International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Field Investigation and Performance Analysis of a Selective Catalytic Reduction (SCR) System in Industrial Diesel Engines

Simeon Petrov[a], Zoran Dimitrovski[b]

[a] *Goce Delcev University, Krste Misirkov No. 10-A, Shtip 2000, Republic of North Macedonia*
[b] *Goce Delcev University, Krste Misirkov No. 10-A, Shtip 2000, Republic of North Macedonia*

A B S T R A C T:

Selective Catalytic Reduction (SCR) is a leading technology for effectively reducing nitrogen oxides (NOx) emissions from diesel engines, power plants, and various industrial applications. This paper examines the principles, components, and operational mechanisms of SCR systems, highlighting their critical role in meeting stringent environmental regulations such as Euro 6/7 standards. SCR operates by converting NOx emissions into harmless nitrogen and water through a catalytic reaction with ammonia, derived from urea-based solutions like AdBlue. The catalytic converters used, typically containing materials like titanium oxide, vanadium oxide, and zeolite-based substances, significantly enhance the efficiency of NOx reduction, often exceeding 90%. Despite its substantial environmental and operational benefits, SCR technology faces challenges including precise ammonia dosing to prevent ammonia slip and catalyst degradation caused by impurities and sulfur content in fuels. Continuous research and development efforts aim to overcome these challenges through improved catalyst materials, dosing strategies, and integrated exhaust treatment systems. This paper emphasizes the growing significance of SCR in achieving regulatory compliance and sustainability objectives, underscoring its essential role in modern emission control strategies for transportation and industrial sectors.

Keywords: Selective Catalytic Reduction (SCR), nitrogen oxides (NOx), ammonia, catalytic converter, emission control, environmental regulations, AdBlue, diesel engines, catalyst degradation, sustainability.

1. Introduction

Selective Catalytic Reduction (SCR) has emerged as one of the most effective technologies in mitigating nitrogen oxides (NOx) emissions from diesel engines, power generation plants, and various industrial processes. Developed initially in response to increasingly stringent environmental regulations aimed at improving air quality, SCR technology has become integral in efforts to comply with emissions standards such as the Euro 6/7 regulations and equivalent guidelines globally.

Nitrogen oxides, primarily NO and NO_2, collectively referred to as NOx, pose substantial environmental and health concerns. They contribute to the formation of ground-level ozone, acid rain, and fine particulate matter, adversely affecting human health, ecosystems, and infrastructure. Consequently, reducing NOx emissions is crucial for environmental protection, public health, and compliance with regulatory standards.

The SCR system works by converting NOx emissions into harmless nitrogen (N_2) and water (H_2O) through a catalytic reaction facilitated by ammonia (NH_3), typically derived from an aqueous urea solution commercially known as AdBlue or Diesel Exhaust Fluid (DEF). Injected upstream of the catalytic converter, the urea decomposes upon exposure to high exhaust temperatures, releasing ammonia, which then reacts selectively with NOx on the surface of a catalyst. The catalysts commonly used in SCR systems are made from metals such as titanium oxide, vanadium oxide, tungsten oxide, or zeolite-based materials, each offering specific advantages in terms of operating temperature ranges, durability, and resistance to catalyst poisoning. One key advantage of SCR technology is its high efficiency in NOx reduction, often exceeding 90%, making it exceptionally suitable for heavy-duty diesel vehicles, maritime engines, and stationary combustion sources such as power plants. Furthermore, SCR allows for optimized engine performance and improved fuel efficiency since engine settings can be adjusted to operate under conditions that naturally produce higher NOx, knowing that emissions will be effectively treated downstream.

Despite its clear benefits, SCR implementation presents certain challenges. The effectiveness of the SCR system heavily relies on accurate dosing and proper mixing of the ammonia or urea solution, as improper dosing can lead to ammonia slip—excess ammonia escaping into the atmosphere, contributing to secondary environmental issues. Additionally, the catalyst's lifespan and performance can be adversely affected by impurities in fuel or lubricants, sulfur content, and prolonged exposure to variable temperature conditions.

1.1 Field investigation of SCR system

The test was performed on a diesel engine, specifically a C-13 CAT Euro 6C type, installed in a Metso Lokotrack LT1213S mobile crusher. The objective of the test was, upon receiving a defect report, to identify and rectify the issue, enabling the machine's return to operational status. Testing was conducted under actual working conditions to detect system faults, record existing errors, and identify deviations from normal sensor and component values.

Through analysis of engine electronics data and diagnostic tools, the investigation aimed to reveal malfunctions or abnormal system behaviors and assess their impact on the overall exhaust gas reduction process. Additionally, remedial actions were performed to rectify identified issues, restoring the system to optimal functionality. Such analyses are crucial to ensure continuous and safe engine operation, particularly under high-load industrial conditions.

1.2 Methodology

The experiment involved testing a Metso Lokotrack LT1213S mobile crusher, featuring the following specifications:

- Engine: Caterpillar C-13, six-cylinder diesel engine
- Emission standard: EURO 6c
- Engine displacement: 12,500 cm^3
- Maximum power: 400 kW (536 hp)
- Maximum torque: 2,353 Nm

The test commenced following an operational fault reported by the machine operator. According to his observations, after starting the machine and engaging the hydraulic components, the engine automatically increased its revolutions from idle (approximately 850 rpm) to about 1,400 rpm. In this phase, the machine prepares to activate all hydraulic elements, transitioning to the next working phase, where the engine should reach 1,700 rpm required to activate hydraulic pumps and begin crushing rock material. Instead, the process halted, the hydraulic system failed to activate, and the engine reverted to idle mode, showing a "safe mode" error due to unsafe operating conditions. This indicated activation of a protective function and signified a fault preventing the normal transition to full operational mode. Such atypical behavior suggested a possible "choking" issue, restricting fuel or air supply or activating an exhaust system protective function, resulting in insufficient power during load.

Diagnostic equipment JALTEST, manufactured by COJALI, was utilized, connected via a 9-pin connector compatible with all Caterpillar aggregates directly linked to the engine's electronic control unit (ECU). Activities conducted included:

- Diagnostic equipment connection to ECU and identification of system modules;
- Reading and analyzing active and stored faults;
- Reading and analyzing active and stored faults;
- Monitoring key parameters in various operational modes;
- Checking pressure and temperature sensors in the exhaust system;
- Checking accumulated soot levels in the diesel particulate filter (DPF);
- Visual and functional checks of air intake, fuel injection, and exhaust systems;
- Reviewing ECU adaptations and calibrations.

2. Diagnostic analysis and identification of the system anomalies

2.1 Diagnostic analysis

Diagnostic tests yielded the following results:

Fig. 1 – Diagnostic test results.

- Fault 4364 FMI:2 – Aftertreatment SCR Conversion Efficiency – Incorrect/intermittent data signaled disrupted SCR functionality, reflecting inconsistent data received by the ECU.

- Fault 3226 FMI:12 – Aftertreatment Outlet NOx – Faulty performance indicated a defective sensor measuring nitrogen oxides at the SCR system outlet and exhaust temperature in the final SCR catalyst

Given critical conditions, forced DPF regeneration was attempted but failed due to active faults, reaching only 80-90% efficiency, far from the optimal 0-12%. Further checks on the system for exhaust gasses has identified the following issues:

- The diesel particulate filter (DPF) was 136.16% full, significantly blocked, causing elevated differential pressure (76 mbar vs. normal 10-20 mbar).
- Abnormal thermal profile in the exhaust system; gases exited the engine at 162.2°C but left the exhaust at 31.4°C, indicating severe blockage.
- Active exhaust system faults (NOx sensor failure) prevented necessary regeneration despite heavy soot accumulation.

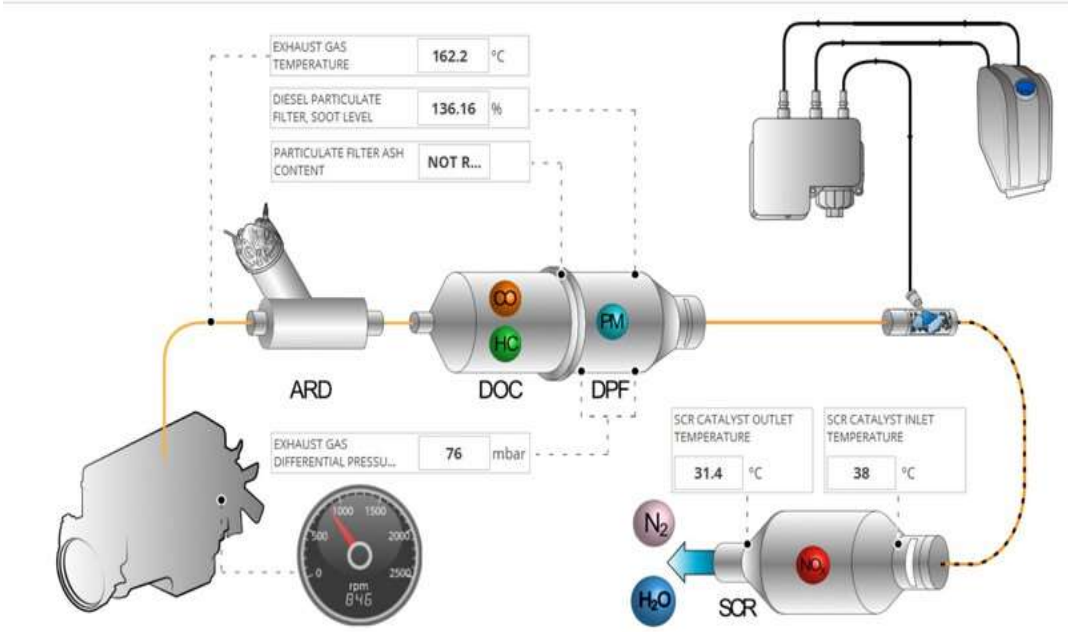

Fig. 2 – Initial condition in the system.

2.2 Physical assessment and identification system anomalies

Upon identification of the malfunction, corrective measures were promptly undertaken. An inspection of the connector and the physical condition of the NOx sensor revealed that the sensor housing was damaged and that, in one location, the wiring harness was completely exposed—an issue likely responsible for erroneous signal readings. Based on these findings and corroborated by the diagnostic fault codes, it was conclusively determined that replacement of the sensor was necessary. During the interim period awaiting the arrival of the replacement component, the machine was withdrawn from service.

3. Remediation strategies and implementation

3.1 Component replacement

Upon receipt of the new NOx sensor, installation was performed in strict accordance with the manufacturer's prescribed procedures. Following replacement:

- The control unit automatically recognized the new sensor;
- The faults within the system were recorded as inactive and subsequently cleared.

Subsequent diagnostic verification confirmed that all exhaust gas treatment subsystems were operating correctly. Due to the substantial soot accumulation (136.16%) within the diesel particulate filter, a forced regeneration procedure was initiated.

3.2 Initiation and monitoring of the regeneration process

Approximately ten minutes after initiation of the regeneration process, a significant accumulation of soot became evident, as indicated by the pronounced temperature differential in the exhaust gases: the temperature at the inlet of the diesel particulate filter (DPF) measured 404.1°C, whereas at the inlet of the SCR catalyst, it was only 122.9°C.

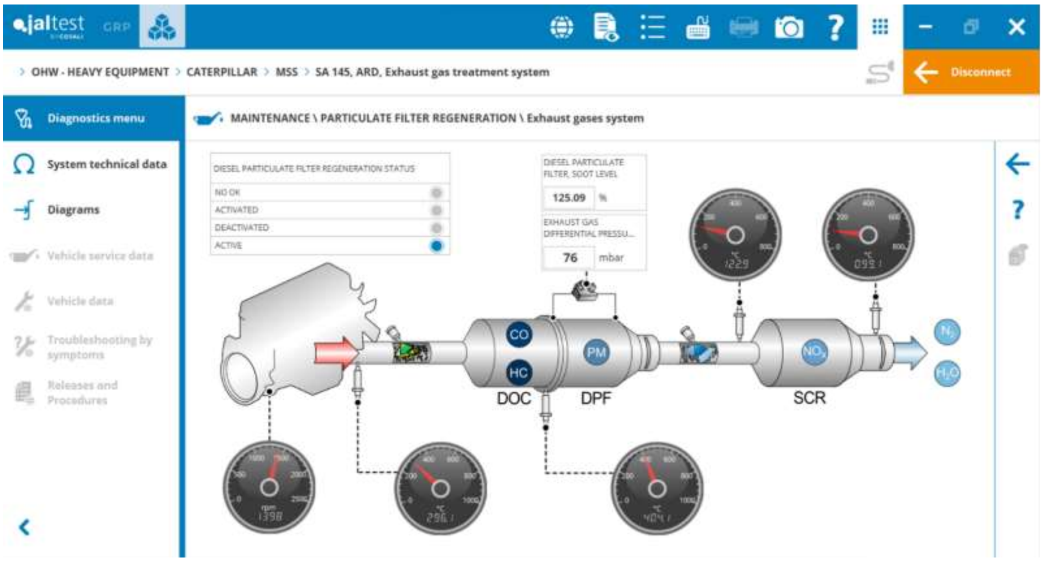

Fig. 3 – Forced regeneration of the DPF – soot level over the limit.

Approximately one hour after the commencement of the regeneration process, substantial progress was observed. The differential pressure had decreased to 22 mbar, and the temperature differential between the inlet of the DPF and the SCR catalyst was likewise reduced. At this stage, the soot loading was measured at 57.65%.

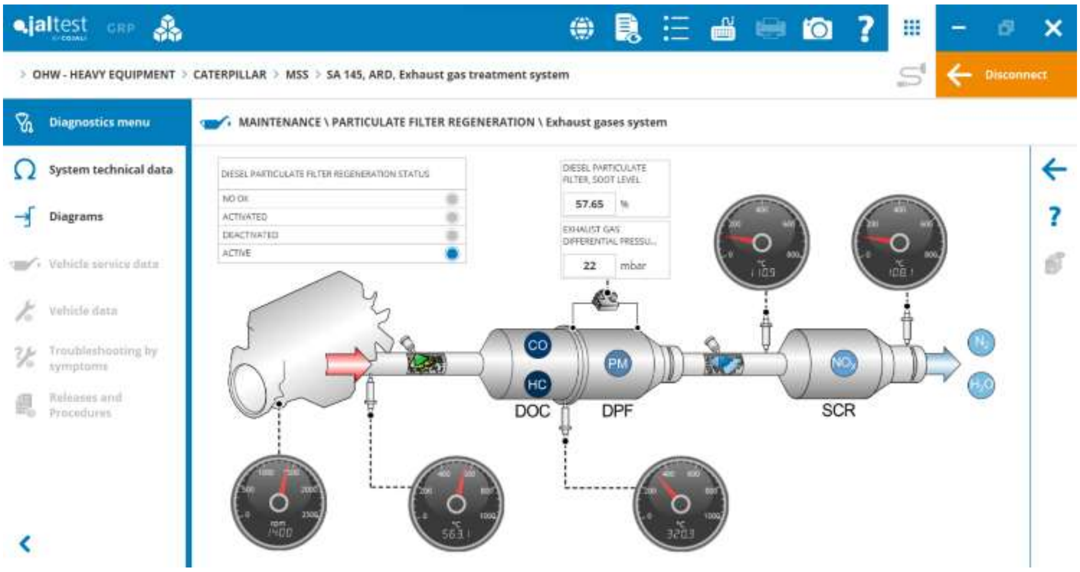

Fig. 4 – Forced regeneration of the DPF – soot level at 57,65%.

After one hour and forty-five minutes, the regeneration process was nearing completion. The differential pressure had been reduced to 14 mbar, falling within optimal parameters and the temperature differential was nearly equalized. The soot concentration had decreased to 10.27%, indicating a successful progression of the regeneration process.

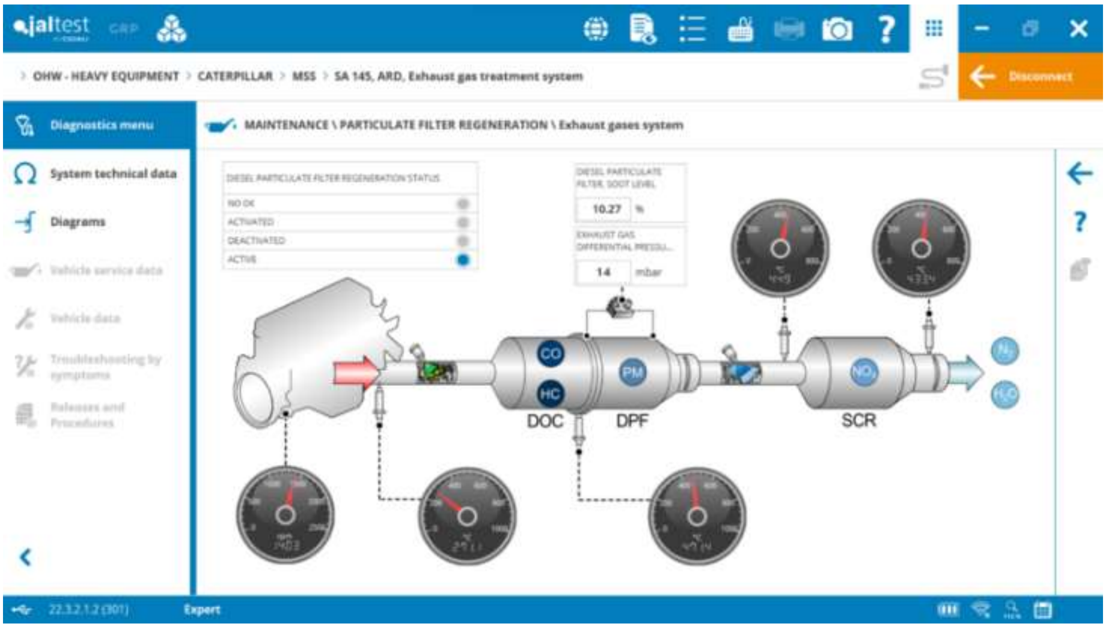

Fig. 5 – Forced regeneration of the DPF – soot level at 10.27%.

4. Evaluation of post-remediation outcome

4.1 Experiment result

After more than two hours, diagnostic evaluation confirmed that the regeneration process had been successfully completed and that the system was operating flawlessly. Upon conclusion of the procedure, a comprehensive inspection of the exhaust gas treatment system was conducted to verify the condition and functionality of each individual component.

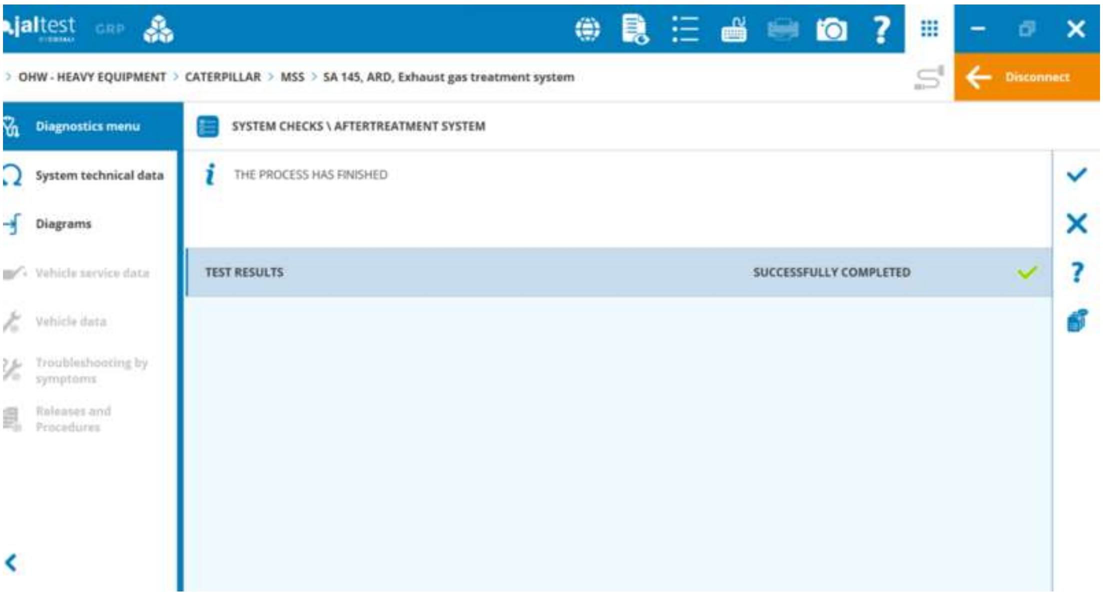

Fig. 6 – Confirmation of successful completion of the process.

This final verification unequivocally confirmed that the fault had been rectified and that the operation of both the diesel particulate filter and the selective catalytic reduction system had been fully restored to normal. The machine was once again fully operational and could be returned to service. Interventions normalized emission parameters and gas flow, enabling machine operation restoration.

4.2 Recommendations

Based on the outcomes and the corrective actions undertaken, the following measures are proposed to enhance the maintenance and performance of the exhaust gas treatment system:

- Regular inspection of NOx sensors: It is advisable to perform both visual and diagnostic inspections of the NOx sensors and their electrical connectors and harnesses during each scheduled service to ensure timely detection of physical damage or corrosion.
- Monitoring soot levels in the DPF: Continuous monitoring of DPF-related parameters—such as soot accumulation percentage and differential pressure—will facilitate timely activation of regeneration and prevent critical system blockages.
- Initiation of regeneration at early signs of reduced efficiency: Regeneration should be initiated immediately upon diagnostic indication of a significant decrease in system efficiency or increased thermal gradients, rather than waiting for soot levels to exceed critical thresholds.
- Operator training for early detection of faults: Operators and responsible personnel should be trained to recognize atypical operating conditions (such as power loss, unusual temperature readings, or prolonged phase transitions) that may signal underlying issues within the exhaust system.
- Retention of diagnostic logs and reports: Maintaining diagnostic log files and visual data (temperatures, soot percentages, faults) allows for improved analysis of long-term system trends and facilitates more efficient interventions in the event of recurrent problems.
- Utilization of original spare parts: When replacing critical components such as NOx sensors, only genuine parts should be used to ensure the accuracy of measurements and full compatibility with the ECU.

5. Conclusion

Based on the comprehensive analysis and diagnostics of the exhaust gas treatment system in the Caterpillar C-13 engine installed in the METSO Lokotrack mobile crusher, a severe malfunction was identified in critical system components, namely the NOx sensor at the SCR catalyst outlet and the diesel particulate filter. The presence of error codes, excessive soot accumulation, and abnormal thermal profiles indicated a significant disruption in the operation of the entire exhaust system. These conditions triggered the activation of the control unit's protective "safe mode" and resulted in a substantial limitation of the machine's operational capabilities.

Through precise diagnostics and the appropriate remediation measures—including replacement of the defective NOx sensor and comprehensive forced regeneration of the DPF, all key emission and exhaust flow parameters were normalized. Post-intervention diagnostic data confirmed stabilized temperatures, normal differential pressures, and valid readings from all sensors, enabling the restoration of the machine to normal operational status.

This case underscores the critical importance of maintaining sensor integrity and regeneration processes within exhaust gas treatment systems in modern diesel engines. Timely diagnostics, combined with proper interventions, not only restore machine functionality but also ensure continued operation in compliance with stringent Euro 6c emission standards.

References

- Boretti, A. (2019). Emission Control Strategies for Internal Combustion Engines. Journal of Engineering for Gas Turbines and Power, ASME.
- Caterpillar Inc. (2018). C13 Engine for Industrial Applications – Systems Operation Testing and Adjusting.
- Wärtsilä. (2020). Exhaust Gas Cleaning Systems Manual. Wärtsilä Corporation.
- Heywood, J. B. (2018). Internal Combustion Engine Fundamentals (2nd ed.). McGraw-Hill Education
- Koebel, M., Elsener, M., & Kleemann, M. (2000). Urea-SCR: A promising technique to reduce NOx emissions from automotive diesel engines. Catalysis Today, 59(3-4), 335-345.
- Johnson, T. V. (2009). Review of Diesel Emissions and Control. SAE International Journal of Fuels and Lubricants, 1(1), 68-81.
- Nova, I., & Tronconi, E. (2014). Urea-SCR Technology for the NOx After Treatment of Diesel Exhausts. Springer, ISBN 978-1-4471-5371-3.
- Majewski, W. A., & Khair, M. K. (2006). Diesel Emissions and Their Control. SAE International.
- (See Chapter 13: Selective Catalytic Reduction (SCR) Systems)
- He, H., & Yu, Y. (2017). Selective Catalytic Reduction (SCR) of NOx by Ammonia over Metal Oxide Catalysts. In: Catalytic Air Pollution Control: Commercial Technology (4th Edition). Wiley.