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Analysis of Exhaust Gas Conditions on Diesel Generator Engine Power on the Rawabi 49

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ABSTRACT

The efficiency and performance of shipboard generators are crucial for safe and uninterrupted vessel operation, and the condition of the exhaust gas is an important indicator of combustion quality and engine health. This study analyses the exhaust gas condition of diesel generator No. 3 (Caterpillar C18) on the offshore vessel Rawabi 49, owned by Rawabi Vallianz Offshore, and its effect on engine power. A descriptive case study was conducted on board for approximately one year, using direct observation of generator operation and inspection of the air intake and exhaust systems, the manufacturer's specifications and operating limits, and a review of the relevant literature. The observations showed an abnormally high exhaust gas temperature on generator No. 3. Inspection traced the problem to a dirty and clogged air cleaner, which reduced the air flow to the engine, upset the air–fuel ratio, and caused incomplete combustion and a loss of output power. Insufficient maintenance of the generator also forced the engine to work harder under high load, which tends to increase nitrogen oxide and particulate emissions. Eleven factors that can raise exhaust gas temperature were identified, including fuel quality, injector and turbocharger condition, load, cooling, and valve clearance. Regular cleaning or replacement of the air cleaner according to the maker's schedule, monitoring of air inlet restriction and exhaust temperature, and planned maintenance are recommended to restore engine power, improve fuel efficiency, and reduce emissions.

Keywords: Air Filter, Diesel Generator, Exhaust Gas Temperature, Engine Power, Rawabi 49

ABSTRAK

Efisiensi dan kinerja generator di kapal sangat penting untuk menjamin kelancaran dan keamanan operasional, dan kondisi gas buang merupakan indikator penting kualitas pembakaran serta kesehatan mesin. Penelitian ini menganalisis kondisi gas buang mesin diesel generator No. 3 (Caterpillar C18) di kapal lepas pantai Rawabi 49 milik Rawabi Vallianz Offshore serta pengaruhnya terhadap daya mesin. Penelitian berupa studi kasus deskriptif yang dilaksanakan di atas kapal selama kurang lebih satu tahun, menggunakan observasi langsung terhadap pengoperasian generator dan pemeriksaan sistem udara masuk serta gas buang, spesifikasi dan batas operasi dari pabrikan, serta kajian literatur yang relevan. Hasil observasi menunjukkan temperatur gas buang yang tinggi secara tidak normal pada generator No. 3. Pemeriksaan menunjukkan bahwa masalah tersebut disebabkan oleh filter udara (air cleaner) yang kotor dan tersumbat, yang mengurangi aliran udara ke mesin, mengganggu perbandingan udara dan bahan bakar, serta menyebabkan pembakaran tidak sempurna dan penurunan daya keluaran. Kurang maksimalnya perawatan generator juga membuat mesin bekerja lebih keras pada beban tinggi, yang cenderung meningkatkan emisi nitrogen oksida dan partikulat. Sebelas faktor yang dapat meningkatkan temperatur gas buang berhasil diidentifikasi, antara lain kualitas bahan bakar, kondisi injektor dan turbocharger, beban, pendinginan, dan celah katup.

Pembersihan atau penggantian filter udara secara rutin sesuai jadwal pabrikan, pemantauan hambatan udara masuk dan temperatur gas buang, serta perawatan terencana direkomendasikan untuk memulihkan daya mesin, meningkatkan efisiensi bahan bakar, dan mengurangi emisi.

Kata kunci: Filter Udara, Generator Diesel, Temperatur Gas Buang, Daya Mesin, Rawabi 49

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1. INTRODUCTION

A generator works on the principle of electromagnetic induction discovered by Michael Faraday in 1831: a changing magnetic field that cuts a conductor induces an electromotive force (voltage) in that conductor, and the induced voltage drives an electric current when the conductor forms part of a closed circuit. When the rotor of a generator turns, the windings cut the lines of magnetic flux at the poles, producing a voltage difference and hence an electric current that flows through the slip rings and brushes to the output terminals. On board ships, generators are driven by diesel engines, which are internal combustion engines that use the heat of compression to ignite the fuel injected into the combustion chamber. Continuous rotation causes friction and wear on the moving parts, while combustion produces high-temperature exhaust gas.

The condition of the exhaust gas is a useful indicator of combustion quality and engine health. Exhaust gas temperature in particular is widely used to detect faults and predict failures in marine diesel engines (Ji et al., 2023; Liu et al., 2023), and abnormal exhaust temperatures on ship engines are commonly associated with problems in the air, fuel, and cooling systems (Prasetyo, 2022). At the same time, exhaust emissions from ships are regulated under MARPOL Annex VI (International

Maritime Organization [IMO], 2017), which has driven the development of emission control technologies for marine diesel engines (Lion et al., 2020).

On the Rawabi 49, a high exhaust gas temperature was observed on Caterpillar (CAT) C18 diesel generator No. 3. One possible cause is a dirty or clogged air cleaner, which reduces the air flow to the engine and upsets the air–fuel mixture. Experimental studies have shown that a clogged air filter reduces engine power and torque and increases fuel consumption and emissions (Thomas et al., 2013; Akal & Selvi, 2023). National studies on shipboard engines have examined the power loss of auxiliary engines (Ridwan et al., 2020) and the maintenance of exhaust valves (Pongkessu et al., 2020), but the link between the condition of the air intake system, the exhaust gas temperature, and the power of offshore vessel generators has rarely been documented. This study therefore analyses the exhaust gas condition of diesel generator No. 3 on the Rawabi 49 and its effect on engine power, identifies the factors that cause abnormal exhaust gas temperatures, and formulates maintenance recommendations.

1.1. Exhaust Gas of Diesel Generators

Generators play a crucial role on board as the main or standby source of electrical energy, so understanding the factors that affect their performance requires an understanding of both the working principle of the generator and the combustion process of the diesel engine that drives it. The exhaust gas of a diesel generator is the gas formed by the combustion of fuel inside the engine, which leaves the cylinders through the exhaust manifold and exhaust pipe after combustion is complete. It consists mainly of nitrogen, carbon dioxide, water vapour, and excess oxygen, together with pollutants such as nitrogen oxides (NOx), carbon monoxide (CO), unburned hydrocarbons (HC), and particulate matter (PM), whose amounts depend on engine technology and combustion conditions (Fiebig et al., 2014; Sagin et al., 2022).

Exhaust gas analysis is therefore an important method for evaluating the efficiency and performance of internal combustion engines, including generators. Emission levels of marine diesel engines vary with engine power range and operating load (Ma et al., 2021), while NOx emissions can be reduced through measures such as exhaust gas recirculation (Sagin & Kuropyatnyk, 2018; Kuropyatnyk & Sagin, 2019).

1.2. Air Intake and Exhaust Gas Cycle of the CAT C18 Generator

The CAT C18 is a turbocharged and aftercooled four-stroke diesel engine. Its air intake and exhaust gas flow are shown in Figure 1 and proceed through the following strokes.

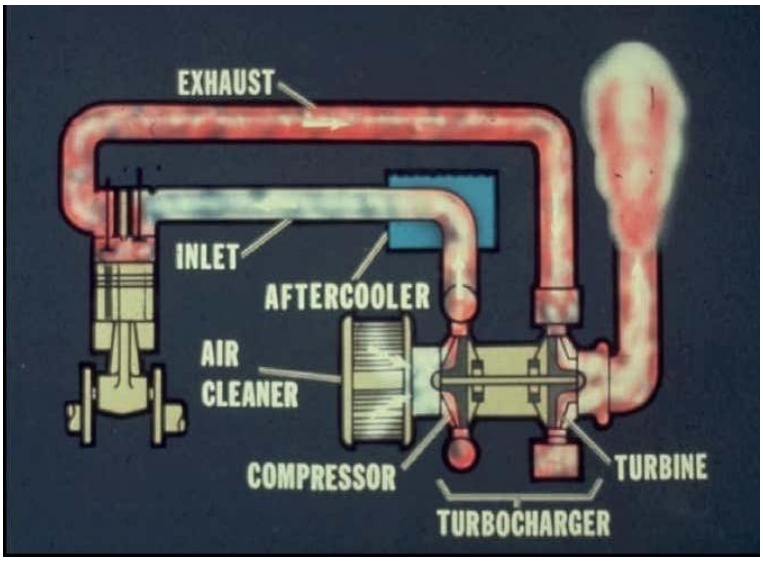


Figure 1. Air Intake and Exhaust Gas Flow of the Turbocharged CAT C18 Diesel Engine (Source: CAT C18 Manual Book)

a. Intake stroke. Clean air passes through the air cleaner and is drawn in by the turbocharger compressor, which raises its pressure. After passing through the aftercooler, the air enters the cylinder through the intake valve, which opens and closes to control the air flow.

b. Compression stroke. The intake and exhaust valves close, and the piston moves towards top dead centre (TDC), compressing the air in the cylinder and raising its temperature.

c. Power stroke. Near the end of compression, the injector sprays diesel fuel into the cylinder, where the high air temperature causes the fuel to ignite spontaneously. Combustion pushes the piston towards bottom dead centre (BDC), producing mechanical power that turns the crankshaft and, through it, the generator.

d. Exhaust stroke. The piston moves back towards TDC and the exhaust valve opens, allowing the combustion gas to leave the cylinder. The exhaust gas then drives the turbocharger turbine, which powers the compressor, before it is discharged to the atmosphere through the exhaust pipe. Because the turbocharger links the intake and exhaust sides, its condition strongly affects engine efficiency and exhaust emissions (Nyongesa et al., 2024).

2. METHOD

This study used a descriptive case study approach conducted on board the Rawabi 49, an offshore vessel owned by Rawabi Vallianz Offshore. Data were collected over approximately one year of vessel operation, focusing on the performance of the diesel generators, particularly generator No. 3.

Data were collected through direct observation and a literature review. Direct observation covered the operation of the generator, the operating parameters displayed by the engine monitoring system, including exhaust gas temperature, and inspection of the air intake and exhaust systems. The engine specifications and the manufacturer's operating limits were taken from the CAT C18 manual book, and the literature review provided theoretical background and comparisons from technical literature and scientific journals.

The observed conditions were compared with the manufacturer's operating limits to identify deviations, and the possible causes of abnormal exhaust gas temperature were traced using a root-cause approach similar to failure diagnosis methods for marine diesel engine systems (Knežević et al., 2020). The results were then used to identify the technical factors affecting engine efficiency and performance and to formulate maintenance and operational recommendations.

3. RESULTS AND DISCUSSION

3.1. Research Object

The research object was diesel generator No. 3 on the Rawabi 49, one of four Caterpillar C18 generator sets on board. The main engine specifications are given in Table 1, and the manufacturer's operating limits and emission data are given in Table 2.

Table 1. Specifications of the CAT C18 Engine

Item	Specification
Cylinders and arrangement	In-line, six cylinders
Bore	145 mm (5.7 in)
Stroke	183 mm (7.2 in)
Output	4 × 550 kW at 1,800 rpm; 440 V, 3-phase, 60 Hz
Aspiration	Turbocharged, aftercooled

Source: CAT C18 manual book.

Table 2. Manufacturer's Operating Limits and Emission Data of the CAT C18 Generator Set

Parameter	Value
Maximum jacket water outlet temperature	89 °C
Maximum aftercooler water inlet temperature (sea-water aftercooled engine)	32 °C
Maximum air inlet restriction	3.7 kPa
Maximum exhaust back pressure	10.0 kPa
Engine coolant temperature	84–110 °C
Engine oil temperature	90–115 °C
Exhaust temperature	100–300 °C
Fuel temperature	50–80 °C
Intake manifold air temperature	40–115 °C
Oil filter differential pressure	55–250 kPa
Oil pressure (least severe)	163 kPa
Combustion air inlet flow rate	48 m^3/min
Maximum allowable combustion air inlet temperature	49.0 °C
Exhaust stack gas temperature	511.4 °C
NOx	2,622.7 mg/Nm^3
CO	65.0 mg/Nm^3
HC	5.6 mg/Nm^3
PM	5.4 mg/Nm^3

Source: CAT C18 generator set manual book.

3.2. Field Findings

During the observation period, the exhaust gas temperature of CAT C18 generator No. 3 was abnormally high. Inspection of the air intake system found that the air cleaner was dirty and clogged. A clogged air cleaner increases the air inlet restriction, for which the manufacturer specifies a maximum of 3.7 kPa (Table 2), and reduces the air flow to the engine. The resulting shortage of combustion air upsets the air–fuel ratio, so that the fuel is not burned completely, more heat leaves the cylinders with the exhaust gas, and the output power of the engine decreases. These findings agree with experimental results showing that a clogged air filter reduces the power and torque of diesel engines and increases their fuel consumption and emissions (Akal & Selvi, 2023), and that the condition of the air filter affects the fuel economy of diesel vehicles (Thomas et al., 2013). Air filter maintenance is therefore an essential part of diesel engine maintenance (Toma & Fileru, 2016).

The observations also indicated that the maintenance of generator No. 3 had not been optimal. When the engine is poorly maintained, it has to work harder to carry the same electrical load, which raises combustion temperatures and tends to

increase NOx and particulate emissions. A similar pattern of power loss in shipboard auxiliary engines was reported by Ridwan et al. (2020).

3.3. Factors Causing Abnormal Exhaust Gas Temperature

Apart from the air cleaner condition found on board, abnormal exhaust gas temperatures in diesel generators can be caused by several other factors. These factors, their effects on combustion, and their typical symptoms are summarised in Table 3.

Table 3. Factors Causing Abnormal Exhaust Gas Temperature in Diesel Generators

No.	Factor	Effect on combustion	Typical symptoms
1	Dirty or clogged air filter	Reduced air flow; unbalanced air–fuel mixture	High exhaust temperature, black smoke, power loss
2	Poor or contaminated fuel	Incomplete combustion; fuel not to engine specification	Black smoke, knocking, reduced performance
3	Clogged or damaged injectors	Disturbed fuel spray and atomisation	Black smoke, lower fuel efficiency
4	Faulty fuel pump	Unstable fuel pressure and injection	Hard starting, unstable performance, higher emissions
5	Exhaust system leakage	Excess air entering and disturbing combustion	Abnormal exhaust readings, noise
6	Incorrect injection timing	Incomplete combustion	Knocking, reduced performance, higher emissions
7	Overloading or underloading	Operation outside the ideal load range	Abnormal temperature, higher fuel consumption and emissions
8	Worn engine components (piston rings, valves, liners)	Compression leakage; inefficient combustion	Low compression, higher oil consumption, blue smoke
9	Ineffective cooling	High engine temperature affecting combustion	Overheating, power loss, higher emissions
10	Damaged or fouled turbocharger	Reduced air supply; restricted exhaust flow	Reduced output, high exhaust temperature
11	Incorrect tappet (valve) clearance	Valves open too much or too little	Improper combustion, reduced performance

The fuel-side factors in Table 3 (items 2–4 and 6) disturb fuel delivery and atomisation; faults of marine fuel injectors, for example, can be detected from their effect on combustion signals (Shi et al., 2023). Turbocharger faults (item 10) reduce the air supply and raise exhaust temperature, which makes the turbocharger a critical component in failure analyses of marine diesel engines (Knežević et al., 2020), and scheduled turbocharger reconditioning has been shown to restore engine efficiency and reduce exhaust emissions (Nyongesa et al., 2024). Operation outside the ideal load range (item 7) changes the emission characteristics of marine diesel engines (Ma et al., 2021), so load management is an important part of optimising diesel power generators (Issa et al., 2019). Mechanical factors such as worn components and incorrect valve clearance (items 8 and 11) are closely linked to the condition of the exhaust valves, whose maintenance directly supports the operation of shipboard engines (Pongkessu et al., 2020).

3.4. Discussion

The results show that the air cleaner condition was the dominant cause of the high exhaust gas temperature of generator No. 3, while the other factors in Table 3 serve as a checklist for troubleshooting. This is consistent with Prasetyo (2022), who related abnormal exhaust gas temperatures of ship engines to problems in the air, fuel, and cooling systems, and with Akal and Selvi (2023), who quantified the loss of power and the increase in emissions caused by clogged air filters. Since a high exhaust gas temperature is an early warning signal of developing faults (Ji et al., 2023; Liu et al., 2023), continuous monitoring of this parameter, together with the air inlet restriction, can help the engine crew detect air intake problems before they cause a significant loss of power. Condition monitoring with modern data-driven methods can further support this task (Koçak et al., 2023).

The findings also have environmental implications. Incomplete combustion and high-load operation increase NOx, CO, HC, and particulate emissions, which must remain within the limits of MARPOL Annex VI (IMO, 2017; Sagin et al., 2022). Keeping the air intake system in good condition is therefore one of the simplest ways to maintain both engine power and emission performance, alongside dedicated emission reduction technologies (Lion et al., 2020; Kuropyatnyk & Sagin, 2019). From a maintenance perspective, air cleaner cleaning or replacement should be scheduled according to the maker's recommendations and integrated into a planned maintenance system, preferably supported by preventive, predictive, or reliability-centred strategies (Jimenez et al., 2020; Eriksen et al., 2021; Song et al., 2022; Karatuğ et al., 2023; Handani & Uchida, 2024).

This study has limitations. The analysis was based on observation and inspection of a single generator, and quantitative measurements of exhaust gas composition (O_2, CO, HC, and NOx) and of output power under different loads were not reported. Future studies should measure these parameters before and after air cleaner maintenance to quantify the effect of the air intake condition on exhaust gas and engine power.

4. CONCLUSION

Based on the results and discussion, the abnormal exhaust gas temperature of the diesel generator on the Rawabi 49 can be attributed to the following causes.

1. A dirty air cleaner reduced the air flow to the engine, causing an imbalance between air and fuel and incomplete combustion, which increased the exhaust gas temperature.
2. Insufficient maintenance of diesel generator No. 3 reduced the supply of oxygen needed for combustion. The resulting incomplete combustion reduced the output power of the engine, while the higher load increased the tendency for NOx and particulate emissions.
3. Regular cleaning or replacement of the air cleaner according to the maker's schedule, monitoring of air inlet restriction and exhaust gas temperature, and implementation of planned maintenance are recommended. Future research should include quantitative measurements of exhaust gas composition and engine power.

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