Experimental and numerical study of impeller modification to improve the performance of centrifugal pump for handling viscous liquids

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Abstract— The impeller is a crucial component of a centrifugal pump, as it converts shaft power into fluid energy. There are three main types of impellers: closed, semi-open, and open, each with distinct characteristics when handling different working fluids. Fluid viscosity can significantly affect pump performance. Closed impellers are particularly effective for pumping water; however, their performance decreases when handling high-viscosity fluids. Modifications to closed impellers can be implemented to address this decline in performance. In contrast, semi-open impellers are better suited for managing high-viscosity fluids than closed impellers. Both experimental and numerical methods were used in this study. Measurements of performance were acquired through the construction of a pump testing facility. Modifications and variations in the shape of the impeller were created using 3D printing techniques with polylactic acid (PLA) as the material. In addition, the experimental results are strengthened by pressure contour analysis in numerical simulations. When pumping molasses at 65 lpm, the highest performance was achieved with a closed impeller, which attained a head of 7,9 m, an efficiency of 17.8%. Conversely, a 6-blade semi-open impeller, achieving a head of 12,2 m, an efficiency of 29%. So, this modification can improve the Head by 54,4 % and the efficiency by 63%.

Keywords: Viscous Fluid; Semi Open Impeller; Number of Blades; 3D Printing

1. INTRODUCTION

A pump is a mechanical device used to move fluid from a low-pressure place to a high-pressure place through a piping installation system. According to Karassik [1]. The use of pumps can be found in various aspects of life, from daily needs to use in outer space exploration, as noted by Ayad et.al.[2]. According to Brian [3], the working principle of the pump is to increase the energy of the fluid being served by transferring mechanical energy to the working fluid so that the fluid can flow from a place with low energy to a place with higher energy. Based on their working principles, they are classified into two groups: positive displacement pumps and dynamic pumps. Positive displacement pumps are a type of pump whose working principle uses changes in the volume of the pump working space caused by the movement of the pump components back and forth or rotating. Dynamic pumps are a type of pump whose working principle utilizes changes in mechanical energy into kinetic energy (dynamic head) and subsequently into the static head, leading to the movement of a fluid, as noted by Khetagurov [4].

Girdhar [5] reported that in the industrial sector, the type of pump that is widely used is a centrifugal pump because the design is not complicated, the operational and maintenance processes are easier, high work efficiency, and the ability to adjust the capacity according to needs leads to high operational reliability. Usually, pumps are designed for water fluids, but if used to serve fluids with higher viscosity, the pump performance will decrease due to the greater friction losses against the walls of the channel through which it passes, as noted by Murakami et al. [6]; Telow [7]; Ippen [8]; Itaya and Nishikawa [9]. Thus far, the prediction of the performance curve of a centrifugal pump when handling viscous fluids is usually calculated using the viscosity correction diagram from the Hydraulic Institute Standards, ANSIHI [10]. In recent years, several experimental and numerical investigations on the effect of viscosity on the performance of centrifugal pumps have been carried out. Li [11], [12], [13] conducted experimental and numerical studies on the impact of viscosity on the performance of centrifugal pumps. Furthermore, Li [14] investigated the effects of flow rate and viscosity on the slip factor and identified the optimal number of blades for pumping fluids with different viscosities and showed some effects of viscosity on the fluid regime within the impeller and volute.

Research by Hui Zhang et al. [15] demonstrated that the method used to define the curvature of the impeller blade influences centrifugal pump performance. Lazarkiewicz [16] addressed several methods for defining impeller blade curvature, including the Single Arc, Double Arc, Circular Arc Method, and Point-by-Point Method. A study by Marimuthu et al. [17] comparing the Point-by-Point and Circular Arc methods found that the Circular Arc method yielded a slightly higher efficiency (58.53%) compared to the Point-by-Point method (57.31%). Impellers can also be into three types: open, semi-open, and closed types. The selection of impeller type depends on the type of the pumped fluid. The closed impeller is a type of impeller that is suitable with low-viscosity fluids, and not mixed with solids and semi-open impellers are more suitable for serving non-Newtonian fluids was discussed by Kulikov [18]; Aldi [19]. Prichard [20] and Irgens [21] addressed non-Newtonian fluid is a type of fluid where the shear stress is not proportional/directly proportional to the deformation rate when subjected to shear stress, such as paint, mayonnaise, and molasses.

Based on economic and manufacturing aspects, semi-open impellers are easier to manufacture, making them more cost-effective than other types of impellers. Some of the main advantages of semi-open impeller centrifugal pumps is that it is less likely to be clogged by solids, and easy to clean even if it is clogged. In addition, all parts are visible, so it is easy to check for wear or damage and the initial cost is lower than a closed impeller. Semi-open impellers also allow for easy trimming or filing to adjust capacity and offer a wider range of specific speed options. They are also better suited for handling fluids with a higher percentage of gas and solid particles compared to closed impellers. Disadvantages of semi-open impellers are their lower efficiency compared to closed impellers, a limited operating temperature range, and unsuitability for volatile and explosive fluids, as reported by Farid Ayad et al. [22].

In a numerical study about the variation of the wrap angle on the centrifugal pump impeller with a variation in the blade curvature between 100°-170° conducted by Hilmi Aksoy [23], it was found that the wrap angle of 110°-126° had an efficiency of 90.6% -91.8%, hydraulic power of 11.60 kW - 11.26 kW and Head of 53.6 m - 52.7 m. Similarly, Hayder K Sakran [24] conducted a numerical study about the wrap angle from 95° to 145° is conducted on a closed impeller pumping water. It was found that the wrap angle of 145° had a maximum efficiency of 80%, while the lowest efficiency was obtained at a wrap angle of 115° of 76.80%. Furthermore, a research study investigating the effects of number of blades and the curvature of the impeller blades on the performance of centrifugal pumps was conducted by Susilo [25], showing that increasing the number of blades can lead to a decrease in flow rate. The highest flow rate was found in a 2-blade impeller with a wrap angle of 130°, which was 404.91 lps. The lowest flow rate was found in a 6-blade impeller with a wrap angle of 160°, which was 279.66 lps. Research by Hossein Yousefi [26] reported that the geometric parameters of the impeller significantly influenced centrifugal pump performance. Specifically, an inlet angle of 35° resulted in the highest flow rate efficiency of nearly 60% when pumping oil, while an outlet angle of 40° yielded a flow rate efficiency of 61%. Shojaee Fard and Ehghaghi [27] experimentally investigated the performance of centrifugal pumps with varying impeller geometries when handling viscous oil and also simulated the fluid flow using CFD code. Furthermore, Pavlovic [28] conducted research on impeller materials for 3D printing, concluding that Polylactic Acid (PLA) is a suitable material for centrifugal pump impellers manufactured using this technique. Numerous parameters can be optimized to enhance the performance of centrifugal pumps, such as the number of blades. Gugau [29] simulated the flow within a centrifugal pump using a sliding mesh technique to analyze the primary phenomena. Numerical research by Chakraborty [30] investigated the impact of varying the number of blades (4 to 12) and rotational speeds (2900, 3300, and 3700 rpm) through CFD analysis. This study reported that a 10-blade impeller yielded the highest efficiency and concluded that increasing rotational speed led to increased head and efficiency. Jafarzadeh [31] explored the effect of varying the number of impeller blades (5, 6, and 7) using the standard k-ε, RNG, and RSM turbulence models. The numerical analysis indicated that the 7-blade impeller produced the highest head coefficient

According to the previous description, limited experimental and numerical research has been conducted on the impact of converting a closed impeller centrifugal pump into a semi-open impeller, particularly regarding its application with fluids of higher viscosity. Therefore, this research was conducted experimentally and focused on the effect of modifying a closed impeller into a semi-open impeller by varying the number of blades to improve pump performance in serving viscous fluids. Numerical simulations were conducted to investigate the detailed phenomena of the flow structure inside the impeller. The impeller was designed using the logarithmic method and was fabricated using 3D printing technology.

2. MATERIAL AND METHOD

2.1.1 Centrifugal Pump equation

Head Effective

$$Heff = \left(\frac{P_d}{\gamma} - \frac{P_s}{\gamma}\right) + hg + \left(\frac{V_d^2 - V_s^2}{2g}\right) \quad (1)$$

Capacity

$$Q_S = n_v \, . Q_t \quad (2)$$

Input Power

$$BHP = \mathrm{V} \times \mathrm{I} \times \cos\varphi \times \eta_{ml} \quad (3)$$

Output Power

$$WHP = \gamma \times Q \times Heff \quad (4)$$

Efficiency

$$\eta_{op} = \frac{WHP}{BHP} \quad (5)$$

2.1.2 Drawing Impeller Curvature

Drawing of the impeller blade curvature using the Spiral logarithmic method. This method is first performed by determining the inlet and outlet diameters and the inlet and outlet angles of the impeller. Then, a point-by-point calculation was carried out to determine the radius length of each impeller center point [32].

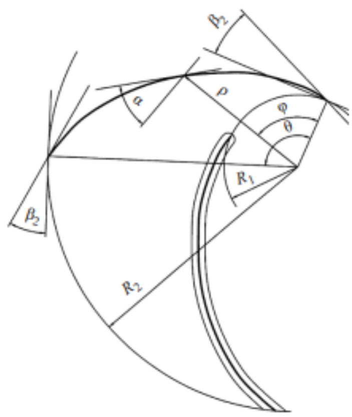


Figure 1 Logarithmic Spiral Method

The length of each radius can be obtained through the following formula [32]:

$$\rho = R_1[1 + \varphi \tan\beta_1 + \frac{\varphi^{n+1}}{\theta^n} \frac{\tan\beta_1 - (1 + \theta\tan\beta_1)\tan\beta_2}{\theta\tan\beta_2 - n - 1}] \quad (7)$$

Where:

$$n = \varphi \tan\beta_2 - 1 - \theta \frac{\tan\beta_1 - (1 + \theta \tan\beta_1)\tan\beta_2}{R_2/R_1 - (1 + \theta \tan\beta_1)} \quad (8)$$

Number of Impeller Blades

$$z = 6{,}5 \times \frac{D_2 + D_1}{D_2 - D_1} \times \sin\frac{(\beta_1 + \beta_2)}{2} \quad [4] \quad (9)$$

2.2 Methods

This research was conducted both experimentally and using numerical analysis. The experimental approach involved the use of a pump testing facility to assess the performance of pumps equipped with both closed and semi-open impellers with variations in the number of blades. The working fluid was water and molasses with a viscosity of 54 centipoise. Figure 2, shows a centrifugal pump test installation and Table 1 shows the names of the components.

2.2.1 Pump Performance Test Installation

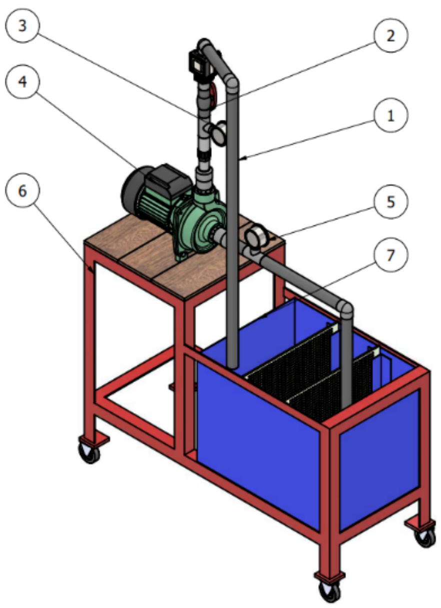


Figure 2. Pump Performance Testing Installation

Tabel 1. Main Component

NO	Component Name
1	Pipe 1,5 inch
2	*Globe valve*
3	Gauge Manometer
4	Pump
5	Vacuum Manometer
6	Installation Frame
7	Reservoir

Tabel 2 Pump Specifications

Pump type	centrifugal
Input power	750 Watt
Output power	400 Watt
Electric motor efficiency	0,533
Voltage	220 Volt
Suction Head	8 Meter
Discharge Head	13.5 Meter
Max capacity	100 lpm
Pipe size ∅	1,5 x 1,5 inchi

2.2.2 Working Fluid

The working fluids were water and molasses (54 cp). The use of molasses fluid to determine pump performance in serving fluids with high viscosity and density. This is because many problems arise when handling molasses in the sugar industry.

2.2.3 Technical Drawing of Impeller

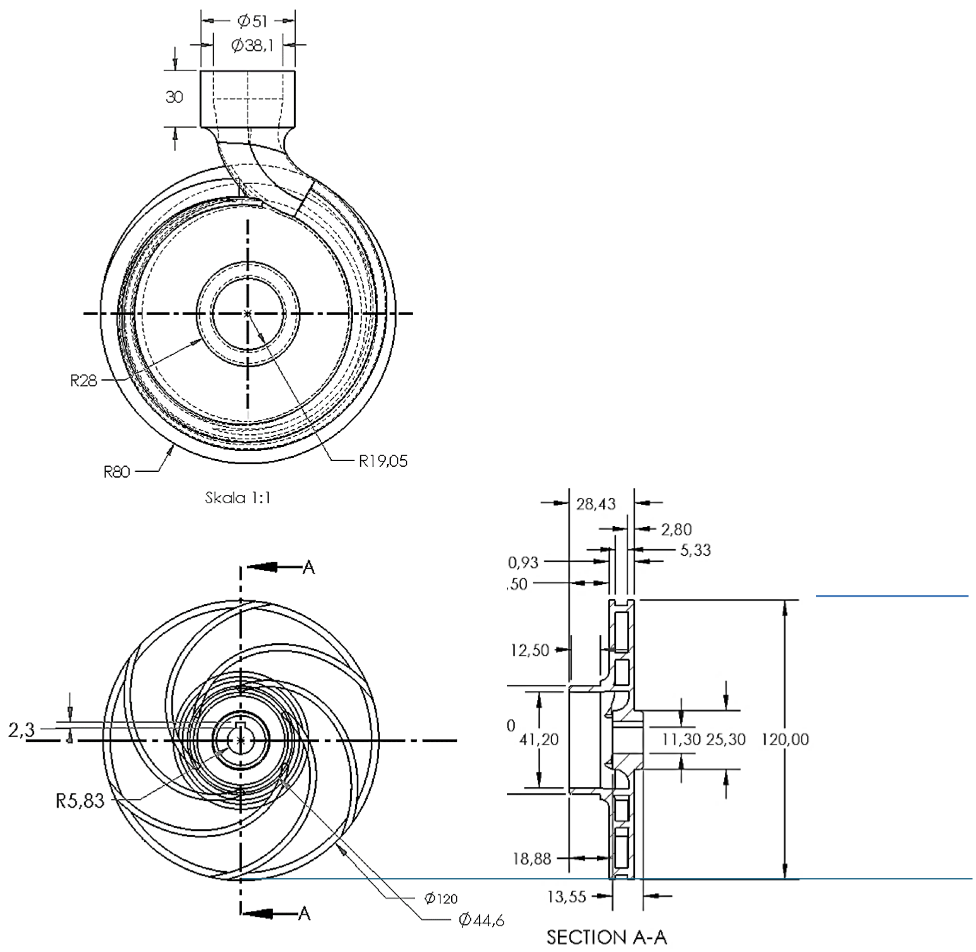


Figure 3. Technical drawing of Impeller

Tabel 3 Pump impeller dimensions closed & semi-open impeller

Outlet Diameter (D_2)	120 mm
Inlet Diameter (D_1)	41,3 mm
Blade width ($b_1 = b_2$)	5,3 mm
Warp angle	130^O
impeller inlet angle (β_1)	15^O
impeller outlet angle (β_2)	20^O
Blade thickness (*t*)	2,5 mm
Blades number (z) closed	6
Blades number (z) semi-open	8, 6, 5 & 4

2.2.4 Impeller Manufacturing

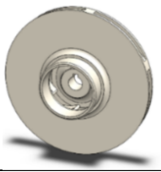
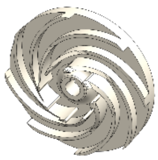
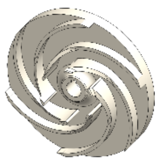
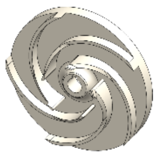
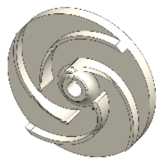
3D printing technology is an additive manufacturing technology that can work on all models that have been designed in previous software. Slicing in 3D Printing is the process of dividing a 3D model into thin layers that are arranged sequentially. FDM is one type of 3D-printing method that is widely used [33]. In the manufacturing of these impellers, Ultimaker Cura software is used to set the parameters. After using Ultimaker Cura software, the file that was originally in. stl format will become .gcode and is ready to be manufactured. The pictures and specifications of the 3D printer machine are given in **Table 4** below.

Figure 4. 3D Printer Machine Ender 3

Tabel 4 Specifications of the 3D printer machine Ender 3

Machine Type	FDM
Machine Bed Size	220 x 220 x 250 mm
File Format	STL, OBJ, G-code
Filament	1,75 mm PLA

Tabel 5 Impeller Modification

Closed impeller	Semi-open 8 blades	Semi-open 6 blades	Semi-open 5 blades	Semi-open 4 blades
				

2.2.5 CFD Simulation

The geometry entered Ansys software is the impeller assembly, volute chamber, shaft, and casing cover, which were created in the SolidWorks application.

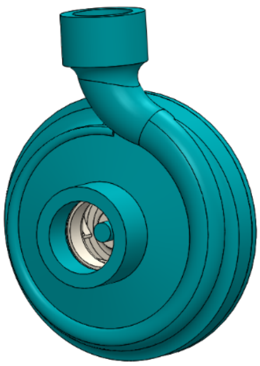


Figure 5. Assembly Geometry Solid Centrifugal Pump

Based on **Figure 5**, an assembly geometry will be used to create the fluid geometry that fills the volute and impeller. When performing a simulation, it is used as a fluid shape and does not include solid geometry. The following is the fluid geometry that fills the volute and impeller.

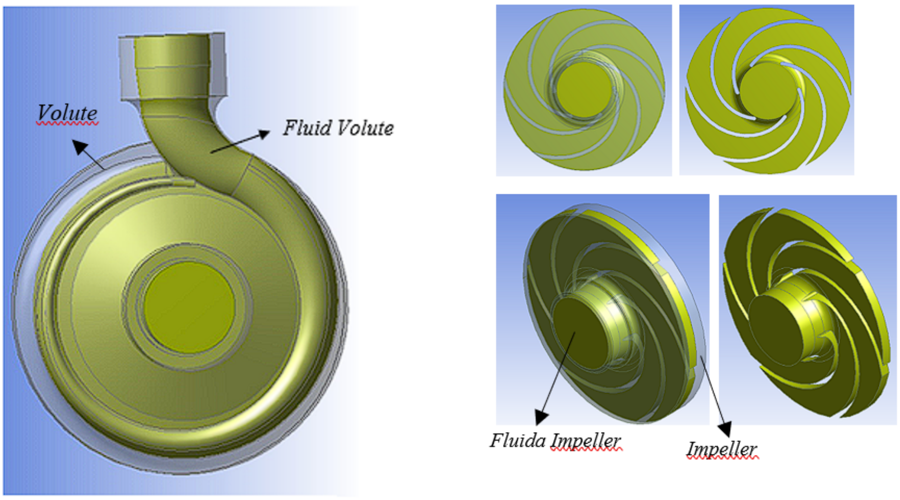


Figure 6. Creating a Fluid Geometry Simulation Filling a Volute and Impeller

a. Computational Domain

Based on **Figure 5**, there is a fluid geometry that fills the volute and impeller. The simulation that will be carried out later uses a boundary condition set up in the outlet area in the form of an outflow. The division of the computational domain is divided into two, namely the stationary and rotary areas. The stationary domain is in the form of volute fluid and fluid in the inlet area. While for the rotary domain, it is the impeller fluid.

b. Meshing

Meshing uses fluent with meshing and directly on the entire body, namely volute fluid and impeller fluid.

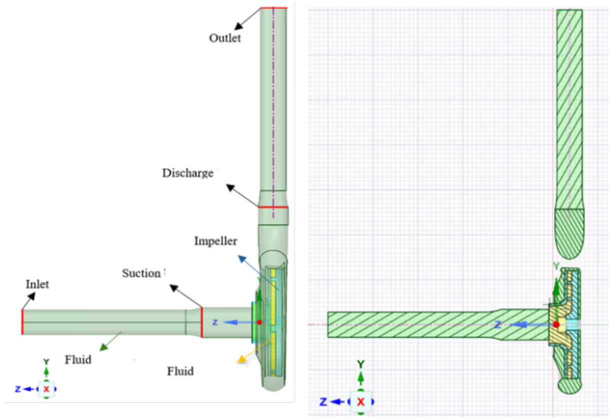


Figure 7. Simulation Computing

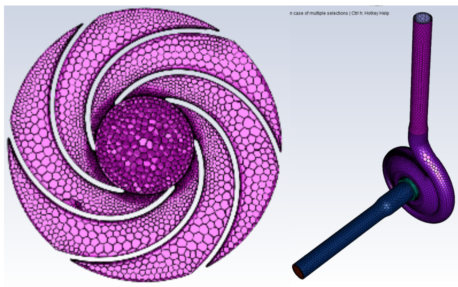


Figure 8. Meshing Fluid on Impeller

c. Set up Simulation

The setup is used to ensure that each simulation uses the same setup and is expected to have results close to the experimental result. Internal flow simulation of the centrifugal pump using Reynolds Averaged Naiver–Stokes (RANS) method. The inlet condition is selected as mass flow, and the outlet condition is outflow. The flow near the wall (stationary or rotary wall) is considered a no-slip condition. The turbulent model uses a realizable K-Epsilon and SIMPLE scheme to solve the combined velocity equation. The second-order upwind scheme is used to solve momentum, turbulent kinetic energy, and turbulent dissipation rate. All residuals converge < 10^{-4}.

3. Results and Discussion

This study analyzed the performance characteristics of centrifugal pumps used to pump water and molasses, focusing on closed and semi-open impellers with varying numbers of blades. The performance graph of the head and efficiency as a capacity function was obtained through experimental measurements of the suction pressure, discharge pressure, voltage, and ampere at various capacities. The experimental result was strengthened by an analysis of the pressure contour in the impeller from the numerical results.

3.1 Grid Independency Test

Figure 9 plots the grid independence of the meshing results in the numerical simulation. The number of meshes with 160,000 cells was then used to perform meshing on other impeller variations.

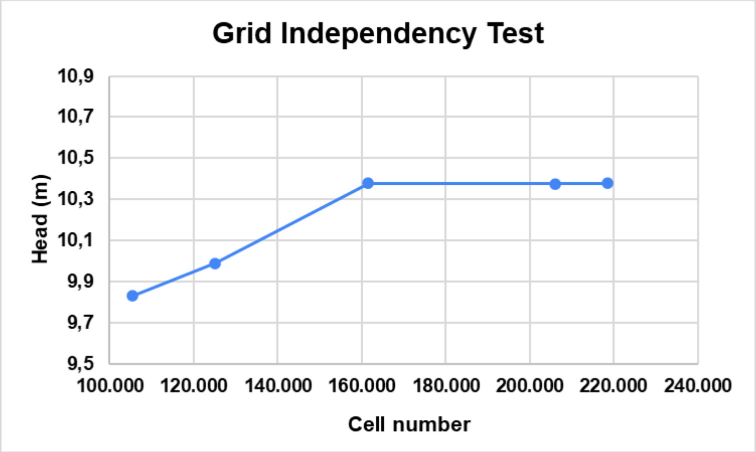


Figure 9. Graph of The Grid Independency Test

3.2 Numerical and experimental validation on Head & Efficiency

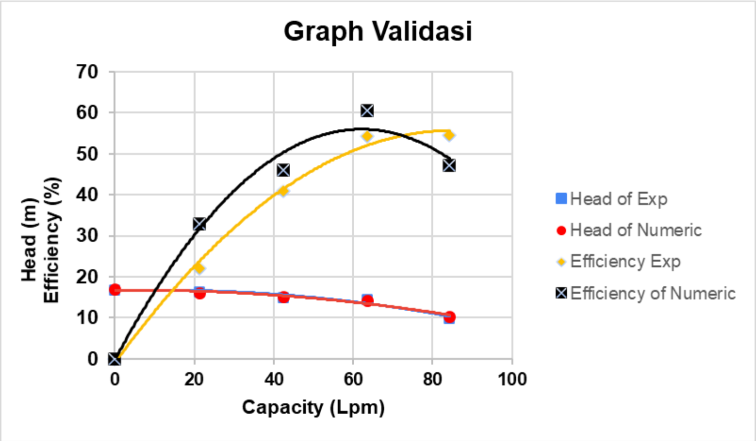


Figure 10. Experimental and numerical Head and Efficiency validation graph

Figure 10, shows a graph of the head and efficiency of a closed impeller centrifugal pump with water fluid, experimental and numerical results. The numerical simulation results were in good agreement with the experimental results. The relative error rate of Head is less than 2.01%, while the efficiency percentage error is less than 4.7%. Thus, the proposed algorithm is reasonable.

3.3 Comparison of the head for each type of impeller when serving water
Experimental result

Figure 11 shows that the closed impeller outperforms the semi-open impeller, even when the number of blades varies. The closed impeller achieves a head of 10,75 m and a capacity of 104,6 lpm under fully open conditions. In comparison, the semi-open impeller with 6-blades reaches a head of 9,5 m and maximum capacity of 94,7 lpm. The enhanced performance of the closed impeller can be attributed to its front and rear shrouds, which effectively guide the fluid to follow the curvature of the blades toward the impeller outlet. As a result, the closed impeller experiences less circulation and reduced flow bypassing the blades, leading to smaller losses from internal leakage. Although the closed impeller has a larger friction area, the frictional losses are not substantial when handling low-viscosity fluids like water. Similarly, the absence of fluid bypass to other blades results in lower internal leakage. Consequently, as shown in the performance curves, the closed impeller achieves a greater capacity than all the tested semi-open impellers.

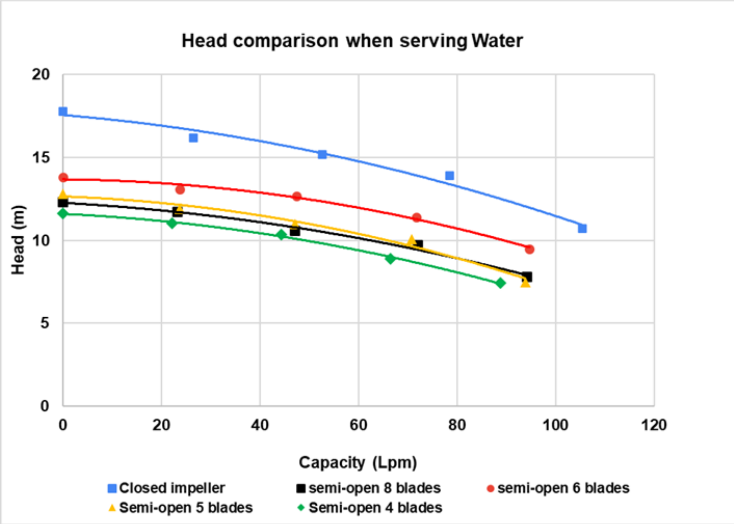


Figure 11. Graph of the head generated when serving water

The enhanced performance of the closed impeller can be attributed to its front and rear shrouds, which effectively guide the fluid to follow the curvature of the blades toward the impeller outlet. As a result, the closed impeller experiences less circulation and reduced flow bypassing the blades, leading to smaller losses from internal leakage. Although the closed impeller has a larger friction area, the frictional losses are not substantial when handling low-viscosity fluids like water. Similarly, the absence of fluid bypass to other blades results in lower internal leakage. Consequently, as shown in the performance curves, the closed impeller achieves a greater capacity than all the tested semi-open impellers.

For all tested semi-open impellers with varying numbers of blades, the generated head was consistently lower than that of the closed impeller. This reduced performance is attributed to the absence of a front shroud in semi-open impellers, which allows for significant flow circulation, bypass over the blades, and return flow towards the suction area. These phenomena lead to a substantial decrease in the generated Head. Despite the smaller friction area in semi-open impellers, the low viscosity of water means that frictional losses have a less significant impact on the reduction in Head compared to the losses caused by circulation and bypass. As shown in **Figure 11**, the 6-blades semi-open impeller produces a better Head compared to the 8, 5, and 4-blades version. This is because impellers with a small number of blades (4 & 5) results in greater circulation or stronger vortex intensity between the blades. This condition could deflect the angle β_2 and leading to the reduction of the pump Head value. While the 8-blade impeller directs the flow more effectively along the blade curvature, its larger friction area compared to the 6-blade impeller results in increased frictional losses.

Numerical Analysis of static pressure when serving water

Static pressure	Closed impeller	Semi-open Blades 8	Semi-open Blades 6	Semi-open Blades 5	Semi-open Blades 4

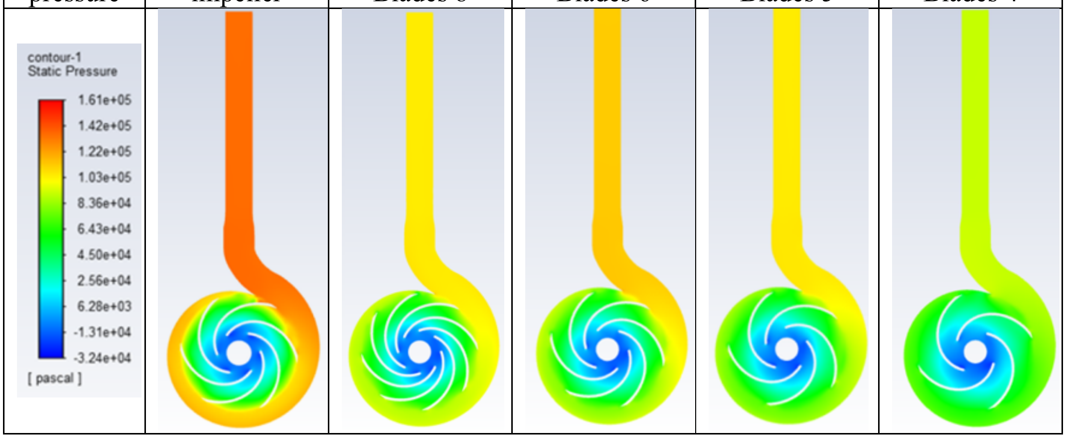


Figure 12. Pressure contour of each blade when serving water (63,4 Lpm)

Numerical simulation is used to further support the analysis of the flow structure inside the impeller that cannot be seen during the experiment. **Figure 12** shows the static pressure contour at midspan at the best efficiency point (BEP). The results of numerical simulations for various types of blades, the BEP value when serving water occurs at a capacity of 65 lpm. It appears that under all suction areas, the impeller is blue. Furthermore, due to the rotation of the impeller, the fluid acquires kinetic energy and is then converted into pressure when it exits the impeller. This transformation is evident from the colour gradient transitioning from blue to green and yellow. The figure shows that the static pressure at the closed impeller discharge has a higher value than other types. This is shown in orange with a value of around 1.6×10^5 Pascal.

In a semi-open impeller with an increasing number of blades, the static pressure at the pump discharge increases. Under this condition, the colour changes from yellow to orange. It appears that semi-open with 6-blades has a higher value than the other semi-open ($\pm 1.6 \times 10^5$ Pascal). When viewed at the same impeller radius with an increasing number of blades, the static pressure increased. This can be seen starting from 4-blade to 6-blade. However, for the addition of the 8-blade, the impeller outlet pressure was lower than that of the 6-blade. Thus, at pump discharge, the number of semi-open 6-blade exhibits a better increase in static pressure than the other semi-open blades.

3.4 Comparison Head for each type of impeller when serving molasses 54 cp.

When centrifugal pumps serve fluids with high density and viscosity, the friction loss between the fluid and the channel wall will increase, and these conditions will reduce the Head generated. **Figure 13** shows that the closed impeller exhibits the lowest performance compared to the semi-open impeller, with variations in the number of blades. Because a closed impeller has front and rear shrouds, the friction area is larger, and with high-viscosity fluids, the losses due to friction are significant.

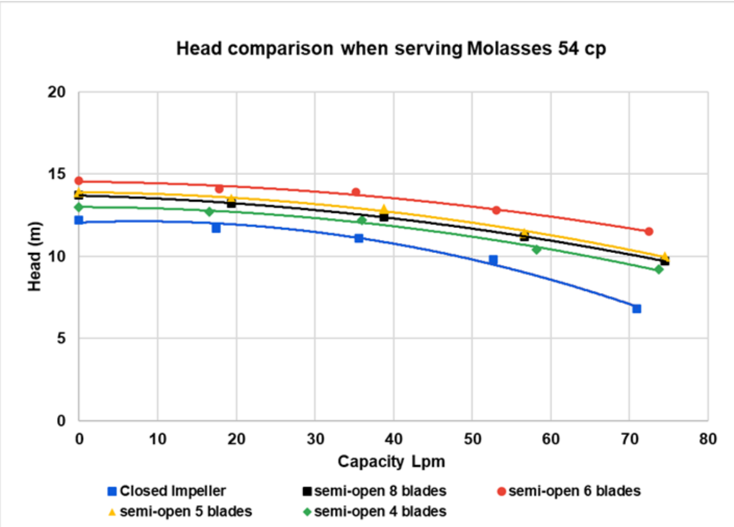


Figure 13. Graph of the head generated when serving molasses 54 cp

For the tested semi-open impeller variations, the generated Head is consistently higher compared to the closed impeller. This is improvement is due to the semi-open impeller does not have a front shroud, which minimizes the friction and thus leading to improved Head. As shown in **Figure 13**, the 6-blade semi-open impeller achieves 11.5 m Head while the closed impeller only reached 6.8 m Head. The addition of the number of blades on the semi-open impeller shows an increase in Head up to a certain point. If the number of blades is further increased, the Head value might decrease instead. As shown **in Figure 13**, increasing the blade number from 4 to 6 increases the Head. However, the Head is decreased instead when the blade number is further increased to 8-blade.

In general, with the increase of blade number, the space between the blades becomes narrower, such that the fluid can be effectively guided along the blade curvature. While an increasing number of blades could lead to higher frictional losses due to wider friction area, the vortex intensity and circulation losses that deflect the □$_2$ angle will also decrease, such that the circulation loss or slip factor is reduced.

Numerical Analysis of static pressure when serving Molasses 57 cp

In **Figure 14**. On the suction side of the impeller, almost all impellers show the same pressure conditions (blue colour). However, the closer to the outlet radius, the colour degradation of each type of impeller is different. In the closed impeller, low pressure (blue) appears to fill almost the entire radius of the impeller, so that the increase in static pressure inside the impeller is very small. This indicates that due to the wider friction area on the closed impeller, the friction loss between the viscous fluid is greater. This is shown in orange with a value of around 1.42×10^5 Pascal.

Static pressure	Closed impeller	Semi-open Blades 8	Semi-open Blades 6	Semi-open Blades 5	Semi-open Blades 4

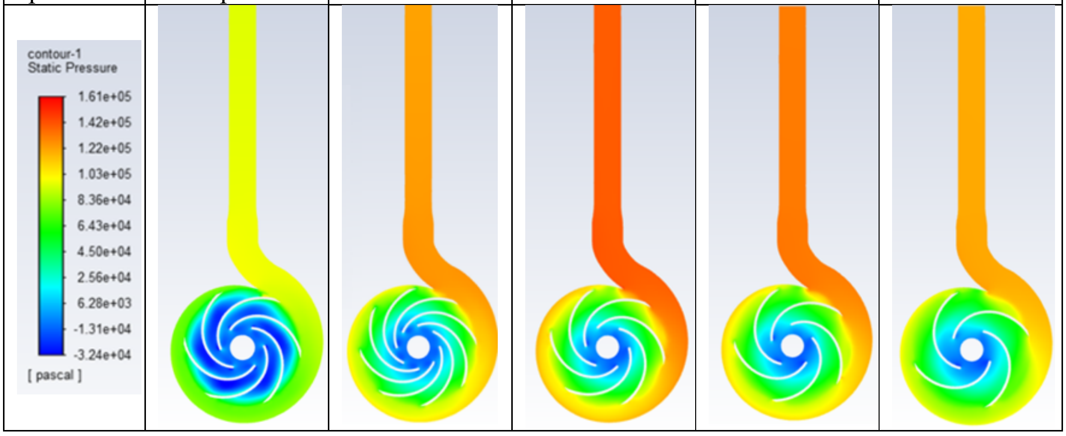


Figure 14. Pressure contour of each blade when serving Molasses 57 cp

While in the semi-open impeller, there is a drastic change from blue to green to yellow on the outlet radius of the impeller. Especially in the semi-open with 6-blades, the outlet radius and volute are dominated by orange. This condition is in line with the experimental results, where the pressure generated is higher than other types of impellers. This condition indicates that friction losses and recirculation losses in the 6-blade impeller produce a suitable pressure increase for molasses 57 cp compared to other types of impellers.

Comparison of Pump Efficiency when Serving Water

Comparison of the efficiency of closed impeller and semi-open impeller centrifugal pumps at various numbers of blades in serving water fluids has been shown in **Figure 15**.

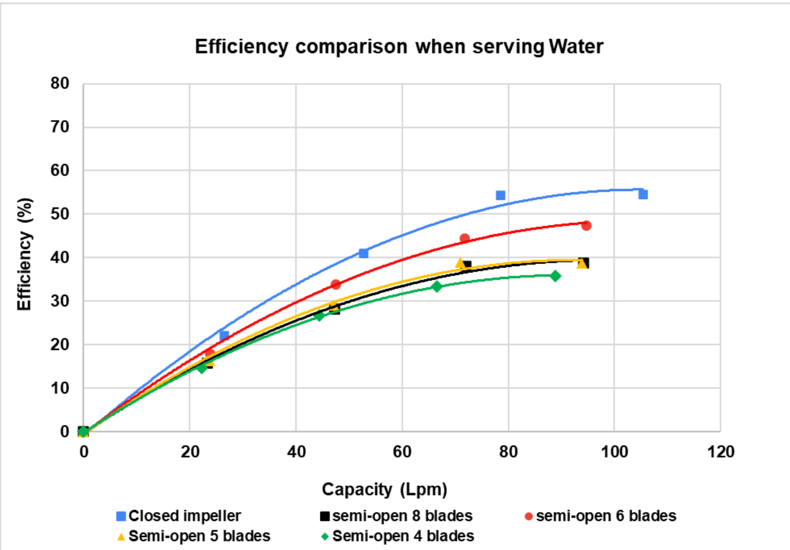


Figure 15. Efficiency comparison when serving water

Figure 15 shows that the closed impeller performs with higher efficiency compared to other type of impellers, which has 53 % at a capacity of 80 lpm. This indicates that the power input is utilized optimally to increase the fluid energy. The increase in fluid energy in the form of increased pressure comes from the conversion of kinetic energy from the impeller rotation. Considering the viscosity of the fluid is relatively low, flow losses due to friction against the wall are also small.

The increase in fluid energy in the form of increased pressure comes from the conversion of kinetic energy from the impeller rotation. Considering the viscosity of water is relatively low, flow losses due to friction against the wall are also small. On the other hand, with the presence of front and rear shrouds on the impeller, the fluid is directed to follow the curvature of the blade to exit the impeller, thus reducing circulation losses and fluid jumping to the opposite blade. In the semi-open impeller, it can be seen that increasing the number of blades can increase efficiency. This can be seen in impellers with 4 to 6-blade at all capacities, experiencing an increase. However, if the number of blades is added again, it will expand the friction area and cause losses to increase even more. This causes the efficiency of the 8-blade semi-open impeller to be lower than the 6-blade one.

Comparison of Pump Efficiency when Serving Molasses 54 CP

Comparison of the efficiency of closed impeller and semi-open impeller centrifugal pumps at various numbers of blades in serving Molasses 57 cp has been shown in **Figure 16**.

Figure 16. Efficiency comparison when serving Molasses 57 cp

Figure 16 shows that the semi-open impeller 6-blade used to serve 57 cp molasses works more efficiently than other types of impellers, where the maximum efficiency is 31 % at a capacity of 70 lpm. This indicates that although the fluid being served has a high viscosity, the modification to a semi-open impeller can reduce the friction losses caused. Thus, the semi-open impeller has better efficiency than the closed impeller. In the semi-open impeller, it is shown that increasing the number of blades can improve efficiency. This condition is seen in the addition of 4-blade to 6-blade experiencing an increase in efficiency at all capacities. However, if the number of blades is increased from 6-blade to 8-blade, the reduction in circulation losses cannot compensate for losses due to increased fluid friction. This causes the efficiency of the 8-blade semi-open impeller to be lower than that of the 6-blade impeller.

3.5 Comparasion Water & Molasses Performance

Head comparison

Figure 17 shows a comparison of the Head at 65 lpm for various types of impellers. If the closed impeller with 6 blades serves water, it produces a Head of 14.2 m, but if it is used to serve molasses fluid, it produces a Head of 7,9 m. So, the pump performance experiences a decrease in head of 44,36 %. If a closed impeller pump is modified into a semi-open impeller with 6 blades, it produces a head of 12.2 m. So that the modification of closed to semi-open with 6 blades produces a head increase of 35,24 %.

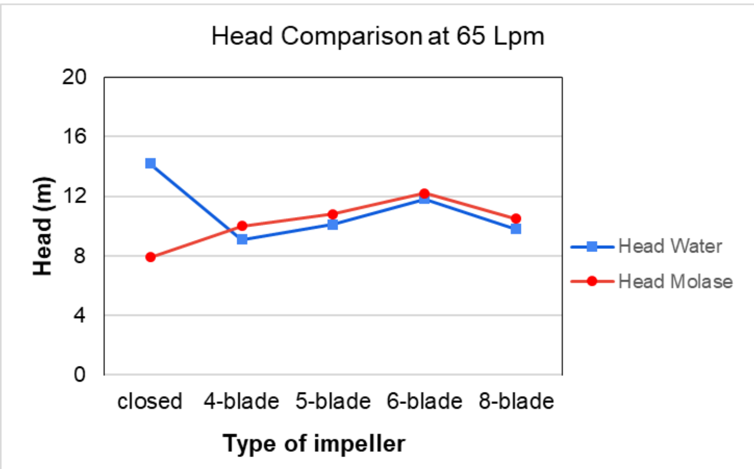


Figure 17. Head comparison when serving Water & Molasses 57 cp

Efficiency Comparison

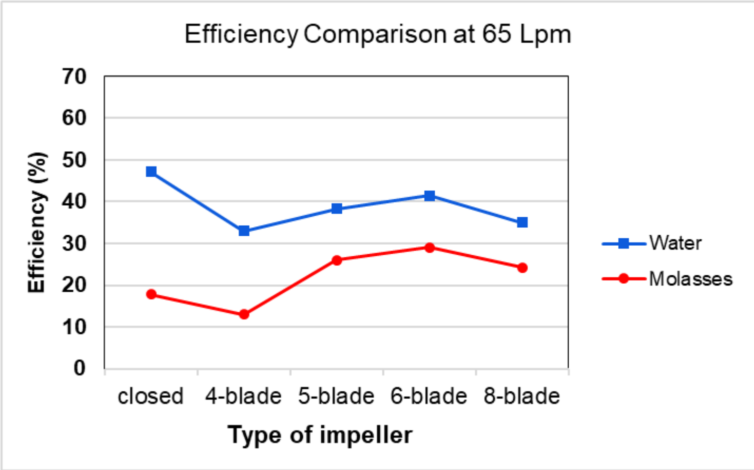


Figure 18. Efficiency comparison when serving Water & Molasses 57 cp

Figure 18 shows a comparison of efficiency at 65 lpm for various types of impellers. If the closed impeller with 6 blades serves water, it produces an efficiency of 47,2%, but if it is used to serve molasses fluid, it produces an efficiency of 17,8%. So that the pump performance experiences a decrease in head of 62.3%. If the closed impeller pump with 6 blades is modified into a semi-open impeller with 6 blades, it produces an efficiency of 29%. So that the modification of closed to semi-open with 6 blades produces an increase in efficiency of 38,6%.

4. Conclusion

1. When the centrifugal pump serves water, the performance of the closed impeller is better than the semi-open impeller with variations in the number of blades, where the closed impeller can produce Head and efficiency of 14.2 m and 47.2% respectively at a capacity of 65 lpm. This is because water has a low viscosity so that even though the friction area is larger, the friction loss that occurs is less significant. In addition, the closed impeller can guide the fluid to follow of the blade curvature without any flow bypasses back to the suction area.
2. Since the molasses has a high viscosity, the impeller is modified into the semi-open type to overcome the high friction loss. While reducing the friction area can decrease the frictional losses. As seen in 4-blade and 5-blade semi-open impellers, the circulation loss, which can deflect the β_2 angle, concurrently increases. However, increasing the number of blades beyond the optimal point could lead to a higher friction loss, which is why 6-blade is better than 8-blade impeller.
3. The centrifugal pump is used to serve 57 cp molasses, the semi-open impeller with 6-blades has a better performance compared to other impellers. Where semi-open impeller with 6-blade can produce a Head of 12,2 m with efficiency of 29 % at a capacity of 65 lpm. Meanwhile, the closed impeller only produces a Head and efficiency of 7,9 m and 17,8 % respectively. So, this modification can improve the Head by 54,4 % and the efficiency by 63%.

Author Contribution

Heru Mirmanto: Carried out the formal analysis, investigation, conceptualization, Writing, review & editing, project administration, and Funding acquisition.
Triyanto: experimental data collection, drafted the manuscript.
Joko Sarsetiyanto & Arino: Methodology, Supervision.
Dedy Zulhidayat: Software, Numerical Simulation, and Data Curation.

Finding Statement

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Competing Interests

The authors declare that they have no competing interests.

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Nomenclature

- P = Pressure (N/m^2)
- ρ = Density (kg/m^3)
- V = Flow velocity (m/s)
- g = Percepatan Gravitasi (m/s^2)
- h = Elevation (m)
- z = number of blades
- ρ = blade radius
- D_1 = inlet diameter impeller
- D_2 = outlet diameter impeller
- β_1 = inlet blade angle
- β_2 = outlet blade angle
- θ = Wrap angle
- φ = wrap angle of each point