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Comparative Analysis of Installed and Actual Pump Power in Bilge and Ballast Systems: Study Case on 60 m Buoy Laying Vessel

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Buoy Laying Vessel
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ABSTRACT – The piping system of a ship is an essential system that is crucial for the ship's operation. An example of tasks related to the ship's piping system is the design of the system itself. When designing a piping system, certain assumptions are made in calculating the pump power. As a result, the installed pump power is often greater than the actual pump power needed. In this thesis, the actual pump power in the bilge and ballast piping system of a 60 m buoy laying vessel needs to be analyzed. To achieve this, comprehensive and detailed data collection of the piping system is required. Then, the piping system must be drawn in full detail using 3D software to match the actual installation of the piping system. After that, the actual pump power for the piping system can be calculated. The calculated pump power is 5.79 kW, with the pump specifications being an centrifugal pump model with an output of 7.5 kW, chosen due to selecting a pump power approximately 16% lesser than the existing power.

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INTRODUCTION

In ship engineering, the bilge and ballast systems play a crucial role in maintaining vessel stability and efficient operation. These systems are integral to the ship's design, particularly concerning the piping layout, which must accommodate the unique demands of fluid movement on board. The main component of these systems is the pump, which functions to transfer fluid by elevating its pressure. Accurate pump power calculation is essential to ensure the effective and economical operation of these systems [1]. It is stated in research conducted that selecting the most suitable ballast water treatment system requires careful consideration of multiple factors, including installation and maintenance costs, environmental impacts, and operational efficiency. Accurate pump power calculation is essential to ensure the effective and economical operation of these systems, as it directly influences both fuel consumption and the overall cost-effectiveness of the chosen method [2][3]. Similiar load analysis method enhances power generation efficiency and reduces energy costs by mathematically modeling the relationship between operation efficiency and load factor, using genetic algorithms to optimize generator power. Accurate pump power calculation is essential to ensure the effective and economical operation of these systems, highlighting the importance of energy efficiency in ship power system design [4].

The ballast system stabilizes the vessel by adjusting its weight distribution when the ship is either empty or fully loaded. This involves pumping seawater into ballast tanks to achieve the desired balance. The bilge system, similarly, involves pumping water out of the bilge and ballast tanks, with the pump increasing water pressure to move it through the pipes efficiently [5]. During interviews with the crew of a 60-meter buoy laying vessel, operational issues were identified with the existing pump systems, particularly concerning fuel consumption, which had decreased significantly. This anomaly in fuel usage could be attributed to head losses occurring at pipe joints and bends, resulting in reduced water pressure and extended tank filling times.

Analyzing a ship's piping system design involves a comprehensive assessment of fluid dynamics to ensure optimal performance and efficiency. The design process requires precise calculations of flow rates and pump head to match the operational demands of the ship. An empirical approach, often employed in this analysis, involves collecting detailed data on the physical characteristics of the system, such as pipe diameter, length, and layout, as well as fluid properties like density and viscosity [6]. This data is used to model the system and determine the required flow rate and pump head using equations for head loss and continuity equations for flow rate [7]. These calculations help in selecting appropriate pump specifications, ensuring the system can handle the necessary fluid transfer tasks without overloading or wasting energy. Study using pressure-dependent models conducted to confirm the effective simulation of flow and pressure conditions in complex systems [8]. Study also found The evaluation of ships revealed that only 15% had sample ports fully aligned with ISO standard, indicating that many existing ballast water sampling installations may not facilitate accurate sample collection due to outdated configurations. Future installations should adhere to ISO standards to ensure representative sampling by aligning with current best practices for ship piping system design [9].

Thus, this study aims to conduct a detailed comparative analysis of the ship's pump performance. By examining the installed pump power against the actual pump power required, the research seeks to align pump capacity with the ballast requirements of the vessel. This alignment will help minimize both fuel and electricity consumption, optimizing the pump's efficiency during tank filling operations. The analysis will also provide insights into selecting appropriate pump specifications, especially in cases of pump failure. Furthermore, the findings can be applied to ships with similar specifications, offering a broader impact on operational efficiency across the fleet. The study will provide valuable data to enhance decision-making regarding pump selection and maintenance, ultimately improving the operational sustainability of buoy laying vessels.

METHOD

Research objects

A buoy laying vessel is a specialized ship designed for the installation and maintenance of navigational buoys and other marine aids to navigation. Unlike other ship types, buoy laying vessels are uniquely designed to meet the demands of buoy deployment and retrieval, requiring a detailed analysis of their design and operational features. This includes evaluating their load handling capabilities, stability during buoy installation, and precise positioning, which are critical to their effective and safe operation [10]. Figure 1 shows the example of this ship type.

Figure 1. Buoy Laying Vessel [11]

The size and type of a ship play a crucial role in piping system analysis due to various factors. Firstly, different ships have varying fluid flow requirements based on their operational needs. The piping system must be designed to accommodate these specific flow rates and volumes to ensure efficient operation. Space constraints are another significant consideration. Larger vessels offer more room for complex piping networks, whereas smaller ships necessitate more compact and efficient designs. The analysis of the piping system must account for these spatial limitations to ensure proper installation and functionality within the available space. Detailed dimensions of the ships analyzed in this study case are presented in Table 1.

Table 1. Ship main dimension

Dimension	Size	Unit
Length Overall	60	m
Length Perpendicular	54	m
Breadth	12	m
Height	4,7	m
Installed Pump Power	8,92	kw

Pressure and pumping needs also vary with the ship's size. Larger ships may require higher pressures to move fluids effectively through longer and larger pipes, while smaller ships require less pressure. The piping system design must consider these pressure requirements to avoid overloading and to ensure effective fluid transfer [12]. Regulatory compliance is another critical factor, as different ship types and sizes may be subject to various regulations and standards for piping systems. These regulations could pertain to safety, environmental protection, and operational efficiency. The design and analysis must adhere to these standards to ensure the vessel remains compliant. Finally, operational efficiency is influenced by the ship's specific type and intended purpose. For specialized operations, such as buoy laying, the piping system must be optimized to perform effectively for those tasks. Analyzing the system with regard to the ship's size and type ensures that it operates efficiently for its designated functions.

Pump System

The pump system is a crucial component of a ship's piping system, essential for maintaining stability and operational efficiency. One of the key systems that relies heavily on pumps is the ballast system, which is responsible for carrying and adjusting ballast water to stabilize the ship. Ballast pumps are auxiliary tools that fill and empty ballast water, allowing the ship to maintain a balanced state [13]. This balance is vital for the safety of both the cargo and crew, especially during operations such as loading and unloading. By controlling the amount of water in the ballast tanks, the pumps ensure that the ship remains stable and properly trimmed, preventing any loss of balance that could compromise safety.

Ballast tanks, which store seawater, are strategically placed within the ship to maintain stability both during voyages and cargo operations. These tanks are located in the aft peak, fore peak, and double bottom areas, allowing the ship to adjust its trim and achieve the correct draft. To determine the capacity of these tanks, calculations are performed using formulas that take into account the volume of the tank and the flow rate as shown in Eq. 1, ensuring that the ballast water can be efficiently managed. The pump system plays a vital role in these calculations, as it determines how quickly and effectively the water can be moved in and out of the tanks [14].

$$Q = \frac{V}{t} \tag{1}$$

In Eq. 1, Q is the flow rate, V is the volume of the tank described in m^3, and t is time in hours. Addition to the ballast system, the ship's pump system also includes the bilge system, which serves as a safety mechanism. The bilge system contains bilge pumps that provide emergency drainage for water from all watertight compartments. There are typically two separate bilge systems on a ship: one for general bilge water, and another specifically for the engine room. The engine room bilge system is designed to handle oil-contaminated water, while the general bilge system deals with clean water [15]. These systems are kept separate to ensure that the different types of fluids are managed appropriately.

Another important component of the ship's pump system is the sea chest, a device connected to the hull below the waterline. The sea chest allows seawater to be drawn into the ship for various purposes, such as filling ballast tanks, washing tanks, cooling engines, and supplying fire-fighting systems. The pump system is integral to the functioning of the sea chest, enabling the controlled flow of seawater into the ship [16].

Finally, the ship's pump system incorporates various types of valves. These valves can be operated manually by turning a flywheel or automatically through electro-hydraulic controls from the cargo control room. The pump system, with its complex network of pumps, tanks, and valves, is essential for the safe and efficient operation of the ship's piping systems, ensuring that all fluid transfer processes are conducted smoothly and in accordance with safety regulations.

The analysis conducted will refer to Biro Klasifikasi Indonesia (BKI) Volume III regulations on Machinery Installation Rules Chapter 11 [17] with the main focus on the piping system. Regarding the Bilge System. Calculation for main and branch bilge pipe are shown in Eq. (2) & (3) respectively.

$$d_H = 1.68\sqrt{(B+H)\,x\,L} + 25 \tag{2}$$

$$d_z = 2.15\sqrt{(B+H)\,x\,L} + 25 \tag{3}$$

Which d_H is the internal diameter calculated for the main bilge pipe and d_z is the internal diameter calculated for the branch bilge pipe, all in mm. B, and H are the dimensions of the ship in m. Lastly, l is the length of the watertight compartement shown in metres. Furthermore, the internal diameter of both main and branch bilge pipes must not be less than 50 mm, although for ships with a length of less than 25 m, the diameter can be reduced to 40 mm. The bilge pump capacity is calculated using Eq. (4):

$$Q = 5.75\,x\,10^{-3}\,d_H^2 \tag{4}$$

Where Q is the minimum capacity, and d_H is the internal diameter calculated for the main bilge pipe.

Fluid Flow in Piping System

According to Al-Shemeri [18], the definition of a fluid is a substance that can move when a force is applied. Fluids have the property of being able to change shape, which is not permanent. Fluids will take the shape of the container they are in. Furthermore, more specifically, fluids can also be categorized based on their flow types, mainly laminar and turbulent flows. Triatmadja [19] state that head loss occured when fluid flows through a pipe, causing energy loss due to friction along its path. This pressure loss can be divided into two categories: Major Head Loss and Minor Head Loss. Major head loss occurs due to friction between the fluid and the pipe walls. This friction happens when the fluid has high viscosity or is thick, and the pipe surface is not smooth. The loss of pressure due to friction can be calculated using the Darcy-Weisbach stated in Eq. (5):

$$hf = f\frac{L.V^2}{D.2g} \tag{5}$$

With hf symbolized the energy loss, g is gravitational acceleration, and f is the friction coefficient value that can be obtained using the Moody Diagram. The f value is found by plotting the Reynolds number (Re) and the relative roughness coefficient (r). Secondary energy losses, or minor losses, are relatively smaller than major losses. Minor losses occur due to flow resistance, such as sudden changes in cross-section, valves, bends, and others. Minor head loss can be obtained using approach written in Eq. (6).

$$hf = f\frac{K.V^2}{2g} \tag{6}$$

With K is the constraction constant which different for each pipe characteristic. Head suction static (Hss) is the sum of the static head and dynamic head. This head represents the amount of loss that must be overcome by the pump from all existing components. In practice, head loss calculations on the pump can be specified for the suction line head and discharge line head. Head suction static is the pump head on the suction side, measured from the fluid surface to the pump centerline. If the fluid surface is below the pump centerline, the head is marked positive, and vice versa. Head suction dynamic (Hsd) is the pump head on the suction side, which is a combination of major losses and minor losses along the pump's suction side. The equation for Hsd can be seen in Eq. (7):

$$Hsd = Hfs + Hm \tag{7}$$

$$Hsd = Fs\frac{l_2}{d_2}x\frac{Vs^2}{2g} + \sum Ks\frac{Vs^2}{2g} \tag{8}$$

Head suction total (Hs) is the total head on the suction side, which is the sum of the Hss and Hsd. Eq. (9) used to calculate Hs.

$$Hs = Hss + Hsd \tag{9}$$

Head discharge static (Hds) is the total pump head on the discharge side, measured from the pump centerline to the top surface of the reservoir. Head discharge dynamic (Hdd) is the pump head on the discharge side, which is a combination of major losses and minor losses on the pump's discharge side. Eq. (10) calculate the total head discharge of the system.

$$Hdt = Hsd + Hdd \tag{10}$$

Head total (Hp) is the total pump head on the discharge side, which is the sum of the head discharge static and head discharge dynamic. The equation for Hp is written in Eq. (11).

$$Hp = Hst + Hdt \tag{11}$$

where Hp is the pump head, Hst is the head suction total, and Hdt is the head discharge total.

Power Calculation

NPSH is the minimum requirement for a pump to operate normally. NPSH concerns what happens at the suction part of the pump, including what reaches the impeller surface. NPSH is affected by the suction pipe and connectors, the height and pressure of the fluid in the suction pipe, fluid velocity, and temperature. NPSH is expressed in feet. There are two types of NPSH: NPSHa (Net Positive Suction Head Available) and NPSHr (Net Positive Suction Head Required). NPSHa is the NPSH value present in the system where the pump will operate. NPSHr is the specific NPSH value required for the pump to function normally, as provided by the manufacturer based on testing results. The formula for calculating NPSH is given in Eq. (14)

$$NPSH_A = (\frac{Pi}{\rho g} + \frac{Vi_2}{2g}) - \frac{Pv}{\rho g} \qquad (12)$$

Where Pi represents the absolute pressure at the inlet (N/m^2), (Vi) is the average velocity at the inlet (m/s), ρ is the fluid density (kg/m^3), (g) is the gravitational acceleration (m/s^2), and (Pv) is the vapor pressure of the fluid (kPa). Additionally, the formula for calculating pump power is given in Eq. (13).

$$N = \frac{QxHx\rho}{3600 \; x \; 75 \; x \; \eta} \qquad (13)$$

In this equation, (Q) represents the pump capacity (m^3/h), η is the pump efficiency (%), and H is the total pump head (m). The constants 3600 and 75 are used to convert hours to seconds and horsepower (HP) to kilowatts (kW), respectively. This equation helps in determining the power required by the pump, considering its efficiency and the properties of the fluid being pumped.

RESULTS AND DISCUSSION

In this analysis, the piping design is visualized in a 3D model. The 3D pipe design yields analysis results that quantify the system's capacity losses and flow rates. These results are then used to determine the required pump power. Design visualization of the piping system are shown in Figure 2 to 5.

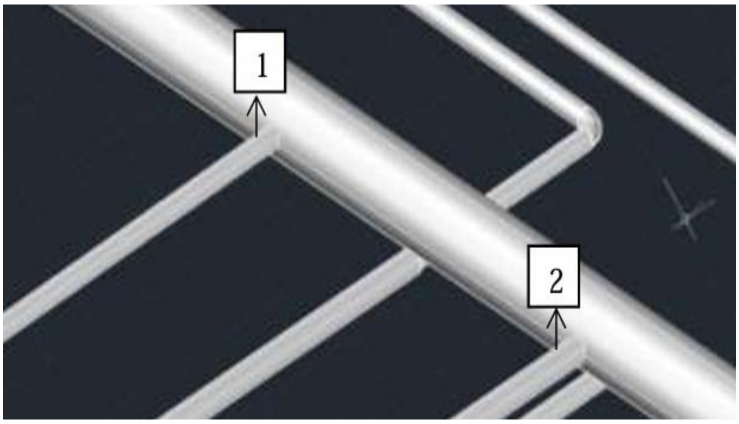
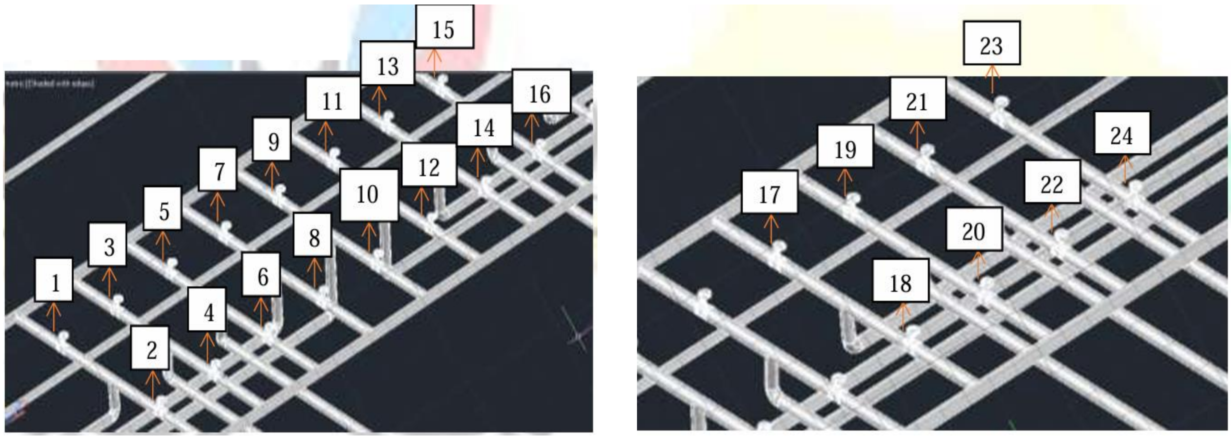
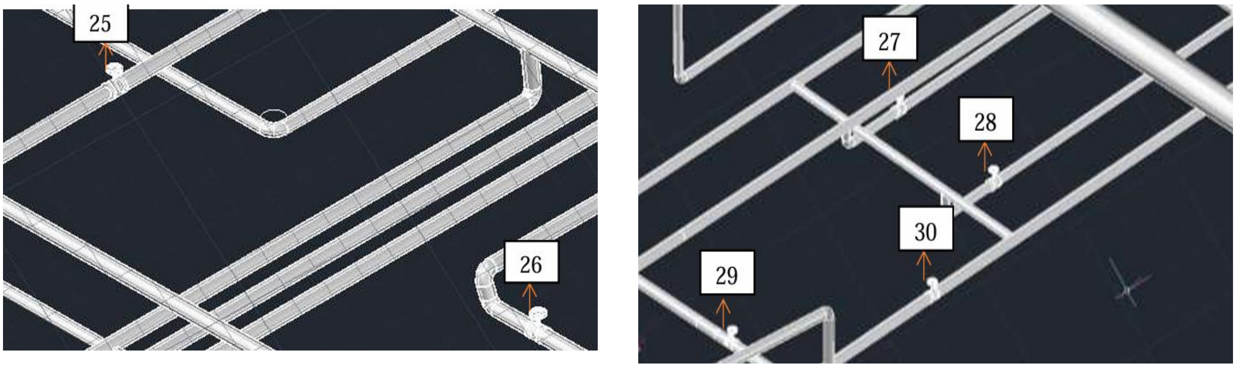


Figure 2. 3D Stranger

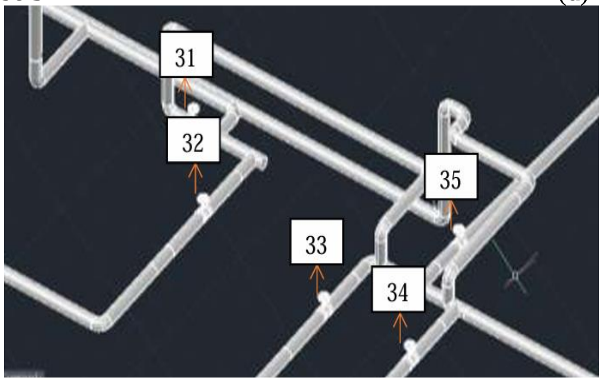


(a) Globe 1

(b) Globe 2



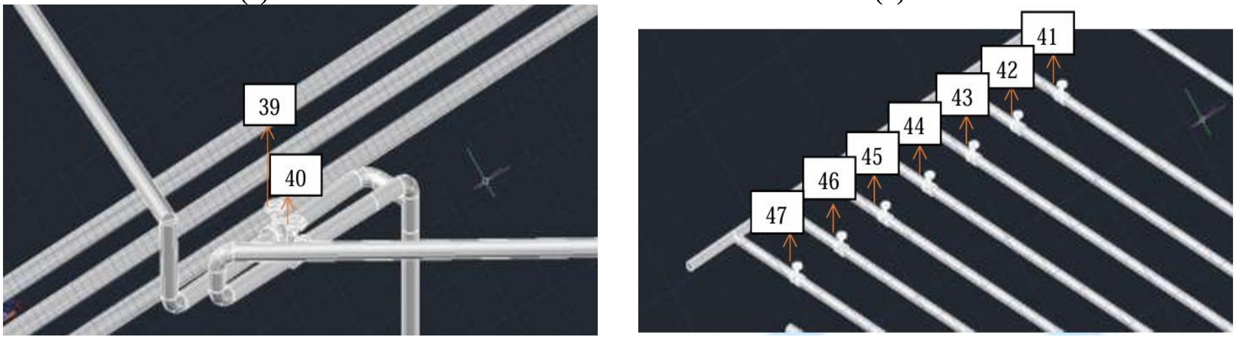
(c) Globe 3 (d) Globe 4



(e) Globe 5

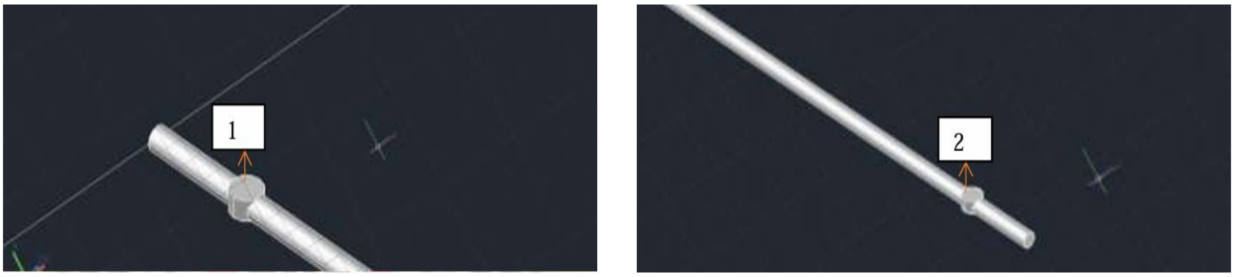
Figure 3. Global Suction Valve

(a) Globe 6 (b) Globe 7



(c) Globe 8 (d) Globe 9

Figure 4. Global Discharge Valve



(a) Gate 1 (b) Gate 2

Figure 5. Gate Valve

To determine the head, it is necessary to calculate the inner and outer diameters of the bilge pipe first. The relevant parameters are concluded in Table 2.

Table 2. Parameters to obtain pipe diameters

Parameters	Size	Unit
Length Perpendicular of the ship	54	m
Ship Internal Width	12	m
Height of the ship to bulkhead deck	4,7	m
Length of watertight compartement	19,8	m

Based on the parameters, the calculated inner diameter of the main bilge pipe is 75,45 mm, which is equivalent to 2.9704 inches. A pipe with a diameter of 3 inches, as specified in JIS G3459, was used. According to BKI regulations, the inner diameter of the main and branch bilge pipes must be at least 50 mm. For ships shorter than 25 m, the diameter can be reduced to 40 mm. Since the ship's LPP was 54 m, the minimum diameter rule of 50 mm was applied. The branch bilge pipe diameter was calculated to 64,09 mm, equivalent to 2.5232 inches. Again, a pipe with a diameter of 3 inches, as per JIS G3459, was used. The bilge system flow rate was calculated to be 32,73 m^3/hour. For the ballast system flow rate, filling a ballast tank with a flow velocity of 2 m/s takes 4 to 10 hours with a pipe diameter of 60 to 200 mm. The ballast tank volumes can be seen in Table 3.

Table 3. Volume of the tanks

Tanks	Size (m^3)
Forepeak tank	195,19
Afterpeak tank	42,71
Total	237,9

The ballast system flow rate was calculated as 59,475 m^3/hour. To calculate the Reynolds number, which is used to determine the type of flow in the system. the flow types were defined as: Laminar flow (Re < 2300), Transitional flow (Rea pprox 2300-4000), and Turbulent flow (Re > 4000). Given the parameters: seawater density, inner pipe diameter, and fluid viscosity which obtained from bernoulli equation. The Reynolds number. With a Reynolds number of 9415, the flow was determined to be turbulent, as it exceeds the threshold of 4000.

To calculate the major head loss (pressure loss) for flow within the pipe, the Darcy-Weisbach formula was used, which requires parameters such as pipe length, diameter, flow velocity, and friction factor. The Moody Diagram was used to find the friction factor, based on the relationship between the Reynolds number and the relative roughness of the pipe. The relative roughness was calculated with e as pipe condition (rusted) is 2 mm and d as pipe diameter of ballast pipe is 60.36 mm. The pipe used had a diameter of 2.5 inches, as per JIS G3459, giving a relative roughness of 0.0331. Using the Moody Diagram, the friction factor was determined to be approximately 0.058.

The longest pipe length was selected for calculations, indicating that the ballast system was the primary consideration for the General Service Pump. The ballast system pipe length was 191.69 m and the bilge system pipe length was 97.8 m. For the main ballast design. Pipe with diameter of 2.5 inches, according to JIS G3459, was used, satisfying the minimum requirement of 50 mm for ships over 25 m. The Darcy-Weisbach equation was applied with the parameters. The installation head was calculated in three parts: Static Head (Hz), Pressure Head Difference (Hp), and Velocity Head Difference (Hv). The static head was calculated as 3.45 m. The pressure head difference was 0 m, as the tank pressures were equal at 1 atm. The velocity head difference was also 0 m, since the suction and discharge velocities were equal.

Using calculation, calculated pump power N is approximately 5.79 kW. For the actual installation, Ebara brand pump catalog used to identify an appropriate pump. According to analysis, the system requires a pump capacity of 59.475 m^3/hour and a total head of 24.24 m. Based on these requirements, the selected pump has a power rating of 7.5 kW. However, the actual power output of the pump is 8.92 kW. When comparing the calculated power (5.79 kW) to the chosen pump power (7.5 kW), there is an increase of about 29.5%. The actual pump power (8.92 kW) is 16% higher than the chosen pump power. Overall, the actual pump power is approximately 65% higher than the initially calculated requirement, which may lead to an overestimation of power usage on the ship. By choosing a pump closer to the calculated power requirement, efficiency in the ship's operation can be improved, leading to potential energy savings and reduced operational costs. This adjustment could significantly enhance the efficiency of the ship's system, reducing power consumption and optimizing performance by approximately 65% compared to the current pump power used.

CONCLUSION

The research aimed to determine the appropriate pump power specifications for the bilge and ballast systems of an existing ship's piping system. Through comprehensive analysis, it was established that the ideal pump power needed for these systems is 5,79 kW. This value was derived from an evaluation of the existing systems and their specific requirements. Calculated value is 65% smaller than the existing pump power installed in the ship. Subsequently, it was concluded that the most suitable pump specifications for the bilge and ballast systems, considering the actual conditions and operational demands, are Ebara centrifugal pumps. The recommended model is the 80x65 FSS2GA, which has an output of 7.5 kW, approximately 16% smaller than the existing pump installed. This particular pump was selected because it provides power output with the closest margin compared to the calculated requirement, ensuring adequate performance and reliability under various operational conditions.

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