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*Original Article*

# Analysis of the Performance and Electricity Consumption of Centrifugal Pumps using Trimming Impellers

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***Abstract*** *- Centrifugal pumps are essential in various industries in various parts of the world. Pump performance and electricity consumption are highly considered in the selection and use of centrifugal pumps, especially to meet industrial needs that do not comply with pump specifications. Impeller trimming is a method of reducing the size of the impeller diameter from its original size to maximize pump performance and efficiency. In this study, the pump performance was analyzed using an original impeller with a diameter of 130 mm and a trimming impeller with a diameter of 108 mm. The results of this study indicate that the use of impeller trimming with a diameter of 108 mm works according to the target operation, namely to produce a capacity of 2.5 m3/H at a head of 10 m so that it can increase pump efficiency by 29% and reduce electricity consumption by 33.387%.*

***Keywords*** *- Centrifugal pump, Impeller trimming, Pump performance and electricity consumption.*

## 1. Introduction

Centrifugal pump is a fluid machine widely used to meet industrial needs and daily household needs[1]–[3]. The more use of pumps, and the more efficient the pump is, the more it is considered to reduce the use of electrical energy globally[4]–[8]. The consumption of electric motors is as much as 46% of the electricity generated in the world, and these electric motors contribute 70% of the total electricity consumption in the industry.[9], [10]. Pump use efficiency in the sector averages less than 40%, with 10% of pumps operating below 10% efficiency. The maximum efficiency produced by large centrifugal pumps is around 93%, while the maximum efficiency produced by small centrifugal pumps is about 70% [12,28]. Efforts to save electrical energy in the pumping system between 30% and 50% can be realized through changes in pumping equipment or control systems[13].

One method to increase the performance efficiency of the pump is "impeller trimming," which changes the performance of a centrifugal pump at a constant speed. Impeller trimming will reduce operating and maintenance costs, lowering wasted fluid energy and eliminating noise, vibration, and wear on pumping system pipes, valves, and pipe supports[14]–[16]. Impeller trimming is done to overcome when the pump is operated in an off-design condition because it will affect the pump performance curve[17]–[19].

Using impeller trimming can reduce energy use and operational costs in pump operation. The impeller trimming process is limited to a maximum of 25% of the maximum diameter of the impeller because it can result in a decrease in centrifugal pump efficiency, which is caused by a clearance between the impeller and the pump casing which makes excess flow circulation[2], [20], [28]. Impeller trimming and fluid viscosity affect the affinity law of the pump. The affinity law states that the output of the pumping system is directly proportional to the speed of the pump[22], [29]. The ratio of the diameter of the impeller diameter after cutting (D2) to the impeller diameter before cutting (D1), that is (D2/D1), depends on the required head ratio (H2/H1), or the required capacity ratio (Q2/Q1). In this case, subscript 1 shows the impeller diameter, head, and pump capacity before impeller cutting, while subscript 2 shows the impeller diameter, head, and pump capacity after impeller cutting.[14].

From various works of literature that have been studied, both experimentally and numerically, impeller trimming of pumps significantly affects the performance of centrifugal pumps, including head, capacity, electric power consumption, and overall pump efficiency. This study aimed to determine the effect of using the original impeller and the trimming modified impeller on centrifugal pumps. The pump performance to be evaluated is the head capacity curve, pump efficiency, and the best efficiency point(BEPs).

## 2. Centrifugal Pump Performance

### *2.1. Law of Affinity for Impeller Trimming Pumps Centrifugal*

The law of affinity states that a pump impeller can be used if it satisfies the conditions of geometric shape and similarity. The affinity law predicts pump performance for speed and pressure when the trimming method modifies the impeller diameter by adjusting the impeller design [15], [18], [23]. The affinity law is applied in two ways: maintaining the impeller rotational speed and diameter. Calculation of the required diameter and head with equations 1, 2, & 3:

$$\frac{Q_2}{Q_1} = \frac{D_2}{D_1} \tag{1}$$

$$\frac{H_2}{H_1} = \left(\frac{D_2}{D_1}\right)^2 \tag{2}$$

$$\frac{bhp_2}{bhp_1} = \frac{H_2 Q_2}{H_1 Q_1} = \left(\frac{D_2}{D_1}\right)^3 \tag{3}$$

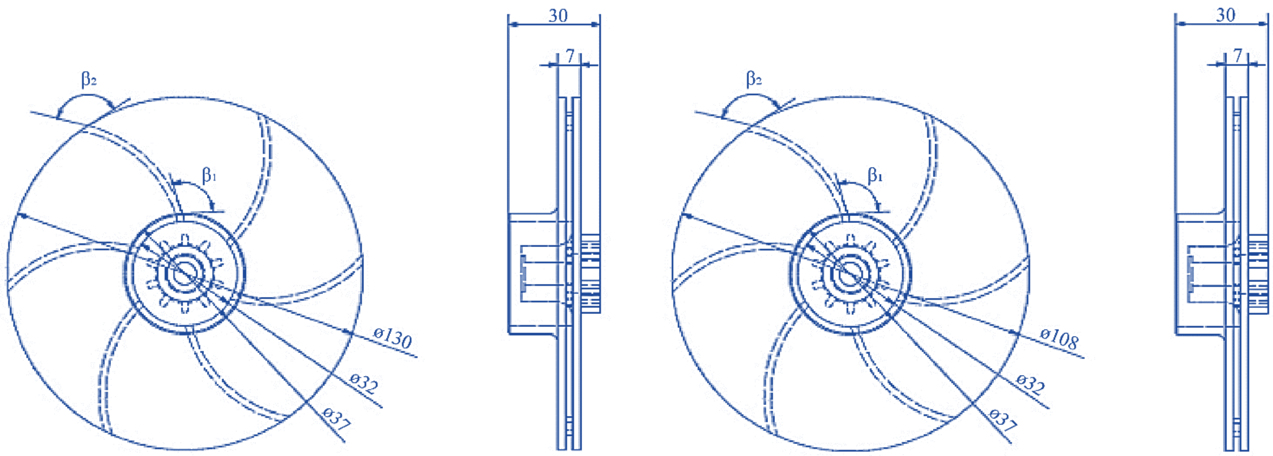
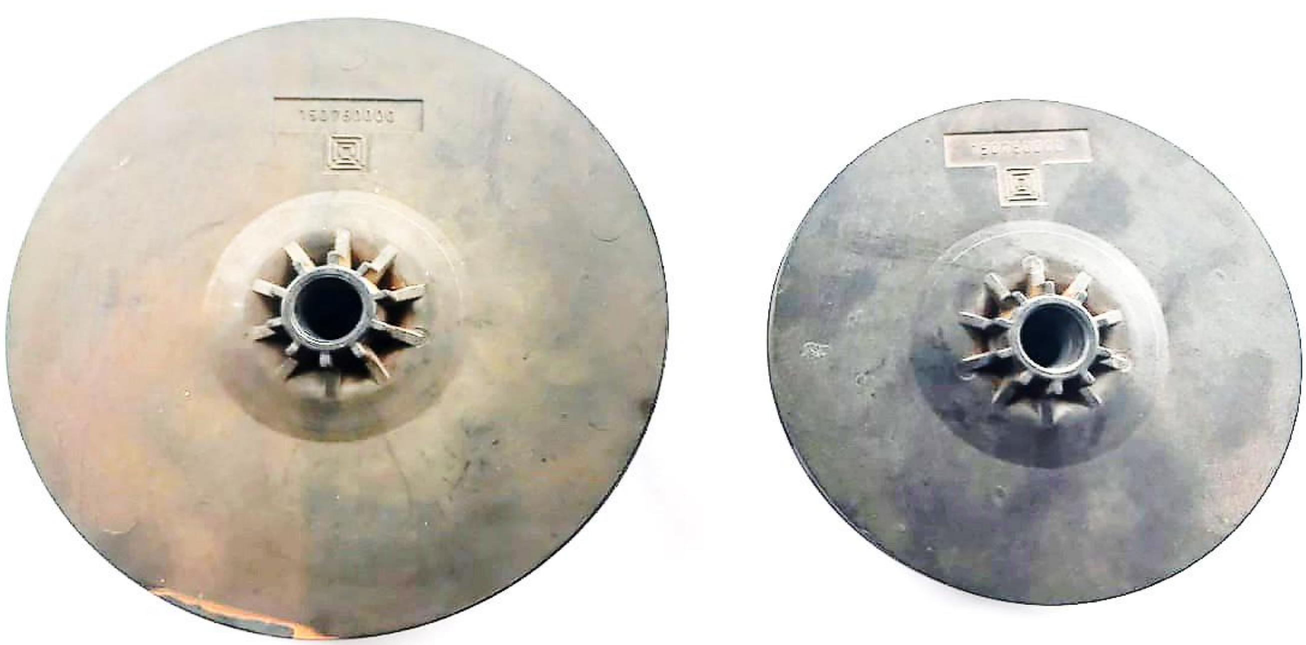



**Fig. 1 Dimensions of the original impeller and the trimmed impeller (units in mm)**



**a)** **b)**

**Fig. 2 Pump impeller: a) Original impeller, b) Impeller after trimming**

### *2.2. Centrifugal Pump Capacity and Efficiency*

Centrifugal pumps will operate with maximum efficiency if the piping system characteristic curve matches the pump head capacity curve under design conditions. Under such operating conditions, the pump will produce a head and capacity by the design capacity and pump head, and the pump is said to be working at the "best efficiency point (BEP) [24]–[26].

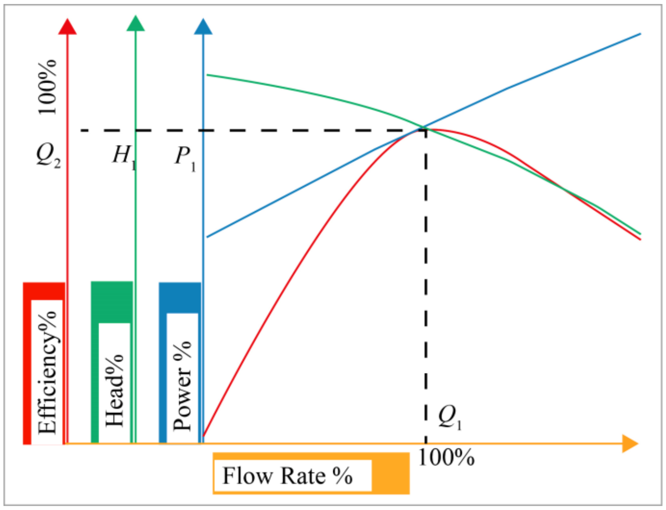



**Fig. 3 Centrifugal pump performance curve**

## 3. Material and Methods

This research was conducted to find the efficiency of pump performance and electricity consumption in the pumping mechanism. The fluid cooling process uses a centrifugal pump to circulate water to a heat exchange vessel, with the required flow capacity of 2.5 M3/Hand a head of 10 m. The centrifugal pump used in this study was the Grundfos NS Basic 4-23 M pump, with the specifications in Table 1. The impeller used in this study was the original impeller with a diameter of 130 mm. The impeller was calculated using the affinity law, namely the resulting 108 mm diameter through impeller trimming.

**Table 1. Centriugal pump specifications**

| | |
|---|---|
| **Brand** | Grundfos |
| **type** | NS Basic 4-23M |
| **Impeller** | closed impeller |
| **Maximum pressure** | 6 bars |
| **Liquid temperature range** | -10ºC to 50ºC |
| **round** | 2800rpm |
| **Voltage** | 220 – 240V |
| **Ampere** | 3 |
| **Power** | 0.65 kW/ 0.5 Hp |
| **Motor efficiency** | 0.8 % |

Figure 4. shows the arrangement of the pump and piping system with piping equipment such as pumps, flow meters, reservoirs, coolers, valves, suction headers, and other fitting components. The inlet pressure and outlet pressure in centrifugal pumps are measured using a manometer installed at the outlet and inlet points of the pump, respectively. The pump flow rate is then controlled using a discharge valve installed between the pump discharge manometer and the flow meter.

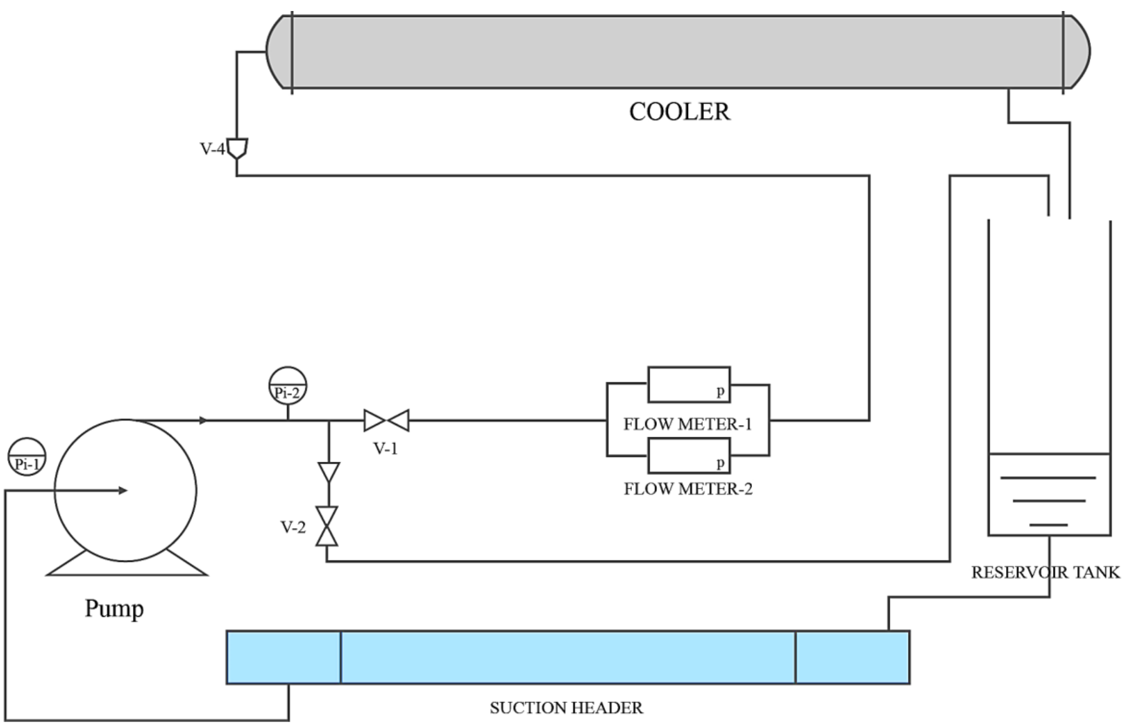



**Fig. 4 Research scheme**

# 4. Results and Discussion

### *4.1. Test Result*

Efforts to supply cooling water needs according to the operating target of 2.50 M3/H with a head of 10 m have been tested using a centrifugal pump using 2 types, 130 mm in diameter as the original impeller and 108 mm in diameter impeller as a result of trimming. The test results are presented in the following table:

**Table 2. Test results for a diameter of 130 mm.**

| Q (m3/H) | H (m) | Efficiency (%) | BEP (%) |
|---|---|---|---|
| 5.32 | 10 | 45 | 71.36% |
| 4.96 | 11 | 47 | 75.63% |
| 4.69 | 12 | 50 | 79.93% |
| 4.31 | 13 | 53 | 84.53% |
| 3.92 | 14 | 54 | 86.24% |
| 3.47 | 15 | 57 | 91.43% |
| 3.14 | 16 | 57 | 90.86% |
| 2.78 | 17 | 56 | 89.16% |
| 2.26 | 18 | 54 | 85.85% |
| 1.47 | 19 | 46 | 74.23% |
| 0.72 | 20 | 27 | 43.54% |
| 0.00 | 21 | 0 | 0.00% |

**Table 3. Test results for a diameter of 108 mm.**

| Q (m3/H) | H (m) | Efficiency (%) | BEP (%) |
|---|---|---|---|
| 4.44 | 7 | 73 | 80.32% |
| 3.98 | 8 | 77 | 84.45% |
| 3.53 | 9 | 83 | 91.11% |
| 3.08 | 10 | 85 | 93.31% |
| 2.64 | 11 | 87 | 96.23% |
| 1.56 | 12 | 72 | 79.36% |
| 0.00 | 12 | 0 | 0.00% |

### *4.2. Simulation*

Simulations were carried out to determine the effect of impeller trimming on the performance of centrifugal pumps. The difference in pressure distribution is visible in each impeller's diameter. Changes in flow conditions at each impeller diameter are expected to affect the performance of centrifugal pumps and effect the distribution of static pressure around the impeller outlet [2]. From the simulation results on the impeller, it can be seen that there is a difference in distribution between the original impeller with a diameter of 130 mm and a trimming impeller with a diameter of 108 mm. Figure 5 shows the pressure distribution in a centrifugal pump with an impeller diameter of 130 mm. The simulation results show that high-pressure distribution is possible because the distance between the impeller and the inlet and outlet of the pump flow is too close to reaching the desired head resulting in higher pressure. Figure 6 shows the pressure distribution in a modified centrifugal pump with an impeller diameter of 108 mm. The simulation results show that a lower pressure distribution is possible because the distance between the impeller and the inlet and outlet of the pump makes the pressure lower.[20].

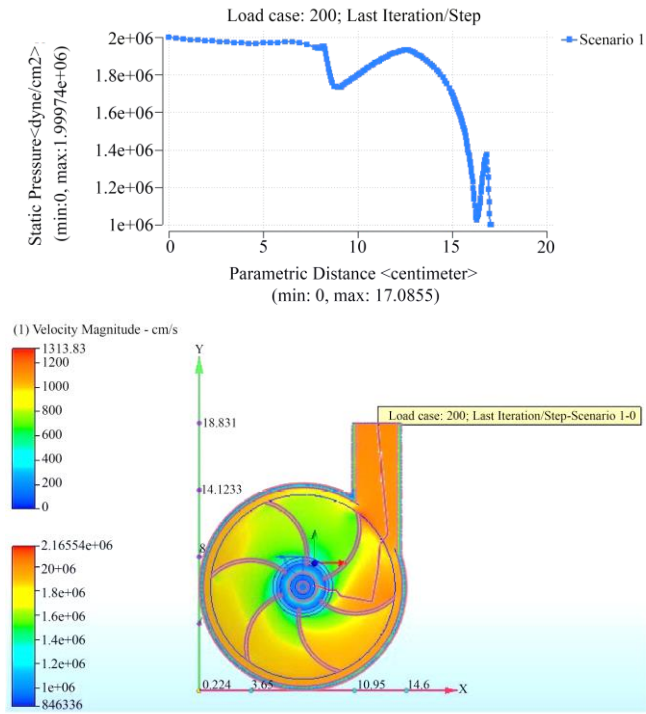



**Fig. 5 Pressure distribution on an impeller with a diameter of 130 mm**

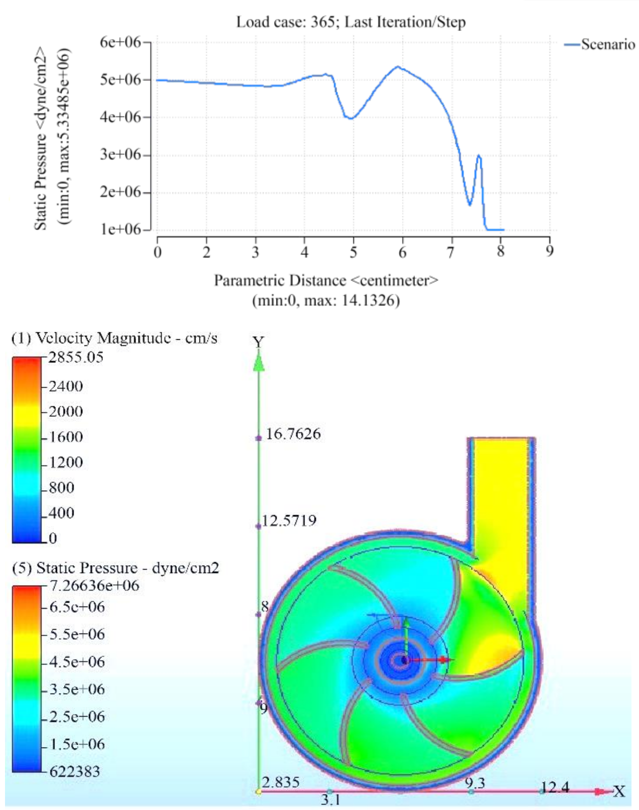
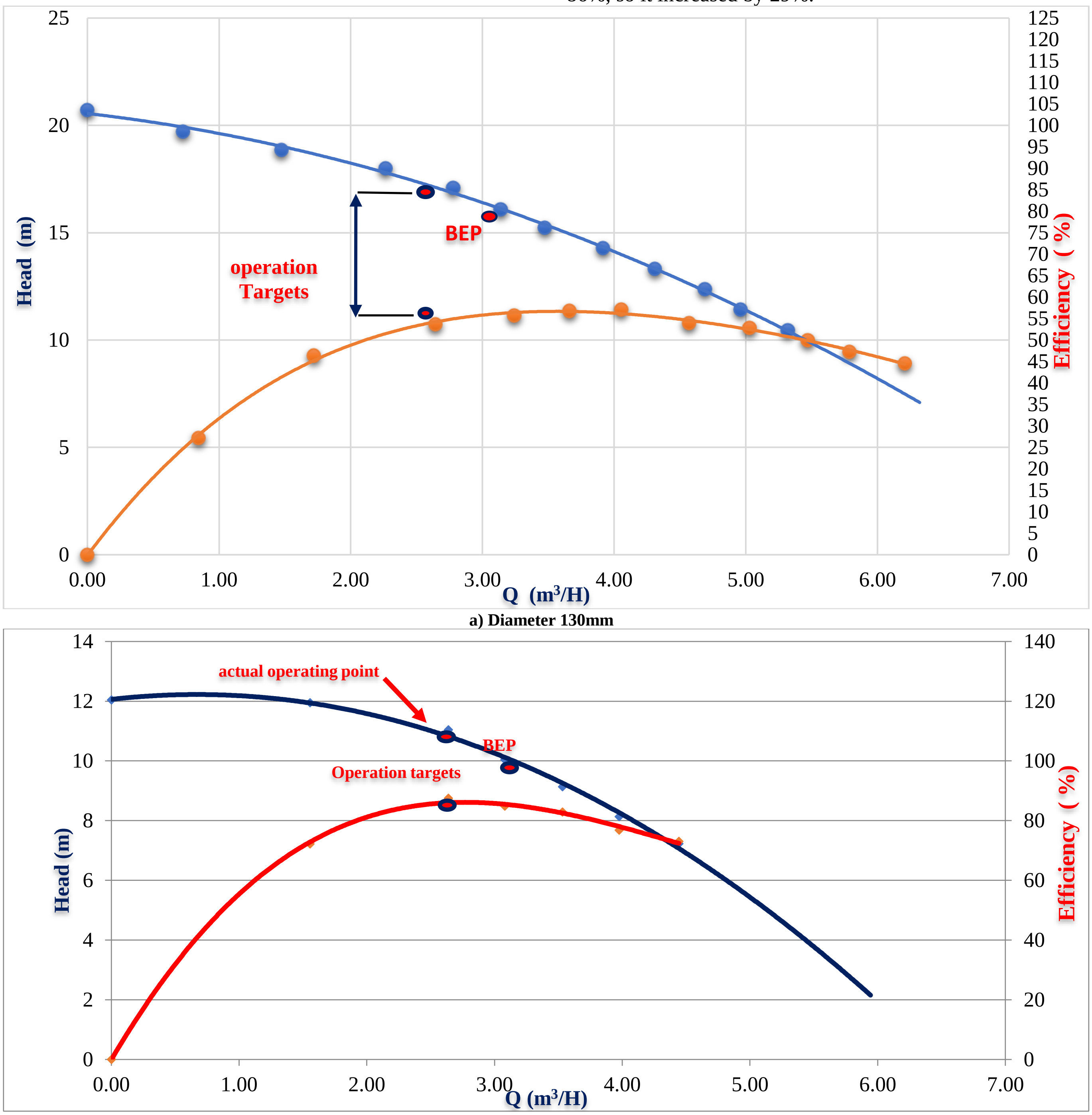



**Fig. 6 Pressure distribution on an impeller with a diameter of 108 mm**

### *4.3. Centriugal Pump Performance*

The performance of a centrifugal pump with a modified impeller from the original impeller with a diameter of 130 mm and trimming the impeller with a diameter of 108 mm was carried out. The test results are outlined in Figure 7; it can be seen that for an impeller diameter of 130 mm. There is an increase in head to 17.3 m, resulting in more than 7.3 m head over the operating target, and the pump efficiency that can be achieved is 57%. Whereas using an impeller with a diameter of 108 mm, the head at the operating point is 11 m, and at the BEP point is 10.6 m, while the resulting pump efficiency is 86%. Designing a pump with a target operating head of 11 m can be achieved by using a trimming impeller. This shows that using a trimming impeller affects the performance of centrifugal pumps [17], [27]. Impeller trimming results in increased efficiency[28]from 57% to 86%, so it increased by 29%.



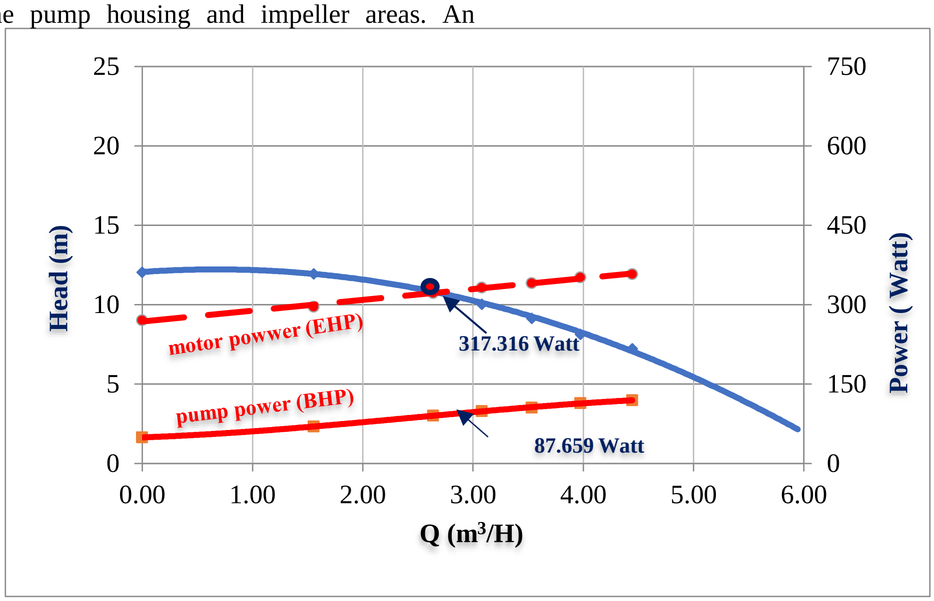

a) Diameter 130mm

b) Diameter 108mm

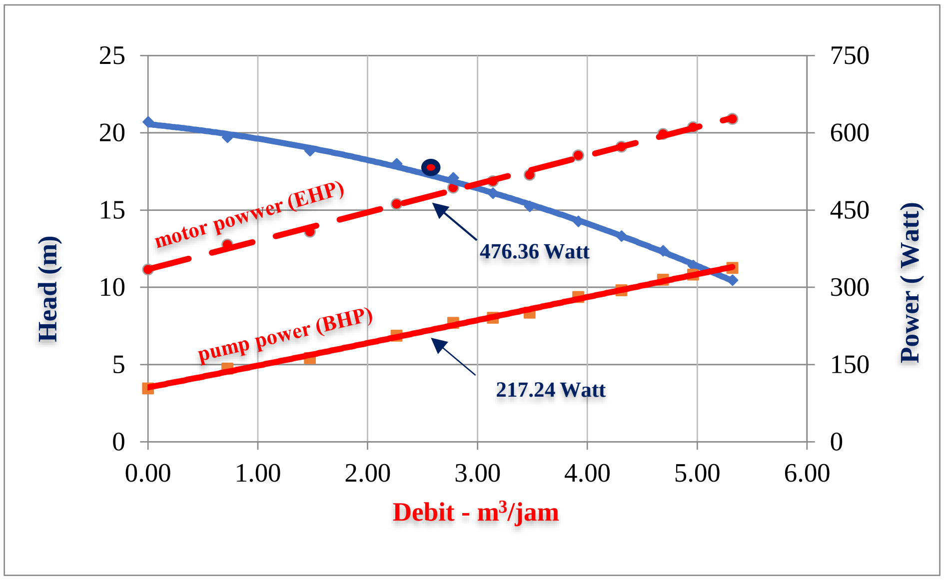
**Fig. 7 Relationship of head, efficiency, and discharge for the original impeller and trimming impeller**

In addition to the impeller trimming centriugal pump performance, it also affects the use of electrical energy. As shown in Figure 8. The power savings obtained use electrical energy to drive motors and pumps. Hence, the savings calculation uses a decrease in motor power consumption (EHP), which is 159.044 Watts. If the pump is operated 12 hours a day, then in one year, there will be electricity savings of 159,044 x 12 x 30 x 12 = 687,070 Watt Hours or 687,070 kWh.

These results show that impeller trimming affects the performance of the pump motor and reduces the required electricity consumption [10]. The difference in using electric energy in centrifugal pumps is due to increased fluid circulation in the pump housing and impeller areas. An increase in fluid circulation dissipates heat energy in the pump so that the input energy consumption becomes greater [28].On a comparison chart head, efficiency, and discharge Figure 9, the actual vs experimental head capacity curve is below the estimated curve line. At a discharge of 2.5 M3/H, there is a head deviation of 0.2 m (1.78%). This deviation occurs because, in the estimation calculation using the affinity formula, the conditions are considered ideal conditions, where the effect of losses on the impeller is ignored. The lower the pump capacity, the greater the deviation[18], [27]. This is because if the pump is operated at a lower discharge capacity, there will be a more significant recirculation in the area (gap) between the types of impellers, resulting in more significant volumetric losses.




**a) Diameter 130mm**




**b) Diameter 108mm**

**Fig. 8 Relationship of head, power, and discharge for the original impeller and trimming the impeller**

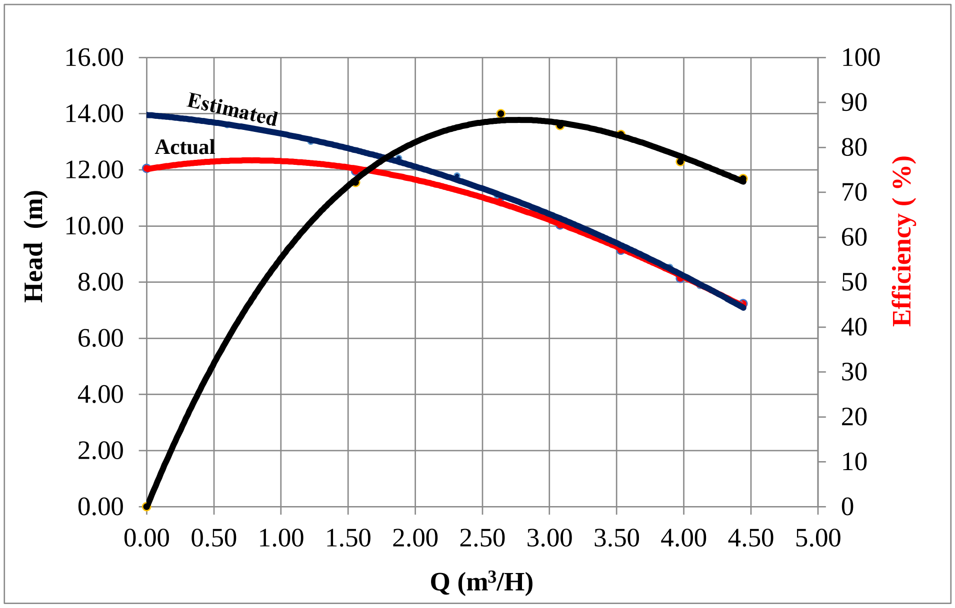



**Fig. 9 Comparison of head, efficiency, and discharge impeller diameter of 108 mm estimated vs actual**

## 5. Conclusion

- The calculations using the affinity formula have resulted in the optimal impeller diameter size for trimming, namely a diameter of 108 mm. Testing has been conducted to produce head and pump capacity according to operating needs.
- For pumps with an impeller diameter of 108 mm, the pump BEP point is shifted to the left, close to the desired operating point. Pump efficiency increased from 57% to 86%, which is 29 %.
- Using an impeller diameter of 108 mm, there is a saving in electricity consumption of 33.387% or 687.070 kWh per year for one pump with a workload of 12 hours per day.

## References


[1] Saurabh Goswami, "Multiphase Pumping to Enhance Oil Recovery," *International Journal of Engineering Trends and Technology*, vol. 21, no. 2, pp. 67–71, 2015. [CrossRef] [Publisher Link]

[2] Hongliang Wang et al., "Effects of the Impeller Blade with a Slot Structure on the Centrifugal Pump Performance," *Energies*, vol. 13, no. 7, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[3] S. Chakraborty, KM Pandey, and B. Roy, "Numerical Analysis on Effects of Blade Number Variations on Performance of Centrifugal Pumps with Various Rotational Speeds," *International Journal of Current Engineering and Technology*, vol. 2, no. 1, pp. 143-152, 2012. [Google Scholar] [Publisher Link]

[4] A. Farid Ayad Hassan, H. M. Abdalla, and A. S. Abo El-Azm Aly, "Effect of Impeller Blade Slot on Centrifugal Pump Performance," *GlobalJournal of Researches in Engineering*, vol. 16, no. 4, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[5] Mario Šavar, Hrvoje Kozmar, and Igor Sutlović, "Improving Centrifugal Pump Efficiency by Impeller Trimming," *Desalination*, vol. 249, no. 2, pp. 654–659, 2009. [CrossRef] [Google Scholar] [Publisher Link]

[6] Davood Khoeini, and Ebrahim Shirani, "Influences of Impeller Splitter Blades on the Performance of A Centrifugal Pump with Viscous Fluids," *International Journal of Fluid Machinery and Systems*, vol. 11, no. 4, pp. 400–411, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[7] Gamal R.H. Abo Elyamin et al., "Effect of Impeller Blades Number on the Performance of A Centrifugal Pump," *Alexandria Engineering Journal*, vol. 58, no. 1, pp. 39–48, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[8] Dadapeer D, and Veeresh G Gunjalli, "Analytical Study of Performance of A Centrifugal Pump for Different Operating Conditions," *International Journal of Engineering Trends and Technology*, vol. 54, no. 3, pp. 175–179, 2017. [CrossRef] [Publisher Link]

[9] Paul Waide, and Conrad U Brunner, "Energy-Efficiency Policy Opportunities for Electric Motor-Driven Systems," *The International Energy Agency*, p. 132, 2011. [CrossRef] [Google Scholar] [Publisher Link]

[10] Arun Shankar Vishnu Kalaiselvan et al, "A Comprehensive Review on Energy Efficiency Enhancement Initiatives in Centrifugal Pumping Systems," *Applied Energy*, vol. 181, pp. 495–513, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[11] G. Kalyan K.L.N. Murty, "Design and Optimization of Centrifugal Pump Guide Vanes," *SSRG International Journal of Mechanical Engineering*, vol. 2, no. 2, pp. 9-14, 2015. [CrossRef] [Publisher Link]

[12] Fan Yang, Hao-ru Zhao, and Chao Liu, "Improvement of the Efficiency of the Axial-Flow Pump At Part Loads Due to Installing Outlet Guide Vanes Mechanism," *Mathematical Problems in Engineering*, vol. 2016, pp. 1-10, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[13] Sustainability Victoria, "Energy Efficiency Best Practice Guide, Pumping Systems, 2009. [Online]. Available: http://www.sustainability.vic.gov.au/~/media/resources/documents/services and advice/business/srsb em/resources and tools/srsb em best practice guide pump 2009.pdf

[14] Wen Guang Li, "Impeller Trimming of An Industrial Centrifugal Viscous Oil Pump," *International Journal of Advanced Design and Manufacturing Technology*, 2011. [Google Scholar] [Publisher Link]

[15] ME Matlakala et al., "Influence of Impeller Diameter on the Performance of Centrifugal Pumps," *IOP Conference Series: Materials Science and Engineering*, vol. 655, no. 1, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[16] Keran Shu et al., "The Effect of Impeller Cut on the Performance of Middle Specific Speed Centrifugal Pump," *IOP Conference Series: Materials Science and Engineering*, vol. 394, no. 3, pp. 1-5, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[17] Khoeini Davood, and Tavakoli Mohammad Reza, "Flow Characteristics of a Centrifugal Pump with Different Impeller Trimming Methods," *FME Transaction*, vol. 46, no. 4, pp. 463–468, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[18] M. Shadab et al., "Effect of Impeller Shroud Trimming on the Hydraulic Performance of Centrifugal Pumps with Low and Medium Specific Speeds," *Engineering Applications of Computational Fluid Mechanics*, vol. 16, no. 1, pp. 514–535, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[19] Bubryur Kim et al., "Optimization of Centrifugal Pump Impeller for Pumping Viscous Fluids Using Direct Design Optimization Technique,"*Machines*, vol. 10, no. 9, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[20] Mohamed Hassan Gobran et al., "Numerical Simulation of Centrifugal Pump and Effect of Impeller Geometry on Its Performance," *Engineering and Applied Sciences*, vol. 4, no. 2, p. 21, 2019. [Google Scholar] [Publisher Link]

[21] Kapil Rangari, and Ravindra Gandhe, "Design and Failure Analysis of Pneumatic Operated 2" Diaphragm Pump," *SSRG International Journal of Mechanical Engineering*, vol. 5, no. 5, pp. 32-39, 2018. [CrossRef] [Publisher Link]

[22] Yuxing Bai et al., "Effects of Impeller DiameteEffects of Impeller Diamete," *Mathematical Problems in Engineering*, vol. 2017, p. 15, 2017. [CrossRef] [Publisher Link]

[23] V.K. Arun Shankar, "Real time simulation of Variable Speed Parallel Pumping system," *Energy Procedia*, vol. 142, pp. 2102-08, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[24] E. Nørgaard et al., "Performance of Components of Ice Slurry Systems: Pumps, Plate Heat Exchangers, and Fittings," *International Journal of Refrigeration*, vol. 28, no. 1, pp. 83–91, 2005. [CrossRef] [Google Scholar] [Publisher Link]

[25] Pratik Kasat et al., "Developing a Digital Twin of Centrifugal Pump for Performance Evaluation," *Materials Today Proceedings*, vol. 72, pp. 1798-1802, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[26] Wenke Zhang et al., "Analysis and Optimization of the Performance for the Ground Source Heat Pump System with the Middle-Deep U-Type Well," *Applied Thermal Engineering*, vol. 219, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[27] Kai Wang et al., "Effects of Impeller Trim on Performance of Two-Stage Self-Priming Centrifugal Pump," *Advances in Mechanical Engineering*, vol. 9, no. 2, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[28] Sutardi Sutardi, and Ridwan Adliansyah, "Effect of Impeller Trimming on Centrifugal Pump," *Rekayasa Mesin*, vol. 12, no. 3, pp. 663–675, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[29] Arun Shankar V.K. et al., "Sensorless Parameter Estimation of VFD Based Cascade Centrifugal Pumping System Using Automatic Pump Curve Adaptation Method," *Energy Reports*, vol. 7, pp. 453–466, 2021. [CrossRef] [Google Scholar] [Publisher Link]