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Enhancing Lubrication System Efficiency in Marine Diesel Engines with Centrifugal Separators - a Case Study Of LPG/C Arimbi: Technical and Cost-Effective Perspectives

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Abstract

The lubrication system in an engine is critical for reducing friction between components, preventing wear, reducing heat, protecting components from deposits, and sealing. Maintaining and extending the life of lubricants is crucial for lowering lubricant usage costs. A centrifugal separator is an auxiliary machine that cleans and separates two insoluble liquids with different densities. This study aims to evaluate the efficiency of lubricant life, lubricant usage cost savings, and return on investment time for a centrifugal separator. The study uses a case study of LPG/C Arimbi, where a centrifugal separator has helped maintain lubricants, prevent wear, and separate fuel and free water from lubricants. The centrifugal separator can also maintain Total Base Number (TBN) and viscosity values by filtering solid particles or wear elements up to a size of 0.5 µm. The study found that the difference in lubricant life was 11,780 hours, and the cost savings obtained were IDR 186,456,666 per year. The return on investment time for purchasing a centrifugal separator is three years and two months, assuming an average working hours of LPG/C Arimbi every year of 3,660 hours. Therefore, using a centrifugal separator can improve the efficiency of lubricant life and reduce lubricant usage costs, providing a positive return on investment in the long run.

1 Introduction

The lubrication system of a driving engine serves multiple purposes, including lubricating the engine to reduce friction, minimizing wear, sealing the engine components, and controlling contamination by carrying particles and contaminants within the engine. Lubricating oils serve as the vital lifeblood for combustion engines, and ensuring their effective operation requires meticulous cleaning. The lubricants employed in the internal combustion engines of ships play a crucial role in minimizing substantial friction losses, particularly in piston systems, where these losses can range from 35 to 45%. Hence, maintaining the cleanliness of the oil is imperative [1-3].

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These functions are critical for efficient engine operation and maintenance [4,5]. To maintain the integrity of the lubrication system, lubricant condition monitoring is essential. This process involves evaluating lubricant properties such as viscosity, base number, and contaminant concentration such as insoluble, water content, flash point, and metal content [6]. Such analysis enables technicians to accurately assess lubricant replacement schedules and prevent wear and corrosion within the system [7].

Previous research has investigated the effect of fuel blending on the properties of Gibson 20W50 lubricants. The study combined five lubricant samples with varying fuel percentages of 0%, 1%, 3%, 5%, and 7%, respectively. The findings indicated that an increase in fuel value caused a decrease in viscosity value and raised the engine temperature. This decrease in viscosity can lead to thinning of the protective film formed by the lubricant, which in turn can cause wear [8]. Moreover, a dry sump-type main engine installed in ships requires substantial lubricant to function effectively. Lubricant condition monitoring can be carried out to determine the appropriate service life and replacement schedule of lubricants. This statement is substantiated by a study that estimated the service life of lubricants in Mack Co. diesel engines. This study conducted an oil analysis of 160 lubricant samples collected from 70 identical engines. The research found that the warning limit for the working hours of lubricants in Mack Co. engines with Generator Speedy lubricants is 100 hours with minimal wear [9].

Another study predicted diesel engine lubricant replacement based on changes in viscosity and Total Base Number (TBN), and replacement is carried out based on condition. The study employed a linearity approach method to predict the increase in viscosity and TBN values beyond their maximum limits. The results showed two linear relations: between operating time and TBN decrease and between operating time and viscosity increase. The prediction of a viscosity increase beyond the limit is expected to occur after an operating time of 276.963 hours, while the prediction of a TBN decrease beyond the limit will occur at an operating time of 270.480 hours [10]. Lubricant replacement based on condition and monitoring of lubricant properties such as viscosity and TBN values can prevent wear and corrosion in the engine system. It also reduces the cost of lubricant replacement. It ensures that the lubricant is always in optimal condition to effectively reduce friction and heat, minimize wear, and seal the engine system.

Implementing lubricant condition monitoring can bring about several benefits, such as using less lubricant, increasing machine availability, and reducing maintenance costs [11]. In addition to condition monitoring, designing the appropriate lubricant filtration and purification system can help maintain the optimal condition of lubricants. According to the Alfa Laval Separator Manual, a centrifugal separator is an auxiliary machine designed to clean liquids from solid particles and separate two insoluble liquids with different densities through centrifugal force [12]. Centrifugation involves obtaining pure oil by utilizing a centrifugal separator to separate suspended particles in the lubricant [13-15]. This process employs a liquid separation aid with a density greater than the oil's, attracting and consolidating the suspended particles. The use of a centrifugal separator can extend the life of lubricants, as demonstrated in case studies of oil analysis on various ships. For example, the LPG/C Arimbi ship used a centrifugal separator. After 21,780 working hours, the lubricant was still within the recommended limit, even though only a small amount was added at certain intervals without replacing a certain sump tank. However, in the case of the KMP. For the Panorama Nusantara ship, the lubricant exceeded the limit of TBN and viscosity after 6,800 working hours despite having a shorter top-up interval than the LPG/C Arimbi. It highlights the importance of using the appropriate lubricant filtration and purification system.

Furthermore, a case study on the KM. Farina Nusantara showed that the lubricant on the ship was replaced with a certain amount of sump tank at an interval of 10,000 working hours due to fuel contamination reaching 22.8% of the lubricant sample volume. Fuel contamination in lubricants can be caused by improper use of the centrifugal separator in the ship's lubrication system. Therefore, proper maintenance and monitoring of the centrifugal separator and lubricant filtration and purification system can help prevent fuel contamination and ensure the optimal condition of the lubricants in a ship's lubrication system.

In recent years, lubricant condition monitoring and maintenance have been the focus of extensive research to optimize the performance and longevity of lubricants and the machines they lubricate. Various methods have been developed to monitor the condition of lubricants, such as viscosity and Total Base Number (TBN) analysis, wear particle analysis, and infrared analysis. These methods allow technicians to detect and analyze the properties of lubricants and the presence of contaminants to predict when to replace lubricants and avoid costly damage to machinery. Drawing from the preceding discussion, the present study is directed towards projecting the effectiveness of lubricant application, evaluating the expenses of employing a centrifugal separator, and establishing the period needed for the investment in the separator to pay off. The novelty of the research lies in its specific focus on the maritime industry, particularly the LPG/C Arimbi vessel, and its comprehensive analysis of the effectiveness of lubricant application and the use of a centrifugal separator. While existing research has extensively explored lubricant condition monitoring in various contexts, this study uniquely addresses the maritime sector's challenges and opportunities. To this end, the analysis will involve a comparative assessment of the efficiency of the centrifugal separator in the context of the LPG/C Arimbi vessel, contrasting its performance with an alternative scenario where the separator is not used. This study is intended to provide a strategy for lubricant performance monitoring to maintain the health and performance of ship engines. It provides valuable insights into the condition of critical components, enabling proactive maintenance, reducing the risk of unexpected failures, and ultimately ensuring the reliable and efficient operation of the entire vessel.

2 Methods

A centrifugal separator uses centrifugal force to remove particles and water from lube oil in a single operation. The contaminants – in the form of sludge and water – are forced outwards, while clean lube oil is continuously transferred back into the engine. The level of contaminants in the lube oil system depends mainly on the output, engine, and fuel type. In addition to particle content, particle size strongly impacts the separation efficiency. Different engine types and fuel types can generate different size ranges for the soot particles.

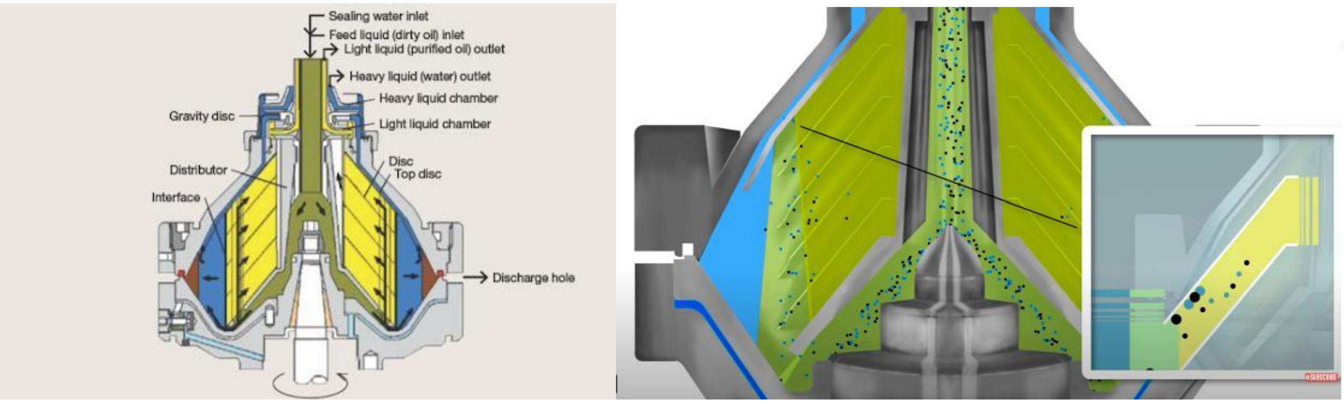

Figure 1. Oil analysis LPG/C Arimbi [16]

This current study compared the optimal lubricant usage and costs on the LPG/C Arimbi (see Figure 1) vessel based on the oil analysis data presented in Table 1. The study will be conducted under two conditions. The first condition is when the LPG/C Arimbi vessel uses a centrifugal separator in the lubrication system, and the second condition is when the LPG/C Arimbi vessel does not use a centrifugal separator based on the working hours and top-up intervals data from the oil analysis of the KMP. Panorama Nusantara. The data used in the calculation of economic analysis is the purchase of Alfa Laval brand centrifugal separator investment model S 815, which the LPG/C Arimbi uses.

Table 1. Oil analysis LPG/C Arimbi [17]

Oil Running Hour (hour)	TBN (mg KOH/g)	Viscosity (cSt)	Fuel (%vol)	Water (%vol)
1000	37.00	15.74	0	0
2500	29.73	18.14	0	0
3000	29.32	17.85	0	0
4134	30.07	17.20	0	0
5000	29.05	17.18	0	0
5216	28.57	17.70	0	0
5500	27.58	17.47	0	0.11
5879	26.40	17.77	0	0.17
7020	29.72	18.51	0	0
7406	22.39	17.98	0	0
10000	28.16	15.45	0	0
14489	22.62	15.59	0	0
17649	26.66	15.65	0	0
18870	28.25	15.63	0	0
19560	28.40	15.43	0	0
20701	27.03	15.45	0	0
21780	27.76	15.45	0	0
Limit				
Min	21.795	11.152		
Max		18.587	5	0.2

2.1 Technical analysis

The discussion in the technical analysis includes the properties of the lubricants themselves, namely TBN, viscosity, fuel content, water content, and wear elements. The technical analysis will discuss the limits recommended by Pertamina's oil clinic and engine makers and conduct an analysis based on a literature study of the causes and effects of lubricant conditions based on oil analysis of the LPG/C Arimbi vessel.

2.1.1 TBN and viscosity

Both increase and decrease in viscosity are bad for machines. A decrease in viscosity can be caused by water or fuel contamination. An increase in viscosity can be caused by contaminants such as dust or soot or can be caused by oxidation that occurs in the lubricant. TBN is a measurement of a lubricant's ability to neutralize the acidic properties present in an engine. These acidic properties are produced by sulfur contamination from fuel, which forms sulfur dioxide. Other causes include the oxidation reaction of sulfur and nitrogen dioxide, which produces acid.

2.1.2 Fuel and water content

Contamination by fuel can cause a decrease in the flash point value. The decrease in flash point value can cause the lubricant to ignite and easily pose a great danger to the engine. The higher the amount of fuel present in the lubricant, the lower the flash point or ignition point of the lubricant. Water contamination can reduce lubricants' ability to carry dirt, increase wear, and increase oxidation and corrosion. The water in lubricants can come from combustion that produces water as a product, condensation, and leaks from the cooling system. Based on this, lubricants must have demulsibility properties, which is the ability of the lubricant to separate from water when an emulsion is formed in a system.

2.1.3 Wear element

Wear element refers to metal particles that originate from engine components due to friction between components and are carried by the lubricant. Lubricant laboratories must analyze the results of wear element testing to determine the allowable limits of wear element content in the lubricant, as there are no definitive limits for wear elements from Original Equipment Manufacturers (OEMs) or lubricant manufacturers. The amount of wear elements in the lubricant can indicate damage to engine components.

2.2 Economical analysis

The economic analysis will be conducted by comparing the costs and lifespan of lubricants from both conditions of the LPG/C Arimbi vessel. The first condition is when the LPG/C Arimbi uses a centrifugal separator, and the second condition is the assumption when the LPG/C Arimbi does not use a centrifugal separator. The calculation for the second condition will be based on the working hours of the KMP. Panorama Nusantara and KM. Farina Nusantara vessels as supporting data. The formula used to calculate the amount of lubricant usage is denoted by Equation 1 [18]:

$$LOC= \frac{(SLOC \times MCR \times OH)}{Density\ @^{\circ}C} \tag{1}$$

where Specific Lube Oil Consumption (SLOC) represents the amount (g) of lubricant circulating in the engine per unit of engine output (kWh), Maximum Continuous Rating (MCR) represents the maximum continuous output of the engine (kW), density represents the density of lubricant at 15 $^{\circ}$C, and Operation Hour (OH) represents the lubricant operating hours. The result of the lube oil consumption calculation is used to determine the cost of lubricant usage, with the formula denoted by Equation 2:

$$LOC\ cost = LOC \times price\ /\ litre \tag{2}$$

The economic analysis will also use the payback period method. The payback period is a method to determine how long it takes for the cash flow return from the investment costs [19]. The payback period also provides information on the break-even point, which is when the finances of a project change from negative to positive [20]. The formula for calculating the Payback Period (PP) is denoted by Equation 3 [21]:

$$PP = \frac{Initial\ investment}{Cash\ inflow} \tag{3}$$

where the initial investment is the cost of purchasing the investment and cash inflow is the total income. This research will take the difference in lubricant usage costs from the two conditions of the LPG/C Arimbi vessel as income (cash inflow). The first condition is using a separator, and the second condition is not using a separator. The price of the Alfa Laval brand separator with model S815 is used as an investment cost worth IDR 600,000,000.

3 Results and Discussion

3.1 Technical analysis

The technical analysis discussion includes the properties of the lubricant, namely TBN, viscosity, fuel content, water content, and wear elements. The technical analysis will discuss the limitations recommended by Pertamina's oil clinic and engine makers and analyze the causes and effects of lubricant conditions based on the oil analysis of the LPG/C Arimbi vessel by conducting a literature study.

3.1.1 TBN and viscosity

Changes in viscosity can be harmful to the engine. An increase in viscosity can be caused by water or fuel contamination. In contrast, a decrease in viscosity can be caused by contaminants such as dust or soot or by oxidation of the lubricant [6]. A case study of oil analysis on the LPG/C Arimbi, a ship that used a separator, as shown in Table 1 and Figure 2, indicates a trend of decreasing viscosity. The change in viscosity on the LPG/C Arimbi was not significant and was still within the recommended limit of 11.152 cSt and 18.587 cSt. The decrease in viscosity was due to the duration of lubricant usage and water contamination in the lubricant, while the increase in viscosity was due to the presence of wear elements in the lubricant. The centrifugal separator played an essential role in extending the life of the LPG/C Arimbi's lubricant by removing free water in the lubricant.

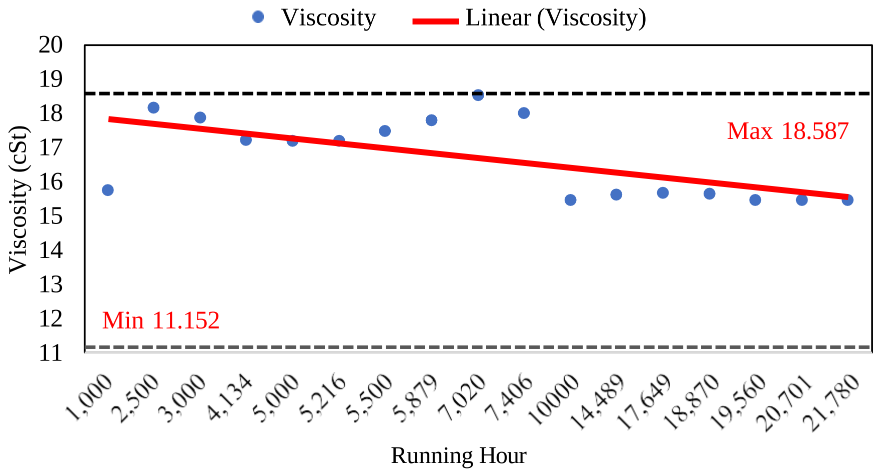

Figure 2. Viscosity value of LPG/C Arimbi

TBN is a measurement of a lubricant's ability to neutralize the acidic properties present in the engine [6]. These acidic properties are produced by the sulfur contamination in the fuel that forms sulfur dioxide. Another cause is the oxidation reaction of sulfur and nitrogen dioxide that produces acid [11]. The case study of LPG/C Arimbi in Table 1 and Figure 3 did not show a drastic decrease in TBN value due to the absence of fuel contamination. Figure 2 also shows that the reduction in TBN value in LPG/C Arimbi was still above the limit recommended by Pertamina. The limit for the TBN value of Medripal 440 lubricant was 21.795 mgKOH/g or 50% of the TBN value of the lubricant in new condition.

Previous research shows that an increase in working hours will be directly proportional to a decrease in TBN value [22]. Therefore, it can be concluded that the decrease in the TBN value that is still above the recommended limit is reasonable because the lubricant performs its function of neutralizing the acid that arises in the engine space to prevent corrosion. The centrifugal separator also plays an important role in maintaining the lubricant against fuel because the separator can separate two or more liquids with different densities.

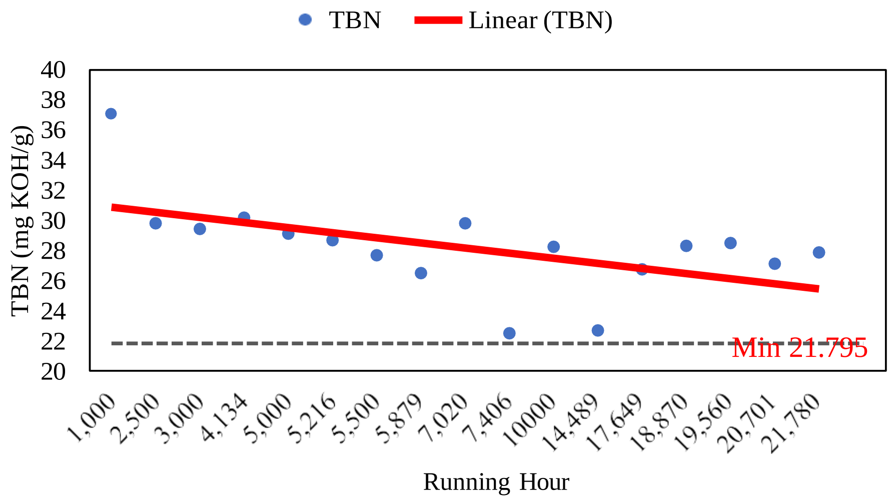

Figure 3. TBN value of LPG/C Arimbi

3.1.2 Fuel and water content

Contamination by fuel can cause a decrease in flash point value. The flash point is the temperature at which a lubricant releases vapours sufficient to ignite when exposed to a flame [23]. Referring to the case study of LPG/C Arimbi in Table 1 and Figure 4, there was no fuel contamination in the lubricant. It was supported by using a centrifugal separator to separate liquids with different densities [24]. Water contamination can reduce lubricants' ability to carry dirt, increase wear and tear, and increase oxidation and corrosion. Water in the lubricant can come from combustion that produces water as a product, condensation of water, and leakage from cooling systems. Therefore, lubricants must have demulsibility properties, which is the ability of lubricants to separate from water when emulsions form in a system.

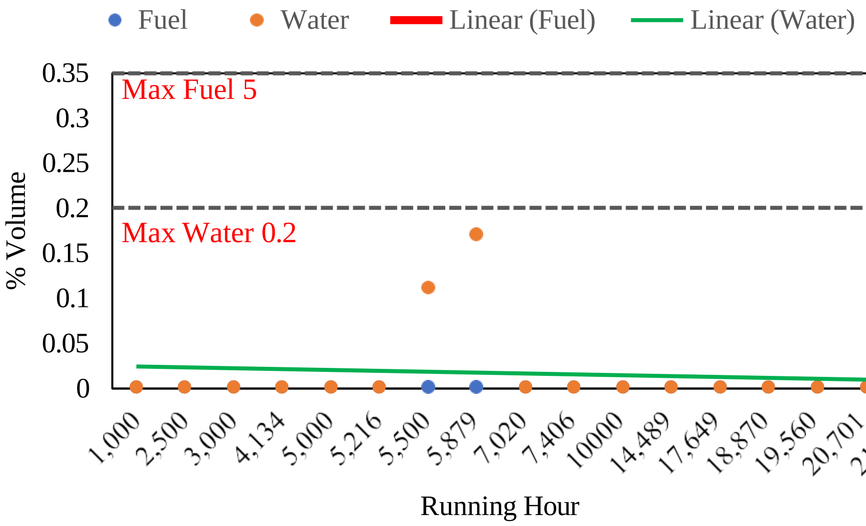

Figure 4. Fuel and water content of LPG/C Arimbi

In LPG/C Arimbi, as seen in Table 1 and Figure 4, the water content was only around 0.11% to 0.17% of the total volume of the lubricant sample. The water content was found at 5,500 and 5,216 working hours. It is supported by using a centrifugal separator, which can separate liquids with different densities, such as free water content in the lubricant.

3.1.3 Wear element

The wear element is a metal that originates from engine components due to friction between components and is carried by the lubricant. There is no definite limit for the allowable wear element content in lubricants. Still, laboratories analyze the results of wear element testing to establish limits based on the analysis of wear element trends [11]. The wear element content in lubricants can indicate damage to engine components. Table 2 shows the damage to engine components based on wear element levels in oil analysis.

Table 2. Source of wear element

Wear	Source
Aluminum (Al)	Piston, bearings
Iron (Fe)	Gearbox, cylinder liners
Copper (Cu)	Thrust, valve
Lead (Pb)	Seals, solder joint
Tin (Sn)	Bearings, bronze

Referring to the case study of LPG/C Arimbi in Table 3 and Figure 5, the wear elements did not exceed the recommended limit until reaching 21,780 operating hours. This was because the centrifugal separator can filter solid particles to a smaller size than the filter, which was 0.5 µm [24].

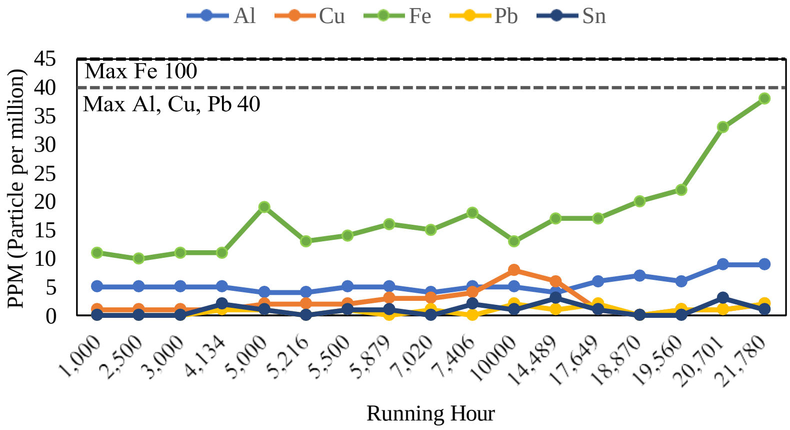

Figure 5. Wear element LPG/C Arimbi

Table 3. Wear element LPG/C Arimbi [17]

Oil Running Hour	**Al**	**Cu**	**Fe**	**Pb**	**Sn**
	Parts per Million (PPM)				
1,000	5	1	11	0	0
2,500	5	1	10	0	0
3,000	5	1	11	0	0
4,134	5	1	11	1	2
5,000	4	2	19	1	1
5,216	4	2	13	0	0
5,500	5	2	14	1	1
5,879	5	3	16	0	1
7,020	4	3	15	1	0
7,406	5	4	18	0	2
10000	5	8	13	13	2
14,489	4	6	17	17	1
17,649	6	1	17	17	2
18,87	7	0	20	20	0
19,56	6	1	22	22	1
20,701	9	1	33	33	1
21,780	9	2	38	38	2
	Limit				
Max	40	40	100	40	-

3.2 Economic analysis

An economic analysis will be conducted by comparing the lubricant's cost and service life of the lubricant in two conditions of the LPG/C Arimbi ship. The first condition is when the LPG/C Arimbi uses a centrifugal separator, and the second condition is an assumption when the LPG/C Arimbi does not use a centrifugal separator. The calculation of the second condition will be based on the top-up interval of the ship and the replacement interval of the lubricant in a certain number of KM. Farina Nusantara as supporting data.

3.2.1 LOC cost LPG/C Arimbi with separator

The aerial videos were collected at time duration from the working hours obtained from using LPG/C Arimbi lubricant, which reached 21,780 hours. The working hour data was used to calculate the cost of using LPG/C Arimbi lubricant with the specifications of the hull, engine, and LPG/C Arimbi lubricant data in Table 4.

Table 4. Specifications and lubricants of LPG/C Arimbi

Vessel Data	
Hull Information	
LOA	103 m
B	18 m
H	7.8 m
GT	5006 ton
Machinery Information	
Maker	STX MAN
Model	6L32/40
Cylinder	6 Cylinders
Cycle	4 strokes
MCR of load engine	2160 kW
SLOC	0.6 ~ 0.8 g/kWh
Sump capacity	6600 litres
Lube Information	
Maker	Pertamina
Series	Medripal 440
Density at 15 celcius	0.9097 kg/l
Price (Dec 2022)	IDR 45,850/l

Referring to Equations 2 and 3 and Table 4, the calculation of the cost of using LPG/C Arimbi lubricant is stated in Equation 4.

$$LOC = \frac{(SLOC \times MCR \times OH)}{Density\ @\ 15\ ℃} \quad (4)$$

The cost of using LPG/C Arimbi lubricant up to 21,780 working hours was IDR 1,422,669,504. In addition to the use of lubricants for 21,780 hours, the lubricant in LPG/C Arimbi was added (topped up) in small amounts at certain intervals. It was intended to maintain the lubricant function in optimal condition. The lubricant (top-up) data for LPG/C Arimbi is described in Table 5.

Table 5. Lubricants top up on LPG/C Arimbi

Oil Running Hour (Hour)	**Top Up (Litre)**	**Interval (Hour)**	**Cost (IDR)**
4134	500	4134	22,925,000
7020	500	2886	22,925,000
10000	500	2980	22,925,000
14,489	500	4489	22,925,000
17,649	500	3160	22,925,000
18,870	500	1221	22,925,000
19,560	500	690	22,925,000
21,780	1000	2220	22,925,000
Average		**2723**	
Total	**4500**		**206,325,000**

Based on Table 5, it can be seen that LPG/C Arimbi lubricant performed top-ups with an average interval of 2,723 hours. It was done to maintain the volume of lubricant rotating inside the engine to ensure that lubricant function was always maintained. The cost of LPG/C Arimbi's lubricant to reach 21,780 hours was by adding the cost of using 21,780 hours plus the top-up cost, IDR 1,628,994,504.

3.2.2 LOC Cost LPG/C Arimbi without a separator

The calculation of lubricant usage in this condition refers to Table 6, which was the KM. Farina Nusantara oil analysis and Table 7 is the KMP. Panorama Nusantara oil analysis. The data in Table 6 can be used to estimate the replacement of lubricants if a separator is not used in the lubrication system. Based on this data, the lifespan of lubricants in KM. Farina Nusantara can be seen. Farina Nusantara was around 10,000 hours. It is proven by the decrease in the value of working hours, which indicates the replacement of lubricants for a certain number of sump tanks when it exceeds 9241 working hours. In addition to the 9241 working hours, the data also showed a decrease in working hours from 10,734 to 10,673, which indicates the replacement of lubricants for a certain number of sump tanks approximately every 10,000 working hours. The data on the interval of replacing a certain number of sump tanks will be used to simulate lubricant usage without using a separator.

Table 6. Oil analysis KM. Farina Nusantara

Oil Running Hour (Hour)	TBN (mgKOH/g)	Viscosity (cSt)	Fuel (%Vol)	Water (%Vol)
454	19.83	15.13	0	0
9241	16.7	31.29	0	0
2371	19.58	15.07	0	0
10734	13.44	9.171	22.8	0
10673	13.6	9.885	20.75	3.68
11520	13.29	11.31	17.02	0
11941	10.02	13.12	19.98	0.76
		Limit		
Min	10	11.84		
Max		19.24	5	0.3

The data in Table 7 determines the interval of lubricant top-up that needs to be added if a separator is not used. Referring to Table 7, the KMP can be determined at what working hours. Panorama Nusantara lubricant needed to be topped up. Table 8 provides details on the time, cost, and interval of top-up performed by KMP. Panorama Nusantara.

Table 7. Oil analysis KMP. Panorama Nusantara

Oil Running Hour (Hour)	TBN (mgKOH/g)	Viscosity (cSt)	Fuel (%Vol)	Water (%Vol)
1826	9.17	11.73	10.53	0
2134	11.12	11.42	10.39	0
2353	10.67	10.8	11.51	0
2688	8.43	15.9	62.48	0.93
2892	9.26	13.94	0	0
6380	12.2	12.11	5.75	0
6627	10.9	11.84	0	0
6800	5.4	8.481	17.24	0
7084	8.1	10.35	9.94	0
7988	8.3	10.5	4.99	0.63
		Limit		
Min	7.5	11.152		
Max		18.587	5	0.2

Based on the data from Table 8 on the top-up of KMP. Panorama Nusantara, the interval at 6380 working hours cannot be determined due to data limitations. Therefore, the average interval was calculated based on the 2134, 2892, 7084, and 7988 working hours. The average interval for top-up lubricants was 668.5 hours. The average value will be simulated to calculate the assumption of the cost of LPG/C Arimbi lubricants without a centrifugal separator.

Table 8. Lubricants top up on KMP. Panorama Nusantara

Oil Running Hour (Hour)	Top Up (Litre)	Interval (Hour)	Cost (IDR)
1826	-	-	-
2134	500	308	22,925,000
2892	500	758	22,925,000
6380	500	-	22,925,000
7084	500	704	22,925,000
7988	500	904	22,925,000
Average		**668.5**	
Total	**2500**		**IDR 114,625,000**

In addition to topping up the lubricant every 668.5 hours, the lubricant, without a separator, will be replaced with a certain sump tank every 10,000 hours. This condition will be simulated to achieve 21,780 working hours. Based on the data on top-up intervals and sump tank replacement intervals, LPG/C Arimbi will be topped up 33 times and will replace the sump tank twice to reach 21,780 working hours. The assumed amount of top-up was 500 litres, and the assumed amount of sump tank replacement was the same as the data for LPG/C Arimbi, which was 6,600 litres. Table 9 will explain the simulation of the cost of using lubricants without using a separator. The working hour data presented in Table 8 is presented every multiple of three so that the amount of each top-up is 1500 litres.

Table 9. Top-up simulation of LPG/C Arimbi without centrifugal separator

Oil Running Hour (Hour)	Top Up (Litre)	Cost (IDR)
2,005.5	1,500	68,775,000
4011.0	1,500	68,775,000
6,016.5	1,500	68,775,000
8,022.0	1,500	68,775,000
10,027.5	7,600	348,460,000
12,033.0	1,500	68,775,000
14,038.5	1,500	68,775,000
16,044.0	1,500	68,775,000
18,049.5	1,500	68,775,000
20,055.0	7,600	302,610,000
22,060.5	1,500	68,775,000
Total	28,700	1,315,895,000

Based on the data from Table 9, it can be seen that the total cost of using lubricants in the simulation of LPG/C Arimbi without using a centrifugal separator was IDR 1,315,895,000. This cost was obtained from the top-up interval of every 668.5 hours and replacing a certain sump tank (6600 litres) every 10,000 working hours. Next, the cost will be added to the cost of using lubricants for 21,780 hours obtained in point a. So, the cost of using LPG/C Arimbi lubricants when simulated without using a separator is IDR 2,738,564,504.

3.2.2 Investment analysis

The investment analysis used the payback period method to determine the return on investment time in purchasing the centrifugal separator. The separator data used was the Alfa Laval S 815 model, with a price of IDR 600,000,000 as an investment. The cash inflow in this calculation was the difference in the estimated cost of using LPG/C Arimbi lubricant in conditions without and without a separator, IDR 1,109,570,000.

The cost savings result was obtained every 21,780 hours or 5.95 years with the assumption that the use of LPG/C Arimbi was 3,660 per year. Therefore, the cost savings per year obtained was IDR 186,456,666. The cost savings per year will be used in the payback period calculation. Referring to Equation 4, the payback period calculation is the ratio between initial investment and cash flow. The payback period for purchasing the Alfa Laval centrifugal separator with a price of IDR 600,000,000 is 3.2 years. The time is only based on the savings of lubricant usage cost and does not include the reduction factor of downtime costs, such as the cost of adding lubricants and machine repair costs.

4 Conclusions

The lubricant in LPG/C Arimbi using the separator could still be used for up to 21,780 working hours. This period can be used without replacing the lubricant in a certain number of sump tanks, only by performing a few top-ups in small amounts. This study also showed that the centrifugal separator can reduce top-ups on lubricants from 28,700 litres to 2,500 litres for 21,780 hours. The number of top-ups was based on the difference in lubricant addition intervals and the interval for replacing the lubricant in a certain number of sump tanks. It can be concluded that using centrifugal separators could save up to 84% of lubricant usage. A case study on the oil analysis of LPG/C Arimbi showed that a centrifugal separator can filter solid particles up to 0.5 µm. Therefore, the wear element content in the lubricant is better preserved. In addition, preserving the wear element content in the lubricant can reduce the oxidation that can occur in the lubricant. The oxidation reduction in the lubricant can maintain the TBN value and viscosity within the recommended range. On the other hand, if LPG/C Arimbi is not always simulated using a centrifugal separator, the TBN and viscosity values of the lubricant cannot be maintained well. This is due to fuel contamination and soot accumulation, which results in wear element content in the lubricant. If left unchecked, it can cause corrosion, lower TBN value, increased viscosity, and lower engine reliability. Using a centrifugal separator can result in a lubricant usage cost savings of IDR 186,456,666 per year, assuming one year of use is 3,660 hours. The lubricant usage cost savings can return the investment cost of the centrifugal separator in 3 years and 2 months. This period is only based on lubricant usage savings and does not take into account the factor of reducing downtime costs. If the factor of reducing downtime costs is included in the calculation, the investment payback period will be faster.

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