Experimental Analysis of Major and Minor Flow Losses in Centrifugal Pump Piping Systems

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Abstract.
Pumping and piping systems play a crucial role in transporting fluids in industrial and laboratory applications. However, energy losses occurring within the piping network can significantly reduce hydraulic performance and overall system efficiency. This study aims to experimentally analyze major and minor head losses in a centrifugal pump piping system under controlled laboratory conditions. The experimental setup employed a ½-inch PVC pipe with three piping configurations, namely a straight pipe, a 45° elbow, and a 90° elbow. Flow conditions were varied by adjusting the valve opening to produce different discharge rates. The measured parameters included flow rate and pressure difference, while flow velocity, Reynolds number, major head loss, and minor head loss were determined through standard fluid mechanics calculations. The experimental results indicate that increasing the flow rate leads to a significant increase in total head loss due to higher flow velocity and greater friction along the pipe wall. Furthermore, the 90° elbow generated higher minor head loss than the 45° elbow because the sharper change in flow direction produced stronger turbulence. These findings are consistent with fluid flow theory and demonstrate that both flow rate and fitting geometry have a substantial influence on energy losses. The results can serve as a useful reference for designing and operating more efficient centrifugal pump piping systems.
Keywords*: centrifugal pump, piping system, major head loss, minor head loss, flow rate, experimental analysis.*

I. INTRODUCTION

Pumping systems are a crucial component in fluid transfer processes across various industrial sectors, power plants, water treatment plants, laboratories, and other fluid distribution systems. Pumps provide mechanical energy to fluids, allowing them to flow through piping networks to their intended locations. For optimal pumping system performance, proper piping design is essential to minimize energy loss during the flow process.

In a piping system, flowing fluids cannot retain their energy completely because some energy is lost due to friction between the fluid and the pipe walls or due to the presence of piping components such as valves, elbows, tees, reducers, and changes in flow direction. This energy loss is known as head loss. The amount of head loss is greatly influenced by the characteristics of the fluid flow, pipe length, pipe diameter, pipe surface roughness, flow velocity, and the number of piping components used.

In general, flow losses are divided into two types: major losses and minor losses. Major losses are energy losses due to friction along a straight pipe, while minor losses result from additional components such as valves, connections, bends, and narrowing or widening of the pipe cross-section. Both types of flow losses significantly impact fluid pressure, flow rate, pump power requirements, and pumping system efficiency. If the flow loss is too large, the pump must work harder to maintain the desired flow rate, thereby increasing energy consumption.

In piping system design, flow loss analysis is a crucial aspect. Mistakes in determining the piping system configuration can lead to decreased pump performance, increased electrical energy consumption, and even shortened pump operating life due to increased workload. Therefore, an analysis capable of describing the magnitude of flow losses is necessary to determine the most effective piping system characteristics.

Several previous studies have shown that flow loss is influenced by various factors such as pipe diameter, pipe length, pipe material type, surface roughness, bend angle, number of fittings, and valve openings. Research on the influence of centrifugal pump configuration also shows that changes in system configuration can affect flow rate, pump head, and system efficiency. Furthermore, research on head loss in piping systems shows that components such as elbows, tees, reducers, and valves contribute significantly to total energy loss. However, most studies only discuss one type of flow loss or focus solely on theoretical analysis without conducting direct testing using a piping system connected to a centrifugal pump.

Based on these conditions, this study was conducted to analyze major and minor flow losses in a centrifugal pump piping system using a laboratory experimental method. Testing was carried out by varying the valve opening to obtain several flow rate conditions. The parameters observed included pressure, flow rate, flow velocity, and fluid flow characteristics. The test data were then analyzed using the continuity equation, Reynolds number, Darcy–Weisbach equation, and the minor flow loss equation to determine the amount of energy loss that occurs in each test condition.

The results of this study are expected to provide information regarding the characteristics of flow losses in centrifugal pump piping systems and serve as a reference in the design and operation of more efficient pumping systems. Furthermore, this study is also expected to contribute as learning material in the field of fluid mechanics, particularly regarding the analysis of flow losses in laboratory-scale piping systems and industrial applications.

II. RESEARCH METHODS

Types of research

This experimental study aims to analyze major and minor head losses in a centrifugal pump piping system. Testing was conducted by varying the valve opening to obtain changes in flow rate, thus determining its effect on flow characteristics and the magnitude of flow losses.

The system consists of a centrifugal pump as a flow driver, a ½ inch diameter PVC pipe as a flow path, a valve to regulate the flow rate, a manometer to measure pressure, and a flowmeter to determine the flow rate during testing.

Data collection technique

The research data was obtained through direct testing on a centrifugal pump piping system with varying valve openings. Measurements were made using a manometer to obtain pressure data and a rotameter (*flowmeter*) to measure the flow rate. The measurement data is then used as the basis for calculating flow velocity, Reynolds number, major flow loss, minor flow loss, and total flow loss.

Data Analysis Techniques

The test data were analyzed descriptively quantitatively. The pressure and flow rate data were processed using the continuity equation to obtain the flow velocity, the Bernoulli equation which has been modified by including the energy loss component (*head loss*), the Darcy–Weisbach equation to calculate major flow losses, the minor loss equation to calculate minor flow losses, and the Reynolds number to determine flow characteristics. The calculation results are presented in the form of tables and graphs, then analyzed to determine the effect of valve opening variations on flow losses in the piping system.

III. RESULTS AND DISCUSSION

Test Results

This study was conducted to determine the effect of flow rate on the magnitude of major head loss and minor head loss in a centrifugal pump piping system. Testing was conducted using three piping configurations: a straight pipe, a pipe with a 45° elbow, and a pipe with a 90° elbow. The valve opening variations used were 0%, 25%, 50%, and 75%. The parameters observed included flow rate, pump pressure, inlet pressure, and outlet pressure, which were then used to calculate major head loss, minor head loss, and total head loss

.Table 1. Results of 0% Valve Opening Test

Tap opening 0%	Types of pipes	Pipe length (m)	Pipe diameter (m)	Flow Rate (M3/s)	Pump Pressure (Kpa)	Inlet Pressure (Kpa)	Outlet Pressure (Kpa)

	Big Straight	1.03	0.17	0.9	2	2.2	2.25
	Elbow 90	2.16	0.16	0.7	2.32	2	2.25
	Elbow 45	1.31	0.23	0.8	2.1	2.24	2.25

Based on Table 4.1, at 0% valve opening, different flow rates are obtained for each piping configuration. A straight pipe produces a flow rate of 0.60 m³/s, a 90° elbow produces 0.70 m³/s, and a 45° elbow produces 0.80 m³/s. These differences in flow rates are followed by changes in pump pressure, inlet pressure, and outlet pressure. The greater the flow rate produced, the greater the energy of the flowing fluid, so that the resulting flow losses also tend to increase.

Table 2 Results of 25% Valve Opening Test

Tap opening 0.25%	Types of pipes	Pipe length (m)	Pipe diameter (m)	Flow Rate (M3/s)	Pump Pressure (Kpa)	Inlet Pressure (Kpa)	Outlet Pressure (Kpa)
	Big Straight	1.03	0.17	0.6	2.45	2.25	2.50
	Elbow 90	2.16	0.16	0.45	2.40	2.1	2.50
	Elbow 45	1.31	0.23	0.46	2.40	2.50	2.51

Based on Table 4.2, after the valve opening was changed to 25%, the flow rate decreased across all piping configurations compared to the 0% opening condition. The straight pipe produced a flow rate of 0.60 m³/s, the 90° elbow 0.50 m³/s, and the 45° elbow 0.46 m³/s. The decrease in flow rate also caused a change in flow pressure, resulting in a decrease in the calculated flow loss compared to the previous condition.

Table 3 Results of 50% Valve Opening Test

Tap opening 0.5%	Types of pipes	Pipe length (m)	Pipe diameter (m)	Flow Rate (M3/s)	Pump Pressure (Kpa)	Inlet Pressure (Kpa)	Outlet Pressure (Kpa)
	Big Straight	1.03	0.17	0.40	2.40	2.20	2.50
	Elbow 90	2.16	0.16	0.34	2.40	2.25	2.52
	Elbow 45	1.31	0.23	0.35	2.40	2.50	2.52

Based on Table 4.3, at 50% valve opening, the flow rate decreases again. The straight pipe produces a flow rate of 0.40 m³/s, the 90° elbow 0.34 m³/s, and the 45° elbow 0.35 m³/s. The pump pressure value does not experience a significant change, but the change in flow rate causes the flow rate to decrease, thus reducing both major and minor flow losses.

Table 4 Results of 75% Valve Opening Test

Tap opening 0.75%	Types of pipes	Pipe length (m)	Pipe diameter (m)	Flow Rate (M3/s)	Pump Pressure (Kpa)	Inlet Pressure (Kpa)	Outlet Pressure (Kpa)
	Big Straight	1.03	0.17	0.30	2.50	1.50	1.95

	Elbow 90	2.16	0.16	0.28	2.50	1.50	1.90
	Elbow 45	1.31	0.23	0.25	2.50	1.60	1.95

Based on Table 4.4, a 75% valve opening produces the smallest flow rate compared to other opening variations. The flow rate for a straight pipe is 0.30 m³/s, a 90° elbow is 0.28 m³/s, and a 45° elbow is 0.25 m³/s. The decrease in flow rate causes the flow velocity to decrease, resulting in lower energy loss due to friction and changes in flow direction compared to larger valve openings.

Test Results Analysis

In general, test results show that changes in valve opening affect the flow rate produced by centrifugal pumps. The larger the valve opening, the greater the flow rate in the piping system. Conversely, a smaller flow rate reduces the flow velocity, thus reducing flow losses in the piping system.

Besides being influenced by flow rate, piping configuration also influences fluid flow characteristics. Straight pipes produce less flow resistance because there is no change in flow direction. Meanwhile, the use of 45° and 90° elbows causes turbulence due to changes in flow direction, resulting in greater energy loss in the system. Therefore, test data from each valve opening variation was then analyzed using a graph of the relationship between flow rate and major head loss, minor head loss, and total head loss.

The Effect of Flow Rate on Major Head Loss

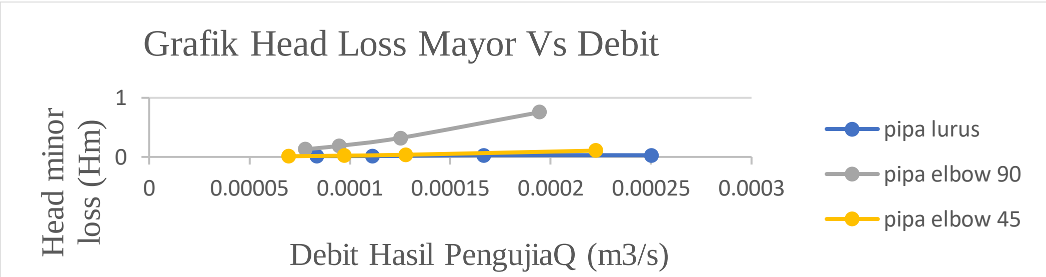

Fig. 1 Graph of the Relationship between Flow Rate and Major Head Loss

Based on Figure 4.1, the major head loss value increases with increasing flow rate in all three piping configurations. Increasing flow rate causes the fluid flow velocity to increase, thus increasing friction between the fluid and the pipe walls. Consequently, energy loss along the pipe increases.

In a straight pipe configuration, major head loss is only affected by friction along the pipe, so its value is relatively smaller. In 45° and 90° elbow configurations, in addition to frictional losses along the pipe, the flow is also affected by changes in flow direction, which causes a less even velocity distribution. This condition causes the major head loss values in both configurations to tend to be higher than in straight pipes.

The results of this study indicate that flow rate is one of the main factors influencing the magnitude of major flow losses in a piping system. The greater the flow rate, the greater the energy lost due to friction along the pipe. This result aligns with the Darcy–Weisbach theory, which states that major head loss is directly proportional to the square of the flow velocity.

Effect of Flow Discharge on Minor Head Loss

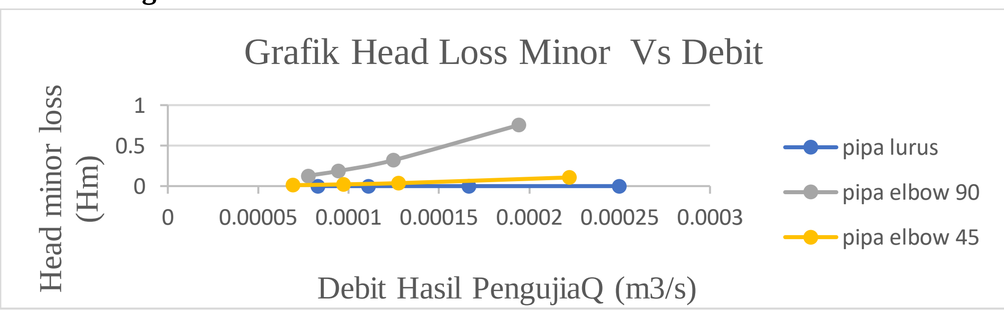

Fig. 2 Relationship between Flow Discharge and Minor Head Loss

Based on Figure 4.2, the minor head loss value is influenced by the flow rate and the piping configuration used. As the flow rate increases, the minor head loss value also increases in piping configurations that use elbows. This indicates that the greater the flow rate, the higher the fluid velocity as it passes through the pipe connection, resulting in greater turbulence.

In a straight pipe configuration, minor head loss is not present because there are no components that cause a change in flow direction. Therefore, energy loss in this configuration comes solely from friction along the pipe (major head loss).

In the 45° elbow configuration, the minor head loss value increases with increasing flow rate. This is due to the 45° change in flow direction, which disrupts the flow pattern. However, the resulting turbulence remains relatively less than in the 90° elbow.

Meanwhile, the 90° elbow configuration produced the largest minor head loss across all flow rate variations. The sharper bend angle causes the flow to change direction significantly, resulting in greater turbulence. This results in increased energy loss due to the fitting compared to other configurations.

The results of this study indicate that the greater the bend angle in a piping system, the greater the minor head loss. This finding aligns with the theory of minor energy loss, which states that energy loss is influenced by the loss coefficient of each fitting type. A 90° elbow has a higher loss coefficient than a 45° elbow, resulting in higher flow losses.

Effect of Flow Rate on Total Head Loss

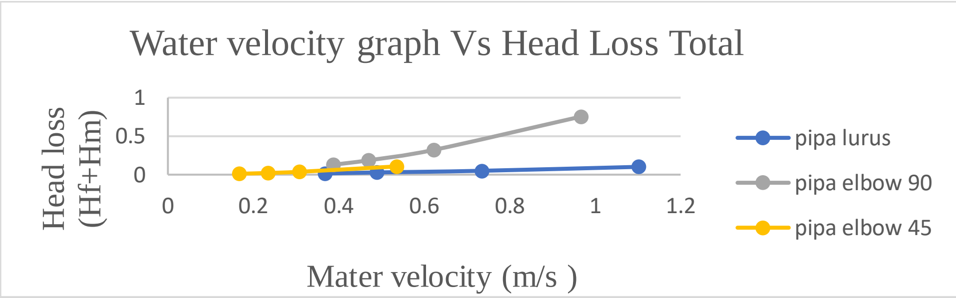

Figure 3 Relationship between Flow Rate and Total Head Loss

Based on Figure 4.3, the total head loss value increases as the flow rate increases across all piping configurations. Total head loss is the sum of major and minor head losses, and is therefore influenced by friction along the pipe and resistance caused by fittings.

In a straight pipe configuration, the total head loss is the result of the major head loss because there is no energy loss due to changes in flow direction. The total head loss in this configuration is the smallest compared to other configurations.

In a 45° elbow configuration, the total head loss is greater than in a straight pipe. This is due to the additional energy loss caused by the 45° elbow, which causes the flow to change direction and generate turbulence. However, the energy loss is still lower than in a 90° elbow configuration.

The 90° elbow configuration produced the highest total head loss for each flow rate variation. This indicates that using an elbow with a larger bend angle creates higher flow resistance, thus increasing energy loss during fluid flow. In addition to friction along the pipe, the magnitude of energy loss in this configuration is influenced by the high minor head loss due to the sharp change in flow direction.

Overall, the research results show that increasing flow rate results in an increase in total head loss across all piping configurations. Furthermore, the use of fittings with larger bend angles also increases energy loss in the piping system. Therefore, when designing a centrifugal pump piping system, the selection of piping configurations must consider the number and type of fittings used to minimize flow losses and maintain system efficiency.

Total Head Loss to Debit Graph

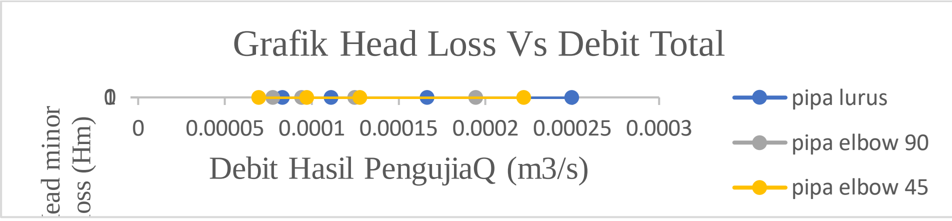

Fig 3 Graph of Total Head Loss Against Debit

Based on the Head Loss versus Flow Rate Graph, it can be seen that the greater the flow rate, the head loss value also increases in all piping system configurations, namely straight pipes, pipes with 45° elbows, and pipes with 90° elbows. This shows that increasing flow rate causes energy loss due to friction and flow resistance to increase.

In straight pipes, head loss is the smallest and increases gradually as the flow rate increases. Meanwhile, pipes with 45° elbows produce slightly greater head loss than straight pipes due to the change in flow direction, which increases resistance in the piping system.

In contrast to these two configurations, the pipe with a 90° elbow produces the highest head loss for each increase in flow rate. The increase in head loss in this configuration is significantly greater than in the straight pipe or the 45° elbow, indicating that the 90° bend causes greater turbulence and energy loss.

Overall, the graph shows a direct relationship between flow rate and head loss. Besides being influenced by the flow rate, the head loss value is also influenced by the piping configuration. Based on the test results, a 90° elbow produces the greatest head loss, followed by a 45° elbow, while a straight pipe produces the smallest head loss. Therefore, it can be concluded that the greater the bend angle in the pipe, the greater the energy loss.

Comparison of Test Results

Based on the test results, it was found that the piping configuration influences the head loss in a centrifugal pump piping system. Across all flowrate and flowrate variations, the head loss values tended to increase with increasing flowrate and flowrate. This indicates that the greater the flow energy passing through the pipe, the greater the energy loss.

Thus, it can be concluded that piping configuration has a significant impact on the efficiency of a piping system. The use of straight pipes results in the lowest energy loss, while the use of elbows, especially 90° elbows, results in greater energy loss and therefore needs to be considered in piping system design.The test data results table is as follows:

Table1 Overall Calculation Result Data

No	Valve Aperture (%)	Pipe Types	Discharge (m^3/s)	Speed (m/s)	Reynolds	Head Loss Major (m)	Head Loss Minor (m)	Total Head Loss (m)
1	0	Straight Pipe	0.000250	1,101977	18,733.61	0.101418	0.000000	0.101418
2	0	90° Elbow	0.000194	0.967578	15,481.25	0.182722	0.572604	0.755326
3	0	Elbow 45°	0.000222	0.535134	12,308.07	0.024972	0.081736	0.106708
4	25	Straight Pipe	0.000167	0.734651	12,489.07	0.049883	0.000000	0.049883
5	25	90° Elbow	0.000125	0.622014	9,952.23	0.084332	0.236637	0.320969
6	25	Elbow 45°	0.000128	0.307702	7,077.14	0.009481	0.027024	0.036505
7	50	Straight Pipe	0.000111	0.489768	8,326.05	0.028585	0.000000	0.028585
8	50	90° Elbow	0.000094	0.469966	7,519.46	0.051637	0.135088	0.186724

No	Valve Aperture (%)	Pipe Types	Discharge (m^3/s)	Speed (m/s)	Reynolds	Head Loss Major (m)	Head Loss Minor (m)	Total Head Loss (m)
9	50	Elbow 45°	0.000097	0.234121	5,384.78	0.005877	0.015645	0.021522
10	75	Straight Pipe	0.000083	0.367326	6,244.54	0.014830	0.000000	0.014830
11	75	90° Elbow	0.000078	0.387031	6,192.50	0.036762	0.091617	0.128378
12	75	Elbow 45°	0.000069	0.167229	3,846.27	0.003262	0.007982	0.011244

The data in Table 1 shows the results of flow rate measurements and the results of flow parameter calculations using the continuity equation, Reynolds number, Darcy–Weisbach equation, and minor flow loss equation.In the 0% valve table, tests were conducted on three types of piping systems, namely straight pipes, 90° elbows, and 45° elbows. In straight pipes, the discharge was obtained at 0.000250 m^3/s, a flow rate of 1.101977 m/s, and a Reynolds number of 18,733.61. The head loss value that occurred was only a major head loss of 0.101418 m because there were no fittings that caused minor flow losses. In pipes with 90° elbows, the discharge decreased to 0.000194 m^3/s with a flow rate of 0.967578 m/s and a Reynolds number of 15,481.25. The major head loss value was 0.182722 m, while the minor head loss was 0.572604 m, so the total head loss reached 0.755326 m, which was the largest value in this condition. Meanwhile, in a pipe with a 45° elbow, the discharge was 0.000222 m^3/s, the flow velocity was 0.535134 m/s, Reynolds number was 12,308.07, the major head loss was 0.024972 m, the minor head loss was 0.081736 m, and the total head loss was 0.106708 m. These results indicate that the 90° elbow produces the greatest flow loss compared to the 45° elbow or the straight pipe.

At 25% valve opening, the flow rate in all three piping variations decreased compared to 0% valve opening. In a straight pipe, a flow rate of 0.000167 m^3/s was obtained with a total head loss of 0.049883 m. At a 90° elbow, a flow rate of 0.000125 m^3/s resulted in a major head loss of 0.084332 m and a minor head loss of 0.236637 m, resulting in a total head loss of 0.320969 m. Meanwhile, at a 45° elbow, a flow rate of 0.000128 m^3/s resulted in a total head loss of 0.036505 m. This condition shows that even though the flow rate decreased, the 90° elbow still provided the greatest flow loss compared to other piping variations.

At 50% valve opening, the flow rate decreased again in all types of piping. The straight pipe produced a flow rate of 0.000111 m^3/s with a total head loss of 0.028585 m. At the 90° elbow, a flow rate of 0.000094 m^3/s resulted in a total head loss of 0.186724 m, while the 45° elbow with a flow rate of 0.000097 m^3/s resulted in a total head loss of 0.021522 m. These results indicate that a decrease in flow rate causes the head loss value to also decrease, but the 90° elbow still provides greater flow resistance than the 45° elbow and straight pipe.

At 75% valve opening, the smallest flow rate was obtained in all piping variations. The straight pipe produced a flow rate of 0.000083 m^3/s with a total head loss of 0.014830 m. At the 90° elbow, a flow rate of 0.000078 m^3/s resulted in a total head loss of 0.128378 m, while the 45° elbow with a flow rate of 0.000069 m^3/s resulted in a total head loss of 0.011244 m. Compared to the previous valve opening conditions, all head loss values decreased. However, the order of magnitude of flow loss remained the same, namely the 90° elbow produced the largest total head loss, followed by the straight pipe and the 45° elbow according to the test data.

IV. CONCLUSION AND SUGGESTIONS

Conclusion

Based on the results of observations and analysis regarding major flow losses and minor flow losses in the centrifugal pump piping system with variations in valve openings in straight pipes, 45° elbow pipes, and 90° elbow pipes, the following conclusions can be drawn:

1. The calculation results show that the head loss value in the centrifugal pump piping system can be determined using the continuity equation, Reynolds number, Darcy–Weisbach equation, and minor loss equation to obtain the major head loss, minor head loss, and total head loss values.
2. Test results show that the greater the flow rate, the greater the major head loss. This is due to the increased flow velocity, which increases friction between the fluid and the pipe walls.
3. Test results show that the use of elbow fittings affects the magnitude of minor head loss. Pipes with 90° elbows produce the greatest minor head loss compared to 45° elbows and straight pipes due to the sharper change in flow direction.
4. Test results show that the greater the flow rate, the greater the total head loss in the piping system. This indicates that flow rate influences the magnitude of flow loss in centrifugal pump piping systems.

Suggestion

Based on the results of the research on the experimental analysis of major and minor flow losses in centrifugal pump piping systems, there are several areas for further development. Therefore, the authors offer the following suggestions:

1. Further research is recommended to use variations in pipe diameter so that the influence of pipe size on the magnitude of major head loss and minor head loss can be known more clearly.
2. Further research can use various types of fittings, such as tees, reducers, or other types of valves, so that the effect of each component on flow losses can be compared.
3. Before testing is carried out, all equipment such as manometers, flowmeters, and pumps should be calibrated first so that the measurement results are more accurate.
4. The number of test repetitions and variations in flow rate should be increased so that the data obtained is more complete and the analysis results are better.

V. THANK-YOU NOTE

The author would like to express his gratitude to all parties who have provided support and assistance in the preparation of this final assignment. His gratitude is extended to Mr. Jhony Custer, ST., MT. as Director of Bengkalis State Polytechnic, Mr. Ibnu Hajar, ST., MT. as Head of the Mechanical Engineering Department, and Mr. Bambang Dwi Haripriadi, ST., MT. as Head of the D-IV Mechanical Production & Maintenance Engineering Study Program for the guidance and facilities provided during the research. His highest appreciation is also extended to Mr.Mr. Burhan Hafid, ST, MT,Abdul Gafur, S.Si., MT as the Final Project Supervisor who has provided direction, input, and motivation so that this final project can be completed well. The author would like to thank all the lecturers of the Mechanical Engineering Department of Bengkalis State Polytechnic for the knowledge and guidance provided during the study period. The author also expresses his deepest gratitude to his parents and family for their prayers, support, and sacrifices, both morally and materially, so that the author can complete the study. Finally, the author also thanks his friends who have helped and supported in the process of compiling this final project.

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