

Investigating Incomplete Combustion Causes and Maintenance in CC 203 Diesel Locomotives

¹Dwi Basuki Wibowo, ^{2*}Agus Suprihanto, ³Ojo Kurdi, ⁴Susilo Adi Widyanto, ⁵Abraham Sahala Parluhutan Hutauruk, ⁶Ian Yulianti

^{1,2,3,4,5}Mechanical Engineering, Faculty of Engineering, Diponegoro University, Jl. Prof. Sudharto, SH., Tembalang-Semarang 50275, Indonesia

⁶Physics Study Program, Universitas Negeri, Semarang, Central Java, Indonesia

*Corresponding Author's E-mail: agusm90@yahoo.com

Abstract - The CC 203 locomotive has been in operation since 1995 and is equipped with features for monitoring and maintenance, including a diagnostic tool known as the pop test. This test evaluates locomotive performance and frequently reveals issues in individual cylinders of the diesel engine. Regular maintenance is essential to preserve optimal combustion standards and ensure engine performance. This study investigates the causes of incomplete combustion in the CC 203 locomotive using the pop test and examines the associated impact on performance. Results indicate that incomplete combustion is primarily attributed to clogged nozzles. Recommendations for effective maintenance and prevention strategies are also discussed.

Keywords: Locomotive CC 203, pop test, diesel engine, maintenance, nozzle clogging.

I. INTRODUCTION

Trains are a key ground transportation system that operates on rail tracks. In Indonesia, trains play a vital role in connecting various regions across the country. A typical train comprises one or more carriages pulled by a locomotive. The locomotive, positioned at the front, houses an engine and transmission system capable of propelling the train at designated speeds [1].

To ensure optimal performance, maintenance of locomotives is conducted at depots as a preventive measure, addressing potential issues before component failures occur. In contrast, repairs are carried out after components are damaged to restore the locomotive's functionality.

One state-owned enterprise responsible for railway management in Indonesia has witnessed significant growth in its user base. According to data from the Indonesian Central Statistics Agency, the number of train passengers in the country reached 277.12 million in 2022. This figure increased by 34.07% to 371.54 million in 2023. These statistics

demonstrate a growing public interest in train travel as a preferred mode of transportation [2][3][4].

In locomotives, combustion is a critical process directly related to the power generated by the engine. Combustion is a chemical reaction that occurs when fuel, atomized into fine particles through a phase-change process, mixes with hot air [5][8]. This reaction is initiated by the high temperature inside the cylinder, which results from compression pressure. Optimal combustion ensures maximum power output that meets performance standards, while suboptimal combustion can lead to decreased efficiency and power output.

Diesel engines are widely used in locomotives for their robust performance and reliability. At one of Indonesia's leading transportation companies in the railway sector, there is a specialized Diesel Division that focuses on locomotive propulsion systems. This division oversees key components of the diesel engine, including the cylinder head, cylinder block, piston, connecting rod, crankshaft, exhaust system, fuel rack, fuel filter, and air filter [9][10].

Maintenance activities for diesel locomotives are conducted at the Locomotive Depot, with three primary types of locomotives undergoing regular servicing: CC 201, CC 203, and CC 206 [6]. Among these, the focus of this discussion is on the CC 203 locomotive, a critical asset in the company's fleet.

At this stage, an inspection of the maintenance process is conducted to identify potential issues, followed by data collection and problem-solving analysis. The author gathers secondary data from various reference sources, including books on production processes, academic journals, and relevant online articles. Additionally, data obtained directly from the company is utilized to support the analysis.

Before progressing to the next stage, the author identifies and prepares the necessary resources and requirements to address the problems encountered during the practical work. The focus of this study is on analyzing the causes of

incomplete combustion in Diesel Locomotive CC 203 engines and the corresponding maintenance strategies. This involves identifying the factors contributing to incomplete combustion and evaluating the maintenance practices implemented to address these issues.

The analysis aims to uncover the underlying causes of incomplete combustion and propose effective handling methods to ensure optimal engine performance.

II. THEORETICS

A locomotive is a vital component of a train, housing the engine that propels it. Typically positioned at the front, locomotives are operated by train drivers based on commands received from the train control center, communicated via signals located alongside the rails. Locomotives are specifically designed to pull or push carriages, wagons, or special equipment and are not intended for directly transporting passengers or goods [9].

The locomotive engine consists of several critical components that work together to ensure optimal performance. The engine block, made from special cast iron, serves as the structural foundation of the engine, supporting all other components and housing the crankshaft and its accessories. The engine cylinder, also constructed from special cast iron, acts as the combustion chamber and facilitates heat dissipation. It includes the cylinder head, cylinder liner, and cylinder jacket, all designed to withstand high pressures and temperatures. The piston plays a vital role by drawing in the air-fuel mixture, compressing it, and transmitting the combustion energy to the crankshaft through the piston rod. Crafted from cast steel and aluminum, the piston is equipped with four compression rings and two oil rings for durability and efficiency.

The connecting rod links the piston to the crankshaft and consists of a master rod and an articulating rod, both made from forged steel alloy to endure high stress. The crankshaft converts the reciprocating motion of the piston into rotary motion to drive the flywheel, and is made of high-quality forged and nitrided steel to ensure durability and precision. The rubber-bonded drive coupling connects the crankshaft to auxiliary gears, protecting it from shock loads generated by the oil and water pumps. The vibration damper absorbs shocks during power strokes, reducing engine vibrations and preventing damage to the crankshaft while also functioning as a flywheel to maintain smooth operation.

The camshaft controls the intake and exhausts valves through its cam lobes and is driven by a timing gear connected to the crankshaft, ensuring precise valve timing. The valve train system manages the opening and closing of the intake

and exhausts ports, which is crucial for efficient combustion and exhaust cycles. The turbocharger uses exhaust gas energy to spin a turbine, compressing clean air and delivering it to each cylinder, thereby improving engine efficiency and power output. Finally, the engine gears synchronize the power transfer from the crankshaft to auxiliary components, ensuring smooth operation throughout the engine cycle. Together, these components ensure that the locomotive engine operates efficiently, reliably, and provides the necessary power to propel the train [11].

III. RESULTS AND DISCUSSIONS

After the data has been collected, an inspection process will be conducted to identify the root cause of the incomplete combustion originating from the cylinder. The results of the POP (Pressure Over Piston) test are presented in Table 1.

Table 1: Result of POP test

Parameter	Idle	Target idle	N 1	N 2	N 3	N 4	N 5	N 6	N 7	N 8	Target N 8
Lube Oil Temp °C	74		68	68	64	69	70	72	73	72	
Water Inlet Temp °C	74		69	70	70	71	73	75	75	73	
Lube Oil Temp °C	77		69	69	70	70	72	73	75	75	75-85
Water Outlet Temp °C	70		71	71	72	73	75	77	80	77	75-85
Manifold Air Temp °C	60		60	61	61	62	63	66	63	60	57-67
Manifold Air Pressure kgf/cm ²	1		1	1	1	1.1	1.4	1.6	1.7	3	2.8-3.5
Fuel Pressure kgf/cm ²	6.6	5,9-6,7	6,7	6,7	6,6	5,3	5,5	5,3	5,3	5,5	4,9-5,7
Water Pressure kgf/cm ²	0,7		1,1	1,1	1,2	1,7	2,3	2,4	2,3	2,6	
Oil Pressure kgf/cm ²	1,4		4,3	4,3	4,6	6,8	7,9	7,8	7,6	8	7,2-8,0
Crankcase Over Pressure kgf/cm ²	-0,1		-0,1	-0,08	-0,1	-0,15	-0,24	-0,26	-0,37	-0,87	
Alternator Voltage	2		110	203	304	397	488	570	624	793	
Alternator Amp	0		249	545	800	1039	1250	1458	1577	1910	
Engine RPM	384	385	585	585	621	795	964	964	963	1051	1050
Target Engine RPM	385		450	534	621	793	964	964	964	1050	
Gross Power Kw	14		53	144	284	478	709	955	1161	1694	
Target Gross Power kW			56	142	283	470	697	951	1152	1677	
Turbo Speed RPM	2745		3240	3860	5229	8028	11973	14501	16400	22713	
Load Pot Percent	100	100	100	100	100	100	100	100	100	100	100

The results of various tests conducted from notch 1 to notch 8 indicate that all parameters are within standard ranges. The lube oil and water temperature tests showed that both inlet and outlet temperatures remained within the acceptable range of 70–85°C. Similarly, the manifold air temperature and pressure tests yielded values within the standard limits, with temperatures ranging from 57–74°C and pressures between 1.0–3.6 kgf/cm². The fuel pressure test results also aligned with the standards, maintaining a range of 4.9–6.7 kgf/cm². In the water and oil pressure tests, the results fell within the acceptable ranges of 1.2–4.0 kgf/cm² for water and 2.2–8.0 kgf/cm² for oil. Finally, the crankcase overpressure test results were within the standard range of -0.010–0.4 kgf/cm².

Additionally, the alternator voltage and current tests show standard values, with voltage ranging from 4 to 785 volts and current between 0 and 1800 amps. Engine RPM and gross power tests align with expected values, although a discrepancy was noted at notch 1, where the gross power measured 53 kW, which is below the target value. Lastly, the turbo speed RPM tests confirm that the values remain within the standard range of 2000 to 13,000 RPM.

The pop test conducted on diesel locomotive engines is a crucial procedure for quickly identifying damaged cylinders among the eight cylinders. By performing this test, maintenance personnel can directly pinpoint the problematic cylinder, allowing them to focus their efforts on the affected component without the need to disassemble each cylinder individually. This efficiency greatly reduces maintenance time and ensures more effective troubleshooting.

The pop test is a crucial procedure for evaluating the performance of the fuel system in the CC 203 locomotive, ensuring efficient operation. To begin, the locomotive should be parked on a level surface and properly secured with safety measures. After gathering the necessary tools, including a fuel pressure gauge, safety goggles, and gloves, access the engine compartment to locate the fuel injector nozzles. Carefully disconnect the fuel lines from the injectors to prevent any spillage, and then attach the fuel pressure gauge to the line leading to the injectors, ensuring all connections are secure. Next, start the engine and allow it to reach its normal operating temperature. Once the engine is at temperature, gradually increase the RPM to the specified range for the pop test. Monitor the pressure readings on the fuel gauge, which should typically range between 4.9 and 6.7 kgf/cm², and observe the spray pattern and fuel flow from each injector to ensure they "pop" consistently at the designated pressure with a uniform pattern [12].

Document all pressure readings and observations related to injector performance, noting any discrepancies from standard values that may require further investigation. After completing the test, turn off the engine, carefully disconnect the gauge, and securely reconnect the fuel lines. Conduct a thorough visual inspection for any leaks or other issues. Analyze the recorded data and, if any problems are detected, schedule the necessary maintenance. This comprehensive procedure is essential to maintaining the performance and reliability of the CC 203 locomotive [13].

The CC 203 series locomotive is equipped with a testing system, known as the pop test, that efficiently analyzes and identifies potential issues within the locomotive's fuel system. However, it is important to note that the pop test can require extended maintenance time since personnel must disassemble each diesel engine cylinder to locate the problematic one. During the pop test, maintenance personnel must be vigilant of certain factors, including:

1. Cylinder knock
2. The color of the exhaust smoke
3. Cylinder firing order

During the maintenance of the CC 203 locomotive cylinders at the Locomotive Depot, various types of issues are encountered. The following Table 2 outlines the common problems experienced by the diesel engine when the pop test is performed on the cylinders.

Table 2: Types of interference that occur during the pop test

No.	Problems	Causes	Discussion
1.	Thick black smoke emission	Excessive fuel entering the cylinder	1.High-pressure pump valve is abnormal 2. Damaged injector
2.	White smoke emitting	There is lubricating oil leakage entering the cylinder.	1. Piston Rings Worn Out 2. Piston Rings Damaged
3.	There is abnormal noise	Presence of damaged components	1.InjectorBroken/Damaged 2. Piston Cracked/Damaged 3. Bent Connecting Rod
4.	Weak or insufficient power output	The combustion process is suboptimal.	1.Insufficient Injector Compression Pressure 2.Incomplete Combustion 3.Clogged Injector Nozzle
5.	The cylinder is not functioning.	Fuel does not enter the cylinder.	The electrical flow from the engine control unit fails to open the solenoid valve of the high-pressure pump.

From the various types of disturbances that occur during the pop test, we can analyze which parts of the system most frequently show problematic data [14][15].

Based on the data obtained from direct observations and the history of cylinder disturbances during the pop test, this data will be analyzed using a Fishbone diagram (also known

as an Ishikawa diagram) to identify the factors influencing the disturbances in the cylinder during the pop test. The Fishbone diagram, shown in Figure 1, helps visualize the potential causes of issues such as misfires, cylinder knocks, and excessive exhaust smoke. By categorizing these factors into areas like equipment, process, people, and materials, the

diagram provides a structured way to identify root causes, facilitating targeted troubleshooting and effective resolution.

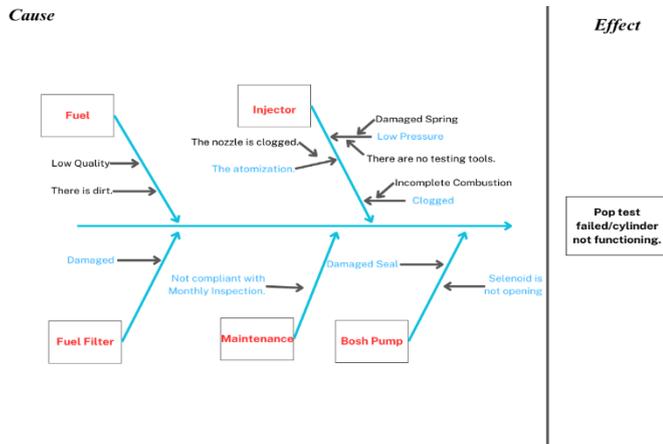


Figure 1: Fishbone Diagram

Based on the Fishbone diagram, numerous factors contribute to abnormal cylinder operation. The causes of these disturbances can be clearly observed in the diagram, which categorizes potential issues across areas such as fuel system, air intake, injectors, and operational conditions.

From the pop test results, it was noted that the problematic parameter lies in the gross power at notch 1, where the value recorded is 53 kW, while the target gross power for notch 1 is 56 kW. Although exceeding the standard value is permissible for gross power, being below the standard suggests the possibility that the nozzle pressure at notch 1 may be below the required specifications. For the CC 203 series locomotive, the standard value for nozzle pressure is between 3800 and 4000 psi. If the nozzle pressure falls below this range, it can affect the combustion process, leading to suboptimal engine performance and a reduction in gross power output, which further impacts the locomotive’s overall efficiency.

By identifying and addressing the nozzle pressure issue, it is possible to correct the disturbances and bring the engine’s performance back to expected levels. Regular maintenance and adjustments of the fuel injection system, including nozzle pressure checks, are essential in ensuring the locomotive’s optimal operation.

From the data analysis process using the fishbone diagram and based on the pop test results with a gross power value of 53 kW, it can be concluded that there are three primary factors contributing to incomplete combustion in the diesel locomotive engine:

1. Clogged Injector Nozzle

A clogged injector nozzle significantly disrupts the fuel atomization process. Deposits from combustion byproducts can cover the nozzle holes, causing obstructions in the fuel delivery channels. This leads to incomplete combustion, as the fuel is not atomized properly for efficient ignition. The presence of combustion soot, carbon, and other residues can clog the injector nozzles. To prevent this, routine inspection and cleaning of the nozzle are necessary. Any buildup should be cleared to maintain the proper functioning of the injector. Additionally, if pressure builds up due to clogging, it can lead to injector rupture, as shown in the figure below.

2. Insufficient Injector Pressure

During routine P6 maintenance, the injector’s pressure is checked, and it is found that, at times, the pressure does not meet the specified standard of 400 psi. The reduction in spring pressure within the injector, which typically occurs due to wear and aging, is a primary cause of insufficient injector pressure. This results in poor fuel atomization and inefficient combustion. The solution is to adjust the injector nozzle pressure by disassembling the nozzle and adding shims. This restores the correct pressure and ensures that the injector is functioning properly. Abnormal injectors with insufficient pressure can be easily identified through this regular maintenance check.

3. Abnormal Combustion Due to Poor-Quality Fuel (Biosolar)

Poor-quality fuel, specifically biosolar, can lead to abnormal combustion. Bio solar is an alternative fuel made by mixing diesel with organic materials such as palm oil, plant waste, or another biomass. While bio solar is a sustainable fuel option, its plant-based components may contain fibers that can clog the injector nozzles. These fibers obstruct the fuel flow, leading to incomplete combustion. If the injector nozzle is found to be clogged with fibers, they must be removed to restore normal fuel flow. Additionally, the accumulated pressure from the blockage can cause the injector to crack or break, further affecting engine performance.

To address these issues, regular inspection, cleaning of the injectors, and ensuring that the injector pressure remains within specification are critical steps. Additionally, fuel quality control, especially when using biosolar, should be monitored to prevent contamination that could cause operational issues. Proper maintenance of the injector system and fuel quality will help mitigate incomplete combustion and improve the engine’s overall performance.

IV. CONCLUSION

Based on the research results, several key conclusions can be drawn regarding the issues observed in the diesel engine of the locomotive:

Impact of Incomplete Combustion: Incomplete combustion results in reduced performance in one of the cylinders, leading to a noticeable decrease in the overall power output of the locomotive's diesel engine. This performance drop is attributed to pressure deficiencies in one of the injector nozzles, which hampers the efficient fuel atomization and combustion process.

Injector Pressure below Standard: A significant cause of incomplete combustion is injectors that do not meet the required pressure. This issue typically arises due to damage to the spring inside the injector or the loss of spring tension over time due to aging, which causes a reduction in injector pressure.

Clogged Nozzles: Another factor contributing to incomplete combustion is the presence of a clogged nozzle, which is often caused by residual soot from incomplete combustion or impurities in the fuel that block the injector nozzle openings.

Fuel Quality Issues: The use of biodiesel, an alternative fuel composed of a blend of fossil fuels (diesel) and organic materials (such as palm oil or plant-based waste), introduces additional challenges. The biodiesel contains plant fibers that can accumulate and block the injector nozzle holes, further hindering the combustion process.

Injector Pressure Issues: To address injectors with pressure issues, the solution involves revising the nozzle pressure by disassembling the injector and adding shims to restore proper pressure and functionality.

Clogged Nozzles: For nozzles that become clogged due to soot accumulation from incomplete combustion, the solution is to conduct routine inspections of the injector nozzles. Any soot buildup should be cleaned to prevent obstructions and ensure smooth fuel flow.

Fuel Residue Blockage: When fuel residues, such as plant fibers from biodiesel, block the nozzle holes, the fibers should be carefully removed. This maintenance step ensures that the injector holes are clear, allowing for proper fuel atomization and optimal combustion.

By addressing these issues systematically, the locomotive's engine performance can be restored to standard levels, improving efficiency and reducing power loss caused by incomplete combustion. Regular maintenance, including nozzle inspection, cleaning, and pressure adjustments, is

essential in maintaining the engine's reliability and performance.

REFERENCES

- [1] Railway Maintenance Office. (2018). Open Wagon ZZOW. Accessed on April 29, 2024.
- [2] Large Locomotive Depot A Cipinang. (2021). Implementation Document of the Quality Management System of Cipinang Locomotive Depot [Power Point Presentation].
- [3] Harjanto, S., Fitriani, E., Jendral, J., & Yani, A. (2018). Simulation of Emergency Braking on Trains Passing Indicated Stop Signals Based on Arduino Uno Microcontroller. *Scientific Journal TEKNO*, 15(2), 43–52.
- [4] INKA. (2016). KAI Prepares 38 Sets of Trains Made by INKA for Carrying Homecomers. Accessed on April 29, 2024.
- [5] Ministry of Transportation. (2010). Technical Specification Standards for Locomotive-pulled Trains. KM 41 Year 2010, 1–18.
- [6] Ministry of Transportation. (2010). Technical Specification Standards for Freight Cars. KM 43 Year 2010, 1–11.
- [7] Ministry of Transportation. (2019). Standards for Railway Equipment Maintenance Places and Tools. PM 18 Year 2019, 1–23.
- [8] Merdeka. (2021). Largest in Indonesia, Construction of Cipinang Locomotive Depot Costs Rp 500 Billion. Accessed on April 28, 2024.
- [9] Indonesian Railway Polytechnic Madiun (2022). Basis of Braking System [Power Point Presentation].
- [10] Sulestyono, E. (2021). Cipinang Train Depot, the Largest in Indonesia. Accessed on April 29, 2024.
- [11] Wikipedia. (2024). Cipinang Station. Accessed on April 28, 2024, from <https://id.wikipedia.org/>
- [12] AS, H. (2012). Diesel Locomotives and Rail Cars in Indonesia. Depok: Ilalang Sakti Communication.
- [13] Franco, F. Method of analysis for nozzle problems in CC-203 locomotives. Accessed on April 29, 2024.
- [14] Henry, P., Prasetya, W., Dadang, A., Atmaja, S., Rochmat, H., Hermawan, S., & Perkeretaapian P. (2021). Analysis of Disturbances in Pop Test Results as Parameters for Diesel Locomotive CC 206 Engine Reliability (Vol. 6, Issue 1).
- [15] Oleh, D., & Gilang Naufal, M. (2019). Main fieldwork report at large locomotive depot a cipinang.

Citation of this Article:

Dwi Basuki Wibowo, Agus Suprihanto, Ojo Kurdi, Susilo Adi Widyanto, Abraham Sahala Parluhutan Hutauruk, & Ian Yulianti. (2024). Investigating Incomplete Combustion Causes and Maintenance in CC 203 Diesel Locomotives. *International Research Journal of Innovations in Engineering and Technology - IRJIET*, 8(11), 245-250. Article DOI: <https://doi.org/10.47001/IRJIET/2024.811031>
