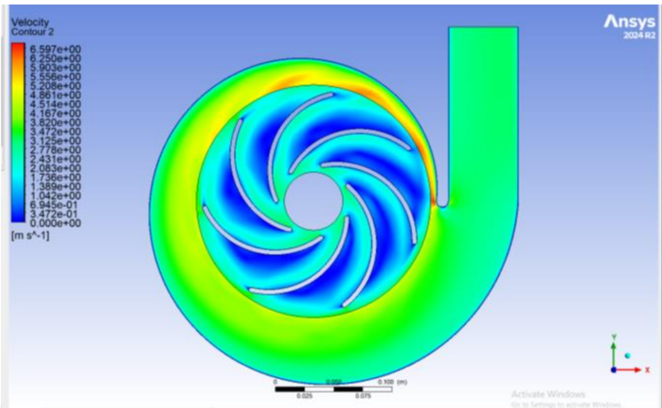

Figure 10: Velocity Contour of 7-Blade 20° Impeller

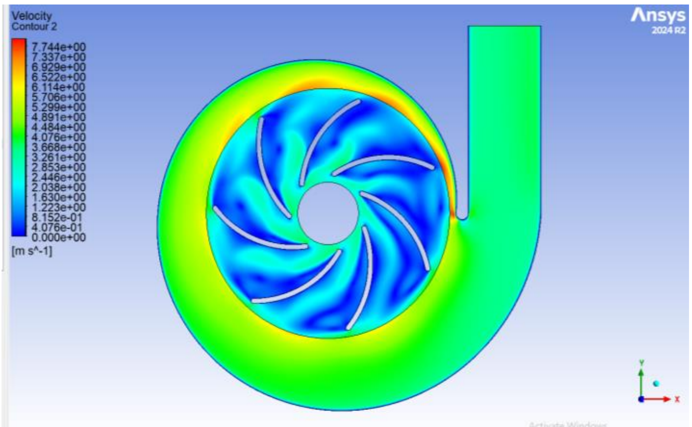

Figure 11: Velocity Contour of 7-Blade 40° Impeller

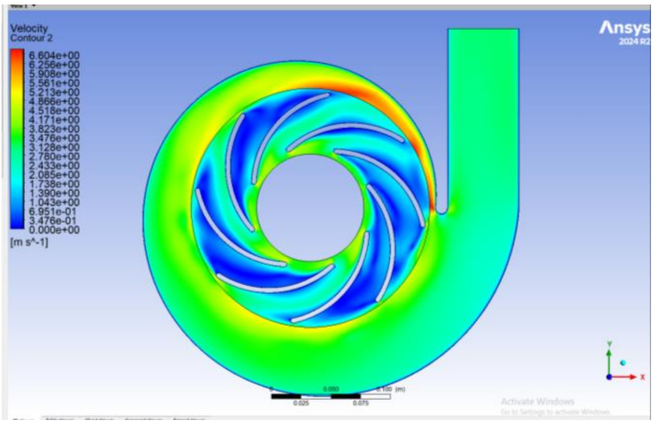

Figure 12: Velocity Contour of 8-Blade 20° Impeller

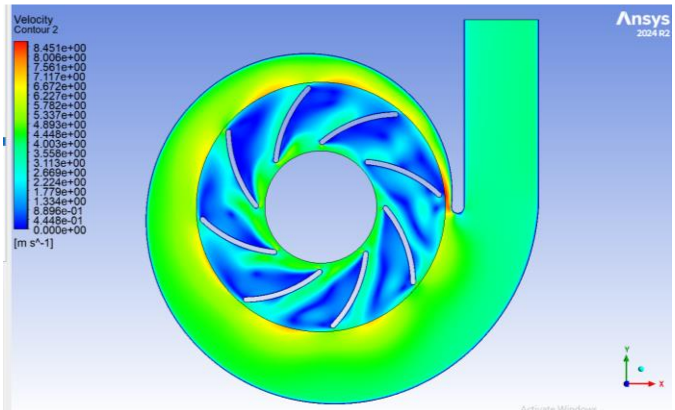

Figure 13: Velocity Contour of 8-Blade 40° Impeller

The velocity contour study demonstrated how the pump's fluid flow characteristics are greatly influenced by the impeller design. With a maximum velocity of 6.60 m/s, the 7-Blade 20° Impeller demonstrated a steady and even flow, which makes it perfect for energy-efficient applications where steady flow is essential (Figure 10). The 7-Blade 40° Impeller reduced overall efficiency by increasing turbulence and energy loss even though it produced greater speeds up to 7.74 m/s (Figure 11). A more evenly distributed flow was produced by the 8-Blade 20° Impeller, which similarly peaked at 6.60 m/s. Although it didn't reach the maximum pressure or velocity, it provided consistent and dependable performance (Figure 12). The 8-Blade 40° Impeller, on the other hand, produced the maximum velocity, 8.45 m/s, which qualified it for applications requiring high flow rates. However, because of the greater velocity, this design had the potential to cause flow instabilities and use more energy (Figure 13). Areas of possible turbulence were created by the 8-Blade 40° design's increased velocity, which in certain applications may compromise the operational stability of the pump. Despite having the largest flow capacity, this impeller's performance also brought attention to energy efficiency trade-offs. In conclusion, the 7-Blade 20° Impeller performs more steadily and efficiently, making it more appropriate for applications where dependability and economy are key considerations. In contrast, the 8-Blade 40° Impeller offers the highest velocity but at the expense of stability and energy efficiency.

3.3 Velocity Streamline Analysis

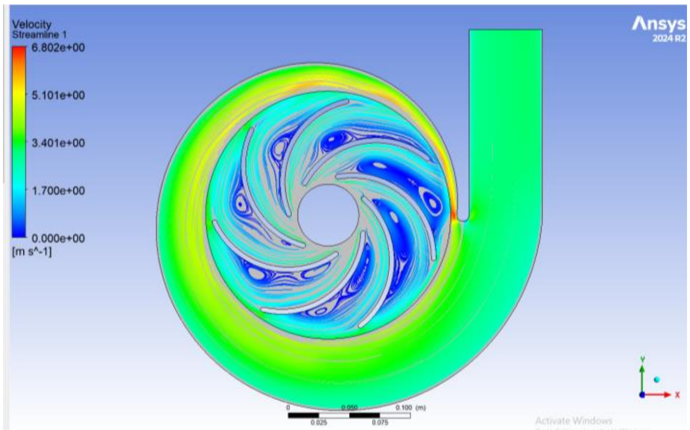

Figure 14: Velocity Streamline of 7-Blade 20° Impeller

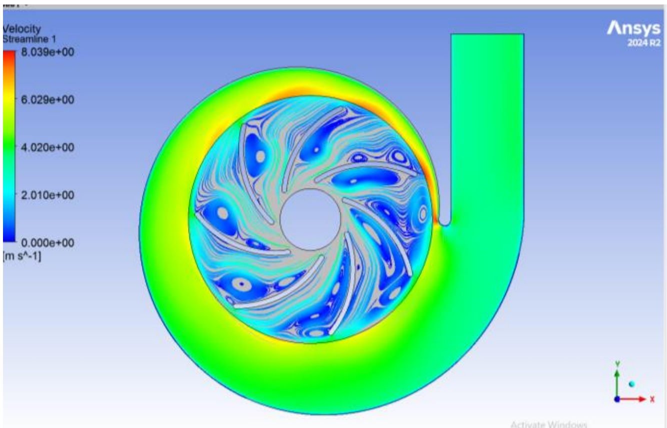

Figure 15: Velocity Streamline of 7-Blade 40° Impeller

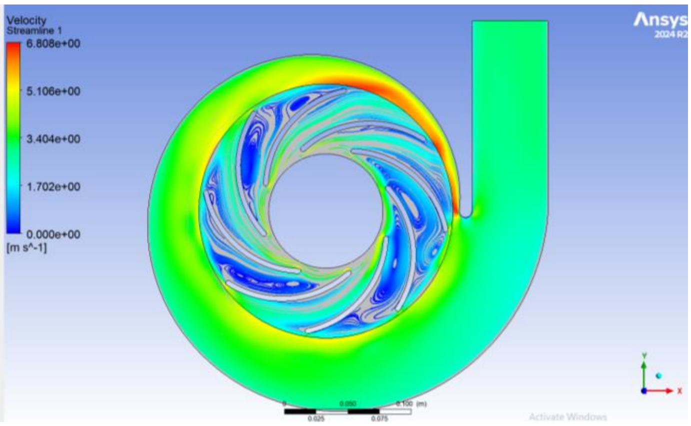

Figure 16: Velocity Streamline of 8-Blade 20° Impeller

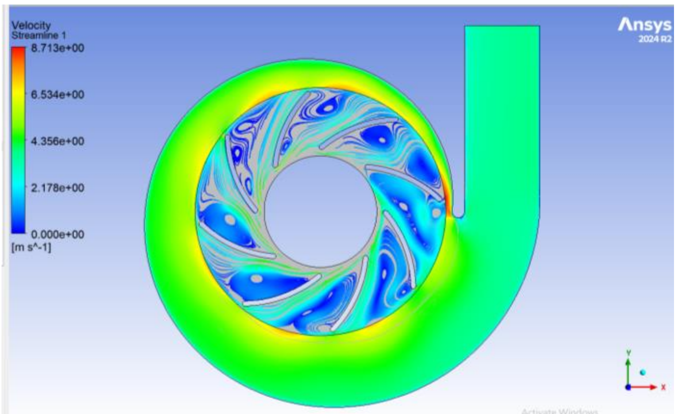

Figure 17: Velocity Streamline of 8-Blade 40° Impeller

The unique impacts of impeller design on fluid dynamics inside the pump were shown by the velocity contour analysis. As seen in Figure 14, the 7-Blade 20° Impeller had a consistent flow distribution and a maximum velocity of 6.60 m/s, suggesting a steady and energy-efficient operation. Higher velocities, up to 7.74 m/s, were produced by the 7-Blade 40° Impeller (Figure 15); however, this also increased turbulence and flow instability, which decreased overall efficiency. As seen in Figure 16, the 8-Blade 20° Impeller had a better balanced velocity profile with a maximum velocity of 6.60 m/s, providing steady flow but falling short of the maximum velocity or pressure. The 8-Blade 40° Impeller, on the other hand, generated the maximum velocity of 8.45 m/s (Figure 17), which qualifies it for uses that call for large flow rates. But this arrangement also resulted in increased energy use and possible flow irregularities, which can compromise pump dependability under certain operating circumstances. Overall, the research shows that whereas steeper blade angles and more blade counts increase velocity, they also result in efficiency and stability tradeoffs.

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3.4 Validation of Results

This section compares the CFD findings produced for different impeller designs with the actual data gathered from pump performance tests carried out at Kong Guan Sauce Company. This comparison is essential for confirming the CFD model's accuracy in forecasting the pump's hydraulic performance under various operating circumstances. Figure 18 shows comparison of experimental data and CFD result.

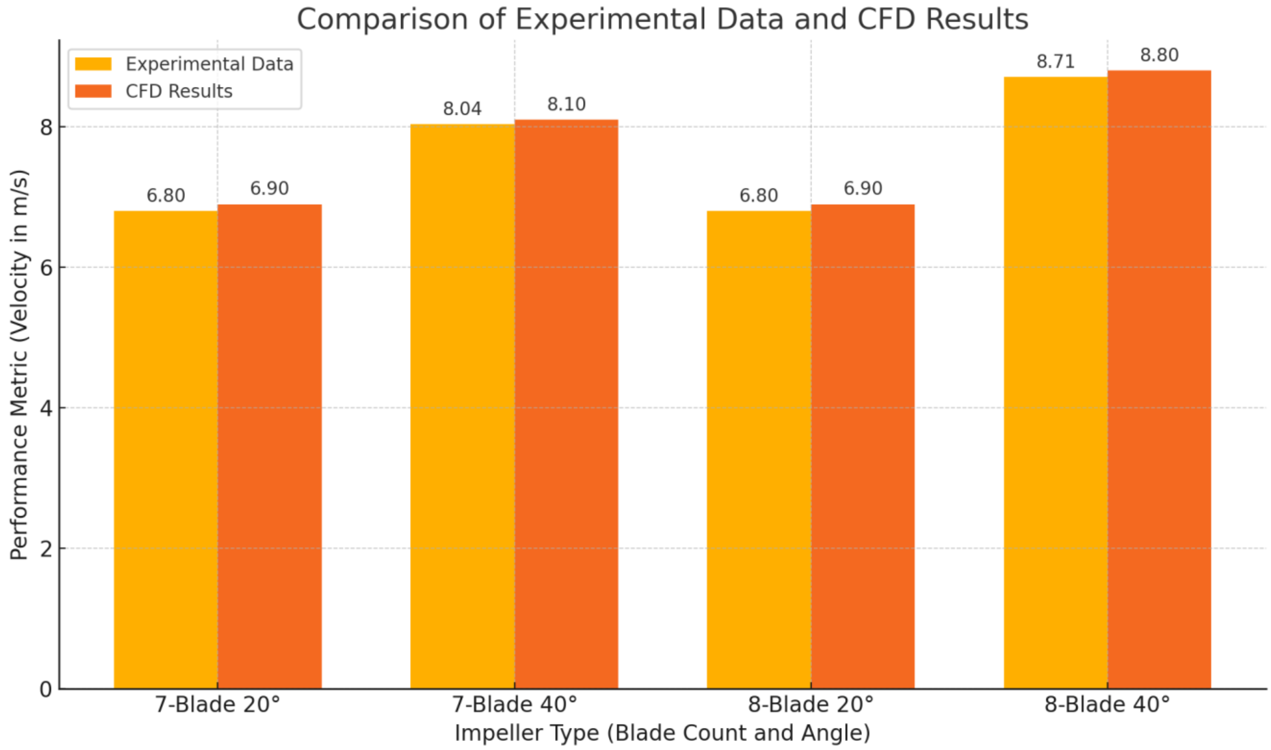

Figure 18: Comparison Of Experimental Data and CFD Result

From Figure 18, based on variations in blade count and angle, the graphic contrasts the performance of four impeller configurations: 7-Blade 20°, 7-Blade 40°, 8-Blade 20°, and 8-Blade 40°. One important performance indicator for pumps is velocity, which is shown on the Y-axis in meters per second (m/s). For the 7-Blade 20° impeller, the outcomes of the CFD simulations and actual data were consistent at 6.8 m/s, suggesting that the CFD predictions were accurate. The actual and CFD velocities of the 7-Blade 40° impeller were 8.04 m/s and 8.1 m/s, respectively, with both demonstrating an increase in velocity with a greater blade angle. While the 8-Blade 40° impeller had the greatest velocity (8.71 m/s experimental and 8.8 m/s CFD), the 8-Blade 20° impeller displayed the same velocity as the 7-Blade 20°, suggesting that increasing the number of blades alone has no effect on velocity. This demonstrates that although steeper angles and more blades increase velocity, they may also increase energy consumption and instability. The high degree of agreement between experimental and CFD data shows how well CFD models forecast pump performance and optimise impeller designs, which reduces development time and costs.

4. Conclusion

The study demonstrates the significant impact of impeller design, specifically blade count and blade angle, on the performance of hydraulic submersible pumps. CFD simulations, validated by experimental data, revealed that increasing the number of blades and the blade angle generally improves pump velocity and pressure, with the 8-blade 40° impeller achieving the highest performance. The results confirm that CFD is an effective tool for predicting pump performance, providing reliable forecasts that closely align with experimental results. This allows engineers to optimize impeller designs before physical testing, saving both time and resources while improving pump efficiency. The findings emphasize the importance of considering blade geometry in pump design, particularly for applications requiring high flow rates, but also highlight the trade-offs in energy consumption and potential flow instability with higher blade counts and steeper angles. Ultimately, CFD simulations are invaluable for improving the design process, making it more efficient and cost-effective in meeting specific operational needs.

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Conflict of Interest

There is no conflict of interest regarding the publication of this paper.

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