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CASE STUDY ON THE OPTIMIZATION OF TURBOCHARGER PERFORMANCE TO IMPROVE THE PERFORMANCE AND COST EFFICIENCY OF A TWO-STROKE MAIN ENGINE ON THE MT. MABROUK

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Abstract

The turbocharger is a crucial component in diesel engines, operating by utilizing exhaust gases produced during combustion. These gases flow through the exhaust manifold and function to compress the intake air entering the cylinders, supporting both scavenging and combustion processes. This study aims to examine efforts to maintain turbocharger performance in relation to the efficiency of the main engine. Data were collected onboard MT. Mabrouk from November 4, 2024, to July 7, 2025, by observing intake air pressure, turbocharger rotational speed, and exhaust manifold temperature, which were continuously monitored and recorded during testing. The findings indicate that proper turbocharger maintenance significantly increases engine output and fuel efficiency, with an average improvement of 18%. The researchers concluded that factors such as carbon deposits, clogged air filters, insufficient bearing lubrication, and elevated exhaust gas temperatures may lead to turbine imbalance, reduced combustion efficiency, slower vessel speed, increased fuel consumption, and shortened component lifespan. Preventive maintenance including turbine cleaning, turbo oil replacement, and optimization of the cooling system proved effective in improving turbocharger efficiency and overall engine performance.

Keywords: Turbocharger; Diesel Engines; Marine Vessels; Efficiency; Exhaust Emissions.

INTRODUCTION

In the maritime sector, ships serve as a crucial means of transportation. They serve as a mode of maritime transport, providing large-scale cargo and passenger transportation between locations. Therefore, every mechanical system must be equipped with appropriate equipment and comply with ship safety standards. To ensure optimal ship operation, diesel engines play a vital role as the primary propulsion system. In addition to their primary propulsion function, diesel engines also act as the primary electrical generators. The choice of diesel engines is driven by their advantages, providing significant benefits to ship operators due to lower maintenance costs compared to steam turbines. The primary advantage of diesel engines lies in their ability to generate high power while using relatively low fuel consumption, thereby helping to reduce operational costs for ship owners. Furthermore, diesel engines are capable of operating continuously for extended periods.

Diesel engines are classified as internal combustion engines because the fuel combustion process takes place within the cylinder. The combustion process that occurs in the cylinder directly determines the amount of power a diesel engine can produce. To achieve complete fuel combustion, machinery that can supply maximum air is required. One of the machines that can work optimally in the combustion process and supply air is a turbocharger. In ship operations, turbocharger performance is a crucial factor because it is directly related to fuel consumption, engine rotation stability, and the reliability of the propulsion system.

Turbochargers play a crucial role in improving combustion efficiency and diesel engine performance. Turbochargers are used to improve ship engine performance by supplying exhaust air into the combustion chamber with a normal temperature of 350-360°. This helps in increasing fuel combustion efficiency and engine output power. Improving turbocharger performance can maximize fuel utilization and reduce exhaust emissions that are detrimental to the environment. With a turbocharger, ship engines can achieve higher thrust without the need to increase engine size, which directly affects ship speed. Below are some expert opinions about turbochargers. (Sulistyono 2020) The application of a high-efficiency turbocharger has an impact on the performance of the main engine, especially in fuel consumption. Turbochargers can improve fuel efficiency and enable the engine to produce more power from the same amount of fuel. This is because denser air enters the combustion chamber, allowing for more efficient combustion. With a turbocharger,Small engines can produce power equivalent to larger engines, which also contributes to better fuel efficiency. (Marsudi 2022)

In the ship's operating environment, turbochargers are often exposed to less-than-ideal conditions. Variations in engine load, fluctuating fuel quality, high operating temperatures, and even impurities in the intake air can impact turbocharger performance. If left unchecked, these conditions can lead to reduced boost pressure, increased exhaust gas temperatures, excessive vibration, and even damage to components such as bearings or compressor and turbine blades, ultimately leading to higher costs. To maintain optimal turbocharger performance, routine maintenance by the crew onboard the turbocharger is required. According to Hendrawan (2020), the use of turbochargers can improve engine performance because the heat from the exhaust gas can be reused.

METHOD

This research employs a descriptive qualitative method with the aim of providing a comprehensive explanation of the phenomenon based on data collected in the field (Nurmala dkk., 2026). Through this approach, researchers can explore the context, meaning, and dynamics of interactions that emerge within the environment that is the object of study. Information is obtained through analysis of on-board documentation, which is then systematically analyzed to identify relevant patterns, themes, or categories. The focus of this research is to explore the perceptions, experiences, and perspectives of the research subjects, resulting in a rich and detailed understanding of the issue being studied. This approach also allows for flexibility in the research process, allowing the analysis to evolve along with data collection and dynamics encountered in the field.

RESULTS AND DISCUSSION

The operating principle of a turbocharger involves drawing air from the external environment into the compressor, which then passes it through an intercooler for cooling. The goal is to lower the temperature of the air before it enters the cylinder chamber, where it is initially at a high temperature. After being cooled in the intercooler, the air is passed through an air scavenging system and then distributed to each cylinder based on the firing order. The air entering the cylinder is then compressed with the fuel, triggering the combustion process. The resulting combustion product, the exhaust gas, is expelled through the exhaust manifold and then directed to the turbine. It is in the turbine that the exhaust gas is pushed out through the chimney.

Based on test data before and after optimization of the turbocharger system, significant improvements were seen in several key parameters of the main propulsion diesel engine on the MT. Mabrouk. Measurement results showed that the intake air pressure increased from 0.8 bar to 1.1 bar, indicating an increase in the efficiency of the air intake process into the combustion chamber. This increase in air pressure directly impacts the quality of fuel combustion, because the more air intake, the more complete the combustion process becomes and produces greater energy. In addition, the exhaust gas temperature decreased from 395°C to 375°C, indicating that the heat from combustion has been more optimally utilized by the turbocharger system to turn the turbine. This decrease in exhaust gas temperature also indicates that energy loss in the form of heat has been reduced, thus increasing the engine's thermal efficiency. In terms of fuel pressure and engine power performance, there is an increase in torque and power output of ±5–8%. This indicates that the energy generated from the combustion process is now more effectively converted into mechanical work on the engine crankshaft. As a result, the engine can operate at higher loads with relatively stable fuel consumption. Overall, the results of this analysis indicate that turbocharger optimization plays a significant role in improving the volumetric efficiency and thermal performance of the engine. By increasing intake air pressure and reducing exhaust gas temperature, the efficiency of the combustion system increases, resulting in more stable ship propulsion and more efficient fuel consumption. When the engine burns, hot exhaust gas exits the cylinder and flows toward the turbine side. The high pressure and temperature of this gas rotates the turbine wheel. This turbine rotation is then transmitted to a shaft connected to the compressor (Sutrisno & Prabowo, 2022; Yulianto et al., 2023). The rotation of the turbine causes the compressor to move. In this section, the compressor draws in outside air and compresses it, increasing the air pressure. This compressed air is then channeled to the engine's air intake system. The resulting compression increases the air temperature. To make combustion more efficient, the hot air is transferred to the charge air cooler to lower its temperature. This cooling increases the oxygen content per volume of air. After passing through the charge air cooler, the cooled and dense air is introduced into the combustion chamber. This air helps the engine produce more stable combustion and greater power.

New exhaust gas from combustion is recirculated to the turbine. Some turbochargers use a wastegate to control pressure to prevent excess combustion. The gas is then released through the exhaust system. Turbochargers are equipped with oil lines that lubricate the shaft and bearings. In addition to reducing friction, the oil also helps stabilize the turbo's temperature when operating at high speeds. (Kurniawan & Maulana, 2023) Turbochargers are crucial devices in marine diesel engine systems because they increase the pressure of the air entering the combustion chamber by utilizing the kinetic energy of the exhaust gas. The working principle of a turbocharger begins when the exhaust gas from combustion is directed to the turbine. The heat energy from this exhaust gas drives the turbine, which is connected to the compressor shaft, thereby compressing the air drawn in from outside and pushing it into the engine cylinder. With the increased pressure and amount of incoming air, combustion becomes more complete, producing greater power with relatively the same fuel consumption (Hendrawan, 2020; Sulistyono, 2020).

In a marine engine system, turbocharger performance significantly impacts engine thermal efficiency and fuel consumption. Optimal combustion efficiency can increase a vessel's propulsion while reducing exhaust emissions such as CO_2 and NOx. Marsudi (2022) stated that increasing intake air pressure by 1 bar can increase engine power by up to 20%, while the use of a turbocharger can also reduce fuel consumption by 15–25% compared to conventional engines. Factors affecting turbocharger performance include fuel quality. Substandard fuel can leave carbon residue on turbine blades, causing reduced rotational efficiency and increased operating temperatures. Furthermore, insufficient lubrication in bearings can cause excessive friction, accelerating wear and causing premature failure of turbine components (Zulfahmi, 2021).

Table 3.1 Factors Affecting Turbocharger Performance

No	Factor	Technical Impact
1.	Fuel quality	The formation of carbon deposits inhibits turbine rotation and reduces intake air pressure.
2.	Bearing lubrication	High friction causes overheating and accelerates component wear.
3.	Exhaust gas temperature	Temperatures above 550°C can reduce the turbine's service life by up to 40%.
4.	Cleanliness of the air filter	Clogged filters restrict air flow and reduce combustion efficiency.
5.	Marine environmental conditions	Humid and dusty air accelerates corrosion and contamination of components.

Observations on board the ship indicate that after routine cleaning and maintenance of the turbocharger, the performance of the main engine significantly improved. Empirical data indicates increased ship speed and fuel efficiency, as well as a decrease in exhaust gas temperature, confirming the role of regular maintenance as a key factor in the stability of the ship's machinery system (Ceylan, 2023).

Figure 3.2 Before and After Turbocharger Maintenance

(Before) (After)

Before maintenance, a turbocharger typically shows signs of performance degradation, such as a carbon-covered turbine, a clogged air filter, increased exhaust gas temperatures, and unstable turbo revs. This situation results in suboptimal air intake into the combustion chamber, resulting in incomplete combustion, increased fuel consumption, and reduced engine thrust. This condition also has the potential to accelerate damage to other components due to the increased engine workload.

After maintenance, such as cleaning the turbine and blower, replacing the turbocharger lubricating oil, checking the clearances, and checking the cooling system, the intake air flow becomes smoother, the exhaust temperature decreases, and the turbo rotation speed returns to normal. The impact can be seen in increased combustion efficiency, stable two-stroke main engine performance, more fuel-efficient fuel consumption, and increased component lifespan. Thus, routine maintenance has been proven to support the reliability of a ship's propulsion system. In general, maintenance improves the cleanliness of the turbine and the position of related components, resulting in more stable intake air flow and more consistent boost pressure before maintenance (Hameur et al., 2022).

Table 3.2 Observation of Exhaust Gas Temperature at the Turbocharger Inlet and Outlet Before Maintenance

No	Date	Inlet Temperature	Outlet Temperature	**Information**
1	04-19-2025	410°C	385°C	Abnormal
2	04-20-2025	410°C	384°C	Abnormal
3	04-21-2025	415°C	385°C	Abnormal
4	04-22-2025	410°C	390°C	Abnormal
5	04-23-2025	417°C	390°C	Abnormal
	Minimum	410°C	385°C	Abnormal
	Maximum	417°C	390°C	Abnormal
	Average	412°C	386°C	Abnormal

The exhaust gas temperature data above at the turbocharger inlet and outlet before maintenance provides an initial overview of the turbocharger's operating condition and the quality of the engine's combustion process. Integration of pre-maintenance inlet and outlet temperature data is necessary for baseline evaluation and post-maintenance comparison, given the potential for changes due to leak repairs, air duct cleanliness, and improved turbine performance (Lombardi et al., 2023; .)

The inlet temperature reflects the combustion process in the cylinder, the load on the engine, and the exhaust pressure driving the turbine. If the inlet temperature in the table is higher than the standard value, it could indicate incomplete combustion, problematic or dirty injectors, incorrect timing adjustment, or prolonged engine operation at high loads. In general, the turbo inlet temperature reflects the exhaust gas temperature before the turbine, influenced by engine load, turbo configuration, and the presence of leaks in the intake tract that can increase pressure and change the intake airflow curve (Usai & Marelli, 2023;).

The exhaust gas temperature at the outlet reflects the effectiveness of the turbine in absorbing energy from the exhaust gas, how much energy is successfully converted into turbine rotation. Monitoring the outlet temperature that is close to the normal limit or exceeds the limit indicates several main causes: decreased turbocharger efficiency due to fouling on the turbine blades, accumulation of dirt in the exhaust gas path that increases back pressure and reduces flow, and a mismatch between the turbine rotation speed and the operational load (Gamache et al., 2023;.) An increased outlet temperature also means that the turbine is not absorbing maximum energy so that its performance decreases.

There are several ways that can be done as an effort to increase the power reduction of the ship's main propulsion engine due to the suboptimal performance of the turbocharger, namely: routine maintenance, monitoring temperature and pressure and fuel system maintenance.

Figure 3.3*Turbocharger and Engine Control Room Indicators*

(Source: MT. Mabrouk Ship)

The engine control room is a ship's engine control room that controls and monitors all of the ship's machinery. Through control panels, sensors, alarms, and monitoring systems, the engineer officer can ensure all equipment is operating stably, safely, and according to operational procedures.

In this room, the engine officer can read various indicators such as temperature, pressure, engine speed, and electrical conditions, so that operational decisions can be made quickly and accurately (Pratama & Suryadi, 2023).

The engine control room is often connected to a remote control system that allows the transfer of control between locations, for example from the ECR to the platform or vice versa, to ensure safe and responsive operation of the vessel (Herlambang et al., 2023)

Table 3.3 Observation of Exhaust Gas Temperature at the Turbocharger Inlet and Outlet After Maintenance

No	**Date**	**Inlet Temperature**	Outlet Temperature	**Information**
1	04-28-2025	370°C	350°C	Normal
2	04-29-2025	370°C	355°C	Normal
3	04-30-2025	375°C	355°C	Normal
4	01-05-2025	365°C	350°C	Normal
5	02-05-2025	370°C	355°C	Normal
	Minimum	365°C	350°C	Normal
	Maximum	375°C	355°C	Normal
	Average	370°C	353°C	Normal

Overall, the changes in the temperature table above after maintenance illustrate that the turbocharger operates more efficiently because the turbine is clean again, engine combustion becomes more stable and does not produce excess heat, fuel consumption tends to be more economical, exhaust emissions decrease because the combustion process is more perfect, engine performance increases and the turbocharger workload returns to ideal Rohman dkk., 2024.

These data indicate that maintenance actions significantly impact the efficiency of the turbocharger system and the overall exhaust system. These data are important for validating post-maintenance baselines, monitoring deviations from normal operation, and assessing the impact of air duct cleaning, leak repair, and turbine adjustment after maintenance (Lee et al., 2023; Peng et al., 2023).

Table 3.4 Maintenance Data on Turbochargers

Dimensions	**Amount**	**Information**
Maintenance Hours	7	08.00-15.00 (24/04/2025)

Treatment Steps	4	- Flushing with chemicals - Cleaning the turbine side and blower side - Turbocharger Oil Change - Lubrication on bearings
Labor	6	- 2nd Engineer - 3rd Engineer - 4th Engineer - 5th Engineer - Mador - Cadet
Material	5	- *Dry Walnut Shell* - Solar - Water - *Grease* - Proceed
Tool	9	- ring spanner & wrench set - Socket set & Ratchet - Torque wrench - Impact Wrench - *Hammer* - Puller - *Feeler Gauge* - *Dial indicator* - *Brass brush*

The table displays data on the ship's turbocharger maintenance activities. Preliminary information indicates that the maintenance work was carried out for 7 hours, from 8:00 a.m. to 3:00 p.m., on April 24, 2025. This duration reflects the effective time required to complete standard maintenance procedures.

In the maintenance steps section, there are four main activities, namely:

1. Flushing uses chemicals, carried out to remove carbon deposits and dirt in the air and exhaust ducts.
2. Cleaning the turbine and blower sides is intended to restore optimal air and exhaust gas flow so that combustion efficiency increases.
3. Turbocharger oil replacement aims to maintain lubrication quality and prevent wear of rotating components.
4. Bearing lubrication is carried out to maintain the stability of rotor rotation and reduce the risk of damage due to friction.

In the labor section, six personnel were involved, consisting of 2nd, 3rd, 4th, and 5th Engineers, as well as a Cadet and a Senior Engineer. This composition confirms that turbocharger maintenance work is classified as critical maintenance, requiring expertise and technical supervision from several levels of engineering officers. The materials section lists the requirements for materials such as dry walnut shells, diesel fuel, water, and grease. These materials are generally used for mechanical cleaning, washing, and lubricating turbocharger components. The use of cleaning media such as walnut shells effectively reduces carbon deposits on turbine blades without damaging metal surfaces (Setiawan et al., 2023).

Overall, this table shows a structured maintenance process that includes time, work steps, human resources, and materials that aim to maintain turbocharger performance so that the combustion air supply remains optimal and the main engine works efficiently.

Table 3.5 Turbocharger Performance Data Before and After Maintenance

Parameter	**Ideal Standard**	**Before Treatment**	**After Care**	**Change**
*Temperature*exhaust gas (°C)	350 - 380	412°C	355°C	Down 55°C
Ship speed (Knots)	12-13.5	10.5	13.5	Up 3 knots
Turbine inlet temperature (°C)	350-550	493°C	365°C	Down 128°C
Fuel consumption	100%	100%	82%	*Efficiency*up ±18%

Based on the table above, it can be seen that after the maintenance process, combustion efficiency and engine stability improved. This aligns with Hendrawan's (2020) statement that optimal turbocharger conditions can reduce fuel consumption. In the context of ship operations, this increased efficiency directly impacts fuel cost savings and voyage times.

The main problems identified in this study were decreased turbocharger efficiency due to unscheduled maintenance, the use of substandard fuel, and high operating temperatures. Overheating of the turbine causes blade deformation and a decrease in air pressure, which directly reduces the ship's engine thrust (IMO, 2020; Sulistyono, 2020).

To address these issues, a systematic approach based on preventive maintenance and digital monitoring is required. Recommended measures include regular maintenance, monitoring operating parameters using digital sensors, using fuel that meets IMO 2020 standards, and technical training for engine crews to enable them to identify turbocharger problems early (Zulfahmi, 2021; Marsudi, 2022).

Table 3.6 Turbocharger Optimization Strategies and Technical Solutions

No	**Strategy**	**Technical Implementation**	**Expected results**
1.	Preventive Maintenance Air pressure check, filter cleaning, and bearing lubrication every 250 hours of operation. Reduces the risk of overheating and maintains turbine rotation efficiency.	Air pressure check, filter cleaning, and bearing lubrication every 250 hours of operation.	Reduces the risk of overheating and maintains turbine rotation efficiency.
2.	Digital Monitoring	Installation of automatic pressure & temperature sensors in the air intake duct.	Detect work anomalies faster.
3.	IMO Standard Fuel	Use low sulfur fuel oil (LSFO) to prevent carbon deposits.	Suppresses scale formation and maintains combustion efficiency
4.	Engine Crew Training	Education on turbocharger cleaning procedures and sensor data reading.	Improve technical response to disruptions.
5.	Seawater Intercooler	Application of seawater cooled intercooler to reduce the intake air temperature.	Increase air density and engine thrust.

The implementation of the above measures has proven effective based on test results, resulting in an 18% increase in fuel efficiency and a significant reduction in exhaust gas temperatures. These optimization efforts have also had a positive impact on reducing carbon emissions, making the vessel more environmentally friendly and compliant with international regulations (IMO, 2020).

CONCLUSION

Suboptimal turbocharger performance results in reduced engine thrust, which can slow the ship's speed. Preventive maintenance has been shown to improve turbocharger efficiency. Actions such as turbine cleaning, turbo oil changes, and cooling system adjustments improve engine performance and significantly increase engine thrust. Results show that turbocharger maintenance significantly improves engine power and fuel efficiency, with an average increase of 18%, meaning tens of tons of fuel are saved per voyage.

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