EXPERIMENTAL STUDY OF THE EFFECT OF THE NUMBER OF IMPELLER BLADES AND FLUID MASS FLOW RATE ON CAVITATION IN CENTRIFUGAL PUMPS OF TCU CASTING MACHINES

Muhamad Safi'i[1*], Nazaruddin Sinaga[2], Eflita Yohana[3], Akhmad Irfan[4], Rouf Muhammad[5], Suheri Suheri[6], Yafid Effendi[7]

[1*] Mechanical Engineering Study Program, Faculty of Engineering and Informatics, Persatuan Guru Republik Indonesia Semarang University.
Jl. Sidodadi Timur, Jalan Dokter Cipto No.24, Karangtempel, Semarang Timur, Semarang City, Central Java 50232.
[2,3] Departement Mechanical Engineering , Faculty of Engineering , Diponegoro University.
Jl. Prof. Soedarto, Tembalang, Semarang City, Centyral Java 50275.
[4] Mechanical Engineering Study Program, Faculty of Engineering and Computer Science, Sains Al Qur'an, Central Java, Wonosobo University.
Jl. KH. Hasyim Asy'ari Km. 03 Kalibeber, Mojotengah, Kab. Wonosobo 56351.
[5] Mechanical Engineering Study Program, Faculty of Engineering, Jakarta Politecnic of State PSDKU Demak.
Jl. Sultan Trenggono No.61, Katonsari, Kabupaten Demak, Central Java 59516.
[6] Mechanical Engineering Study Program, Faculty of Sains and Technology, Samudra University, Langsa, Aceh.
Jl. Prof. Dr. Syarief Thayeb, Meurandeh, Langsa Lama, Langsa City, Aceh 24416.
[7] Mechanical Engineering Study Program, Faculty of Engineering, Muhammadiyah Tangerang University.
Jl. Perintis Kemerdekaan I No.33, RT.007/RW.003, Babakan, Cikokol, Tangerang, Tangerang, City, Banten 15118.

[*]Email: muhamadsafii@upgris.ac.id.

Abstrak

Cavitation is a major issue in centrifugal pumps because it impacts their performance and efficiency. Experimental research was conducted to investigate the effect of the number of impeller blades and mass flow rate on the cavitation phenomenon in centrifugal pumps, as well as to characterize them. The Ebara brand centrifugal pump type 65x50 FSS4JA used in the TCU installation of the Casting Machine has a number of blades of 4 and 6 with a fixed inclination angle of 60° as the object of research. The fluid mass flow rate varies with values of 1.67 kg/s, 3.33 kg/s, 5.67 kg/s, and 7.33 kg/s. The research findings show that the highest cavitation occurs in the centrifugal pump with 4 blades, with an NPSH value reaching 2.02 at a mass flow rate of 5.67 kg/s, while the lowest value is found in the pump with 6 blades with an NPSH of 1.88 at a mass flow rate of 7.33 kg/s. A 6-blade centrifugal pump operating at a mass flow rate of 7.33 kg/s demonstrated the best results in this study and is feasible for field application.

***Keywords**: Impeller, Cavitation, Pump, Centrifugal.*

INTRODUCTION

In casting machines, centrifugal pumps have an important role in supplying fluids (Safi'i, M et al., 2025). In practice, cavitation is an important problem that influences its development (Ariawan, A, I et al., 2025). In centrifugal pumps, cavitation is confirmed to cause production cost losses (Safi'i, M et al., 2024). Generally, the cause of cavitation is influenced by its geometric shape (Youssef, E et al., 2025). Cavitation occurs due to a decrease in the fluid flow rate, so that the pump pressure decreases below the fluid's saturated vapor pressure (Dongwei, W et al., 2025). The impact of cavitation on centrifugal pumps is a major problem for damage to the impeller and volute of the pump (Yanyu, C et al., 2025). Cavitation has also caused loud noises (Safi'i, M et al., 2024) and the appearance of abnormal vibrations in the centrifugal pump (Ahmed, R. A., A and Ali, H, S., 2025), so that an in-depth study to determine the effect of cavitation on pump effectiveness is an interesting topic (Safi'i, M et al., 2025). The NPSH value is generally used to evaluate the level of cavitation in centrifugal pumps (Sayed, E et al., 2024). Further investigations to determine the cavitation characteristics of centrifugal pumps based on NPSH values were also carried out experimentally and numerically to determine the performance and efficiency of the pump (Bowen, S et al., 2025).

There have been many studies on the phenomenon of cavitation in centrifugal pumps, but most of the researchers do not provide an accurate early detection method for the phenomenon of cavitation (Hui, S et al., 2024). Especially the effects of blade geometry such as the angle and number of blades (Alvaro, P, V et al., 2026). In addition, operational conditions that tend to focus on fluids in the form of clean water and ideal gases which limit research results (Ilario, C et al., 2026). In this case, the need for the use of advanced technology that can monitor cavitation phenomena in real time is very helpful for researchers and technicians in understanding the characteristics and phenomena of cavitation in centrifugal pumps needs to be done and integrated directly (Zhengzhuang, Z et al., 2026).

To reduce the effects of cavitation in centrifugal pumps, various methods have been employed. One such method involves increasing the impeller blade angle by 28º. The result is a decrease in critical cavitation values by 0.186° (Weixiang, Y et al., 2025). Flow rate conditions of 15 m^3/h, 50 m^3/h, and 70 m^3/h were developed to characterize the impact of cavitation on centrifugal pumps using an experimental scheme. The test results showed that the flow rate condition of 50 m^3/h had the highest reduction in cavitation impact of up to 16% (Leilei, J et al., 2025). A centrifugal pump was developed to characterize its cavitation. Pump frequencies of 3000 Hz and 5000 Hz bands were proposed in this research to characterize the effects of vibration and noise due to cavitation. The research results revealed that cavitation can be reduced by up to 19.2% at a pump frequency variation of 3000 Hz band at a discharge of 25 m^3/h (Bingyang, S et al., 2025). A study was conducted to determine the effect of increasing the number of blades on a centrifugal pump impeller, modifying it to 3 and 5 blades. The study found that modifying the number of blades on a centrifugal pump impeller to 3 and 5 blades reduced cavitation by 45.7% and 43.1%, respectively (Song, P et al., 2022). Single radial vanes and double radial vanes integrated into a centrifugal pump were characterized using experimental and simulation schemes to understand the cavitation phenomenon. The results showed that the double radial vane had the lowest ΔP value, at 1.583 Pa, with an NPSH of 1.117 (Ramirez, R et al., 2020).

Mass flow rates of 1.67 kg/s, 3.33 kg/s, 5.67 kg/s, and 7.33 kg/s were characterized by experimental methods on the effects of centrifugal pump cavitation; the number of impeller blades of 4 and 6 pcs was proposed as a geometry variation parameter. The experimental results found that the number of impeller blades of 4 pcs had the largest NPSH value with a value of 2.02 at a mass flow rate variation of 5.67 kg/s (Safi'i, M et al., 2025). The head coefficient of a centrifugal pump varied by 0.10 m and 0.15 m, respectively, using experimental and numerical approaches. The research results revealed that the head coefficient variations in the proposed centrifugal pump were able to provide a reduction in the NPSH value by 2.1% and 5%, respectively (Xianwei, L et al., 2024). The influence of the pump frequency and rpm parameters has a very big impact on the occurrence of pump cavitation. It is known that, based on experimental studies, the large values of the pump frequency and rpm will also increase the pump's NPSHa value (Wang, D et al., 2023).

Previous research focused on the case of centrifugal pump cavitation on parameters such as the geometry of the impeller blade, Rpm, vibration frequency, head, and pressure on the phenomenon of centrifugal pump cavitation. In addition, an experimental study of the influence of the geometry of the number of impeller blades and the fluid mass flow rate on cavitation in centrifugal pumps is very interesting to be discussed further. The object of the research focused on the Ebara brand centrifugal pump type 65x50 FSS4JA installed in the TCU installation of the Casting Machine. This experimental study varied the number of impeller blades by 4 and 6 pieces with an impeller blade inclination angle of 60º, which was characterized by a fluid mass flow rate of 1.67 kg/s, 3.33 kg/s, 5.67 kg/s, and 7.33 kg/s for an in-depth analysis of pump cavitation. Water fluid with a temperature of 25ºC produced by a chiller machine was used as a medium to determine the characteristics of water and the effects of cavitation. The results of this study are expected to be recommended for operation in real-time operating conditions of the TCU Casting machine centrifugal pump, and can be applied practically in the field related to the production process of pump components.

RESEARCH METHOD

Physical Model

Figure 1 shows the geometry of the EBARA 65x50 FSS4JA centrifugal pump, the object of this study. The centrifugal pump in this study works by converting mechanical energy from the engine into kinetic energy in the pumped fluid. Centrifugal pumps work by utilizing centrifugal force to direct the fluid from the center of the impeller to the outside. In this study, the centrifugal pump has the specifications listed in Table 1.

Figure 1. EBARA 65x50 FSS4JA Centrifugal Pump on Casting Machine TCU.

Table 1. Specifications of the EBARA 65x50 FSS4JA Centrifugal Pump.

Model	65x50 FSS4JA
Power (kW)	3,7
Frame No	112 M
Diameter Impeller	260 mm
Coupling CLA	125
Shaft Diameter Pump (mm)	24 mm
Shaft Diameter Motor (mm)	28 mm
Capacity	0,34 m³/m
Head	25 m
Rotating	1450 Rpm
Frequency	50 Hz
Voltage	380 V

Experiment Scheme

Experimental Setup on Ebara Brand Centrifugal Pump Type 65x50 FSS4JA Installed in TCU. The installation of the Casting Machine is explained in Figure 2. Initially, the chiller machine produces cold water with a temperature of about 5ºC and a pressure of 10 Bar. This water has material properties in the form of a density (ρ) of 998 kg/m³, dynamic viscosity (μ) = 1.5 x 10^{-5} kg/m.s, kinematic viscosity (v) 1.518 x 10^{-5} m²/s, specific heat capacity (Cp) = 1.0057.10^{3} J/kg.K, and thermal conductivity (K) = 0.024458 Wm. K. The water flows with a volume capacity of 0.34 cubic meters per second, with varying fluid mass flow rates, namely 1.67 kg/s, 3.33 kg/s, 5.67 kg/s, and 7.33 kg/s. The water flows through a centrifugal pump with a head of 25 m. The pump is operated by a 3.7 kW motor equivalent to 3 Hp, 1400 Rpm rotation using 4 poles, 380 V three-phase electrical voltage, and a frequency of 50 Hz. The pump, which is installed with a foot mounting, uses the Mitsubishi brand and is used to flow water to the TCU Casting machine. 1. Water that has been cooled from the casting machine with a temperature of 80ºC flows through a 1.25-inch diameter pipe, then returns to the chiller machine to be cooled again.

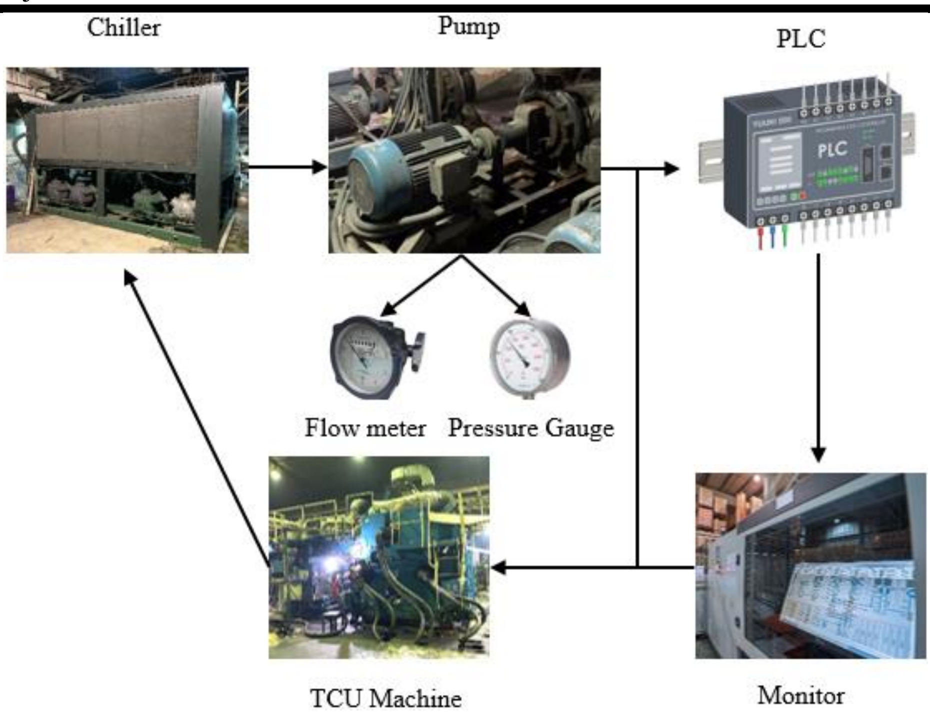

Figure 2. Experimental Scheme.

Measurement Methods

In general, the measurement method for several important quantities, such as vibration, fluid mass flow rate, pressure, temperature, and pump speed, is directly integrated into the PLC system on the computer. The fluid mass flow rate and pressure can also be directly measured on the pressure gauge component. A proximity sensor is used to measure pump speed, and a K thermocouple is used to measure temperature, as described in Figure 2.

Experimental Data Reduction

The results of the experimental data include the average values of flow rate, pressure, and pump discharge, which are used to determine the NPSH value. In this experiment, the fluid used is water. Kinematic viscosity is obtained through the correlation between dynamic viscosity divided by air density, calculated using Equation 1.

$$\mu = \frac{v}{\rho} \qquad (1)$$

The average water velocity flowing in the pump pipe is between 1.67 and 6.33 kg per second, and the number of impellers consists of 6 rows. The average Reynolds number is calculated using Equation 2.

$$R_e = \frac{\rho . D . U_\infty}{\mu} \qquad (2)$$

The calculation of the discharge through the pump is calculated using Equation 3.

$$Q = V \times \mathrm{A} \qquad (3)$$

Head is the mechanical capacity of a pump, acting on each unit weight, to flow fluid to a certain height. Pump stalling occurs when the pump capacity drops to zero when it reaches its maximum capacity. The total pump head can be calculated using Equation 4.

$$H_p = h_a + h_f \quad (4)$$

There are two types of losses on the pump flow side:

Major head loss, which is friction loss in the piping system, can be calculated using Equation 5.

$$H_{my} = f.\frac{L}{D}.\frac{Vd^2}{2g} \quad (5)$$

The head is the flow loss in a piping system, such as elbows, valves, fittings, filters, etc., and can be calculated using Equation 6.

$$H_{mn} = f.\frac{Vd^2}{2g} \quad (6)$$

If an electric motor is used to drive the pump, the rotational speed must be determined. In this case, the use of synchronous rotation over standard rotation in an electric motor is a consideration that requires careful consideration. Induction electric motors with a rotational speed of 1 to 20 percent are chosen for safety reasons to prevent slippage. The pump can flow fluid as much as 1.67 kg/s with a head of 25 m. In addition, the pump index is also a primary consideration in determining the capacity and pressure head to be used to achieve maximum efficiency. This impacts the shape and profile of the impeller, so the pump rotational speed can be calculated using Equation 7.

$$Ns = n.\frac{Q^{1/2}}{H^{3/4}} \quad (7)$$

Capacity, head, speed (Rpm), specific rpm, and other losses are the main parameters that affect pump efficiency. To determine this, a graph showing the relationship between specific rpm and fluid flow capacity is required, as discussed in the discussion on specific rpm. Therefore, pump capacity is calculated using Equation 8.

$$P = \frac{\gamma.H.Q}{\eta \text{ pompa}} \quad (8)$$

In general, induction motors are used to drive centrifugal pumps directly, and the motor power can be calculated using Equation 9.

$$Pm = P\frac{1+a}{\eta_t} \quad (9)$$

The net positive head is used to determine the safety measure of the pump against cavitation phenomena, and the net positive head is calculated using Equation 10.

$$H_{sv} = \frac{Pa-pv}{\gamma} - h_a - h_{f\,suction} \quad (10)$$

The required NPSH depends on the capacity, pressure head, and rotational speed of the pump and can be calculated using Equation 11.

$$NPSH_{svn} = \left(\frac{n}{s}\right)^{4/3}.\ Q^{2/3} \quad (11)$$

RESULTS AND DISCUSSION

The Effect of Constant Number and Angle of Impeller Blades

Experimental studies were conducted on an Ebara 65x50 FSS4JA centrifugal pump, and its characteristics were sought when the fluid mass flow rate varied. Centrifugal pump systems work by converting mechanical energy from external sources, such as electric motors, into pressure differences between the suction point and the discharge point, especially in applications such as Casting Unit Machines. The number of fixed impeller blades, namely 6 pieces with a blade inclination angle of 60 degrees, influences the flow pattern, fluid velocity, and fluid mixing efficiency. In this study, the effect of the number of blades and the angle of the impeller blades was also studied on the cavitation zone and the contact zone between the impeller and the fluid.

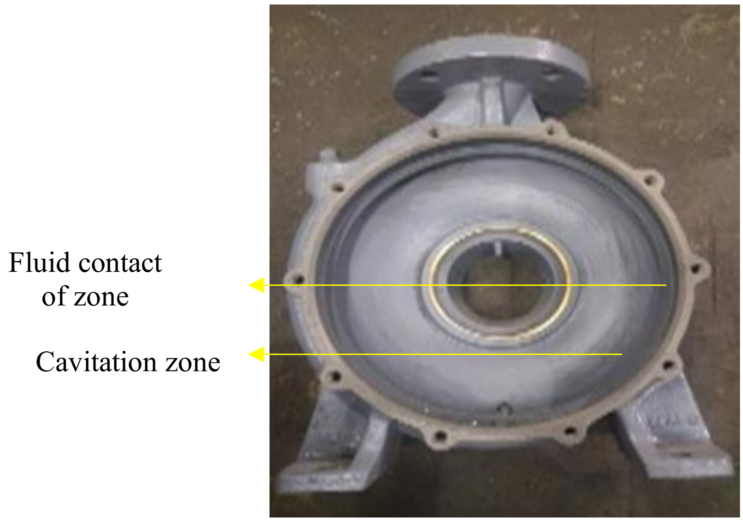

Figure 3. Cavitation in the Volute.

The lack of head and pressure in the pump causes noise and vibration in the pump volute area. This makes the application of the ideal fluid mass flow rate a primary focus, because the distribution of fluid flow that occurs in the volute boundary layer has a major impact on the occurrence of cavitation, as seen in Figure 3. The impact of the flow pattern on the number of impeller blades, as many as 6 pieces with various variations in fluid mass flow rates, can form a fast flow back, where the flow moves straight from the impeller and returns to the impeller area. In addition, the more the number of impeller blades, the higher the resulting fluid flow velocity, so that the performance and efficiency of the centrifugal pump increase. However, strangely, the working pressure becomes higher. As a result, the friction factor also increases, which causes an increase in the NPSH value. Meanwhile, the flow pattern with the number of impeller blades as many as 4 pieces in various variations in fluid mass flow rates shows excessive vortex intensity in the contact zone, so that cavitation becomes more dominant. Figure 4 shows the characteristics of cavitation on the impeller of the TCU Casting Machine centrifugal pump with the number of impeller blades as many as 6 pieces. The cavitation zone is the area where a phase transition from liquid to gas occurs, known as cavitation, while the contact zone is formed due to the boundary between two fluids with different densities in the reservoir.

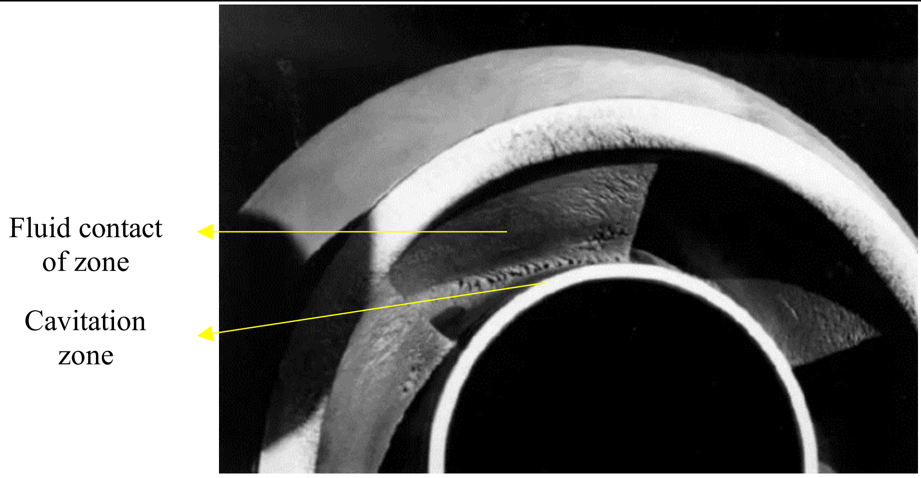

Figure 4. Cavitation Characteristics of the Centrifugal Pump Impeller of the TCU Casting Machine with 6 Impeller Blades.

Static pressure and dynamic friction losses are likely also contributing factors to cavitation in pumps. Increasing the number of impeller blades in a centrifugal pump is expected to achieve higher hydrostatic back pressure and reduce friction. The pressure difference between the suction and discharge sides of a properly functioning centrifugal pump will result in a significant increase in pumping power, thereby improving pump efficiency. Theoretically, increasing the number of impeller blades in a centrifugal pump is believed to increase the water power produced. Centrifugal pumps work by converting the kinetic energy of a fluid into potential or dynamic energy. The fluid enters through the rotating impeller and is then pushed towards the edge of the impeller by centrifugal force. Furthermore, centrifugal pumps exhibit flexibility in various applications because they can operate at both low and high pressures, making them optimal for delivering water power.

Table 1. Value of Deviation NPSH Number

Mass Flow Rate (kg/s)	NPSH Number for Blade 6 Pcs	NPSH Number for Blade 4 Pcs	Deviation (%)
1.67	0,209	0,319	0.790
3.33	0,653	0,732	0.346
5,67	1,902	2,022	0,902
7.33	1,886	1,976	0,886

The Table 1 shows a comparison of the Net Positive Suction Head (NPSH) Number values between impellers with different numbers of blades, namely 6 blades and 4 blades, at various variations in mass flow rates. As the Mass Flow Rate increases (from 1.67 kg/s to 7.33 kg/s), the NPSH Number values for both types of impellers tend to increase. This is logical because at higher discharges, the flow velocity increases and the static pressure at the pump inlet area decreases, so the risk of cavitation (represented by NPSH) becomes greater. Consistently, the 6-blade impeller has a lower NPSH Number value than the 4-blade impeller at each flow point. A lower NPSH indicates that the 6-blade design is more resistant to cavitation or has more efficient suction performance than the 4-blade design under these conditions. Interestingly, at low flow (1.67 kg/s), the deviation was quite high (0.790), but decreased dramatically when the flow increased to 3.33 kg/s (0.346). At high flow (5.67 - 7.33 kg/s), the deviation increased again and stabilized in the range of 0.88 - 0.90. This indicates that at high loads, differences in the number of blades have a significant and consistent impact on the pump's suction characteristics.

The Effect of Fluid Mass Flow Rate

The effect of fluid mass flow rates of 1.67 kg/s, 3.33 kg/s, 5.67 kg/s, and 7.33 kg/s was studied in experiments to observe the phenomenon of cavitation in pumps. The inclination angle of the fixed blades in a centrifugal pump can influence the occurrence of cavitation. Cavitation is a condition that occurs when the local pressure is below the saturated vapor pressure of the fluid. Higher flow rates can increase the level of cavitation in the pump. The magnitude of the fluid mass flow rate has the potential to increase turbulence around the pump blades, resulting in swirling and vortex flow around the impeller. When the fluid is at high pressure and is affected by centrifugal force and drag on the impeller, it can create bubbles that simultaneously collapse due to the pressure drop. This results in cavitation, a detrimental phenomenon that can damage pump components, especially the impeller. A high fluid mass flow rate does not guarantee good pump performance; it can actually exacerbate cavitation because the suction pressure gradually decreases, especially in four-blade impellers.

Figure 5 shows the relationship between fluid mass flow rate and NPSH. Increasing fluid mass flow rate is crucial for cavitation phenomena. In general, a higher fluid mass flow rate will lead to greater cavitation. In this study, the cavitation rate for a six-blade pump tested experimentally showed a cavitation rate of 0.2 at a fluid mass flow rate of 1.67 kg/s, 0.65 at 3.33 kg/s, 1.9 at 5.67 kg/s, and 1.88 at 7.33 kg/s. These results indicate that the higher the fluid mass flow rate, the higher the cavitation rate. However, surprisingly, when the flow rate was increased from 5.67 kg/s to 7.33 kg/s, the cavitation rate actually decreased gradually. This suggests that a fluid mass flow rate of 7.33 kg/s is likely the most optimal and applicable flow rate in the field. This finding aligns with experimental test results on a four-blade centrifugal pump, which exhibited nearly identical cavitation characteristics.

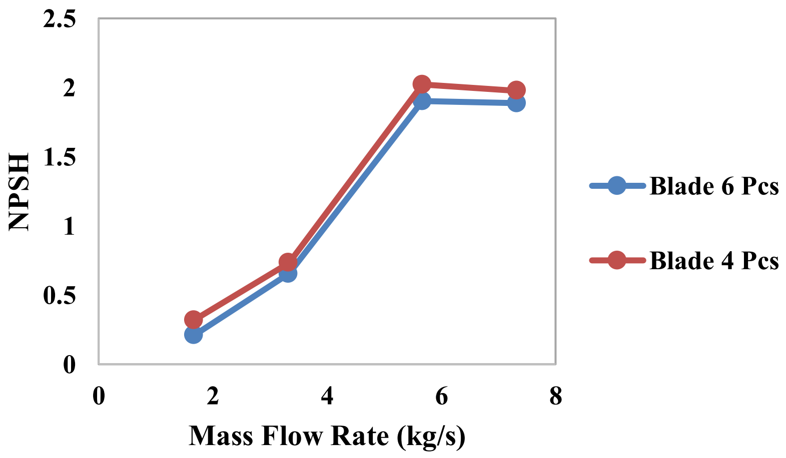

Figure 5. Relationship between Fluid Mass Flow Rate and NPSH.

CONCLUSION

The highest cavitation value was found in a 4-blade centrifugal pump, with an NPSH of 2.02 at a fluid mass flow rate of 5.67 kg/s. Meanwhile, the lowest value was recorded in a 6-blade centrifugal pump, which showed an NPSH of 1.88 at a fluid mass flow rate of 7.33 kg/s. The 6-blade centrifugal pump operating at a fluid mass flow rate of 7.33 kg/s achieved the best results in this study and can be practically implemented in the field and recommended in the operation of the TCU Casting Machine. However, the results of our research only show the content of the results of damage to the impeller and volute parts of the pump, it would be better if this research was combined with simulations using the Computational Fluid Dynamics (CFD) computer application to validate the experimental results and determine the characteristics and behavior of the fluid in the cavitation phenomenon of the TCU Casting pump.

Competing Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Thank-you Note

Beasiswa Pendidikan Indonesia (BPI). Building C, Floor 13.
Jenderal Sudirman Street, Senayan, Central Jakarta 10270. Call Center: 177.

Energy Conversion Laboratory, Persatuan Guru Republik Indonesia Semarang University.
Pawitan Luhur III Street, No.1, Bendan Duwur, Gajahmungkur, Semarang City, Central Java, 50233.

PT. POLIDAYAGUNA PERKASA UNGARAN, Central Java.
Karimunjawa Street, Kali-tengah, Gedanganak, Ungaran, Semarang, Central Java, 50519.

REFERENCES

Safi'i, M., Sinaga, N., Yohana, E., Nugroho, A., & Setyoadi, Y. (2025). Kaji Eksperimen Pengaruh Jumlah Blade Impeller dan Laju Aliran Massa Fluida terhadap Kavitasi Pompa Sentrifugal Mesin Tcu Casting. *Journal CRANKSHAFT, 8* (2), 11-20. https://doi.org/10.24176/cra.v8i2.14572.

Safi'i, M., Ramdhani, M., Idrokul, Fahmi, M., Maulana, Rozaki, & S., Ramadhan, H. (2025). Experimental Study of The Effect of Fluid Mass Flow Rate on Cavitation in Ebara Brand Centrifugal Pump Type 65x50 FSS4JA. *CATHA SAINTIFICA: Journal of Creativity and Innovation Technology*, *3* (1), 20-26. https://doi.org/10.32699/cathasaintifica.v3i1.8868.

Safi'i, M., Muhammad, R., & Baiti, Jannati, N. (2024). Analisa Kerusakan Pompa Oli Temperature Control Unit pada Mesin Longitudinal Strecher Ditinjau dari Kerugian Biaya Produksi di PT. Polidayaguna Perkasa Ungaran. *STORAGE: Jurnal Ilmiah Teknik Dan Ilmu Komputer*, *3* (1), 106–115. https://doi.org/10.55123/storage.v3i1.3173.

Ariawan, A, I., Safi'i, M., Ramdhani, A., Idrokul, F, M., Maulana, R, S., Ramadhan, R., Juli, S, M., Widi, P, A., Effendi, Y., & Heriyani, O. (2025). Studi Numerik Pengaruh External Force terhadap Kekuatan Poros Pompa Sentrifugal Jenis N 32–125. *Motor Bakar*: *Jurnal Teknik Mesin Universitas Muhammadiyah Tangerang*, *9* (1), 44-51. http://dx.doi.org/10.31000/mbjtm.v9i1.13185.

Youssef, E., Abdullah, E., Amr, E., & Maher, R. (2025). Performance Optimization of Centrifugal Pumps: Experimental Analysis of Flow Enhancement and Cavitation Mitigation Under Variable Operating Conditions. *Flow Measurement and Instrumentation, 106* (1), 1-12. https://doi.org/10.1016/j.flowmeasinst.2025.103043.

Dongwei, W., Wensheng, M., Weiguo, Z., Rui, C., & Youchao, Y. (2025). Experimental Acoustic Analysis of Cavitation in a Centrifugal Pump. *Fluid Dynamics & Materials Processing*, *21* (4), 877-890. https://doi.org/10.32604/fdmp.2024.055220.

Yanyu, C., Futai, G., Qingmiao, D., & Bin, C. (2025). Investigation of Cavitation Damage Patterns in Centrifugal Pump Blades Under Rotating Flow Fields. *Journal of Pipeline Science and Engineering. 5* (4), 1-12. https://doi.org/10.1016/j.jpse.2025.100288.

Ahmed, R, and Ali, H, S. (2025). Experimental and Numerical Study of the Effect of Cavitation Detection on Hydraulic Performance of the Centrifugal Pump Based on Different Geometrical Configurations. *Journal of Engineering Research, 230* (2), 1-21. 2025. https://doi.org/10.1016/j.jer.2024.11.006.

Seyed, E H., Amin, D., Pouyan, T., Hayder, I M., & Amir, K. (2024). Developing a Numerical Framework to Study the Cavitation and Non-Cavitation Behaviour of a Centrifugal Pump Inducer. *International Journal of Naval Architecture and Ocean Engineering, 16* (4), 1-17. https://doi.org/10.1016/j.ijnaoe.2024.100606.

Weixiang. Y., Hao. Liu, Hong. Wang, & Xianwu, Lu. (2025). Towards the Pumped-Hydro Energy Storage: Improvement on the Flow Instability and Cavitation Performance With Application-Oriented Forward Skew angle of Impeller Blades. *Energy, 361* (1). 1-15. https://doi.org/10.1016/j.energy.2025.134565.

Leilei, J., Wei, P., Wei, L., Weidong, S., Yang, Y, Cui, X., Fei, T., Jie, Z., & Ramesh, A. (2025). PIV Experimental Study on Dynamic and Static Interference Flow Field of Multi-Operating Centrifugal Pump Under the Influence of Impeller Wake. *Experimental Thermal and Fluid Science, 161* (1), 1-14. https://doi.org/10.1016/j.expthermflusci.2024.111355.

Bingyang, S., Zheming, & T., Hao, L. (2025). A Lightweight Vision Transformer Framework Integrated with Flow Visualization for Incipient Cavitation Diagnosis in Centrifugal Pumps. *Flow Measurement and Instrumentation, 106* (4), 1-14. https://doi.org/10.1016/j.flowmeasinst.2025.103016.

Song, P., Wei, Z., Zhen, H., Liu, M., & Ren, J. (2022). Effects of Pre-Whirl and Blade Profile on the Hydraulic and Cavitation Performance of a Centrifugal Pump. *International Journal of Multiphase Flow, 157* (4), 1-14. https://doi.org/10.1016/j.ijmultiphaseflow.2022.104261.

Ramirez, R., Avila, E., Lopez, L., Bula, A., Forero, J D. (2020). CFD Characterization and Optimization of the Cavitation Phenomenon in Dredging Centrifugal Pumps. *Alexandria Engineering Journal, 59* (2), 291-309. https://doi.org/10.1016/j.aej.2019.12.041.

Xianwei, L., Jiangfeng, F., Junjie, Y., Dewen, Y., Zhenhua, Z., & Huacong, L. (2024). Numerical Simulation Research on Multiphase Flow of Aviation Centrifugal Pump Based on Open Foam. *Chinese Journal of Aeronautics. 37* (4), 256-275. y Elsevier Chinese Journal of Aeronautics, (2024), 37(4): 256–275. https://doi.org/10.1016/j.cja.2023.11.016.

Hui, S., Qingqi, L., Qiaorui, S., Ning, C., Shouqi, Y. (2024). Cavitation Detection Via Motor Current Signal Analysis for a Centrifugal Pump in the Pumped Storage Pump Station. *Journal of Energy Storage. 81* (1), 1-15. https://doi.org/10.1016/j.est.2024.110417.

Alvaro, P, V., Adrián, P., Raúl, B, P., José, G, P., (2026). Numerical Assessment of the Cavitation-Induced Impeller-Volute Interaction in a Centrifugal Pump. *European Journal of Mechanics - B/Fluids*, *119* (1), 1-21. https://doi.org/10.1016/j.euromechflu.2026.204501.

Ilario, C., Fabio, B., Giovanni, P., Roberto, T., Stefano, F. (2026). Performance and Cavitation in Automotive Centrifugal Pumps: Experimental Analysis and 3D-CFD Modelling Assessment. *Applied Thermal Engineering*, *284* (2), 1-22. https://doi.org/10.1016/j.applthermaleng.2025.129130.

Zhengzhuang, Z., Bowen, S., Kelin, W., Dazhuan, W. (2026). An Interpretable Cavitation Recognition Method for Centrifugal Pumps Based on Multiscale Convolutional Neural Network. *Mechanical Systems and Signal Processing*, *241* (4), 1-18. https://doi.org/10.1016/j.ymssp.2025.113503.