UIJRT ISSN: 2582-6832
United International Journal for Research & Technology
Volume 06, Issue 05, 2025 | Open Access | ISSN: 2582-6832

Implementation of Reliability Centered Maintenance Method on the Biosolar B35 Ship Fuel System

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***Abstract*—** The Indonesian government has mandated the use of Biosolar B35 fuel starting from 1^st February 2023, introducing new challenges for ships operation in one of Indonesia's shipping companies, PT ABC. The purpose of this research is to identify components that cause failures in the B35 fuel system and determine effective maintenance types using the Reliability Centered Maintenance (RCM) method. This research using a qualitative approach, involving FMECA analysis for failure identification and the development of preventive maintenance tasks. The result indicates that the critical components in the B35 ship fuel system include Transfer Pump, Heater, Separator, Filter, Booster Pump, and Fuel Injection Pump. Among these, the critical components with the highest risk are Separator, Filter, and Fuel Injection Pump. Out of 18 analyzed task list, Preventive Maintenance (PM) emerged as the primary strategy (50%), followed by Condition Monitoring (39%), and Failure Finding (11%).

***Keywords*—** Biosolar B35, RCM, FMECA, Fuel oil system.

I. INTRODUCTION

In early 2023, the topic of mandatory B35 biosolar gained significant attention in discussion forums and media headlines. This heightened interest is evident from Google Trends data, which shows an increase in searches for the keyword "B35." The peak of this attention occurred after the Ministry of Energy and Mineral Resources (ESDM) announced the implementation of the mandatory B35 biosolar program on February 1, 2023 [1]. The trend of interest in B35 searches can be seen in Figure 1.

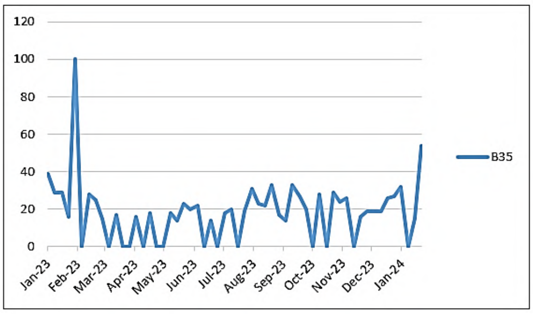

***Fig 1.** The trend of interest in B35 searches.*
***Source:** Google Trend, 2024*

The mandatory implementation of B35 biosolar, as mandated by the Government, has prompted industries, including the shipping companies, to transition from fossil-based fuels to renewable energy sources. The Government's primary objectives for implementing this biosolar policy are as follows: first, to reduce diesel imports amidst global uncertainties and high global oil prices; second, to support Indonesia's commitment to using clean energy in an effort to reduce Greenhouse Gas (GHG) emissions by 29% from Business as Usual (BaU) by 2030, in line with the Nationally Determined Contribution (NDC); third, as a means to control commodity prices, particularly Crude Palm Oil (CPO); and fourth, to create jobs and save the country's foreign exchange [2].

Biosolar B35 consists of 35% palm oil-based biodiesel (Fatty Acid Methyl Esters / FAME) and 65% diesel fuel. The biodiesel-blending program began in 2008 under Ministerial Regulation No. 32/2008. Initially implemented with a 2.5% blend (B1-B2.5) in transportation, industry, and power sectors, the blend percentage has increased over time: 15% (B15) in 2015, 20% (B20) in 2016 for Public Service Obligation (PSO) sectors, 30% (B30) in 2020, and 35% (B35) in 2023. The B35 mandate, effective from 2023, follows presidential directives from the Cabinet Meeting on December 6, 2022, and is based on Decision of the Minister ESDM Number 295.K/EK.01/MEM.e/2022 and Decision the Director General of EBTKE No. 3.K/EK.05/DJE/2023.

Biosolar has several advantages for marine engines, such us good quality exhaust, sustainability and biodegradability [3]. However, it also has some drawbacks. It is prone to water contamination, has a lower energy content, and can face issues at low temperatures [4]. Biosolar can also because sediment build up that may clog fuel lines [5]. A study on tugboats using biosolar found fuel filter blockages caused by sediment, leading to injector pump and nozzle issues [6]. Similar issues have been reported in ships owned by PT ABC, as confirmed by an interview with the Vice President of Fuels.

Due to the need for more frequent maintenance with B35 biosolar fuel, effective management strategies are essential. The goal of maintenance is to ensure the reliability of the engine for optimal operation. Reliability Centered Maintenance (RCM) is a method that can be employed to analyze the cause of damage, impact caused and determination of appropriate and effective maintenance task. The purpose of this research is to identify components that cause failures in the B35 fuel system and determine effective maintenance types using the Reliability Centered Maintenance (RCM) method.

This study aligns with Sustainable Development Goal 7 (SDG 7) – Affordable and Clean Energy. By evaluating the impact of the B35 biosolar mandate, the research supports SDG 7 by promoting the use of renewable energy sources and enhancing energy efficiency. The shift towards higher biodiesel blends not only contributes to reducing dependence on fossil fuels but also helps in achieving Indonesia's targets for clean energy and greenhouse gas reduction. This alignment with SDG 7 underscores the study's relevance in advancing sustainable energy practices and supporting global efforts to transition towards cleaner and more efficient energy systems.

II. LITERATURE REVIEW

Maintenance is Requires decisions that consider facility capacity, production demands, and personnel necessary to maintain a reliable and stable process [7]. Maintenance management activities must be carried out optimally, with a focus on ensuring the reliability of equipment. One of the maintenance management strategies currently in use is Reliability-Centered Maintenance (RCM).

RCM is a process used to determine the maintenance requirements of any physical asset in its operating context [8]. This means that RCM is a process designed to determine what needs to be done to ensure that each physical asset continues to perform as required by the user within its operational context. Various RCM processes should ensure that the following questions are answered effectively:

Function & Performance Standards – Has the function of each item/equipment met the specifications or standards applied?

Functional Failure – How does the item/equipment fail to perform its function?

Functional Mode – What causes the functional failure to occur?

Failure Effect – What happens when the failure occurs?

Failure Consequence – How does the failure affect the overall system?

Preventive Task – What can be done to predict or prevent each of these failures?

Default Action – What should be done if no suitable proactive actions can be identified?

RCM consists of four main components that aim to optimize maintenance strategies is Preventif Maintenace, Reactive Maintenace, Predictive Testing & Inspection and Proactive Maintenance. RCM analysis can identify equipment items and their failure modes that will cause high-risk functional failures using Failure Mode, Effect, and Criticality Analysis (FMECA). FMECA is a systematic method used to identify potential problems by examining the effects of failure modes in design or processes. It consists of two distinct analyses, Failure Mode and Effects Analysis (FMEA), which focuses on identifying and evaluating failure modes and their impacts, and Criticality Analysis, which prioritizes these failure modes based on their severity and likelihood. Beyond risk identification, RCM also used to determine the specific maintenance task. Task Selection functions as a Logic Tree Analysis that assists in selecting the appropriate management strategy to address existing failures. The output RCM is the optimal preventive maintenance schedule for critical component machinery and equipment.

III. RESEARCH METHODS

The research design used in this study is a method qualitative. The qualitative analysis is conducted to identify critical components of equipment using FMECA and to develop task decisions obtained through Focus Group Discussions (FGD) with experts at PT ABC, following American Bureau of Shipping (ABS) RCM Guide [9]. The population in this study consists of employees involved in ship maintenance at PT ABC. The sample is drawn from this population using a nonprobability sampling method, specifically convenience sampling. The selected informants for the sample are managerial-level employees, including the Vice President of Engineering and Passenger Ships Engineering Manager, who can provide systematic and relevant information. Figure 2 shows a conceptual model of research.

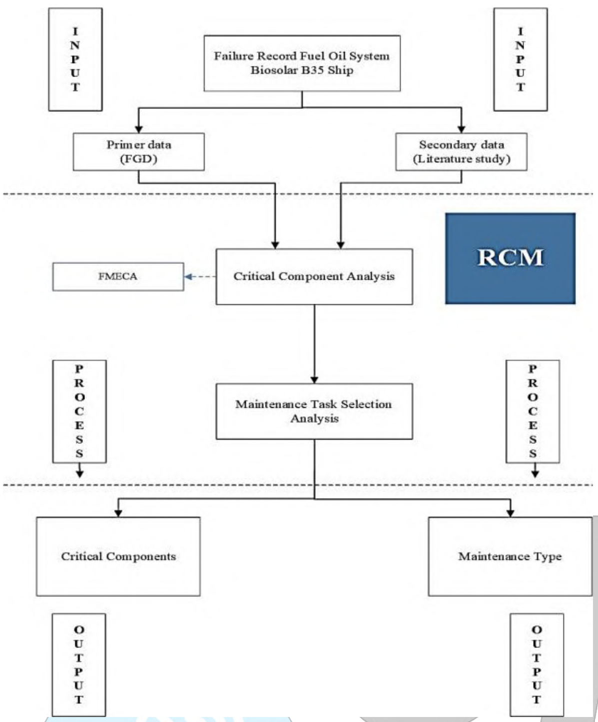

Fig 2. *Research conceptual model*
Source: *Result of self data processing*

In this study, FMECA analysis will be used with a bottom-up approach, focusing on the potential impact of equipment failures on the overall system. The FMECA analysis will be conducted following these steps American Bureau of Shipping ABS (2018):

Operating mode and context

The operating mode of the fuel system refers to the characteristics or operational conditions of the fuel system used in each operational task. Each operating mode influences how the system functions on the ship and how the engine is operated. This operating mode then determines the development of the operating context for each specific functional group on the ship.

Partitioning system

A ship consists of many complex systems and subsystems, the next step is to divide the ship into functional groups and then into specific systems, subsystems, equipment items, and components within each functional group.

System Block Diagram (SBD)

After completing the operation characteristic and partitioning stages, the next step is to compile a list of functions related to the selected functional group and associated equipment. These functions are identified based on the operational context of the functional group and the equipment within it. One method for identifying functions is by developing a system block diagram. A system block diagram is a graphical representation of system operations.

Function and Functional Failures

For each function within a functional group, a series of functional failures must be identified. In general, every function will have its corresponding functional failures. These failures can manifest as either a total loss of function or a partial degradation of performance.

FMECA

The FMECA procedure is divided into the following steps:

1. Identification failure mode
2. Identification failure effect
3. Identification failure detection
4. Identification corrective measure
5. Critically analysis

It is used to assign a risk rating to each failure mode identified during the FMECA by assessing the severity of the end effect, current likelihood using risk matrix.

Table I. *Severity Level Desricption*

Severity level	Description
1	Minor, Negligible
2	Major, Marginal, Moderate
3	Critical, Hazardous Significant
4	Catastrophic, Critical
Source: RCM ABS Guide (2018)	

Table II. *Likelihood Description*

Likelihood of failure	Description
Improbable	Less than 0.001 events/year
Remote	0.001 to 0.01 events/year
Occasional	0.01 to 0.1 events/year
Probable	0.1 to 1 events/year
Frequent	1 or more events/year

Source: *RCM ABS Guide (2018)*

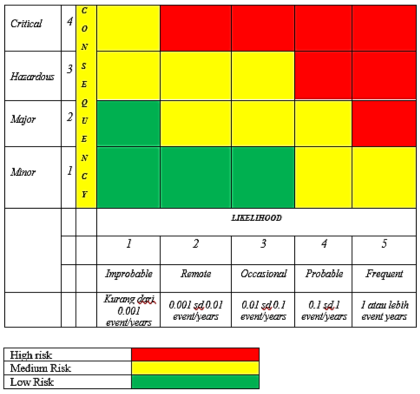

Fig 3. *Risk Matrix*
Source: *RCM ABS Guide (2018)*

RCM Maintenance Task

Task Selection serves as a Logic Tree Analysis that helps in selecting the appropriate management strategy to address the existing failures.

IV. RESULTS & DISCUSSION

The operating modes are first identified to determine the operational context of the ship's fuel system. Table III presents the operating modes and operational context of the fuel system on ship PT ABC. Ship was selected due to a previous blackout caused by issues with its fuel system during the use of Biosolar B35 fuel.

Table III. *Operating modes and context of the fuel system on ship PT ABC.*

Operating Content Fuel Oil System	
The fuel system uses marine diesel fuel, which is supplied to the main engine (8M 601 C type) from Krupp MaK. This main engine delivers a performance with a rated power of 8520 kW and operates at a rated speed of 428 rpm.	
Common Characterictic	Operating Modes On Sea/Manuvering
Enviromental paramaters	Ambient Temperature 24
Manner of use	The transfer pump, heater, separator, filter, and booster pump No. 1 are operated for one voyage, while No. 2 is kept on standby for the next voyage (as a backup). The annual service hours for components No. 1 and No. 2 are estimated to be the same. As for the fuel injection pump, the type used is L'orange PGO-GO 15C. At the inlet position, the fuel pressure must be within the range of 1.5–3.0 bar, and at the outlet position, the fuel pressure must be greater than 380 bar.
Perfomance Capability	Capable of delivering main engine performance with a rated power of 8520 kW at a rated speed of 428 rpm.

Source: Result of self data processing

There are many complex systems that need to be classified into system functions. This classification is based on disciplines, functional groups, systems, subsystems, and components. System partitioning of the ship's fuel system biosolar B35 PT ABC shown in Figure 4.

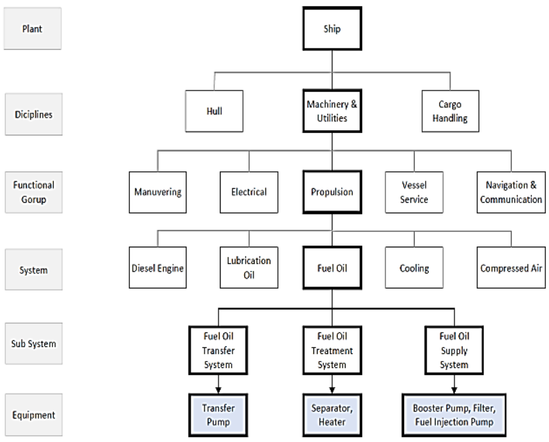

Fig 4. *Partitioning Fuel Oil Ship B35 System*
Source: *Result of self data processing*

After the system identification is determined, the next step is to identify the system block diagram of the ship's fuel system. The system block diagram (SBD) in Figure 5 illustrates the overall workflow of the six components of the fuel system (Transfer pump, heater, separator, filter, booster pump, and fuel injection pump) to support the operation of the ship's main engine. The next step is to identify functions and functional failures. The system block diagram is used to identify the functions required for the engine to operate effectively at sea. Functional failures are then identified for each function statement. These failures include both total and partial loss of each function. In this study, the identification of functional failures is based on the condition of the components when using Biosolar B35 fuel and the FMECA process is then carried out.

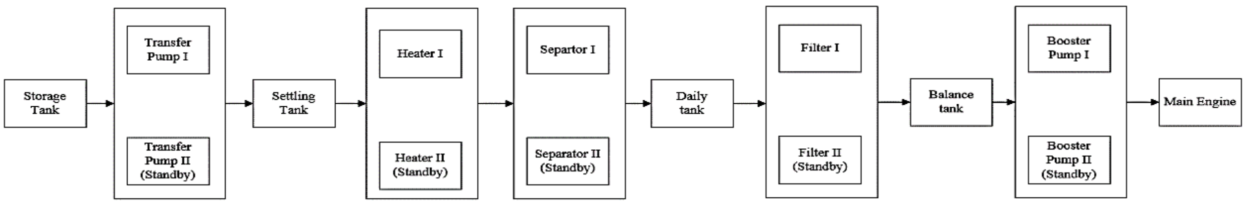

Fig 5. *SBD Fuel Oil Ship B35 System*
Source: *Result of self data processing*

Table IV. *FMECA + Maintenance Task Selection of Transfer Pump*

No: 1	Description : Transfer Pump												
Item	Failure Mode	Failure Char	Hidden atau evident	Effects			Risk Characterization			Task Selection			
				Local	Functional Failure	End	Severity	Current likelihood	Current Risk	Proposed Action	Projected Likelihood	Projected Risk	Dispotition
1.1	Pump wear	Random	Hidden	No fuel flow from the transfer pump to continue the function	Transfer pump is not operating at a capacity of 35 m³/h during operation	Overall system performance is disrupted.	Level 3	Probable	High	Overhaul	Remote	Medium	Acceptable
1.2	Operating with low output	Wear out	Hidden	Decrease in fuel flow to the ship's system	Transfer pump operates at less than 35 m³/h capacity during operation	Decline in engine performance and operational efficiency	Level 2	Probable	Medium	Pump Analysis	Remote	Medium	Acceptable
1.3	Leakage	Wear out	Evident	Decrease in fuel flow to the ship's system	Transfer pump operates at less than 35 m³/h capacity during operation	Decline in engine performance and operational efficiency	Level 2	Probable	Medium	Optical Leak Inspection	Remote	Low	Monitor periodically
1.4	Excessive pump vibration	Random	Evident	Reduction in pump lifespan	Transfer pump operates at less than 35 m³/h capacity during operation	Potential damage to the transfer pump and possible reduction in pump lifespan	Level 2	Occasional	Medium	Calibration	Remote	Low	Monitor periodically

Source: *Result of self data processing*

Volume 06, Issue 05, 2025 | Open Access | ISSN: 2582-6832

Table V. *FMECA + Maintenance Task Selection of Heater*

No : 2	Description : Heater													
Item	Failure Mode	Failure Char	Hiddent atau evident	Effects			Risk Characterization			Task Selection				
				Local	Functional Failure	End	Severity	Current likelihood	Current Risk	Proposed Action	Projected Likelihood	Projected Risk	Dispotition
2.1	Heater not hot	Random	Evident	High fuel viscosity	Heater is unable to heat the fuel at a capacity of 3.9 m³/h during operation	Fuel flow is disrupted	Level 2	Probable	Medium	Clean heater system	Remote	Medium	Acceptable
2.2	Overheating	Random	Evident	Evaporation	Heater is unable to heat the fuel at a capacity of 3.9 m³/h during operation	Damage to the fuel pump, filter, or potential fire hazard	Level 2	Ocassional	Medium	Temperature check	Remote	Low	Monitor periodically
2.3	Leakage	Random	Evident	Fuel reduction	Heater is unable to heat the fuel at a capacity of 3.9 m³/h during operation	Decline in system function	Level 3	Probable	High	Visual inspection	Remote	Medium	Monitor periodically

Source: Result of self data processing

Table VI. *FMECA + Maintenance Task Selection of Separator*

No : 3	Description :Separator												
Item	Failure Mode	Failure Char	Hiddent atau evident	Effects			Risk Characterization			Task Selection			
				Local	Functional Failure	End	Severity	Current likelihood	Current Risk	Proposed Action	Projected Likelihood	Projected Risk	Dispotition
3.1	Separator does not separate effectively	Random	Hidden	Impurities or water particles are not fully separated from the fuel	Separator is unable to clean the fuel from water and sludge content at a capacity of 3.9 m³/h during operation	Decline in fuel quality	Level 3	Probable	High	Functional Test	Remote	Medium	Acceptable
3.2	Leakage	Random	Evident	Fuel or other liquids are leaking from the	Separator is unable to clean the fuel from water and	Damage to the fuel pump, filter, or potenti	Level 2	Probable	Medium	Visual inspection	Remote	Low	Monitor periodically

				separator.	sludge content at a capacity of 3.9 m³/h during operation	al fire hazard							
3.3	Clogged	Random	Evident	Decrease in fuel flow	Separator is unable the clean the fuel from water and sludge content at a capacity of 3.9 m³/h during operation	Engine damage	Level 3	Probable	High	Clean separator	Remote	Medium	Monitor periodically

Source: Result of self data processing

***Table VII.** FMECA + Maintenance Task Selection of Filter*

No : 4	Description : Filter												
Item	Failure Mode	Failure Char	Hidden atau evident	Effects			Risk Characterization			Task Selection			
				Local	Functional Failure	End	Severity	Current likelihood	Current Risk	Proposed Action	Projected Likelihood	Projected Risk	Dispotition
4.1	Clogged	Random	Hidden	Fuel flow is obstructed	Filter is unable to remove dirt or particles from the fuel that are smaller than 13 millimicrons	Decline in system function	Level 3	Frequent	High	Manual cleaning	Probable	Medium	Acceptable
4.2	Leak / rupture	Wear out	Hidden	Reduces pressure in the system	Filter is unable to remove dirt or particles from the fuel that are smaller than 13 millimicrons	Fire, fuel loss, system damage	Level 3	Frequent	High	Visual inspection	Probable	Medium	Acceptable

***Source:** Result of self data processing*

***Table VIII.** FMECA + Maintenance Task Selection of Booster Pump*

No : 5	Description : Booster Pump												
Item	Failure Mode	Failure Char	Hidden atau evident	Effects			Risk Characterization			Task Selection			
				Local	Functional Failure	End	Severity	Current likelihood	Current Risk	Proposed Action	Projected Likelihood	Projected Risk	Dispotition
5.1	Leak / rupture	Random	Hidden	Fuel loss	Booster pump transfers fuel from the balance tank to the main engine at a capacity of less than 4.5 m³/h during	Loss of system efficiency	Level 3	Occasional	Medium	Overhaul	Remote	Low	Monitor periodically

					operation.								
5.2	Fall off while running	Wear out	Hidden	Fuel cannot be pumped to the main engine	Booster pump is unable to transfer fuel from the balance tank to the main engine at a capacity of 4.5 m³/h during operation	Operational delay	Level 3	Occasional	Medium	Pump Analysis	Remote	Medium	Acceptable
5.3	Operating with low output.	Wear out	Hidden	Fuel flow is insufficient to meet system requirements	Booster pump transfers fuel from the balance tank to the main engine at a capacity of less than 4.5 m³/h during operation.	engine does not operate optimally	Level 3	Probable	High	Optical Leak Inspection	Remote	Medium	Monitor periodically
5.4	Overheating	Random	Evident	High temperature in the pump may potentially damage internal components	Booster pump is unable to transfer fuel from the balance tank to the main engine at a capacity of 4.5 m³/h during operation	Fuel system damage	Level 2	Remote	Medium	Temperature check	Remote	Low	Monitor periodically

Source: *Result of self data processing*

Table IX. *FMECA + Maintenance Task Selection of Fuel Injection Pump*

No : 6	**Description : Filter**												
Item	Failure Mode	Failure Char	Hidden atau evident	Effects			Risk Characterization			Task Selection			
				Local	Functional Failure	End	Severity	Current likelihood	Current Risk	Proposed Action	Projected Likelihood	Projected Risk	Dispotition
6.1	Clogged	Random	Hidden	System pressure drop	Fuel injection pump is unable to transfer fuel to the injector at a	Decrease in efficiency.	Level 3	Probable	High	Visual inspection	Probable	Medium	Acceptable

					pressure of 380 bar during operation								
6.2	Leak / rupture	Random	Hidden	No fuel is supplied to the injector	Fuel injection pump transfers fuel to the injector at a pressure of less than 380 bar during operation	Blackout	Level 4	Ocassional	High	Overhaul	Occasional	Medium	Acceptable

Source: *Result of self data processing*

The results of the FMECA analysis can be presented in the FMECA Worksheet, as shown in Table IV, V, VI, VII, VIII and IX. This data is the result of a Focus Group Discussion (FGD) involving the researcher, the Vice President of Engineering, and the Passenger Ship Engineering Manager. The analysis aims to identify potential failure modes, their causes, and impacts on the Biosolar B35 ship fuel system, as well as to assess risk levels based on severity, likelihood of occurrence, and failure detection. In the separator component, functional failures in item numbers 3.1 and 3.3 fall within the propulsion matrix, with a severity level categorized as high, specifically Level 3 (Hazardous). The assessment of the likelihood of failure (Current likelihood) for these functional failures falls within the Probable level, meaning an occurrence probability of 0.1 to 1 event per year. Consequently, the risk assessment for functional failures in item numbers 3.1 and 3.3 is classified as high risk.

For the filter component, functional failures in item numbers 4.1 and 4.2 also fall within the propulsion matrix, with a severity level classified as high, specifically Level 3 (Hazardous). The likelihood of failure (Current likelihood) for these functional failures is categorized as Frequent, indicating a probability of one or more occurrences per year. As a result, the risk assessment for functional failures in item numbers 4.1 and 4.2 falls into the high-risk category.

Regarding the Fuel Injection Pump component, the functional failure in item number 6.1 falls within the propulsion matrix with a severity level of 3 (Hazardous). The likelihood of failure (Current likelihood) for this functional failure is classified as Probable, with an occurrence probability of 0.1 to 1 event per year.

Meanwhile, item number 6.2 is categorized within the propulsion matrix with a severity level of 4 (Critical). The likelihood of failure (Current likelihood) for this functional failure is rated as Occasional, meaning a probability of 0.01 to 0.1 events per year. Therefore, the risk assessment for functional failures in item numbers 6.1 and 6.2 is classified as high risk.

This study indicates that in the biosolar B35 fuel system, the most critical components are the fuel injection pump, separator, and filter. One of the main characteristics of biosolar fuel is its susceptibility to water contamination [4]. When biosolar fuel mixes with water, its quality can deteriorate, potentially causing damage to key components of the fuel system, such as separator. The separator is responsible for removing water and impurities from the fuel before it enters the engine. If the fuel is contaminated with water, the separator must work harder to separate these elements.

Additionally, biosolar B35 tends to generate deposits that can clog fuel lines [5], particularly affecting the filter and fuel injection pump. Filter, which is designed to maintain fuel cleanliness and protect engine components, may experience reduced performance, potentially leading to further issues in the ship's main engine. Also Fuel Injection Pump functions to transfer fuel to the injector. If deposit are not properly filtered, unfiltered contaminants can lead to a decline in engine performance due to abnormal fuel pressure in the injector.

Based on the maintenance task selection analysis, most fuel system failure modes are evident failures, detectable by crew members, with varying levels of importance, especially regarding human and environmental safety. Hidden failures, on the other hand, are not immediately visible and cannot be detected by the crew. Percentage of evident and hidden failure modes can be seen in Figure 6 below. From Figure 6, it can be observed that the analysis of the overall components in the biosolar B35 fuel system identifies a total of 18 failure modes. Based on this analysis, 10 failure modes (56% of the total) are classified as evident failures, while 8 failure modes (44% of the total) fall into the hidden failure category.

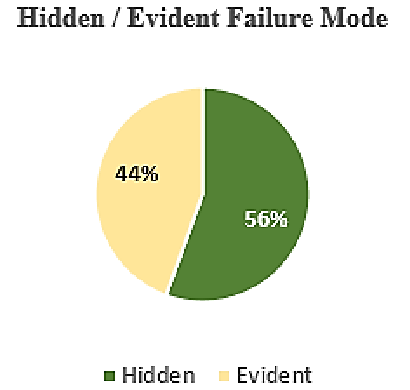

Fig 6. *Percentage Hidden or Evident Failure*
Source: *Result of self data processing*

Based on the overall summary of maintenance tasks, a total of 18 maintenance tasks (task list) have been identified, which can be categorized into the following maintenance types:

- Category A — Can be performed at sea by the ship's crew.
- Category B — Must be carried out jointly with the equipment vendor or using dock facilities.
- Category C — Must be performed at a dock facility.

Table X. *Summary of Maintenance Category Percentages*

Percentage of Maintenance Category		
Maintenance Category	Failures Mode	
	Amount	Percentage (%)
A	100%	100%
Amount Tasklist	18	100%

Source: Result of self data processing

Table X shown all failure modes fall under Category A, accounting for 100% of the total 18 task lists. Category A has the highest percentage because most of the recommended maintenance actions can be performed directly on-site by the ship's crew. Therefore, this responsibility fully falls under the shipowner's duties, which, in this case, are carried out by the crew themselves. In addition to maintenance categories, these 18 task lists are also identified based on their task type.

Table XI. *Persentation Maintenance Task*

Maintenance Category A		
Task Type	Amount Task	Persentase
Preventif Maintenance (PM)	9	50%
Condition Monitoring (CM)	7	39%
Failure Finding (FF)	2	11%
One-Time Change (OTC)	0	0%
Total	18	100%

Source: *Result of self data processing*

Table XI summarizes the maintenance types for category A: 50% preventive maintenance, 39% condition monitoring, 11% failure finding, and 0% one-time change (OTC). From this percentage, preventive maintenance is the primary recommended approach for maintenance actions. It is expected to extend the operational lifespan of each component, ensuring reliability and efficiency in the fuel system ship biosolar B35.

V. CONCLUSION

1. Critical Component

Based on the FMECA analysis, the components that can cause failure in the Biosolar B35 Ship Fuel System of PT ABC are the Transfer Pump, Heater, Separator, Filter, Booster Pump, and Fuel Injection Pump. Among these components, the most critical or high-risk ones are the Separator, Filter, and Fuel Injection Pump.

2. Maintenance Type

All failure modes analyzed fall into category A with a percentage of 100%, meaning maintenance can be performed directly by the ship's crew. Of the 18 task lists analyzed, Preventive Maintenance (PM) is the main recommendation with the largest percentage (50%), followed by Condition Monitoring (39%), Failure Finding (11%), and One-Time Change (0%).

ACKNOLEDGMENT

The researcher would like to express sincere gratitude to PT ABC for providing valuable data and support throughout this study. Special thanks also go to Mercu Buana University for its guidance and academic support. Lastly, the researcher extends appreciation to family and colleagues for their encouragement and assistance during the research process.

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