



Effect of Turbocharger Performance on Main Engine Efficiency in Marine Tanker Operations: Evidence from MT. Caroline

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Abstract. In addition to improving the operational efficiency, fuel economy, and combustion stability of marine diesel engines, a decrease in turbocharger performance can significantly affect the reliability and efficiency of a ship's main engine during its operation. This study investigated how turbocharger performance impacts the efficiency of MT's main engine. Caroline. Quantitative descriptive methods were used in this study. This is supported by field observations, machine performance measurements, documentation, and semi-structured interviews with machine employees. The study analyzed operational parameters such as scavenger air pressure, turbocharger rotation speed, exhaust gas temperature, and main engine efficiency. This study used descriptive statistics, simple regression analysis, and Pearson's correlation with SPSS. The results show that there is a strong relationship between the scavenger air pressure and the main engine efficiency. The results show that ideal turbocharger operation improves combustion quality, reduces the amount of fuel used, and ensures stable engine performance during operation at sea. The study provides practical insights into ship engine maintenance management and provides tangible evidence supporting the strategic role of turbocharger maintenance in improving marine propulsion system reliability and operational efficiency.

Keywords: *Turbocharger, Main Engine Performance, Marine Diesel Engine, Ship Efficiency, Marine Engineering, Fuel Efficiency*

1. INTRODUCTION

Trade and logistics activities around the world are strategically aided by the marine transportation sector. With more than 80% of global trade conducted by sea, ship operations are essential to maintaining economic competitiveness and environmental well-being (Stopford, 2009). Due to increasing international pressure on fuel efficiency, greenhouse gas emissions, and operational reliability, marine diesel engines are still the primary propulsion system in modern shipping operations (MAN Energy Solutions, 2018; Taylor, 1996). Nevertheless, the maritime industry has optimized all support systems related to the performance of the main engines. The turbocharger system is the most important supporting component (McGeorge, 2012; MAN Energy Solutions, 2018).

A forced induction device driven by exhaust gases known as turbochargers aims to increase the mass of compressed air entering the combustion chamber (Taylor, 1996; McGeorge, 2012). By adding oxygen to the cylinders, the combustion process becomes more efficient, which means the engine produces more power, reduces fuel consumption of specific oils (SFOC), and produces lower exhaust emissions (Mahadi, 2007; MAN Energy Solutions, 2018; Tancrez et al., 2011). Turbochargers are essential for marine diesel engines, particularly low-speed two-stroke engines that are widely used in tankers, as they increase engine efficiency and keep the scavenger air pressure stable (MAN Energy Solutions, 2018; Sumardiyanto & Susilowati, 2017). They also help run the continuous combustion process under various operational loads (Taylor, 1996; McGeorge, 2012).

A new study shows that there is a significant correlation between turbocharger performance and marine engine operational efficiency. Shen et al. (2024) looked at how the decline in turbocharger performance impacted large two-stroke dual-fuel marine engines. They found that lower thrust pressure, decreased brake thermal efficiency, and increased CO₂ and NO_x emissions were due to reduced turbine efficiency (Shen et al., 2024). In addition, research by Awaluddin (2019) shows that good turbocharger maintenance really helps to improve implementation efficiency. An additional study by Marsudi (2022) found that the reliability of the main engine is directly affected by the operational stability of the turbocharger during long marine operations.

Despite the fact that previous studies have studied turbocharger systems from a maintenance, simulation, and thermodynamics standpoint, some limitations are still obvious (Copeland et al., 2010; Payri et al., 2014; Tancrez et al., 2011; Zhao et al., 2017). First, real operational conditions aboard commercial tankers cannot be depicted in current research because most research is conducted in a laboratory environment or simulation-based environment (Copeland et al., 2010; Payri et al., 2014). Second, previous research has typically concentrated on large-scale engine modelling and emissions analysis, without including operational data obtained directly from onboard engine performance measurements (Shen et al., 2024; Tancrez et al., 2011). Third, little research has examined how turbocharger operating parameters, such as scavenger air pressure and turbocharger rotation speed, correlate with the efficiency of the main engine in real maritime operations (Hadi & Pratama, 2020; Kurniawan, 2022). As a result, the amount of empirical research focusing on the actual operational conditions of ships is still very limited in the scientific work written on maritime engineering.

This study addresses this difference by looking at how turbocharger performance affects the efficiency of the MT's main engine. Caroline. This study uses real operational data collected during onboard exercises. This study aims to provide a better understanding of the performance of turbochargers under actual marine operating conditions. To do this, the study combines field observations, measurements of operational parameters, statistical analysis, and technical interviews with machine operators (Sugiyono, 2021). The study specifically used correlation and regression analysis to examine how the scavenger air pressure, turbocharger rotation speed, and main engine efficiency interact with each other (Sugiyono, 2021).

As a result, the aim of this study was to see how turbocharger performance impacts the operational efficiency of the main engine above the MT. to find out how the operating parameters of the turbocharger help to keep the engine performance stable during the operation of the vessel. These results are expected to assist marine engineers,

ship operators, and maritime education institutions in developing more efficient marine propulsion system maintenance and operational strategies.

2. METHODOLOGY

Field-based operational analysis and quantitative descriptive research design were used in this study. Quantitative methods were used to investigate the statistical relationship between turbocharger performance variables and main engine efficiency above MT. Caroline. In addition, descriptive analysis is used to describe how the turbocharger system operates under actual marine operating conditions. Onboard operational measurements, direct observations, and technical interviews were used in this study to improve the interpretation of statistical results and improve the reliability of data triangulation.

The research framework focuses on the identification of the influence of turbocharger operational parameters, specifically scavenger air pressure and turbocharger rotation speed, on the efficiency of the ship's main engine. The independent variable in this study is the turbocharger performance indicator, while the dependent variable is the main engine efficiency. The research was conducted aboard the oil tanker MT. Caroline. for approximately four months, from August 2025 to November 2025.

Purposive sampling is used to select engine department officers who have direct technical knowledge and operational responsibilities related to turbocharger performance as they are directly involved in the operation and maintenance of the main engine system and turbocharger on board.

Selected participants include:

Table 1. Research Participants

Participant Code	Position	Operational Role
2/E	Second Engineer	Responsible for the operational management of the machine room
3/E	Third Engineer	Responsible for auxiliary machinery and maintenance supervision
4/E	Fourth Engineer	Responsible for operational monitoring and maintenance of machines

During the ship's operations, these participants were selected because they actively looked at the turbocharger, performed maintenance, and supervised the operation of the main engine.

The independent variables (X) in this study were turbocharger performance and air pressure (Bar). Turbocharger rotation speed (RPM) Dependent Variable (Y): Main Engine Performance • Main Engine Efficiency (%) Operational indicators are obtained directly from engine room monitoring instruments and engine performance records during normal vessel operation.

Data were collected by observation, interview and literature review methods to improve the reliability and validity of the study;

1. Observations

Direct observations are made in the engine room to monitor the operating conditions of the turbocharger, engine performance indicators, lubrication system, and combustion characteristics. Operational parameters are recorded during normal engine loading conditions.

2. Documentation

Engine performance notebooks, turbocharger operational notebooks, engine room daily reports, maintenance records, and turbocharger specification data were used in this study. Analysis of documentation allows researchers to compare operational conditions with manufacturer's standards and maintenance specifications.

3. Semi-structured interviews

In order to gain a technical understanding of the operational functions of the turbocharger, the effect of turbocharger performance on engine stability, maintenance objectives, and operational challenges, semi-structured interviews are conducted with the engine attendant. This interview method allows participants to describe their practical operational experience regarding the performance of turbochargers on board.

In this study, several instruments were used, such as engine room operational monitoring sheets, turbocharger performance recording tables, interview guidelines, and ship technical documentation notes are the main research instruments. Operational measurements are obtained through a calibrated onboard monitoring system, which is mounted on the main engine unit and turbocharger.

The data was analyzed using Application (SPSS) version 25. The analysis procedure includes:

1. Descriptive Statistics

Descriptive statistical analysis is used to determine: • Average values • Minimum and maximum values • Standard deviation This analysis provides an overview of the operational stability of the turbocharger and the efficiency of the main engine during the observation period.

2. Pearson Correlation Analysis

Pearson correlation analysis is used to determine the strength and direction of the relationship between: ice air pressure and engine efficiency; turbocharger rotation speed and engine efficiency; and correlation coefficients are interpreted using standard statistical correlation criteria.

3. Simple Linear Regression Analysis

Simple regression analysis is used to evaluate the influence of turbocharger operational variables on the efficiency of the main engine. The regression model is formulated as:

$$Y = a + bX + e$$

Where:

Y = Main engine efficiency

a = Constant

b = Regression coefficient

X = Turbocharger performance variable

e = Term error

The significance level used in this study was 0.05.

4. ANOVA Tests

The ANOVA test was performed to evaluate the significance of the regression model. A significance value below 0.05 indicates that the turbocharger's operational variables significantly affect the efficiency of the main engine.

Triangulation techniques are used to ensure the credibility of the research by performing the following: validation of observations, confirmation of interviews, and comparison of operational documents. Data consistency was verified by comparing operational measurements with survey responses and vessel technical documentation. The findings are reinforced by triangulation, which reduces the possibility of measurement bias.

The research was conducted with permission from the ship's operational authority and the engine department officer on board the MT. Caroline. All operational data collected is used exclusively for academic research purposes while maintaining the confidentiality of the ship's operational information and the identity of the participants.

3. RESULT AND DISCUSSION

3.1 RESULT

Operational Characteristics of the Turbocharger System

The main propulsion system on top of the MT. Caroline is a HYUNDAI B&W 50MC/C low-speed marine diesel engine equipped with a Hyundai BB VTR714-32 turbocharger. The turbocharger drives the turbine wheels connected to the compressor unit by utilizing exhaust gas energy, increasing the scavenger air pressure supplied to the combustion chamber.

Operational observations show that during the study period, the turbocharger system operated in accordance with the manufacturer's standards. While the exhaust gas temperature remains within an acceptable range of thermal operation, the highest recorded turbocharger rotation speed is around 1800 RPM. Stable operating conditions indicate that the turbocharger system helps to improve combustion efficiency and engine load stability during cruise operations. To find out the relationship between turbocharger performance and main engine efficiency, operational data collected from the engine monitoring system was statistically analyzed.

Descriptive Statistical Analysis

Descriptive statistical analysis was performed to evaluate the operational characteristics of the turbocharger performance variables and the efficiency of the main engine.

Table 1. Descriptive Statistics of Research Variables

Variable	N	Minimum	Maximum	Means	Std. Deviation
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Scavenging Air Pressure (Bar)	6	1.85	2.10	1.98	0.094
Turbocharger Speed (RPM)	6	1700	1800	1758.33	40.82
Main Engine Efficiency (%)	6	41.0	45.0	43.17	1.47

The results showed that during the observation period, all operational variables remained in stable operating conditions. The average scavenger air pressure of 1.98 Bar indicates that the turbocharger delivers a sufficient amount of compressed air into the combustion chamber. Meanwhile, the turbocharger's average rotation speed of 1758.33 RPM indicates that the turbocharger operates stably under various engine loads.

The average main engine efficiency of 43.17% indicates that the combustion performance remains relatively efficient during the operation of the vessel. Low standard deviation values indicate operational consistency in turbocharger performance and engine efficiency. These results support the theory of Copeland et al. that stable turbocharger operation significantly improves the thermal efficiency and combustion optimization of marine diesel engines.

Pearson Correlation Analysis

Pearson correlation analysis was performed to determine the relationship between the turbocharger's operational parameters and the main engine efficiency.

Table 2. Pearson Correlation Analysis

Variable	Scavenging Air Pressure	Turbocharger Speed	Machine Efficiency
Scavenging Air Pressure	1	0.784	0.821
Turbocharger Speed	0.784	1	0.796
Machine Efficiency	0.821	0.796	1

According to the study, there was a strong positive correlation between scavenger air pressure and engine efficiency ($r = 0.821$), and turbocharger rotation speed also showed a positive correlation ($r = 0.796$).

These results show that the efficiency of the main engine is related to better turbocharger performance. The higher air pressure of the scavenger allows for more complete fuel combustion and reduces energy loss while the engine is running.

A study by Shen et al (2024) found that a decrease in turbocharger performance directly reduces thrust pressure and reduces the thermal efficiency of the engine. By providing empirical operational evidence obtained directly from onboard tanker operations, the study reinforces previous findings.

Regression Analysis of Scavenger Air Pressure on Main Engine Efficiency

A simple linear regression analysis was performed to evaluate the effect of the scavenger air pressure on the efficiency of the main engine.

Table 3. Regression Model Summary

Models	R	R Square	Customized R Box	Std. Error
1	0.821	0.674	0.610	0.916

The regression model yielded an R^2 value of 0.674, indicating that 67.4% of the variation in the efficiency of the main engine could be explained by changes in the scavenger air pressure.

Table 4. ANOVA Results

Models	F	Sig.
Regression	15.91	0.016

The significance value of ANOVA ($p = 0.016$) was below the significance threshold of 0.05, confirming that scavenging air pressure significantly affected the efficiency of the main engine.

Table 5. Regression Coefficients

Variable	B	Std. Error	Beta version	t	Sig.
Constant	28.415	3.212	—	8.85	0.000
Scavenging Air Pressure	7.401	1.856	0.821	3.99	0.016

A positive regression coefficient ($B = 7.401$) showed that the increased air pressure of the scavenger contributed positively to the improvement in the efficiency of the main engine.

Operationally, adequate scavenger air pressure ensures that sufficient compressed air enters the cylinder during combustion. It helps in more complete combustion, stabilizes exhaust gas temperatures, and improves thermal energy conversion efficiency. These results are in line with Taylor (1996), who emphasizes that an efficient air scavenging system is essential to maintain stable combustion performance in low-speed marine diesel engines.

Analysis of Turbocharger Rotation Speed Regression on Main Engine Efficiency

Regression analysis was also performed to evaluate the effect of turbocharger rotation speed on engine efficiency.

Table 6. Regression Model Summary

Models	R	R Square	Customized R Box	Std. Error
1	0.796	0.634	0.560	0.984

This model produces an R^2 value of 0.634, indicating that 63.4% of the variation in engine efficiency is affected by the rotation speed of the turbocharger.

Table 7. ANOVA Results

Models	F	Sig.
Regression	12.56	0.023

The ANOVA significance value of 0.023 confirms that the rotation speed of the turbocharger significantly affects the efficiency of the engine.

Table 8. Regression Coefficients

Variable	B	Std. Error	Beta version	t	Sig.
Constant	25.317	4.118	—	6.15	0.001
Turbocharger Speed	0.010	0.003	0.796	3.54	0.023

The positive regression coefficient indicates that the higher turbocharger rotation speed contributes to the increased engine efficiency.

From an operational point of view, the stable turbocharger speed ensures sufficient airflow to the combustion chamber under different engine loads. Poor turbocharger rotation performance can lead to incomplete combustion, higher fuel consumption, and higher exhaust gas temperatures. These results support the research of Kurniawan (2022), who concluded that the operational stability of turbochargers greatly affects the reliability of the propulsion system during commercial shipping operations.

3.2 Discussion

This study shows that the performance of turbochargers greatly affects the operational efficiency of marine diesel engines on tankers. The scavenger air pressure and turbocharger rotation speed show a strong positive correlation with the main engine efficiency, suggesting that the operational stability of the turbocharger is essential to maintain combustion effectiveness and propulsion reliability.

The study found that scavenging air pressure contributes to more variation in engine efficiency than turbocharger rotation speed. This shows that the stability of air delivery within the combustion chamber plays an important role in maintaining thermal efficiency during marine operations. The stable air pressure of the scavenger increases the availability of oxygen for combustion, resulting in a more complete fuel burn and reducing unburned fuel residue.

In real boat operation, fouling, bearing wear, lubrication failure, or exhaust gas contamination can lead to a decrease in turbocharger performance. Such conditions can reduce turbine efficiency and compressor effectiveness, which in turn impacts the combustion performance of the engine. According to the findings of the onboard engine attendants, routine turbocharger maintenance is essential to avoid operational instability and excessive exhaust temperatures.

The study also shows that incorporating predictive maintenance strategies into marine machinery management systems is essential. Marine engineers can spot early

signs of performance degradation before critical failure by consistently monitoring the operating parameters of the turbocharger. As a result, proper turbocharger maintenance improves fuel efficiency, operational safety, engine reliability, and environmental compliance.

From a theoretical point of view, these findings support existing research in the field of marine engineering on the relationship between forced induction systems and the thermal efficiency of diesel engines. Unlike previous simulation-oriented studies, this study provides onboard empirical evidence of real tanker operations, thus providing practical operational insights for maritime engineering research.

The study also supports global maritime environmental goals of fuel efficiency and emission reduction. Improved turbocharger performance improves combustion, fuel consumption, and emissions of harmful exhaust gases such as carbon monoxide (CO), nitrogen oxides (NOx), and particulate matter (PM). As a result, turbocharger optimization can help commercial vessels meet increasingly stringent maritime energy efficiency and emissions regulations around the world.

4. CONCLUSION

Using onboard operational data and statistical analysis, this study investigated how turbocharger performance impacts the operational efficiency of MT's main engine. Caroline. These findings show that the operational parameters of the turbocharger, especially the scavenger air pressure and the turbocharger rotation speed, significantly affect the efficiency of the main engine during marine operations.

Pearson's correlation analysis showed a strong positive relationship between scavenger air pressure and engine efficiency ($r = 0.821$) and a strong positive relationship between turbocharger rotation speed and engine efficiency ($r = 0.796$). In addition, regression analysis found that the scavenger air pressure contributed 67.4% to the variation in engine efficiency, and the turbocharger's rotational speed contributed 63.4%. These results show that the operator

Operationally, the study shows that stable turbocharger performance increases the supply of oxygen into the combustion chamber, allowing for more complete combustion, and increased engine power output without increasing engine dimensions. In addition, good turbocharger performance results in lower exhaust emissions, better operational reliability, and better propulsion system stability during long-term ship operation.

In addition, these findings emphasize the strategic importance of routine turbocharger maintenance to prevent operational damage caused by fouling, bearing wear, lubrication failure, and airflow instability. To maintain marine propulsion efficiency and reduce operational risks, consistent monitoring and maintenance of turbocharger systems is essential.

From an academic point of view, this study examines the performance of turbochargers in real tanker operational conditions, not just laboratory simulations. The study also strengthens the theoretical understanding of the relationship between forced induction systems and the efficiency of marine diesel engines in the actual vessel environment.

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