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Optimization of Centrifugal Pump Impeller to Increase Pump Hydraulic Efficiency using Solidworks Flow Simulation

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Abstract: The performance of a centrifugal pump is determined by the impeller geometry. Modifying geometric parameters such as outlet blade angle has a substantial influence on discharge head and efficiency because the blade pressure blade rises when angle. Since the pump operated continuously it is prone to wear and tear due to its function and therefore is vulnerable to failures that affect the pump performance. This research was conducted to enhance pump performance by optimizing impeller outlet blade angle. This research methodology consists of a few stages. Initially, the original pump is measured. Then, the measured parameter has been used to design the pump using Solidworks software. For impeller optimization, the outlet blade angle optimized by varying its outlet blade angle (β_2) from β_2=29.0 ˚, 30.0 ˚, 31.0 ˚, 32.0 ˚, 33.0 ˚, 34.0 ˚ and 35.0 ˚. Then the best outlet blade angle for the first optimization will be further refined which varying from β_2=32.8˚, 32.9˚, 33˚, 33.1˚, 33.2 ˚ and 33.3 ˚ by using Solidworks Flow Simulation Software. The optimum β_2 has been used for the new optimized impeller. As for results, the original impeller shows a 15.72 m discharge head and 51.48 % efficiency. Then the optimized outlet blade angle that produces optimum performance was outlet blade angle β_2=33.0 ˚, with a 15.87 m discharge head and 56.27 % efficiency. Furthermore, the outlet blade angle β_2=33.0 ˚ was further refined and shows that the outlet blade angle that produce the best performance was β_2=33.1˚, which yield 15.90 m discharge head and 56.53 % efficiency. In conclusion, increasing the outlet blade angle shows a significant improvement in discharge head and efficiency as in theory by previous researchers. Then, its shows that by using Solidworks Flow Simulation achieve these research objectives.

Keywords: Pump, Centrifugal Pump, Impeller Outlet Blade Angle, Discharge Head, Efficiency, Computational Fluid Dynamics

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1. Introduction

Pump is a mechanical device use for transporting fluids. One of the most utilized pumps in industrial sector is centrifugal pump. It uses the impeller kinetic energy to increase the pressure from lower pressure area to higher pressure area. Since pump operated continuously and usually exposed to different substances with different liquids its impeller is prone to wear and tear. This happened due to friction, chemical and high-pressure formation, resulting a decrease in pump performance and increase the operating cost. Therefore, the impeller optimization needs to be emphasized since impeller has the most significant effect in performance.

Recently, there are several researchers that improve impeller based on geometric parameter such as number of blades, blade pitch and addition of splitter blade. Increasing number of blades has significant effect on head performance[1]. Meanwhile, increasing blade pitch resulting an increase in efficiency [2]. This shows that modifying impeller geometric parameter has significant effect in improving centrifugal pump performance. Therefore, the purpose of this research is to design original centrifugal pump and improve its performance by optimizing its outlet blade angle. Besides that, it is expected to define the performance in terms of discharge head and efficiency by conducting SolidWorks Flow Simulation.

2. Literature Review

A centrifugal pump produces kinetic energy by rotational motion from impeller that generated by electric motor, which makes the fluid surrounding it rotate and impart centrifugal force to the fluid. The water flow radially out and this radial movement in the impeller resulting higher centrifugal forces and higher discharge pressure with a low volume of flowrate, this is due to the rise of both pressure and kinetic energy by the mechanical energy transferred to the fluid. Since rotational motion happened at the suction side, the fluid being displace so the negative pressure have been induced at eye of the impeller, such low-pressure help sucking water stream into the system.

2.1 Pump Performance

In relation to centrifugal pump performance, a few considerations should be focus on to determine performance. The performance of a pump can be measure using three main analytical models, which is the pump volumetric flow rate, head, and efficiency. the pump performance represented in a form of curve. The curve known as pump characteristic curve.

2.1.2 Head

Pump head is defined as the kinetic energy produced by the pump. It is a measurement of the height, which the pump can deliver a liquid at a specific volumetric flowrate. The head and flowrate will determine the performance of the pump. Instead of pressure, the centrifugal pump uses the head to determine its performance, this is because the pressure will change, while the height of the fluid is not depending on the specific gravity of the liquid. Eq. 1 used to determine the pump head from simulation.

$$H\ (m) = \frac{P_{outlet} - P_{Inlet}}{\rho g} \quad Eq. 1$$

2.1.3 Efficiency

There are many types of efficiency, which vary such as ratio of outlet power and inlet power, ratio of water horsepower output from the pump to the shaft horsepower input for the pump. However, in this research the pump efficiency is focus on the difference in pressure times flowrate divided by an angular velocity of impeller times the torque transmitted by the shaft as shown in following Equation 2.2.

$$\eta = \frac{(Poutlet - Pinlet)Q}{\omega T} \qquad Eq.2$$

2.2 Impeller Geometric Parameters

When it comes to the efficiency of a centrifugal pump, there are several factors to consider. However, the most one of the most important factors is the impeller geometric parameters. There are several impeller design parameters influences the performance of centrifugal pumps such as impeller blades pitch. Pitch angle refers to the angle of inclination from the horizontal or vertical plane. In impeller designing impeller blade the pitch angle is important to determine the impeller efficiency in distribution of fluid flow. An increase in blade exit angle increases the efficiency and the discharge head of the pump [2]. However, the pitch angle should be determined carefully to find a suitable value angle. The larger blade value of angle creates vacuum, while smaller value increases the clogging of water inside the impeller [3]. Figure 1 shows the outlet blade angle and inlet blade angle of impeller.

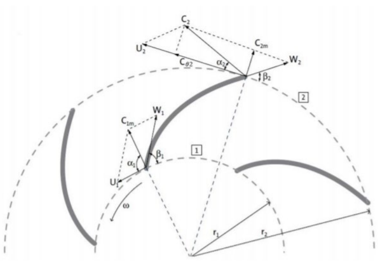


Figure 1: Impeller blade pitch [3]

3. Methodology

3.1 Centrifugal Pump Selection

Centrifugal pump used in research was the ASP 50-32-125. It is an ASP AS Series (End Suction Pump). This pump was selected since it is a stationary pump model used for practical studies, where it is accessible for measurement work, which is necessary in this research to design the pump in Solidworks modelling software. Figure 2 shows the existing centrifugal pump used in this research.

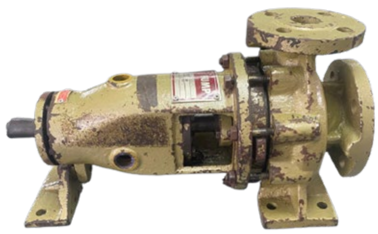


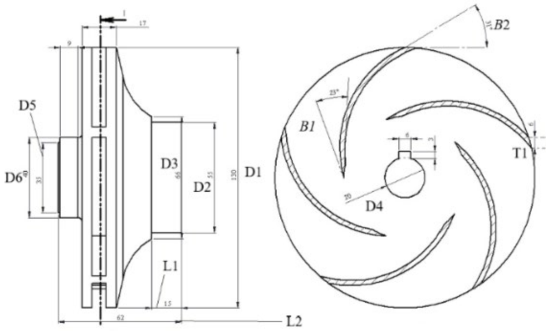
Figure 2: Original Pump ASP 50-32-125

3.2 Pump Component Measurement and Modelling

In order to design the existing pump each component was measured, and the tools used for measurement is digital vernier caliper and half circle bevel protractor, the tools and the parameters labelled alphabetically to distinguish each other for measuring each part. Below shows sample measurement for Impeller. Table 1 shows measurement label and tools for impeller. Diameter labelled as D1, D2, D3, D4, D5 and D6 which measured by using the calliper outside large jaws and inside jaws. The overall length of the impeller labelled as L2 and measured by using calliper depth rod. The blade number is counted by counting blade of the impeller. Then, the thickness of the blade (T1) is measured by using calliper inside jaws.

Meanwhile, the impeller outlet angle (β_2) and inlet blade angle (β_1) measured by using bevel protractor. To measure the angel, the protractor ruler will be stick inside the vane and the protractor is set to be tangent with the impeller outside diameter.

Table 1: Impeller Measurement



Parameter	Label	Tools
Impeller diameter	D1	Vernier caliper (outside jaws)
Suction eye outer diameter	D2	Vernier caliper (outside jaws)
Suction eye inner diameter	D3	Vernier caliper (outside jaws)
Shaft chamber diameter	D4	Vernier caliper (inside jaws)
Rear chamber diameter	D5	Vernier caliper (outside jaws)
Rear ring clearance	D6	Vernier caliper (outside jaws)
Impeller overall length	L1	Vernier caliper (outside jaws)
Suction eye length	L2	Vernier caliper (depth rod)
Blade thickness	T1	Vernier caliper (outside jaws)
Inlet blade angle	β_1	Half circle bevel protractor
Outlet blade angle	β_2	Half circle bevel protractor

3.3 Solidworks Flow Simulation Configurations

Since the original pump operates at 2900 rpm, the configurations for simulation used the same speed to duplicate its performance. Then, the boundary condition used for discharge vane was environmental pressure, while the boundary condition for the inlet side was subjected flowrate. To determine the pump performance, the simulation results configuration will be based on surface goals and equation goals. Table 2 shows the analysis goals and its purpose that used in this research.

Table 2: Analysis goal and its Purpose

Goal	Goal Type	Surface	Purpose
Suction Pressure	Surface	Inlet lid	To measure the pressure from the suction
Discharge Pressure	Surface	Outlet lid	To measure the pressure at discharge
Torque	Surface	Impeller	To measure the torque at impeller
Discharge Flowrate	Surface	Outlet lid	To measure the discharge flowrate
Pressure Difference	Equation	N/A	To obtain the pressure difference between suction and discharge
Head	Equation	N/A	To measure head produced by the pump
Efficiency	Equation	N/A	To measure the efficiency of the pump

3.4 Impeller Optimization

The impeller has been modified by optimizing its outlet blade angle. The impeller outlet blade angle was varied from an angle that lower than original impeller to wider angle. Then, the performance of each impeller is then evaluated, with the aim to determine which impellers give a significant improvement over the original impeller. The impeller with the optimum performance will further be refined sequentially to identify the ideal impeller for this research.

4. Results and Discussion

4.1 Measurement and Design Results

Each part has been measured and designed by using Solidworks modelling software. The specification for impeller shown in Table 3.

Table 3: Impeller Specifications

Parameter	Label	Measurement
Impeller diameter	D1	130 mm
Suction eye outer diameter	D2	55 mm
Suction eye inner diameter	D3	66 mm
Shaft chamber diameter	D4	20 mm
Rear chamber diameter	D5	35 mm
Rear ring clearance	D6	40 mm
Impeller overall length	L1	15 mm
Suction eye length	L2	62 mm
Blade thickness	T1	6 mm
Inlet blade angle	β_1	31˚
Outlet blade angle	β_2	23˚
Number of Blade	Z	5

According to the table above, the impeller diameter (D1) was 130 mm. Then, the suction eye outer diameter (D2) was 55 mm. Meanwhile, the suction eye inner diameter (D3) shown 66 mm. The shaft chamber diameter (D4) has the diameter of 20 mm. Next for shaft chamber diameter (D5) and rear chamber (D6) has the diameter of 35 mm and 40 mm respectively. Moreover, the overall impeller length (L2) was 62 mm. T1 is the thickness of the blade, where the thickness was 6 mm. β_1 and β_2 is the impeller inlet blade angle and outlet blade angle. Both have the angle of 23.0 ˚ and 31.0 ˚ respectively. Finally, the impeller blade number was 5. Figure 2 shows the impeller that has been designed based on the specification above.

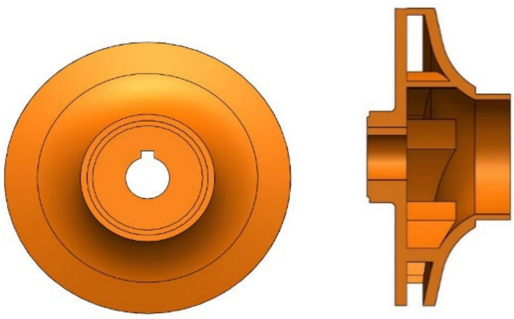


Figure 3: Designed Impeller

Each designed component has been assembled in Solidworks Assembly as shown in Figure 4. This model has been analysed by using Solidworks Flow Simulation on the following subtopic below.

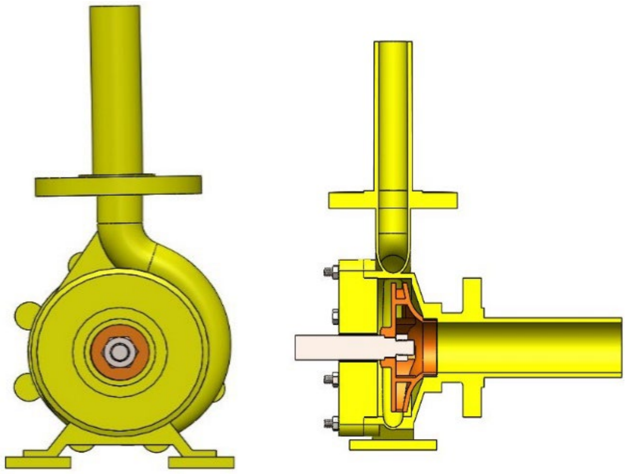


Figure 4: Assemble Pump Model

4.2 Original Impeller Analysis

The simulation result for original impeller shows, the pressure at inlet was -50506.1157 Pa, the pressure is negative since it is suction pressure. Meanwhile, outlet pressure developed by the pump was 103749.216 Pa. The torque on the impeller was 4.23577949 N/m^2 and the discharge volume flowrate is 0.00433066284 m^3/s. Then to obtain the pump head and efficiency performance, the result was calculated based on Eq. 3 and Eq.4 as shown below.

Discharge Head Calculation:

$$H\ (m) = \frac{103749.216\ \text{Pa} - (-50506.1157\ \text{Pa})}{1000\left(\frac{kg}{m^3}\right) x\ 9.81\left(\frac{m}{s^2}\right)}\ Eq.\ 3$$

$$= 15.72\ \text{m}$$

Efficiency Calculation:

$$\eta = \frac{((103749.216\ Pa - (-50506.1157\ Pa))(0.00433066284\ m^3/s)}{303.68729\left(\frac{\text{rad}}{\text{s}}\right) \text{x}\ 4.23577949\left(\frac{\text{N}}{m^2}\right)} x\ 100\ Eq.\ 4$$

$$= 51.84\%$$

the discharge flowrate will be converted to m^3/h by multiplying it to 3600 conversion factors. Based on the calculation above, the performance of original impeller at 2900 RPM shows a discharge head of 15.72 m and has the efficiency of 51.48 % as shown in table 4.

Table 4: Original Impeller Performance

RPM	Discharge Head (m)	Efficiency (%)
2900	15.72	51.48

4.3 Optimized Impeller Analysis

In this topic, there are total of six outlet blade angles has been observed which is β_2 = 29.0 ˚,30.0 ˚ ,33.0 ˚,34.0 ˚ and 35.0 ˚. This is a necessary process in this research since the angle with optimum performance chosen for further optimization. Meanwhile, the performance of each angle will be evaluated by discharge head and efficiency. The calculation was done in simulation by using equation goal, and the result of each impeller shown in table 5.

Table 5: Optimize Impeller Performance Results

RPM	β_2 (˚)	Discharge head (m)	Efficiency (%)
	29	15.58	50.48
	30	15.63	50.61
	32	15.87	51.94
2900	33	15.87	56.27
	34	15.89	51.38
	35	15.98	51.26
	29	15.58	50.48

As seen in table 5, the performance of every optimized blade angle that operates at 2900 RPM has been obtained. At impeller with β^2 = 29.0 ˚, shows a discharge head of 15.58 m, and an efficiency 50.48 %. While impeller β^2 = 30.0 ˚ show 15.63 m head discharge and 50.61% efficiency. At impeller β^2 =32.0 ˚, the discharge head is 15.87 m, and the efficiency is 51.38 %. Moreover, the impeller β_2 = 33.0 ˚ has a discharge head 15.87 m and efficiency of 56.27 %. Meanwhile, at impeller β_2 = 34.0 ˚ the discharge head was 15.89 m and an efficiency of 51.38 %. Finally, at impeller β_2 = 35.0 ˚, the discharge head was 15.98%, and the efficiency was 51.26 %. Figure 3 illustrate the performance of discharge head on every optimized impeller.

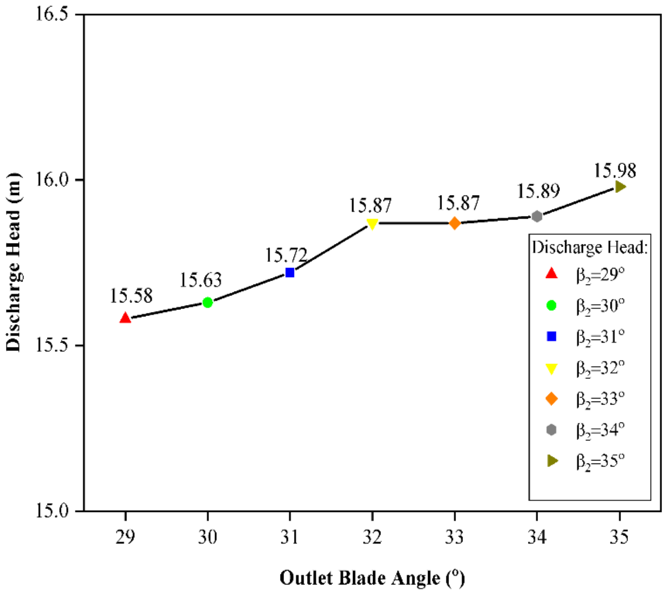


Figure 5: Optimized Impeller Head Performance

Based on Figure 5, modifying outlet blade angle, does affect the discharge head performance. Where the discharge head gradually increases from 15.58 m at β^2 = 29.0 ˚, then 15.63 m at β^2 = 30.0 ˚. While the discharge heads for both β^2 = 32˚ and 33˚ increased to 15.87 m. Next, the discharge head increase more at β^2 = 34.0 ˚ until β^2 = 35.0 ˚ respectively from 15.89 m to 15.98 m. This indicate that head performance increase when the outlet blade angle increase. This finding is precisely similar with the research conducted by [4] whom study the effects of varied outlet blade angle. In his result the increase in blade outlet angles the head increased with the increase in outlet blade angle. This was happened when the outlet blade angle increases the pressure rises across the impeller and simultaneously improve the discharge head. [5]. To prove the pump head increases as the outlet blade angle increases, figure 6 show the pressure distribution on each outlet blade angle which generated from the simulation.

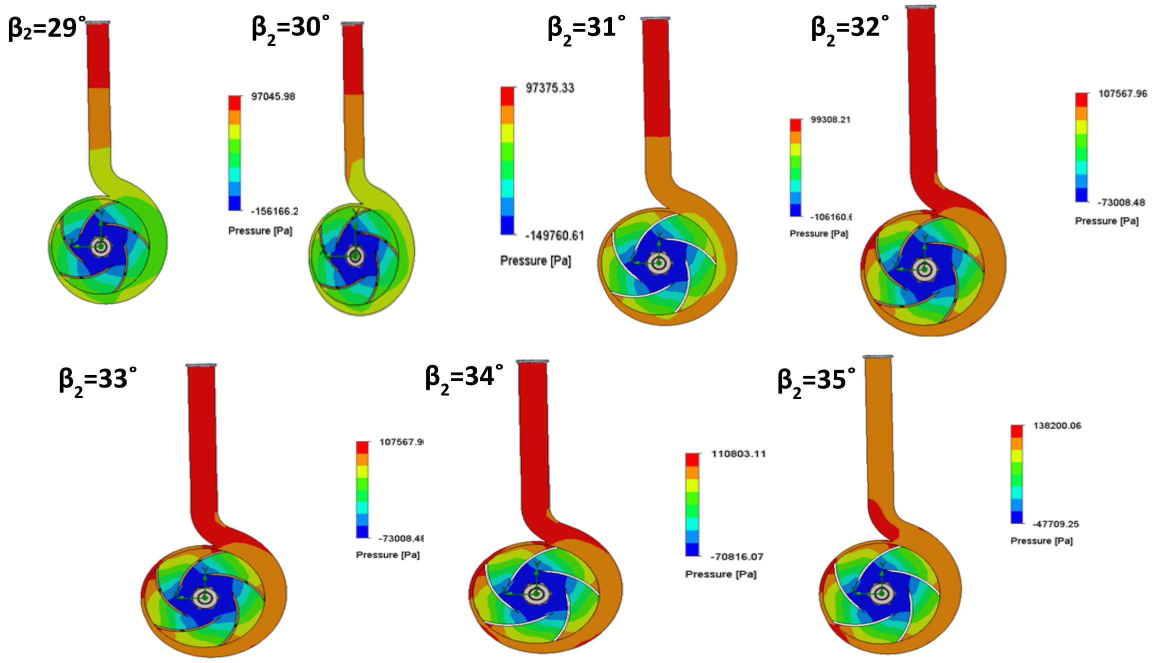


Figure 6: Pressure distribution on every outlet blade angle

Figure 6 show the pressure distribution on different outlet blade angle that vary from β^2 =29.0 ˚, 30.0 ˚, 31.0 ˚, 32.0 ˚, 33.0 ˚and 35.0 ˚. According to the pressure cut plot, the maximum pressure in the pump increases as the angle increases, from 97045.98 Pa at 29.0 ˚ to 138200.06 Pa at 35.0 ˚. With a pressure difference of 41154.1 Pa, the pressure within the pump rises 42.40 %. The head increases when the pressure increase because when pump produce more pressure, it can pump fluid higher and produce higher head.

However, to find the optimum outlet blade angle, the efficiency of each blade angle needs to be considered. This is because a higher discharge head does not always guarantee better pump performance. Figure 7 shows the efficiency result obtained from analysis.

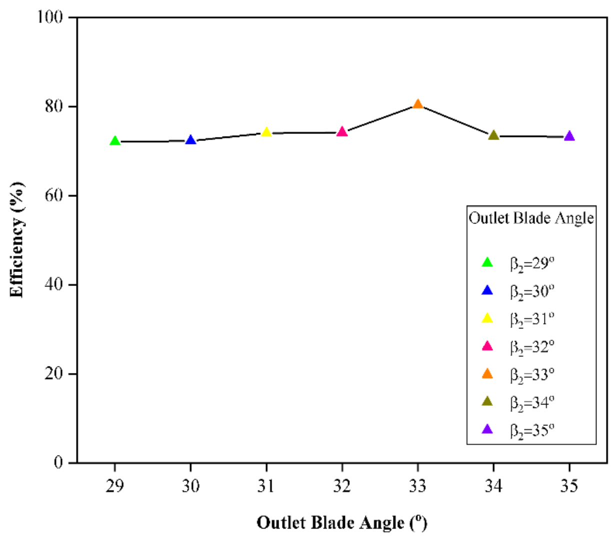


Figure 7: Efficiency on Optimized Impeller

According to the Figure 7, efficiency does not apply with head concept, where the discharge head increases as the outlet blade angle increases. As seen above when the outlet blade angle increases, the efficiency gradually increases from 50.48 % at β_2 = 29.0 ˚ to highest efficiency which is 56.27 % at β_2

= 33.0 ˚, then efficiency drops significantly from 51.38 % (β_2=34.0 ˚) to 51.26 % (β_2=35.0 ˚). It can be concluded that outlet blade angle 33.0 ˚ which yields 15.87 m discharge head and 56.27 % efficiency is the optimum angle for this research's final performance optimization. After obtaining the optimum outlet blade angle, the following topic will focus on the optimizing the outlet blade angle β_2 = 33.0 ˚ to further improve its performance.

4.4 Reoptimize Impeller 33˚

After identifying the best outlet blade angle that produce optimum performance, the angle has been fine-tuned to achieve the best performance from the angle. Based on the observation above, the optimum outlet blade angle was β_2 = 33.0 ˚. To obtain the best performance from this angle, the outlet blade angle tuned decimally from β_2 = 32.8 ˚, 32.9 ˚, 33.1 ˚, 33.2 ˚and 33.3 ˚ Each outlet blade angle analyzed and decided which blade angle produce better result than 33.0 ˚. Table 6 show the result on every angle that has been refined.

Table 6: Refined Impeller Results

RPM	β_2 (˚)	Discharge head (m)	Efficiency (%)
2900	32.8	15.58	50.48
	32.9	15.63	50.61
	33.1	15.87	51.94
	33.2	15.87	56.27
	33.3	15.89	51.38

According to Table 6, impeller with outlet blade angle β_2 = 32.8 show a discharge head of 15.80 m and 55.95 % efficiency. At β_2 = 32.9, the discharge head was 15.81 m, and the efficiency was 56.27 %, then at β_2 = 33.1, discharge head show a 15.90 m while the efficiency was 56.93 %. Finally, the discharge head for both β_2 = 33.2 and β_2 = 33.3 show a 15.91 and 15.87 m respectively, while the efficiency was 52.08 % and 51.33 %. Figure 8 show the head and efficiency for the refined outlet blade angle.

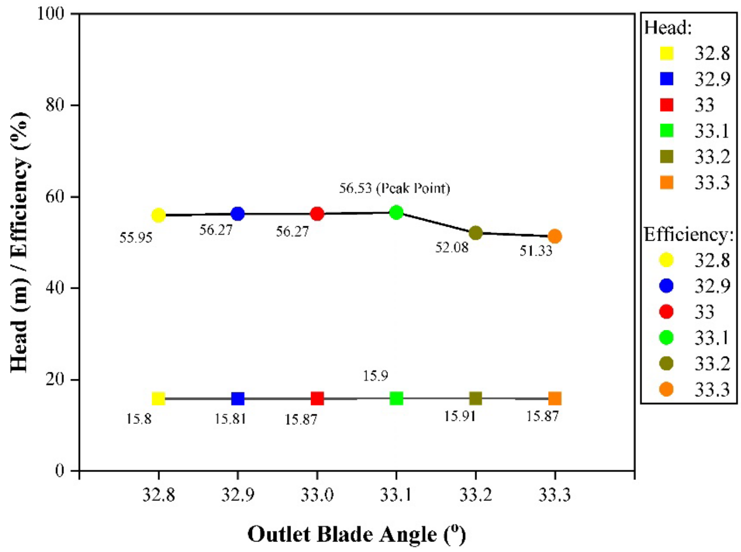


Figure 8: Refined Impeller Performance

As seen in Figure 8, the impeller that has smaller outlet blade angle than β_2 = 33.0 ˚ which is β_2 = 32.8 ˚ and β_2 = 32.9 ˚ show a lower discharge head and lesser efficiency. Meanwhile, when the outlet blade angle refined from β_2 = 33.0 ˚ to β_2 = 33.1 ˚ the discharge head and efficiency show a significant increase. However, at β_2 = 33.2 ˚ and β_2 = 33.3 ˚ show an increase in head but a dropped in efficiency which happened because, the efficiency affected by flowrate, when the outlet blade angle increases the discharge flowrate on the outlet blade angle increase which result to hydraulic loss [6]. This means that the optimum outlet blade for this research was β_2 = 33.1 ˚, which yield 15.90 m discharge head and 56.53 % efficiency. Figure 9 depicts the pump characteristics curve that operates with different rpm to show the improvement from original impeller and optimized impeller.

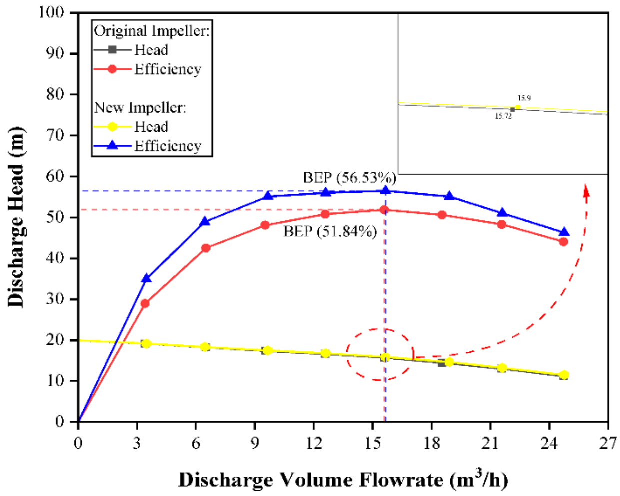


Figure 9: Pump Characteristic Curve (Original vs Optimized Impeller)

Based on the pump characteristic curve, the discharge flowrate shows that the optimized impeller discharges more flowrate than original impeller, which is 15.65 m^3/h, while original impeller discharges 15.59 m^3/h, indicating a 0.38 % increase in discharge flowrate. Furthermore, as seen in the close-up perspective of the discharge head in the top right corner, the value of the discharge head improves from 15.72 m to 15.90 m, indicating that the improved impeller can deliver fluid 1.14 % higher than the original impeller. While the best efficiency point (BEP) results show a significant increase from 51.84 % on the original impeller to 56.53 % on the improved impeller. This represents a 9.80 % improvement over the original impeller. This result is consistent with findings by [7] which demonstrate that the range of outlet blade angles influences centrifugal pump performance in terms of pump head and efficiency.

In conclusion, modifying outlet blade angle show a significant effect on performance. This research show that increasing outlet blade angle show significant influence on the efficiency and has a little influence on discharge head. The discharge head increase after the pressure near the tip of the blade rises when the outlet blade angle increase. However, when the angle was too high, the efficiency dropped significantly since the efficiency depended on flowrate. This happened when the angle increases the flowrate fluctuates as the pressure at tip of the blade rise.

5. Conclusion and Recommendations

The main objective of this research has been accomplished which was to redesign and enhance centrifugal pump performance by modifying outlet blade angle. This show that by modifying the impeller outlet blade angle does show a significant improvement in to pump performance. Increasing impeller outlet blade angle the pressure inside the pump increase and resulting a higher discharge head. However, it is different with efficiency. Initially the efficiency increases as the angle increase, but it starts to drop as it reach its peak point. This happen because lower angle clogged the impeller, while higher angle produces more vacuum. To improve pump performance discharge head itself was not enough, because higher discharge head does not mean higher efficiency. Every aspect needs to be observed carefully. As the conclusion, the impeller with outlet blade angle β_2 = 33.1 ˚ has shown better performance when compared with original impeller even though the angle just tuned decimally but it still produces a significant increase in performance.

As for recommendations, to have more accurate geometry of the pump, reverse engineering method can be applied, because the approach consist of 3D scanning the actual object and generating more precise model of the object. While for impeller optimization, the impeller can be improved by modifying both its outlet blade angle and inlet blade angle. Furthermore, for future research, it can be suggested that combining three impeller modification methods, which are adding splitter blades, modifying outlet blade angle, and modifying the inlet blade angle for improving pump performance. These recommendations should guide future research in achieving better and more accurate results.

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