

BOILER COMBUSTION FAILURE: A CASE STUDY IN MV SINAR SANUR

Navarro Saiful Ghazi*, Amad Narto, Ely Sulistyowati

Marine Engineering Study Program Politeknik Ilmu Pelayaran Semarang. Jl. Singosari Raya No.2A.

*Corresponding author: saiful.navarro24@gmail.com

Abstract

Boiler combustion failures on the MV Sinar Sanur pose significant challenges to the vessel's operational efficiency, impacting both environmental sustainability and economic performance. This research investigates the underlying causes of combustion failures, evaluates their impact on ship performance, and proposes innovative technical solutions to mitigate future occurrences. A qualitative descriptive approach, coupled with the SHELL (Software, Hardware, Environment, Liveware) analysis model, was employed to identify key factors contributing to these failures. Primary data were collected through direct observation, crew interviews, and documentation, while secondary data were sourced from technical reports and relevant literature. The result show from a combination of factors, including dirty burners, low fuel pressure due to clogged filters, the use of low-quality and high-viscosity fuel oil, and suboptimal fuel piping system design. These failures lead to decreased machinery efficiency, impaired steam supply, increased crew workload, and potential damage to boiler components. The research proposes several innovative solutions: the implementation of continuous boiler system parameter monitoring, the use of higher-quality fuel, and modifications to the fuel piping system, including replacing 25A pipes with 20A pipes to optimize combustion efficiency. This study underscores the critical importance of regular maintenance, quality fuel usage, and efficient system design in ensuring sustainable operations. The proposed solutions not only enhance the vessel's operational efficiency but also contribute to reducing environmental impact by improving fuel utilization and minimizing waste.

Keywords: Boiler, Combustion, Failure, Fuel Oil, SHELL methods, Steam.

INTRODUCTION

An auxiliary steam boiler is a closed chamber that can form steam pressure exceeding than 1 atmosphere, by heating the feed water in it with hot gases from fuel combustion (Narto, 2018: 17). Among the various types of boilers used on vessels, fire tube boilers are one of the most common. In a fire tube boiler, the hot gases of combustion pass through tubes surrounded by water (Narto *et al*, 2023). The transfer of heat from the gas to the water produces steam, which is to be used for various functions on board, such as heating fuel oil, turning turbines, and maintaining engine operations. Fire-tube boilers are relevantly used due to their simple design and robust operation, but they are also prone to inefficiency and failure if not properly maintained.

The reliability of steam boilers on board is critical to ensure smooth operations, especially in the context of delivering steam to engines and heating systems. One of the common problems faced by operators is combustion failure, which not only reduces energy efficiency but can also cause system shutdowns, increase operational costs, and damage critical boiler components. This research focuses on MV Sinar Sanur, a vessel that has been facing combustion failures, resulting in significant disruptions in its operational efficiency. This research identifies the key factors contributing to these failures, examines their impact on vessel operations, and proposes short- and long-term solutions to prevent their re-occurrence. This research is expected to provide valuable insights for readers and become an educational resource for maritime professionals, especially in solving combustion failures in steam boilers on MV Sinar Sanur. By providing both theoretical and practical

contributions, this research aims to support the maritime industry in improving boiler reliability and operational efficiency, also encourage the further advancement of maritime technology and education.

LITERATURE REVIEW

This research has high relevance in the context of ship operations and maritime technology development, particularly in ensuring the efficiency and sustainability of boiler usage. Boilers are vital components in supporting various important functions on ships, such as fuel heating, cooling system management, and hot water provision for crew needs (Jie, 2018). Failure in boiler operations not only hampers energy efficiency but can also lead to increased operational costs, risk of damage to engine components, and even threaten ship safety.



Figure 1: MV Sinar Sanur

The relevance of this research is heightened because it addresses a real problem faced by the MV Sinar Sanur, namely combustion failure caused by a combination of technical factors, fuel quality, and inappropriate fuel system design. Through the application of the SHELL analysis model, this research not only identifies the main causes of the failure but also offers practical solutions, such as piping system modifications and the use of better fuel quality.

The findings of this study make an important contribution in completing the literature gap regarding the relationship between piping system design, fuel viscosity and combustion efficiency. The practical implications are highly relevant to ship operators, boiler manufacturers and maritime industry regulators in improving boiler system efficiency, reducing the risk of failure and supporting more sustainable operations.

RESEARCH METHOD

The descriptive qualitative approach, as defined by Sugiyono (2022: 88), is a method aimed at describing and understanding social phenomena by exploring meanings, concepts, and perceptions from the subject's point of view. The qualitative method was selected because it is in accordance with the view of postpositivism, which recognizes the complexity of human experience that cannot be fully captured through quantitative methods. Thus, it allows researchers to obtain accurate and in-depth data through triangulation techniques, such as observations, interviews, and document analysis (Moloeng, 2006: 330). These methods and techniques were used in order to

obtain comprehensive insights from the crew's point of view, technical documentation, and maintenance records. Also investigating the root cause of the combustion failure in the auxiliary steam boiler on MV Sinar Sanur, which was conducted during the researcher's sea project from November 26, 2022, to December 16, 2023.

In this study, the data analysis technique used is SHELL. SHELL data analysis technique is an analysis model consisting of categories; Software, Hardware, Environment, Liveware. This model helps identify and analyze human factors that can affect system performance and safety as well as, analysis techniques that are often used in the scope of shipping safety. To understand the categories of SHEL analysis techniques further, as follows:

- A. Software: is a component that organizes the way humans interact with non-physical elements, such as procedures, checklists, and rules, through symbols, terms, and layouts, with the aim of facilitating understanding to prevent misinterpretation that can be fatal. (Muyhidin, 2020).
- B. Hardware: focuses on systems of physical objects, such as equipment that impact human performance (Muhyidin, 2020).
- C. Environment: Environmental factors that affect human performance such as temperature and noise, so that it can hamper operational efficiency. (Muhyidin, 2020).
- D. Liveware: evaluates human capabilities, taking into account how stress, motivation, and attention affect decision making. Applied in this study, the SHEL model identifies the main contributors to combustion failure (Muhyidin, 2020).

Table 1. SHEL factors

Category	Factors
Software (S)	- Maintenance procedures that have not been fully implemented according to a set schedule
Hardware (H)	- The burner condition on the boiler is dirty. - Low fuel pressure
Environment (E)	- Poor quality of HFO (Heavy Fuel Oil) fuel.
Liveware (L)	- The crew's ability to analyze problems and determine appropriate solutions.

To increase the validity of the data, the researcher conducted primary data collection involving structured observations on board MV Sinar Sanur and interviews with the crew, focusing on operational practices and maintenance routines. Secondary data was collected from technical documentation, maintenance records, and relevant literature.

RESULTS AND DISCUSSION

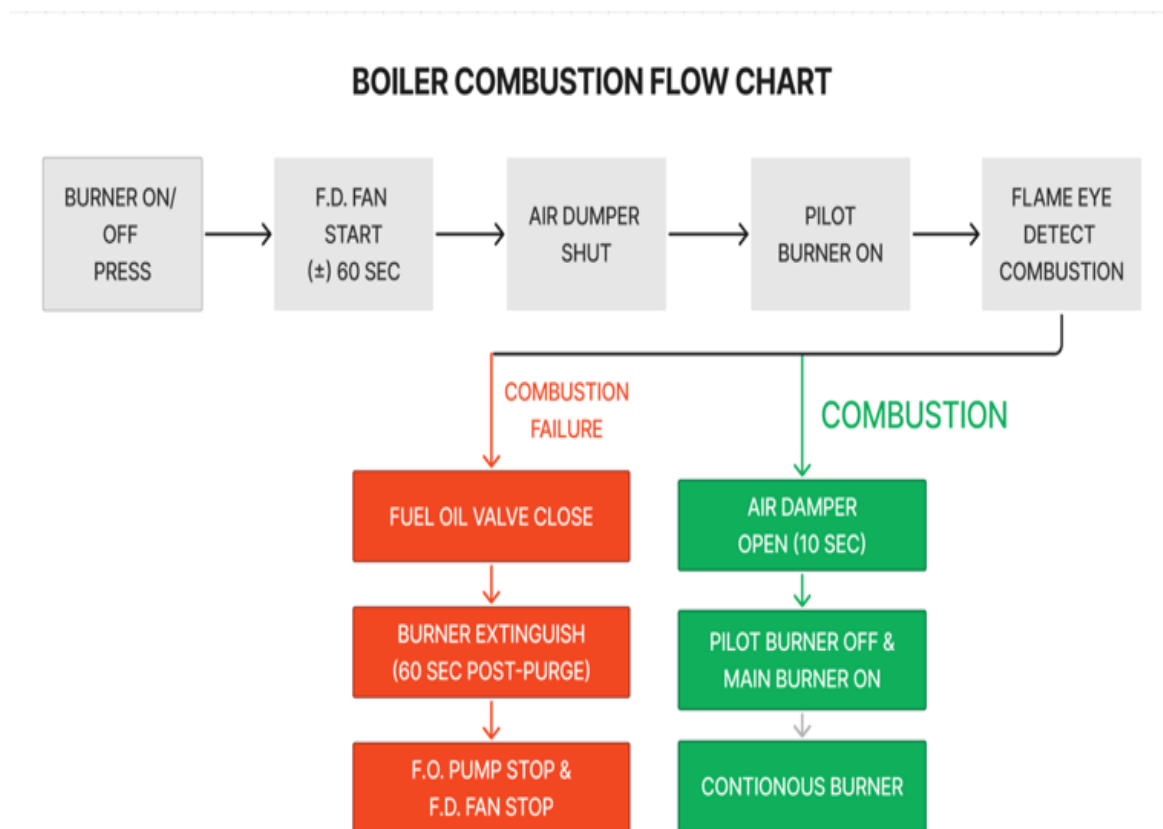


Figure 1:Boiler combustion chart

The combustion process in a boiler is a complex sequence that involves careful coordination of fuel supply, ignition systems, and monitoring controls to ensuring optimal boiler performance and safety. This process involves several stages, from purging the furnace to the stabilization of the main burner flame. Below is how it can work according to the main steps involved:

- A. **Pre-Combustion Preparation and Furnace Purging:** Before ignition, it is essential to ensure that the combustion chamber is adequately prepared. This begins with purging the furnace to eliminate any residual combustible gases, thus preventing the risk of explosion or incomplete combustion. A Force Draft Fan (F.D. Fan) is employed to supply a flow of fresh air into the combustion chamber, effectively clearing out any remaining flammable gases. This step is critical for maintaining safe operational conditions.
- B. **Pilot Burner Ignition:** once the furnace is purged, the pilot burner is ignited to initiate the combustion process. At this stage, the solenoid valve controlling the fuel supply opens, allowing Marine Diesel Oil (MDO) from the D.O. Service Tank to flow to the pilot burner. The fuel is then pumped via a dedicated pilot burner pump, and once ignited, the pilot burner serves as a stable ignition source for the main burner.
- C. **Main Burner Ignition and Stabilization:** Following successful ignition of the pilot burner, a flame eye sensor detects the flame and sends a signal to the control system. This ensures that the pilot flame is stable, confirming that the combustion process is on track. Once stability is confirmed, the fuel oil solenoid valve opens to supply the main burner. The fuel is atomized and ignited by the pilot flame, which then establishes the main burner flame. This marks the

start of the primary combustion phase, where the boiler generates the thermal energy necessary for its operation.

- D. Fuel Selection and Transition between MDO and HFO: The main burner can operate on two types of fuel; Heavy Fuel Oil (HFO) and Marine Diesel Oil (MDO). If the temperature of HFO is insufficient for optimal atomization and combustion, MDO is used as a transitional fuel. During this period, steam produced by the burner is utilized to heat the HFO to the appropriate temperature, ensuring that it can be efficiently atomized and combusted when introduced into the main burner. This dual-fuel approach allows for flexibility in fuel choice and ensures continuous, stable operation of the boiler.

However, the researcher found and saw several problems in the incomplete boiler combustion process at MV Sinar Sanur which was disrupted due to several factors, dirty main burner conditions, low fuel pressure, poor fuel quality, inappropriate pipe sizes, and empty de-aerating tanks. The combustion process from the fuel tank to the boiler burner, which is based on factors related to the fuel system. For ease of illustration, a diagram of fuel oil piping in the boiler is attached to the figure 2.

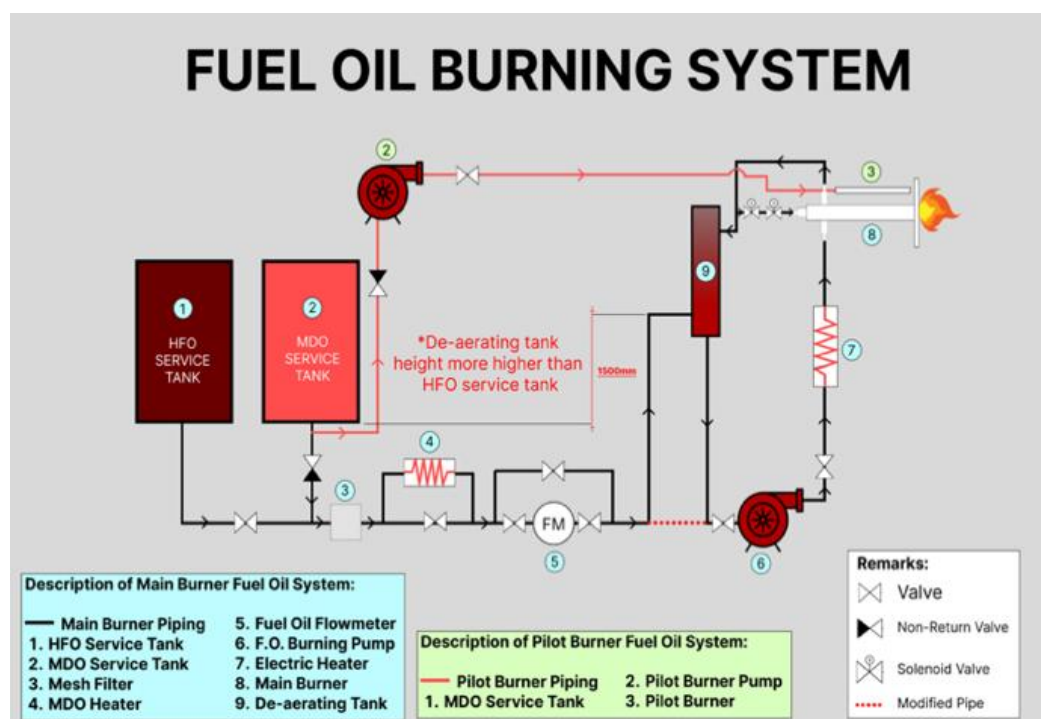


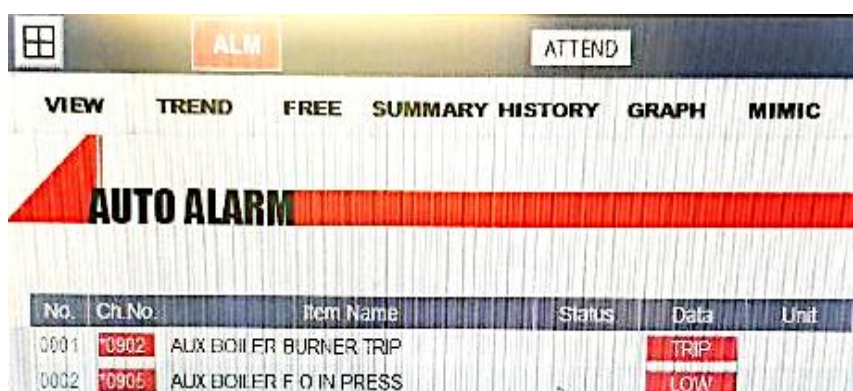
Figure 2: F.O. Burning system pipin diagram
Source: *Book Piping Diagram in Engine Room MV Sinar Sanur*

In Figure 2 is the flow of the main burner fuel system, the following is an explanation:

- 1) Fuel comes from the F.O. Service Tank or D.O. Service Tank.
- 2) Then passes through several filters and flow meters.
- 3) Fuel enters the de-aerating tank / mixing tank (is a fuel mixing tank, from fuel coming from the service tank and F.O. return from the main burner).
- 4) Fuel comes out of the de-aerating tank and is pumped using the F.O. burning pump to the main burner through the F.O. heater to be heated or maintain its temperature.
- 5) Fuel enters the main burner to be atomized and then the combustion process occurs.
- 6) Excess fuel will return to the de-aerating tank and be reused.

Analysis of Combustion Failure in Auxiliary Boiler

When the MV Sinar Sanur finished with engine and anchored at Chittagong Anchorage. The researcher, who was on watch duty with the third engineer and oiler, heard an alarm in the Engine Room (E/R). After checking the Engine Control Room (ECR) monitor, the warnings “Auxiliary Burner Trip” and “Auxiliary Fuel Oil Inlet Pressure Low” were found. “Trip” in this context refers to the automatic shutdown of the boiler due to an unsafe condition or malfunction (Anish, 2021). Boiler trip is a safety mechanism that prevents equipment damage. Common causes of this trip relate to problems in the fuel supply that trigger the “Auxiliary Fuel Oil Inlet Pressure Low” alarm, combustion failure, or problems in the air system. The boiler will resume operation until the problem is resolved and the system is reset (Osaka Boiler Instruction Manual Book, 2021: 166).



No.	Ch.No.	Item Name	Status	Data	Unit
0001	0902	AUX BOILER BURNER TRIP	TRIP		
0002	0905	AUX BOILER F O IN PRESS	LOW		

Figure 3: Alarm list on engine control room

The aim of this study was to identify the combustion failure factors of the boilers at MV Sinar Sanur that affect operational efficiency. The SHEL (Software, Hardware, Environment, Liveware) framework was applied to systematically assess each factor contributing to the failure. This analysis highlights critical issues related to maintenance practices, equipment condition, fuel quality, and crew competency.

Findings Summary

The key findings are summarized in Table 1, which highlights the identified factors in each category of the SHEL model.

Table 1. SHEL identified factors	
Category	Identified Factors
Software	Maintenance procedures were not consistently implemented according to the established schedule.
Hardware	Soot accumulation on the burner, low fuel pressure.
Environment	Poor quality Heavy Fuel Oil (HFO) with high viscosity and sludge content.
Liveware	Crew's capacity to analyze and address technical issues effectively under pressure.

Source: authors

Interpretation of Results

Software: Maintenance Procedure

The Inconsistent execution of planning maintenance system procedures contributes significantly to combustion failures. Irregular inspections according to established schedules and preventive measures are delayed or inadequately performed, causing soot and debris to accumulate on critical components such as burners and filters.

Interpretation: Regular and thorough maintenance is essential to maintain boiler performance, the impact of irregular maintenance will have an impact on boiler efficiency. (Narto, A. *et al.*, 2023).

MONTHLY MAINTAINANCE PARTS RECORD																																					
AUXILIARY MACHINERY "C"																																					
Ship's Name : MV. Sinar Sanur				Monthly No. : 2023				Last RH/ Date : 133.22 hrs / 31 December 2022																													
Machinery : Auxiliary Boiler				M : 1				Recent RH/ Date : 241.02 hrs / 31 January 2023																													
YEAR	MONTH	WORK	REMARKS	SINCE LAST	INTERVAL		DATE																														
					HOURS	DAILY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2023	JANUARY	A. BOILER BURNER INSPECTION																																			
		ATOMIZER	CHECK/ CLEAN	27/12/22	-	1 WEEK																															
		CAPNUT	CHECK/ CLEAN	27/12/22	-	1 WEEK																															
		SPRAYER	CHECK/ CLEAN	27/12/22	-	1 WEEK																															
		SWIRLER	CHECK/ CLEAN	27/12/22	-	1 WEEK																															
		PILOT BURNER ATOMIZER	CHECK/ CLEAN	27/12/22	-	1 WEEK																															
		ELECTRODE	CHECK/ CLEAN	27/12/22	-	1 WEEK																															
		FLAME EYE CABLE	CHECK/ CLEAN	27/12/22	-	1 WEEK																															
		AUTOMATIC DEVICE CONTROL	CHECK/ CLEAN	31/12/22	-	1 DAY																															
		B. F.O. BURNING SYSTEM																																			
		PUMP	CHECK	31/12/22	-	1 DAY																															
		COUPLING (W/ RUBER)	CHECK	31/12/23	-	1 DAY																															
		FILTER	CHECK/ CLEAN	31/12/24	-	1 DAY																															
		MOTOR BEARING	CHECK	31/12/25	-	1 DAY																															
		AUTOMATIC DEVICE CONTROL	CHECK	31/12/22	-	1 DAY																															
		C. BOILER WATER ANALYSIS																																			
		ALKALINITY	200-300 PPM	29/12/22	-	3 DAY																															
		CHLORIDE	< 300 PPM	29/12/22	-	3 DAY																															
		DEHA	0.03-0.10 PPM	29/12/22	-	3 DAY																															
		PH	8-11	29/12/22	-	3 DAY																															
		BOTTOM BLOW DOWN	0.5 M3	29/12/22	-	1 WEEK																															
		SURFACE BLOW DOWN	0.2 M3	31/12/22	-	1 DAY																															

Chief Engineer:

CORNELIS GANUR

Reporter:

3/E IRVAN DWI SEPTIAN

Chief Engineer: CORNELIS GANUR

Reporter: 3/E IRVAN DWI SEPTIAN

Figure 4: Boiler monthly maintainance record

Hardware: Burner Condition and Fuel Pressure

The burner condition deteriorates due to soot buildup, which interferes with fuel atomization and leads to incomplete combustion (Hee, 2014). In addition, low fuel pressure due to clogging of the fuel filter leads to decreased fuel pressure and makes. This also occurred in the empty de-aerating tank due to unstable fuel supply.



Figure 5: Burner & F.O. Filter Condition



Figure 6: Empty De-aerating Tank

Interpretation: The correlation between burner condition and combustion efficiency is very important, as poor atomization reduces the quality of fuel-air mixing, leading to inefficient combustion. Khaq (2024) observed a similar effect in MT Pancaran Infinity, where low fuel pressure and dirty burners hindered boiler performance.

Environment: Fuel Quality

Table 2: F.O. Comparison

	Fuel Supply in Singapore
Viscosity	225.6 cSt
Density	0.9512
Service TK C	120

Source: Viswa Lab Bunker Analysis

The quality of HFO supply from Singapore bunkers used in MV Sinar Sanur was found to be substandard, with high viscosity and sludge content. The small piping system and small pipes were inadequate to handle the high-viscosity fuel, leading to flow disruption and pressure drop in the boilers (Ou *et al.*, 2023).

Interpretation: High viscosity fuels require optimized piping and pumping systems. This supports the findings of Pranto (2020), who noted decreased pump efficiency with high-viscosity fluids. Utomo (2021), who recommended larger diameter pipes for better handling of viscous fuels.

So the design of the fuel piping system at MV Sinar Sanur needs improvement and modification as a solution to overcome combustion failures in the steam boiler. By making a variety of modifications to the boiler fuel piping system to solve fuel flow problems, especially when using Heavy Fuel Oil (HFO). These modifications require permits and approvals from authorized parties (e.g. ship management, shipbuilder, ship classification society), as well as inspections to ensure safety, performance and compliance with applicable regulations. Here are the main steps need to be taken by the engine crew:

- A. Initial Check and Problem Identification: The fuel flow problem was first detected when the De-Aerating Tank (Mixing Tank) was empty, indicating an interruption in fuel flow. The problem was thought to be caused by blockages due to dirt and undersized pipes, which were unable to support the flow of high-viscosity fuels such as HFO.

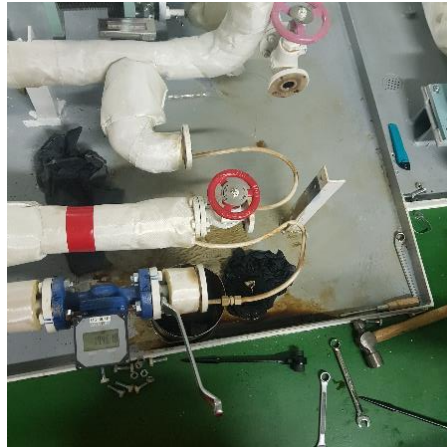


Figure 7: Checked valve flange
Source: author

- B. Temporary Action: The crew tried to resolve the flow issues with manual methods, such as hammering valves and piping and flushing with Marine Diesel Oil (MDO). Although these measures succeeded in temporarily starting the boiler, problems occurred, especially with the De-Aerating Tank continuing to empty.
- C. Initial Modification Efforts: The crew opened several flanges on the piping system to remove trapped air, but only drops of fuel came out. This indicated that the problem was not trapped air, but rather fuel flow resistance.
- D. Fuel Changeover: At Chittagong port, the crew made a changeover from HFO to MDO, which has a lower viscosity. With MDO, the boiler was able to operate normally, but when using HFO, the problem kept tripping the system.



Figure 8: Smooth Drain of MDO Fuel
Source: Authors

- E. Modifications: The main modification was to change the 25A to 20A fuel pipe of 3000mm length (can be seen in the Figure 2 in the dashed red line section) that connects the outlet of the flow meter with the suction of the boiler burning pump. The purpose of this change was to increase the pressure in the system and allow a smoother flow of fuel.

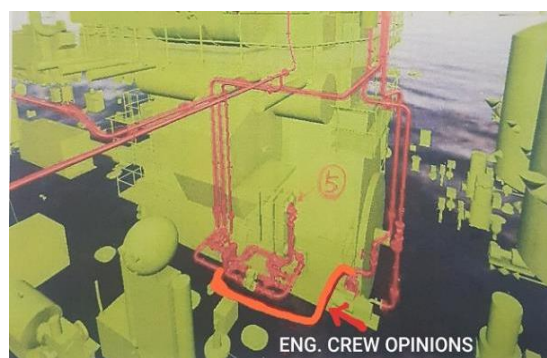


Figure 8 Modfiy Fuel Oil Pipe design
Source: authors



Figure 9: Results of modified boiler fuel oil pipe system
Source: authors

- F. Final Checks and Tests: After the modification, the crew conducted a series of tests by operating the boiler manually and automatically. Flange temperature and flow pressure checks were also carried out, and the results showed that the system was functioning stably without any trips.

Liveware: Crew Capabilities and Stress Levels

Crew members demonstrated varying abilities in troubleshooting and responding to combustion failures. The stressful conditions aboard, compounded by the equipment issues, occasionally led to delayed response times and impacted decision-making.

Interpretation: Crew competency and stress management play vital roles in handling equipment failures. Training in technical problem-solving and stress management is essential for improving responses to equipment failures, as supported by Aji (2022) in his study on MV *HI 02*.

Comparitive Analysis with Previous Research

The study's findings align with several previous studies on boiler combustion failures:

- A. Khaq (2024): Observed that low fuel pressure and burner fouling caused boiler failure on MT *Pancaran Infinity*.
- B. Mochamad (2023): Found that irregular maintenance and soot-clogged components led to operational inefficiencies on KM *Nggapulu*.

- C. Aji (2022): Reported issues with fuel quality and burner malfunction in MV *HI 02*, affecting combustion efficiency.
- D. Pranto (2020): Demonstrated the impact of high-viscosity fluids on pump efficiency, relevant to the boiler's fuel handling.
- E. Utomo (2021): Suggested that larger-diameter pipes are needed for high-viscosity fluids to reduce pressure losses.

This study contributes new insights by integrating the SHEL framework and by emphasizing the combined effects of maintenance irregularities, equipment conditions, and environmental factors.

CONCLUSION

In conclusion, the combustion failure on board MV Sinar Sanur was mainly caused by the unscheduled maintenance planning, dirty burner condition, low fuel pressure, poor HFO quality, and inadequate fuel pipe design. These factors combined to create a situation of boiler failure on MV Sinar Sanur, causing operational inefficiency and disruption. Immediate solutions, such as using higher quality fuel and modifying the fuel piping system, helped alleviate the problem. However, long-term strategies should include regular maintenance to prevent soot buildup, use of higher-quality fuels with lower viscosity and sludge content, and re-evaluation of the fuel system design to ensure compatibility with fuel characteristics. Future research could explore alternative fuels and their impact on combustion efficiency, as well as compare the performance of different boiler systems under the same operational conditions.

ACKNOWLEDGEMENT

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