

Research Paper

Thermal Analysis of the Exhaust Gas Temperature Increase Phenomenon in the Starboard Main Engine Mitsubishi S6R2-T2MTK3L

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Abstract: This study aims to analyze the thermal performance of the starboard main engine on a tugboat, specifically a Mitsubishi type S6R2-T2MTK3L, by focusing on the phenomenon of exhaust gas temperature increase. Measurements were conducted over six days under two operational conditions: towing an empty barge and towing a fully loaded barge. The results indicate that the exhaust gas temperature was significantly high in both conditions, with a temperature difference of 40 °C at low engine speed and up to 100 °C at high speed. These findings suggest incomplete combustion, indicating the need for further improvement in the engine's combustion process. Meanwhile, fuel temperature remained relatively stable in both conditions, with a maximum difference of only 3 °C at medium and high engine speeds, suggesting that the fuel delivery system is operating safely. The analysis of specific fuel consumption (SFC) revealed inconsistent trends in relation to engine speed. The highest SFC was recorded at 600 rpm while towing a fully loaded barge, at 0.01855 l/kWh. The highest engine torque was 7523.885 Nm at medium speed, while the lowest torque was 7165.605 Nm at high speed. This study concludes that high exhaust gas temperatures serve as a primary indicator of combustion inefficiency in the starboard main engine, requiring further evaluation to maintain operational efficiency and safety of the tugboat.

Keywords: Exhaust gas temperature; Gas Boiler; Fuel; Combustion, Torque

1. Introduction

Ships play a crucial role in supporting the smooth operation of both national and global trade. In Indonesia—an archipelagic country comprised of thousands of islands connected by vast waters—maritime transportation serves as the backbone of distribution and economic connectivity. It is also considered a key pillar for national stability and prosperity. One of the most commonly used vessels in Indonesian waters is the tugboat, which assists larger ships in maneuvering, towing, and pushing barges, particularly in port areas.

The main component of a tugboat is its diesel engine, which generally operates using either a four-stroke or two-stroke cycle. The combustion process within the engine produces exhaust gases with distinct thermal characteristics. The Exhaust Gas Temperature (EGT) is a critical parameter for assessing combustion efficiency and the thermal health of the engine [1],[2]. Typically, the EGT of marine diesel engines ranges between 380–400 °C. However, this value may rise under high-load conditions, inefficient combustion, or fuel system malfunctions [3]. A significant increase in EGT often signals the early onset of component failure or a decline in engine performance. For instance, studies on waste heat recovery systems in marine diesel engines have shown that EGT is a primary factor affecting the efficiency of systems such as the Organic Rankine Cycle (ORC); even after the exhaust gas boiler, the temperature often remains between 170–180 °C, meaning that increased EGT can significantly reduce ORC efficiency [4].

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Environmental temperature variations—both ambient air and seawater—also affect marine diesel engine performance. A simulation study using an engine room simulator of a tanker vessel equipped with a MAN B&W 6S50 MC-C engine revealed that seasonal temperature differences led to substantial changes in parameters such as scavenge pressure, compression pressure, emissions (NO_x , SO_x , CO_x), fuel consumption, and EGT [5]. EGT increases are closely linked with higher fuel consumption and lower thermal performance, especially in high-duty vessels like tugboats[6]. Karthick and De Poures further highlighted that the use of hydrogen-blended fuels significantly alters the EGT pattern. Additional studies have also shown that changes in engine speed and fuel quality affect Specific Fuel Consumption (SFC) and exhaust emissions[7]. Moreover, advanced AI-based approaches, such as BiLSTM and digital twin models, have been developed to predict EGT trends in real-time [8], [9],[10].

Thermal performance analysis of Exhaust Gas Boiler (EGB) systems indicates that both exhaust gas temperature and flow rate significantly impact heat transfer efficiency. Additional technologies such as Exhaust Gas Recirculation (EGR) and two-stage turbocharging have proven effective in reducing EGT and fuel consumption by 11.6 g/kWh, while also lowering NO_x emissions by 12%. In the context of tugboats, actual engine performance is heavily influenced by torque, SFC, and EGT [11][12]. Abnormal increases in EGT are frequently early symptoms of injector malfunction, turbocharger inefficiency, or cooling system failure. Numerical simulations on biodiesel-fueled engines have confirmed that increased combustion temperatures are often accompanied by higher particulate emissions when not properly controlled[13][14]

A thermodynamic modeling study using MATLAB/Simulink on a two-stroke diesel engine demonstrates that various performance failures—such as high engine room temperature, intake filter blockage, fouled intercooler, and worn turbocharger bearings—can be diagnosed through the relative deviation of thermodynamic parameters. By applying a normalization method that eliminates the influence of engine room temperature and cooling water temperature, failures can be accurately detected across the entire engine operating range, making it an effective approach for condition monitoring and fault diagnosis of marine diesel engines.[15][16]. A predictive model for exhaust gas temperature (EGT) in marine diesel engines based on deep learning has been developed using a hybrid CNN-BiLSTM-Attention architecture. This model has proven to be more accurate than other neural networks in monitoring operating conditions and providing early fault warnings. By integrating the Mahalanobis distance and a mathematical model, the system can precisely set monitoring thresholds, making it an innovative approach for health management and early fault detection in marine diesel engines [17][18].

This study investigates the influence of exhaust gas temperature and flow velocity on the heat transfer coefficient of exhaust gas boilers in existing ships to meet the IMO's EEXI standards. By modeling heat transfer using a hybrid approach and lumped parameter method, it was found that each gas flow velocity has an optimal temperature for maximum efficiency, ranging between 224–230 °C. These findings provide theoretical guidance for the operational management of ship boilers to enhance energy efficiency and reduce carbon emissions[19][20].

Based on empirical observations aboard Tugboat Prima 2029 over approximately 15 months, it was recorded that the starboard main engine's EGT consistently ranged between 450 °C and 520 °C, far above the ideal operational range. This suggests potential issues in the combustion system or the overall operational performance of the main engine. The consistently high exhaust gas temperature indicates a need for a comprehensive evaluation of engine speed, fuel temperature, and specific fuel consumption, and their influence on EGT and engine torque. Therefore, this study is entitled. The influence of engine speed and fuel consumption on exhaust gas temperature and performance of the starboard main engine on tugboat prima 2029. This research aims to analyze the relationship between engine speed, fuel temperature, specific fuel consumption (SFC), and torque in relation to exhaust gas temperature characteristics. The results are expected to contribute to improving main engine efficiency and prolonging engine life in tugboat operations across Indonesia.

2. Research and Methodology

2.1. Research Framework

The workflow of this research was systematically structured as follows: Identification and formulation of the problem. Literature review and collection of secondary data on the diesel engine of Tugboat Prima 2029. Data collection during the voyage. Analysis of measurement results: power, engine speed (rpm), temperature, torque, Specific Fuel Consumption (SFC), and exhaust gas temperature. Conclusion drawing

2.2. Tools and Materials

2.2.1. Tools

The tools used for data collection in this research are as follows: Handle Remote Couple Functions to adjust or change the main engine's rpm according to the test requirements. Tachometer Used to measure the rotational speed (rpm) of the main engine. Flowmeter Functions to measure the fuel consumption (diesel) used by the main engine. Thermometer Gauge Used to measure the incoming fuel temperature and the exhaust gas temperature from the main engine. Diesel Engine (Main Engine). The main object of research, for which thermal characteristics and fuel consumption are observed.

2.1.2. Materials

The materials used in this study include: Diesel Fuel Serves as the main fuel for operating the ship's diesel engine. Lubricating Oil Used to support performance and ensure smooth operation of the diesel engine.

2.3. Data Collection Procedure

The data collection was carried out through the following steps: Preparing all necessary components such as the diesel engine, thermometer, flowmeter, and tachometer. Ensuring that the engine is filled with fuel and lubricating oil before starting. Starting the diesel engine and setting the load and engine speed based on the testing scenario. Recording data on fuel temperature, engine rpm, exhaust gas temperature, and fuel consumption under each load condition. Repeating measurements for each condition: unloaded and fully loaded, at three engine speed variations (600 rpm, 800 rpm, and 1000 rpm).

2.4. Calibration of Measuring Instruments

Before use, all measuring instruments were calibrated to ensure data accuracy and reliability. The results of calibration were: Tachometer and Flowmeter showed initial readings of zero before measurements began. Thermometer Gauge showed an ambient room temperature of approximately $\pm 31^{\circ}\text{C}$, in accordance with the initial test standard.

3. Results and Discussion

3.1. Calculated Data Results for Tugboat Pulling an Empty Barge

Based on the data collection process, the following are the results obtained during the tugboat operation while pulling an empty barge. Figure 3.1 Graph of the relationship between engine speed and exhaust gas temperature while pulling a loaded barge.

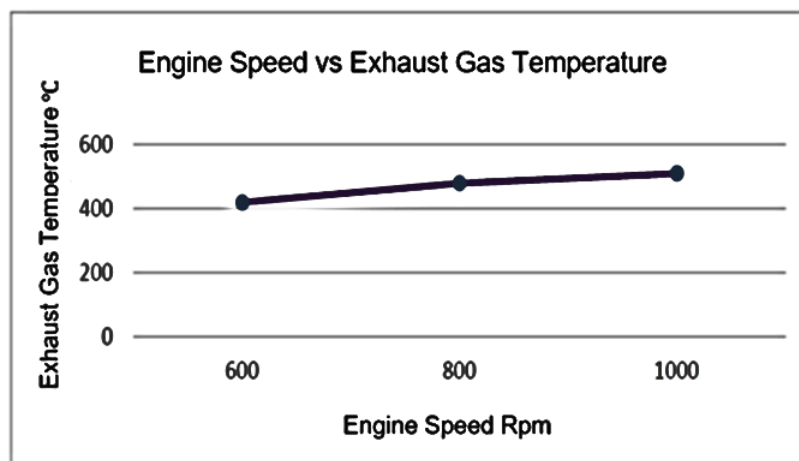


Figure 3.1 Graph of the relationship between engine speed and exhaust gas temperature while pulling a loaded barge.

Figure 3.1. Illustrates the relationship between increasing engine speed and exhaust gas temperature. As the engine speed increases, the exhaust gas temperature of the main engine also rises. However, the rate of increase differs between speed intervals. From 600 rpm to 800 rpm, the exhaust gas temperature increases by 60 °C, whereas from 800 rpm to 1000 rpm, it increases by only 30 °C. This indicates that at higher engine speeds, the rise in exhaust gas temperature becomes less significant compared to the increase observed at medium engine speeds.

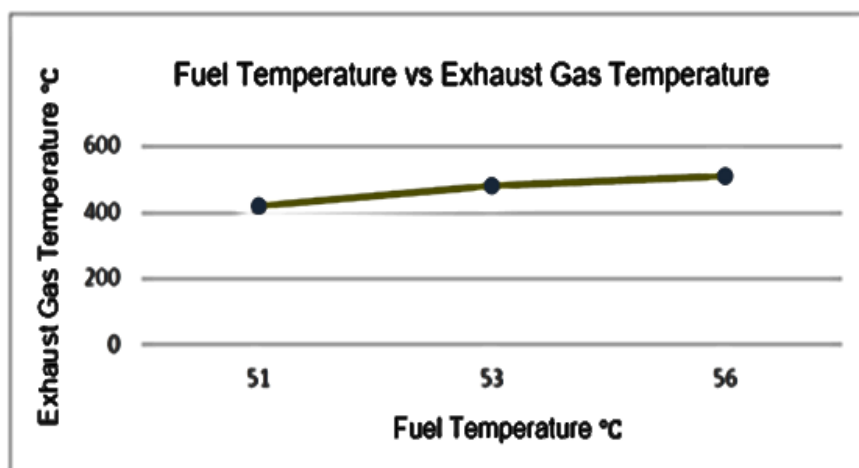


Figure 3.2 Graph of the relationship between fuel temperature and exhaust gas temperature while pulling an empty barge.

Figure 3.2 shows the graph of the relationship between fuel temperature and exhaust gas temperature while the tugboat is pulling an empty barge. The graph demonstrates that an increase in fuel temperature leads to a rise in the exhaust gas temperature of the main engine. However, the rate of increase varies at different temperature intervals. When the fuel temperature increases from 51 °C to 53 °C, the exhaust gas temperature rises by 60 °C, whereas an increase from 53 °C to 56 °C results in only a 30 °C rise. This indicates that the effect of increasing fuel temperature on exhaust gas temperature is similar to the effect of increasing engine speed—both show a diminishing rate of temperature increase at higher input levels.

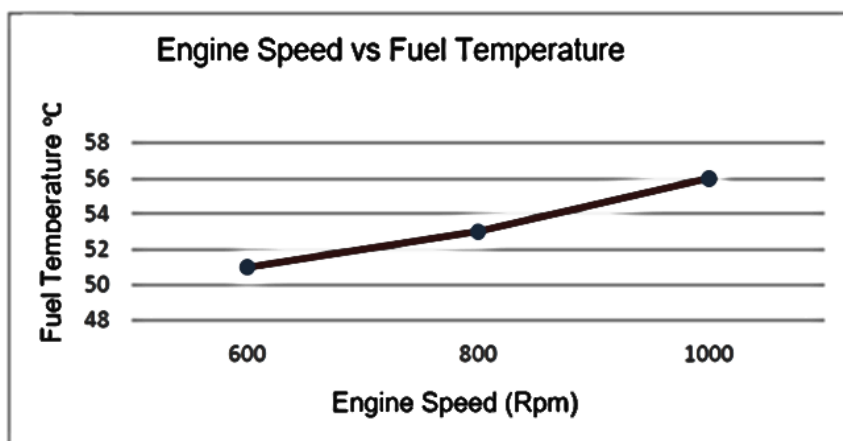


Figure 3.3 Graph of the Relationship between Engine Speed and Fuel Temperature while Pulling an Empty Barge

Figure 3.3 illustrates the graph of the relationship between engine speed and fuel temperature while the tugboat is pulling an empty barge. The graph shows that as the engine speed increases, the fuel temperature also rises. Specifically, the increase in fuel temperature from low to medium engine speed is 2 °C, while the increase from medium to high engine speed is 3 °C. This indicates that the rise in fuel temperature is more significant at higher engine speeds compared to moderate speeds.

3.2. Calculated Data Results for Tugboat Pulling a Fully Loaded Barge

The following are the results of data analysis during the tugboat operation while pulling a fully loaded barge.

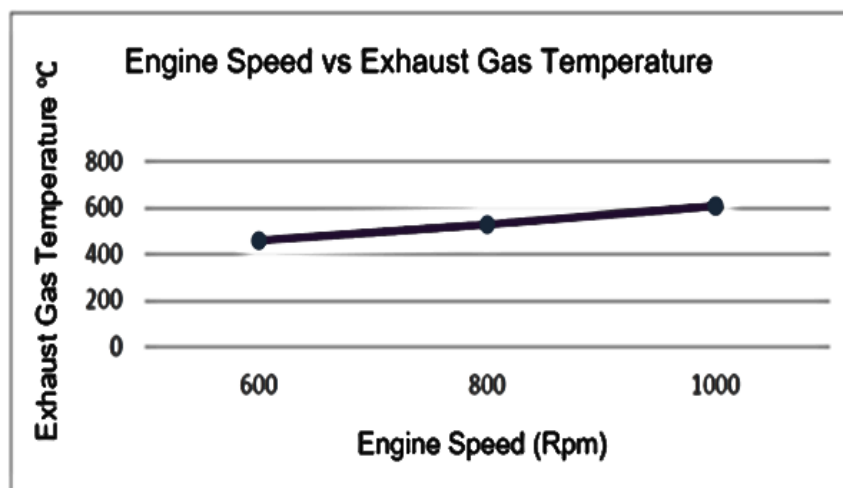


Figure 3.4 Graph of the relationship between engine speed and exhaust gas temperature while pulling a fully loaded barge.

Figure 3.4 shows the graph of the relationship between engine speed and exhaust gas temperature while the tugboat is pulling a fully loaded barge. The graph indicates that an increase in engine speed results in a rise in the exhaust gas temperature of the main engine. However, the rate of increase varies between speed intervals. From 600 rpm to 800 rpm, the exhaust gas temperature increases by 70 °C, whereas from 800 rpm to 1000 rpm, it rises by 80 °C. This suggests that at higher engine speeds, the increase in exhaust gas temperature is greater compared to the increase observed at medium engine speeds.

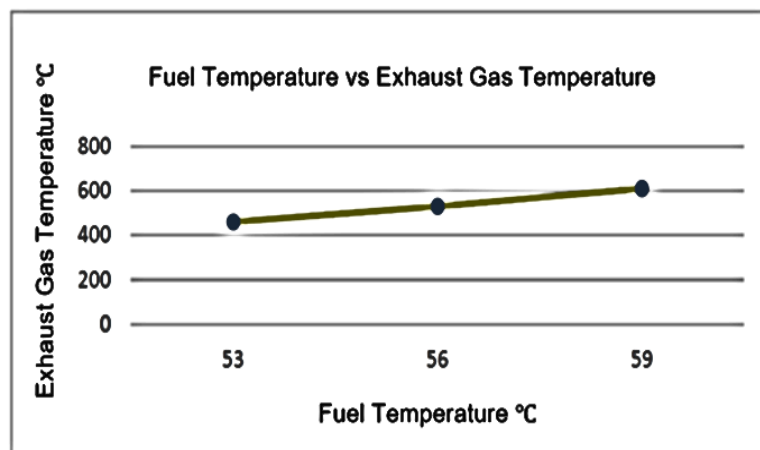


Figure 3.5 Graph of the relationship between fuel temperature and exhaust gas temperature while pulling a fully loaded barge.

Figure 3.5 presents the graph showing the relationship between fuel temperature and exhaust gas temperature while the tugboat is pulling a fully loaded barge. The graph illustrates that an increase in fuel temperature leads to a corresponding rise in the exhaust gas temperature of the main engine. However, the rate of increase differs between intervals. When the fuel temperature increases from 53 °C to 56 °C, the exhaust gas temperature rises by 70 °C, whereas an increase from 56 °C to 59 °C results in an 80 °C rise. This indicates that the effect of increasing fuel temperature on exhaust gas temperature is similar to the effect of increasing engine speed — both show a greater impact on exhaust gas temperature at higher input levels.

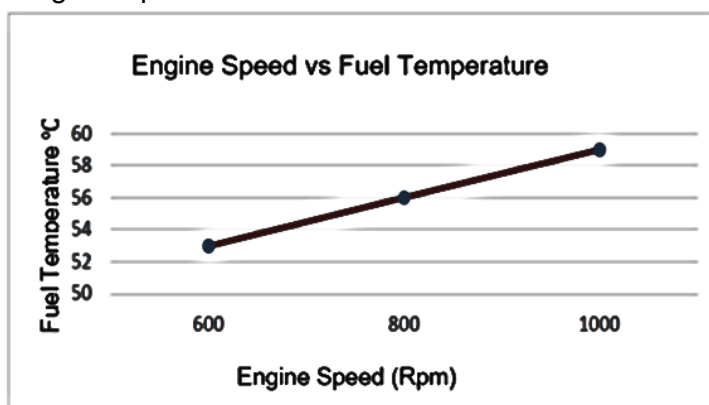


Figure 3.6 Graph of the relationship between engine speed and fuel temperature while pulling a fully loaded barge.

Figure 3.6 illustrates the graph of the relationship between engine speed and fuel temperature while the tugboat is pulling a fully loaded barge. The graph shows that as the engine speed increases, the fuel temperature also rises. Based on the data, the increase in fuel temperature from low to medium engine speed is 3 °C, and the increase from medium to high engine speed is also 3 °C. This indicates that the rise in fuel temperature is equally significant at both medium and high engine speeds.

4. Conclusion

Engine speed is directly proportional to exhaust gas temperature, where an increase from 600 rpm to 1000 rpm results in a significant rise in exhaust temperature—particularly under fully loaded conditions, with temperatures reaching up to 100 °C higher than in unloaded conditions. An increase in fuel temperature also contributes to higher exhaust gas temperatures, with a more pronounced effect under full load. This relationship aligns with the influence of engine speed on exhaust temperature, indicating that both factors collectively contribute to the rise in emission temperature. The most efficient Specific Fuel Consumption (SFC) is achieved at medium engine speed (800 rpm)

for both load conditions. The trends in SFC and torque indicate that optimal combustion efficiency and mechanical output occur at medium rpm. At high engine speeds, however, there is a noticeable decrease in torque and an increase in specific fuel consumption, reflecting reduced mechanical efficiency.

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Conflict of Interest: The authors declare that there is no conflict of interest regarding the publication of this article.

5. References

- [1] C. Ezgi, "Thermodynamic Analysis of Marine Diesel Engine Exhaust Heat-Driven Organic and Inorganic Rankine Cycle Onboard Ships," *Applied Sciences*, 2024.
- [2] G. Jiang, Y. Yuan, H. Guo, and G. Wu, "Numerical Simulation Study on Combustion Characteristics of a Low-Speed Marine Engine Using Biodiesel," *Journal of Marine Science and Engineering*, 2025.
- [3] L. Luo, Y. Fan, Y. Wang, P. Ni, X. Zhang, and G. Xi, "Experiment Study on the Exhaust-Gas Heat Exchanger for Small and Medium-Sized Marine Diesel Engine," *Energy Engineering: Journal of the Association of Energy Engineers*, vol. 120, no. 1, pp. 125–145, 2023. <https://doi.org/10.32604/ee.2022.022295>
- [4] T. Stanivuk et al., "Simulation Modelling of Marine Diesel Engine Cooling System," *Transactions on Maritime Science*, vol. 10, no. 1, pp. 112–125, 2021.
- [5] B. O. Ceylan, "Investigation of Seasonal Effects on Two-Stroke Marine Diesel Engine Performance Parameters and Emissions," *Journal of Marine Science and Application*, vol. 22, no. 4, pp. 795–808, 2023, <https://doi.org/10.1007/s11804-023-00383-1>
- [6] K. S. Jo, K. J. Kong, and S. H. Han, "Optimizing Fuel Efficiency and Emissions of Marine Diesel Engines When Using Biodiesel Mixtures," *Journal of Marine Science and Engineering*, vol. 13, no. 6, 2025, <https://doi.org/10.3390/jmse13061192>
- [7] A. Coraddu et al., "Physical, Data-Driven and Hybrid Approaches to Model Engine Exhaust Gas Temperatures in Operational Conditions," *Ships and Offshore Structures*, vol. 17, no. 6, pp. 1360–1381, 2022, <https://doi.org/10.1080/17445302.2021.1920095>
- [8] S. Lebedevas, L. Norkevičius, and P. Zhou, "Effect of Using LNG as Fuel in Seaport Tugboats," *Journal of Marine Science and Engineering*, vol. 9, no. 2, 2021, <https://doi.org/10.3390/jmse9020123>
- [9] A. A. Salazar et al., "Improving Fuel Consumption Prediction for Marine Diesel Engines Using Hierarchical Neural Networks," *Energies*, vol. 18, no. 1, 2025, <https://doi.org/10.3390/en18010017>
- [10] J. Sun, H. Zeng, and K. Ye, "Short-Term Exhaust Gas Temperature Trend Prediction ..." *Journal of Marine Science and Engineering*, vol. 12, no. 4, 2024, <https://doi.org/10.3390/jmse12040541>

- [11] L. Mocerino et al., "Validation of an Emission Model for a Marine Diesel Engine with Data from Sea Operations," *Journal of Marine Science and Application*, vol. 20, no. 3, pp. 534–545, 2022, <https://doi.org/10.1007/s11804-021-00227-w>
- [12] Y. Z., X. L., and K. Li, "Optimization Method of Fuel Saving and Cost Reduction of Tugboat Main Engine Based on Genetic Algorithm," *International Journal of System Assurance Engineering and Management*, vol. 13, pp. 605–614, 2022.
- [13] H. Zhang et al., "Performance, Energy and Exergy Characteristics of Turbocharged Marine Engine," *Processes*, vol. 11, no. 10, 2023, <https://doi.org/10.3390/pr11102924>
- [14] Brighthubengineering, "Reasons for High Exhaust Gas Temperature (EGT) in Marine Diesel Engines," 2024.
- [15] Y. Hu et al., "Performance Failure Simulation of Marine Diesel Engine Turbocharging," *Journal of Advanced Marine Engineering and Technology*, vol. 45, no. 4, pp. 140–153, 2021, <https://doi.org/10.5916/jamet.2021.45.4.140>
- [16] Y. K. A et al., "Exhaust Emission Factors for Marine Diesel Engines on Tug Vessels," *Regional Studies in Marine Science*, vol. 79, 2024.
- [17] Z. Ji, H. Gan, and B. Liu, "A Deep Learning-Based Fault Warning Model for Marine Diesel Engine," *Journal of Marine Science and Engineering*, vol. 11, no. 8, 2023, <https://doi.org/10.3390/jmse11081509>
- [18] Z. Korczewski, "Exhaust temperature measurements of the marine turbocharged diesel engines in operation," *Journal of Polish CIMAC*, vol. 9, pp. 127–136, 2014.
- [19] D. Jiang et al., "Influence of Exhaust Temperature and Flow on Boiler Heat Transfer," *Sustainability*, vol. 15, no. 1, 2023. <https://doi.org/10.3390/su15010753>
- [20] Ö. E. Karaçay and O. A. Özsoysal, "Techno-Economic Investigation of Tugboat Propulsion Systems," *Energy Conversion and Management*, vol. 12, 2021.
- [21] "Fault Diagnosis and Isolation of the Marine Diesel Engine Turbocharger System," *Academia.edu PDF*.
- [22] "Fault Tree Analysis and Failure Diagnosis of Marine Diesel Engine Turbocharger System," *Journal of Marine Science and Engineering*, vol. 8, no. 12, p. 1004, 2020. <https://doi.org/10.3390/jmse8121004>
- [23] E. F. Pehlivan and İ. Altın, "CFD Model of Scavenge Air Inlet Temperature on Exhaust Emissions," *International Journal of Energy Studies*, vol. 9, no. 3, pp. 493–517, 2024.
- [24] A. Youssef et al., "A Survey on Data Driven Fault Diagnostic Techniques for Marine Diesel Engines," *arXiv preprint*, Apr. 2024.
- [25] V. Valerie and E. Hadrian, "Analisis Strategi Optimalisasi Kinerja Boiler pada Kapal MV. Navigator Aries," *Meteor: Jurnal Ilmu Pelayaran*, 2024.
- [26] J. D. Hasibuan, "Simulasi Perpindahan Panas pada Dinding Ruang Bakar Boiler Dengan ANSYS Workbench," *Skripsi, Universitas Medan Area*, 2023.
- [27] D. Pratama, R. Widodo, and A. N. Jaya, "Optimalisasi Perawatan Sistem Auxiliary Boiler," *Jurnal Diplomati & Diving Boiler Pelayaran*, vol. 5, no. 2, pp. 45–52, 2022.