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Optimization of Centrifugal Pump Properties to Improve the Accuracy of Water Discharge and Pump Head Measurements

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Abstract

Centrifugal pumps are extensively used in industries and water management systems, where accurate measurements of water flow rate and pump head are essential for evaluating performance. However, inaccuracies arising from suboptimal designs of training kits present challenges in educational environments. This study aimed to optimize a centrifugal pump training kit to enhance measurement accuracy and reliability. The research was conducted over four months, involving modifications to the impeller, casing, and pressure measurement systems, along with rigorous calibration to minimize errors. Measurements of suction pressure, discharge pressure, water flow rate, and pump head were repeated under standardized conditions to ensure data consistency. The results demonstrated significant improvements, with consistent measurements of suction pressure (21 inHg), discharge pressure (15 PSI), water flow rate (0.5 L/s), and pump head (1.38 mH₂O). These optimizations reduced system inefficiencies, such as backflow and turbulence, and enhanced the kit's ability to replicate real-world operating conditions. The improved training kit provides students with a reliable tool for practical learning, bridging theoretical concepts with real-world applications in fluid mechanics. This study underscores the importance of continual enhancement of laboratory teaching tools to support effective education and industrial relevance.

Keywords: *accuracy, centrifugal pump, fluid mechanics, measurement, teaching aids*

Introduction

Centrifugal pumps play a vital role in various applications, including industrial processes, water treatment, and piping systems in multi-storey buildings (Gunawan et al., 2021; Permana, Hanifi, & Kardiman, 2021; Tarigan, 2020; Utama & Kusuma, 2018). These pumps operate by converting mechanical energy into fluid kinetic energy and pressure through the rotation of an impeller (Gunawan et al., 2021). This process ensures continuous fluid movement, making centrifugal pumps essential in both industrial and academic contexts. The effectiveness of a centrifugal pump system is influenced by factors such as design, maintenance, and operational parameters. Utama and Kusuma (2018) emphasized the importance of regular maintenance, including lubrication and component checks, to prevent efficiency losses and mechanical failures. Similarly, Gunawan et al. (2021) highlighted that improper system design, such as neglecting head losses in the piping network, can lead to cavitation and reduced pump performance. Permana et al. (2021) added that discrepancies between theoretical and actual pump performance often arise from friction losses and suboptimal configurations, necessitating accurate performance assessments and adjustments.

In academic settings, centrifugal pump trainers are critical for teaching fluid mechanics principles. These trainers enable students to directly measure key parameters such as flow rate and head, bridging theoretical knowledge with practical applications (Saputra, 2020; Yani et al., 2022). However, many trainers are hindered by design limitations that result in measurement inaccuracies, which can obstruct students' understanding of pump operations. Addressing these issues through system optimization, as suggested by Saputra (2020), not only enhances data accuracy but also improves the educational experience. Design improvements to centrifugal pump trainers must address key components, including the impeller, casing, and measurement systems, while minimizing losses and ensuring proper calibration (Gunawan et al., 2021). Optimized trainers can simulate real-world pumping conditions more effectively, enabling students to analyze pump characteristics such as series and parallel configurations, and gain deeper insights into operational efficiency.

This study aims to optimize laboratory centrifugal pump trainers to improve the accuracy of flow rate and pump head measurements. The findings are expected to enhance the quality of practical learning in fluid mechanics and provide educational institutions with guidelines for improving mechanical engineering teaching tools.

Research Methods

This study was conducted over four months, from August to November 2024, at the Manufacturing Process Laboratory, Faculty of Industrial Technology, Universitas Nahdlatul Ulama Al Ghazali Cilacap. The research aimed to optimize the laboratory centrifugal pump equipment and improve the accuracy of water flow rate and pump head measurements. The sample used was a centrifugal pump training kit, focusing on components such as the impeller, casing, and pressure measurement system. The research variables included component modifications as the independent variable, measurement accuracy of flow rate and head as the dependent variables, and operating conditions of the equipment as the controlled variable. The research methodology involved literature review, equipment preparation, testing, measurement, and data analysis.

1. Literature Review

   The first step involved conducting a literature review on the working principles of centrifugal pumps, parameters for measuring water flow rate and pump head, and optimization techniques for laboratory teaching aids. The literature consulted included scientific journals, fluid mechanics textbooks, and centrifugal pump testing references. The aim of this review was to understand key aspects influencing the performance of centrifugal pumps, which formed the basis for optimizing the equipment design.

2. Preparation of the Centrifugal Pump Training Kit

   In this phase, the centrifugal pump equipment was prepared and calibrated in the laboratory. Optimization was performed by improving the main components as follows:

   (1) Impeller: Ensured the impeller was in optimal condition to operate effectively and produce stable pressure.

   (2) Casing and Piping: Inspected the condition of the housing and piping to ensure no obstructions hinder fluid flow and maintained the impeller’s efficiency.

   (3) Pressure Gauge and Flow Meter: Calibrated using standard methods to ensure the gauges provided accurate measurements aligned with operational conditions. These adjustments aimed to minimize measurement errors caused by suboptimal equipment components.

3. Testing Process

   After preparing the training kit, tests were conducted by flowing water through the centrifugal pump. Testing involved measuring each parameter using two pumps under the same operating conditions, with all four valves fully open. Key parameters measured included inlet pressure, outlet pressure, water flow rate, and pump head. Each measurement was repeated three times to ensure the consistency and stability of the results.

4. Performance Parameter Measurements

The main parameters measured during testing were as follows:

(1) Suction Pressure and Discharge Pressure: Measured using pressure gauges, recording the pressures at the suction and discharge sides of the pump.
(2) Water Flow Rate: Determined by recording the height of water collected in the storage tank over one minute and calculating the flow rate per unit time.
(3) Pump Head: Calculated based on the height and length of the pipes and the number of bends in the system. Each measurement was repeated three times to ensure consistent data results.

5. Data Analysis

Data collected from the measurements of water flow rate and pump head were analyzed to assess the performance of the training kit after optimization. The analysis involved comparing measurement results from three test repetitions to ensure data consistency and stability. The focus was on the accuracy of the measurements and the conformity of the training kit with the simulated operating conditions of an actual centrifugal pump.

6. Evaluation and Conclusion

After data collection and analysis, an evaluation was conducted to assess the performance of the training kit post-optimization. This evaluation included the effectiveness of the optimization in generating consistent data for suction pressure, discharge pressure, and water flow. The findings of this study provided insights into the stability of the training kit in simulating centrifugal pump operating conditions and supported student practical learning through more accurate and reliable measurement data.

Results and Discussions

A. Results of Suction Pressure Measurement

The suction pressure was measured in inHg using a pressure gauge. Three tests were conducted under the same operating conditions, using two pumps with all four valves fully open. The suction pressure measurements are as follows Table 1:

Table 1. Suction Pressure Measurement

No	Test	Suction Pressure (inHg)
1	First Test	21
2	Second Test	21
3	Third Test	21

The suction pressure consistently measured at 21 inHg, reflecting an ideal and stable condition based on proper calibration of the equipment and system settings. This value is within the expected range for normal operating conditions of the centrifugal pump training kit. The calibration of the pressure gauge minimized errors from mechanical wear or misalignment, ensuring accurate and reliable measurements.

The adjustments to the impeller and casing also played a critical role in reducing system inefficiencies, such as backflow or air leakage, thereby improving the stability of the suction pressure. This stability is essential for maintaining steady fluid intake and efficient energy transfer during pump operation. External factors, such as ambient temperature fluctuations and surrounding air pressure conditions, were controlled to minimize their influence on the results.

The stable suction pressure demonstrates the effectiveness of the optimization process in improving the trainer's performance. It ensures that the pump operates within its design specifications, providing students with a reliable baseline for understanding suction pressure principles and their relationship to system performance. This consistency highlights the training kit’s value as a practical tool for teaching fluid mechanics and preparing students for real-world applications.

B. Results of Discharge Pressure Measuremen

Discharge pressure was measured in PSI with the same testing conditions as suction pressure. The readings are as follows Table 2:

Table 2. Discharge Pressure Measurement

No	Test	Discharge Pressure (PSI)
1	First Test	15
2	Second Test	15
3	Third Test	15

The discharge pressure consistently measured at 15 PSI across all tests, indicating that the optimized centrifugal pump training kit can maintain stable output under similar operating conditions. The stability of the discharge pressure highlights the success of the calibration and optimization process in reducing variability caused by mechanical inefficiencies or external disturbances.

Achieving a stable discharge pressure of 15 PSI underscores the effectiveness of optimizing the impeller design and ensuring proper alignment within the casing. These modifications minimized energy losses during the conversion of mechanical energy to pressure energy. Additionally, the calibration of the discharge pressure gauge ensured precise measurements, enabling the trainer to replicate real-world operating conditions.

This consistency is critical in industrial applications, where predictable performance is essential for piping systems requiring precise pressure management. For students, the results illustrate the importance of discharge pressure as a key parameter for evaluating pump performance. The training kit not only provides accurate and reliable data but also serves as a practical tool for teaching the principles of fluid dynamics and demonstrating how design and calibration influence real-world outcomes.

C. Results of Water Flow Rate Measuremen

The water flow rate was measured by recording the height of water collected in a storage tank over 1 minute. Testing was conducted using two pumps with all four valves fully open. The results are as follows Table 3:

Table 3. Water Flow Rate Measurement

No	Test	Flow Rate (L/s)
1	First Test	0,5
2	Second Test	0,5
3	Third Test	0,5

The water flow rate was consistently 0.5 L/s across all tests, aligning closely with theoretical calculations based on the pump's design specifications. This consistency indicates that the optimized centrifugal pump training kit accurately simulates real-world pumping conditions, making it a reliable platform for practical learning.

The consistent flow rate highlights the effectiveness of optimizing the pipe configuration and eliminating obstructions, which ensured smoother fluid flow by reducing turbulence and resistance within the system. Additionally, the calibration of the flow meter contributed to the accuracy of the measurements, providing reliable data for analyzing pump efficiency. Such optimizations enhance the trainer's ability to replicate real-life fluid transfer systems and meet the demands of precision in industrial applications.

For students, the results provide a practical understanding of flow rate dynamics and the factors affecting them, bridging theoretical concepts and their application in fluid mechanics. Achieving consistent flow rates is also essential in industrial systems where precise fluid delivery is critical, further validating the effectiveness of the training kit's optimization.

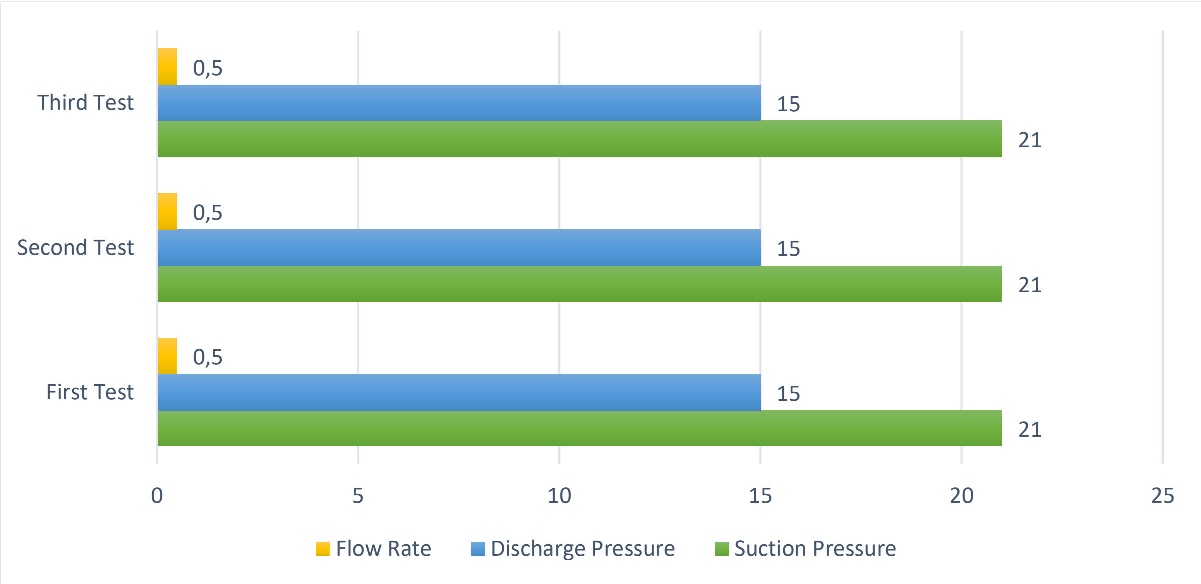

Figure 1. Comparison of Suction Pressure, Discharge Pressure, and Water Flow Rate Across All Tests

Figure 1 presents the comparison of suction pressure, discharge pressure, and water flow rate for the three tests conducted. As shown, the suction pressure remained consistently at 21 inHg across all tests, the discharge pressure was stable at 15 PSI, and the water flow rate was consistently measured at 0.5 L/s. This consistency across parameters indicates the successful optimization of the training kit, ensuring stable and reliable performance during the experiments.

D. Results of Pump Head Measurement

The pump head was measured by calculating the pipe height from the water level to the suction port and accounting for pipe bends within the system. The results are Shown on the Table 4 below:

Table 4. Pump Head Measurement

No	Measurement	Result
1	Vertical Pipe	262 cm
2	Horizontal Pipe	127 cm
3	Suction Pipe	100 cm

4	Number of Elbows	11 units
5	Number of Valves	4 units

The pump head was calculated using Equation (1):

$$Pump\ Head = \frac{Height\ Difference}{1} + \frac{Total\ Pipe\ Length}{3} + (Number\ of\ Bends \times 0{,}5) \quad (1)$$

Substituting values using Equation (2):

$$Pump\ Head = 1 + \frac{389}{3} + (15 \times 0{,}5) = 138{,}17 cmH_2O \approx 1{,}38\ mH_2O \quad (2)$$

The calculated pump head of 1.38 mH_2O demonstrates that the optimized training kit provides realistic pump head values for operational conditions typically encountered in centrifugal pump applications. By optimizing the system, including pipe configuration, gauge calibration, and bend adjustments, the equipment accurately simulates flow and resistance conditions, ensuring efficient energy transfer from the pump to the fluid. These optimizations reduced unnecessary resistance and balanced the system, providing reliable data for analyzing the relationship between flow resistance and energy transfer in a pumping system. The accurate simulation of head losses also enhances students' understanding of the interplay between pump head, pipe length, and resistance, offering practical insights into the design and efficiency of piping systems.

From an industrial perspective, the results validate the training kit as an effective simulation tool for designing and testing efficient piping systems. For educational purposes, the stable pump head value helps students explore key principles of fluid mechanics and energy efficiency, preparing them for real-world engineering applications. In future studies, it is recommended to investigate the effects of varying valve openings, such as 25%, 50%, 75%, and 100%, on key parameters including water discharge, pump head, suction pressure, and discharge pressure. Exploring these variations could provide deeper insights into the influence of operational conditions on pump performance and facilitate further optimization of the training kit for enhanced educational and industrial applications.

Conclusions

The consistent measurements of suction pressure (21 inHg), discharge pressure (15 PSI), and water flow rate (0.5 L/s) demonstrate the effectiveness of the optimized centrifugal pump training kit in providing accurate and reliable data. The improvements to the impeller design, casing, and measurement system successfully reduced variability and enhanced the system’s reliability for simulating key centrifugal pump parameters. The steady-state operation, indicated by stable suction and discharge pressures, ensures fluid flow remains unaffected by pressure fluctuations, maintaining accuracy in flow rate and pump head measurements. Additionally, the optimization of the training kit addressed prior technical issues, such as leaking pipes, malfunctioning pressure gauges, and system instability, resulting in significantly improved performance across all measured parameters. These optimizations not only improve measurement accuracy but also enhance the efficiency of laboratory-based learning. By providing consistent and reliable data, the training kit facilitates a better understanding of fluid mechanics, enabling students to connect theoretical concepts with practical applications. This enhanced reliability reduces distractions caused by equipment inconsistencies, allowing instructors to focus on advanced concepts during instruction.

In the long term, the improved training kit contributes to developing students' practical skills and preparing them for industrial challenges. It also supports practice-based technical education, fostering innovation and aligning with the needs of modern technological advancements. Despite its success, some limitations remain, such as the susceptibility of pipe joints to leakage, which can affect measurement accuracy. Ensuring tight seals and careful maintenance is essential to maintaining the system's performance. Future studies should explore further optimizations, including varying valve openings and refining piping configurations, to deepen understanding of pump performance under diverse operational conditions.

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