STUDIES ON REDUCING EMISSIONS USING PREHEATING OF EXHAUST GASES IN THE ISUZU 4JB1 DIESEL ENGINE

Picus Claudiu-Marian[1], Beniuga Marius-Constantin[1], Cezar-Ion Adomnitei[2,3]

[1]Department of Mechanical Engineering, Stefan cel Mare University of Suceava, Romania 13 University Street, 720229, e.mail: claudiu.picus@usm.ro
[2] Integrated Center for Research, Development and Innovation in Advanced Materials, Nanotechnologies and Distributed Systems for Fabrication and Control, Stefan cel Mare University of Suceava, 720229 Suceava, Romania
[3]Department of Computers, Electronics and Automation, Stefan cel Mare University of Suceava, 720229 Suceava, Romaniaepartment of Mechanical Engineering, Stefan cel Mare University of Suceava, Romania
13 University Street, 720229,

Abstract: *The purpose of this research is to develop and apply an exhaust gas preheating module based on the principle of thermal induction, with the aim of reducing nitrogen oxide (NOx) emissions in diesel engines. The study explores the use of an induction coil, specially designed and integrated into the exhaust system, to increase the temperature of the exhaust gases. Thus, it improves the efficiency of the catalytic reduction process of emissions by optimizing the heating of AdBlue microdroplets, a reduction agent used in emission control technology. The induction process is achieved by placing an electromagnetic coil around or inside the exhaust piping. When an electric current pass through the coil, a variable magnetic field is generated which, in turn, induces heat in the exhaust pipe's metal. This heat is then quickly transferred to the AdBlue vapors and compressed air, effectively preheating the AdBlue solution during cold engine operation. This preheating improves the performance of the catalyst in the subsequent injection of AdBlue into the exhaust gases, thus contributing to a significant reduction in NOx emissions in diesel engines.*

Keywords: *Preheater, AdBlue, Exhaust Gases, Induction*

1. Heating methods for exhaust gases before selective catalytic convertor (SCR) in diesel engines for cold operation

In diesel engines, it is crucial for the exhaust gases to be heated to the optimum temperature before reaching the normal operating level of the Selective Catalytic Reduction (SCR) catalyst. This is necessary to improve engine performance and reduce emissions, especially during the start-up period and when the engine is cold, in the case of very short distances traveled by the vehicle. Therefore, current systems used to preheat the exhaust gases before the SCR are analyzed. Some SCR systems are equipped with dedicated heating elements, which can be activated before starting the engine or during operation in cold environmental conditions.

These elements heat the exhaust gases at the entry to the SCR catalyst to rapidly reach the chemical conversion temperature, allowing for a quicker reduction of emissions right from the first few seconds of operation.

1.1. Recirculation of heated exhaust gases

Advanced systems for controlling pollutant emissions can include the technique of recirculating heated exhaust gases (EGR - Exhaust Gas Recirculation) to deliver higher temperature gases to the Selective Catalytic Reduction (SCR) catalyst. This method can help accelerate the heating process of the catalyst and improve the efficiency of nitrogen oxides (NOx) emission reduction. However, in the case of cold starts of diesel engines, the EGR system is not sufficient to bring the exhaust gases to the optimal reaction temperature of over 160°C in a short time frame. For this reason, additional heating systems are implemented to ensure the thermal conditions necessary for the efficient activation of the SCR catalyst, thus optimizing the overall performance of the NOx reduction process under low-temperature conditions.

1.2. Exhaust gas heating systems

The solution used in Selective Catalytic Reduction (SCR) systems to reduce NOx emissions involves preheating the exhaust gases before their diffusive contact with AdBlue droplets. This ensures a more efficient chemical reaction, facilitating the evaporation process.

This can be achieved through induction heating elements. Ensuring an optimal temperature in the SCR catalyst and the AdBlue injection system can significantly improve the performance of the SCR system and reduce emissions, especially during operations at low temperatures. These heating techniques are essential to comply with emission standards and to minimize the negative impact on the environment [3]. Figure 1 presents such a system used in vehicles.

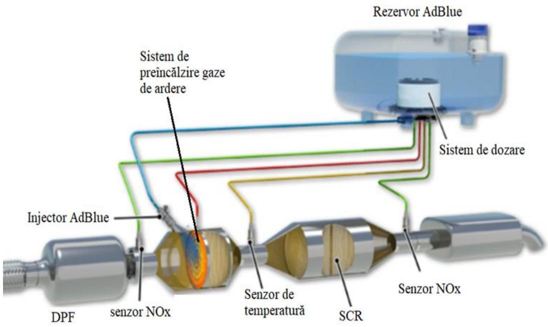

Figure 1: *EMITEC preheated SCR system [1].*

A control unit equipped with temperature and NOx sensors ensures the efficient operation of the system. After starting the engine, the preheating system increases the temperature of the exhaust gases to the required level. The temperature sensor then sends information about the temperature status to activate the SCR system and operate the AdBlue injector. AdBlue is injected directly onto the exhaust gas heating system. The solution evaporates on the hot surface and forms ammonia, which is used for the catalytic conversion reaction in the SCR to decompose nitrogen oxides into nitrogen and water. The injected quantity is regulated by the control system based on data transmitted by NOx sensors located before and after the system. The exhaust gas heating system is turned off when the engine produces sufficiently warm exhaust gases.

During longer pauses, when the engine is off or idling, the heated catalyst is reactivated by the control unit as needed.

Figure 2 illustrates the heating mode, where the red line in the graph represents the temperature evolution with a preheating system implemented, and the blue line represents the transient characteristic of the conventional system with Euro IV emission standard.

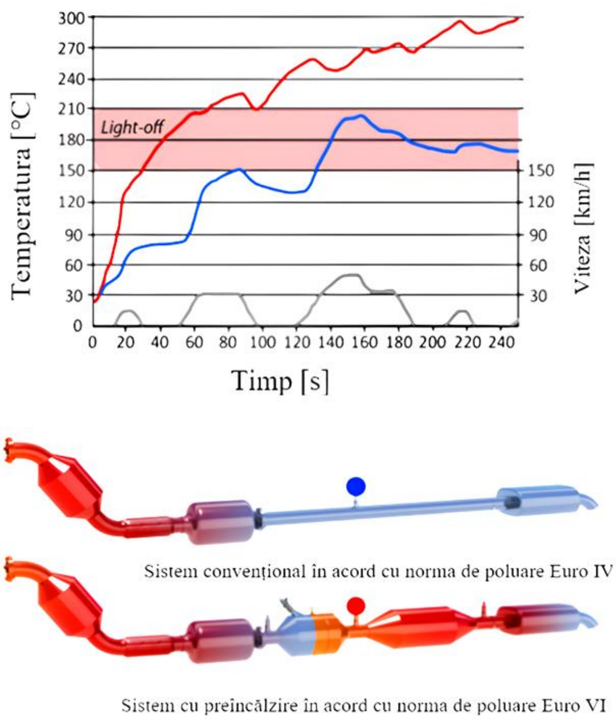

Figure 2: *Method of heating the exhaust piping using a gas preheating system compared to a system without preheating [1].*

The system maintains temperatures at a constant level while the engine is idling or turned off. This significantly reduces NOx emissions in urban traffic by over 90%.

2. Research on the preheating of exhaust gases

The proposed system is designed to rapidly heat the exhaust gases within milliseconds, which is critical in reducing the time needed for the SCR system to reach optimal operating capacity. The induction coil can be precisely controlled to keep the exhaust gases at an ideal temperature, ensuring minimal temperature difference during the injection of AdBlue vapors.

For cold starts of the vehicle, the induction coil is activated for a set duration (such as 1 minute) to ensure the heating of exhaust gases from the particulate filter (DPF). Consequently, AdBlue is injected at temperatures above 180°C, conducive to favorable chemical conversion.

Figure 3 depicts the suggested configuration [2] of the system, comprising an AdBlue vapor injection system, numbered 2, integrated with an induction preheating system, numbered 1. This setup undergoes a simulation at 1000°C, tracking the temperature progression over time to analyze thermal changes. The temperature dynamics of the atomized jet, composed of AdBlue and compressed air flowing at a steady pressure of 1 bar and idle speed, are also monitored. This process reveals consistent and targeted heating of the atomized jet. Additionally [2], the simulation demonstrates heat dissipation in the stagnation area of the ejector. Such thermal analysis and temperature mapping are crucial for understanding the system's performance under high-temperature operating conditions and assessing the impact of inductive preheating and atomization on the overall efficacy of the AdBlue vapor injection system under extreme conditions.

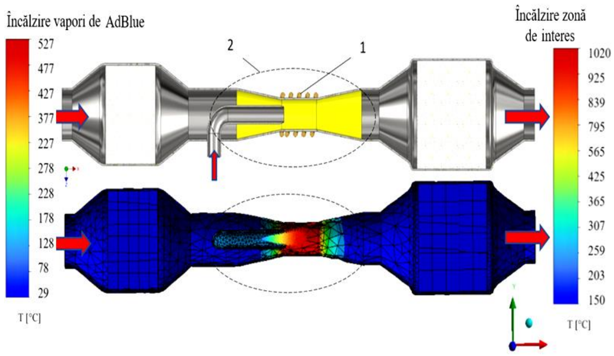

Figure 3: *Ansys simulation of the proposed preheating method.*

A simulation was conducted in the Ansys design environment (Figure 3), where the heating mode of the chosen system can be observed. The simulation highlights localized temperature intensification, with the heating system having a favorable impact on the AdBlue microdroplets

2.1. The adopted equipment for heating the exhaust gas particles atomized AdBlue droplets before the SCR.

Figure 4 details the heating equipment [2], primarily used for heating the exhaust gases resulting from combustion before injecting AdBlue into the NOx conversion process using an SCR.

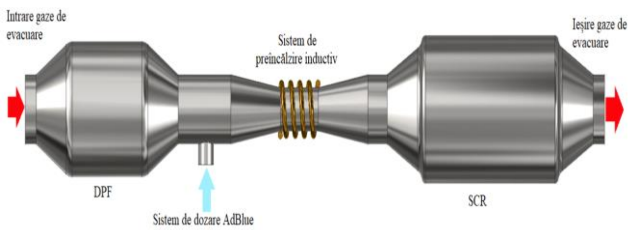

Figure 4: *Proposed preheating system.*

In this particular setup, an induction coil is employed, mounted on a section of the constructive solution attached to the exhaust muffler, as shown in Figure 5. The process adopts an inductive method to facilitate efficient and rapid heating of the AdBlue-exhaust gas mixture before it enters the SCR honeycomb.

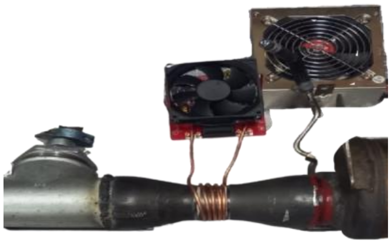

Figure 5: *Assembly of the induction heating system in the injection area.*

The induction heating unit is illustrated in Figure 6 and incorporates a high-frequency generator 1 for contactless heating of the steel exhaust piping, using electromagnetic induction.

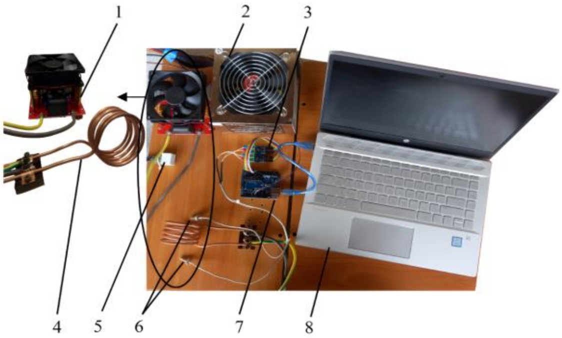

Figure 6: *The preheating control system.*

When alternating current is applied through the current source 2 to a coil consisting of five turns 4, which surrounds the stagnation area of the metal ejector, a magnetic field is generated by the current flowing in the coil. Simultaneously, in the alternating magnetic field, an oscillating current (eddy current) is generated by electromagnetic induction. This Foucault current causes Joule heating and will generate a heat loss of electromagnetic energy (eddy current loss). The high-frequency induction heating equipment achieves heating by utilizing two heating principles, namely hysteresis loss and eddy current loss. The degree of heating in the stagnation zone of the ejection system is controlled by the values generated by the optocouplers 6 that monitor the temperature inside the piping and the surface temperature of the ejector. These values are interpreted through conversion from resistance values to C programming code by the drivers 3, which generate a binary signal for the Arduino Uno acquisition board, denoted as 7. The data generated by the acquisition board are then sent to the computer 8, which will plot the temperature graphs.

The preheating system is activated or deactivated by the relay 5, which receives a signal from the acquisition board 7. The operation process is defined by the temperature values provided by the sensors 6.

When the sensor located in the exhaust gas piping detects a temperature lower than the optimal one for catalytic conversion, relay 5 is activated, initiating the heating process. The second sensor monitors a local temperature on the material subjected to heat. This sensor oversees the temperature state and generates a response regarding the operation of the induction system. This temperature monitoring system is influenced both by the engine start contact and by the AdBlue addition control module. Thus, the injection of AdBlue will occur when the temperature inside the exhaust gases reaches a normal value for optimal chemical conversion.

3. Results and conclusions

Figure 7 shows a detailed image of the positioning of the inductive heating system [2], and on the left side, the propagation of local temperature is depicted.

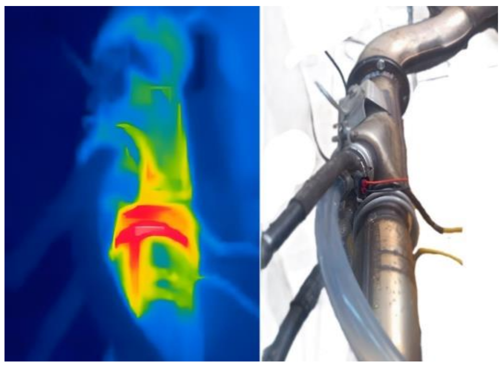

Figure 7: *Detail of the positioning of the inductive heating system on the exhaust piping.*

Figure 8 illustrates the evolution of NOx emissions during the test using a conventional injector. According to observations, for the selected injection system, the NOx concentration progressively increases until it reaches a maximum value and then stabilizes. In Figure 8, at 1000 revolutions per minute (rpm), the NOx concentration reaches 28 ppm after a 1-second test period. The area value corresponding to the portion under the curve is 1016 mm².

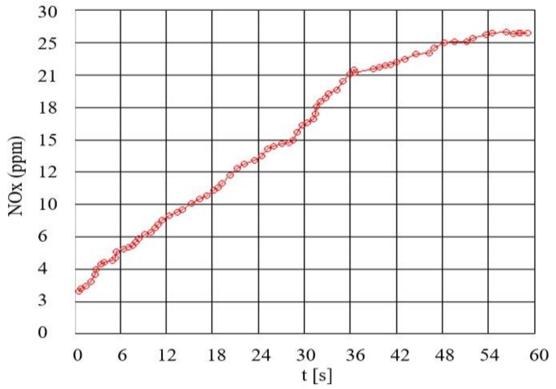

Figure 8: *The NOx value in the case of the conventional injector at 1000 rpm and 60 seconds without preheating.*

Figure 9 demonstrates the evolution of nitrogen oxide (NOx) emissions during the test conducted at 1000 rpm. In the case of the injection system with induction heating, it is observed that the NOx concentration gradually increases until it reaches a peak, stabilizing at approximately 11 ppm. Subsequently, a slight increase in concentration is noted, peaking at 24 ppm, after which it stabilizes. The area value corresponding to the portion under the curve is considerably smaller than in other cases, being 1012 mm².

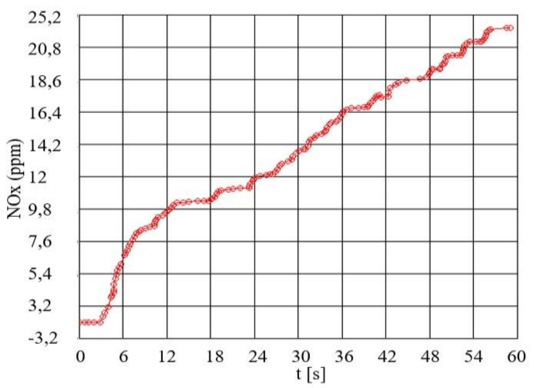

Figure 9: *Representation of the NOx curve at 1000 rpm for 60 seconds with preheating, in the case of the injector.*

The graph in Figure 9 shows the variation of nitrogen oxides (NOx) over time in a specific process or experiment. This graph illustrates the progression of NOx levels, which initially increase rapidly, reaching a peak of 11 ppm.

It is significant that this sharp increase in the initial milliseconds indicates a reaction or process involving substantial NOx production in the early stages of the experiment.

The curves in Figure 10 represent the values obtained during laboratory tests under the same environmental conditions, at an engine speed of 1000 rpm. These tests were conducted on an engine test stand in the laboratory, both without and with the preheating system installed in the configuration.

As follows, the figure shows a comparison of the NOx value for the injector at 1000 rpm with the preheating system attached.

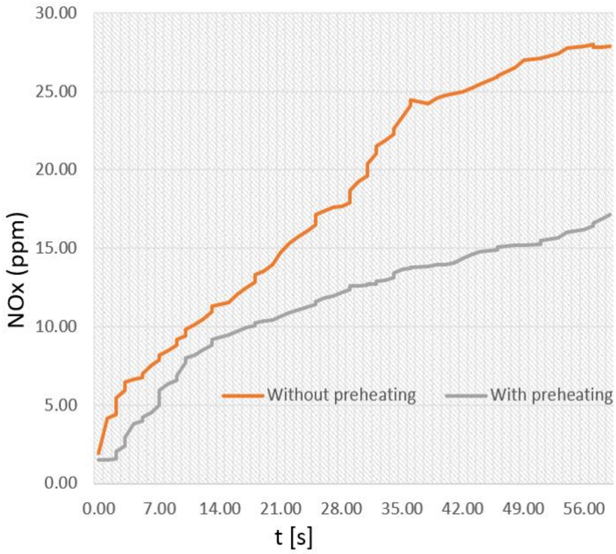

Figure 10: *Comparing NOx emissions in the injector scenario at 1000rpm with and without preheating.*

Proper heating of exhaust gases and the AdBlue solution is crucial for ensuring efficient operation of the SCR system, particularly during startup and when the engine is cold. Using the inductive heating system, heating occurs instantaneously. At moment T1, the local temperature is approximately 500°C.

The induction coil is an effective option for rapidly heating AdBlue before its injection into the SCR process. It generates heat directly and locally in the required area, ensuring an optimal temperature for chemical conversion. It is important to note that, according to the control system of the inductive heating, the temperature measured during one minute of engine operation reached a value of 1200°C.

Furthermore, it is suggested that the inductive heating system and the uniformity of temperature in the injection area have a significant impact on the amount of NOx observed in Figure 10.

With Preheating (Induction Heated Injector):

- Maximum NOx Value: 24 ppm
- Time to reach the maximum value: approximately 1 second

Without Preheating (Conventional Injector):

- Maximum NOx Value: 28 ppm
- Time to reach the maximum value: approximately 1 second

The results indicate that, in both cases, NOx emissions increase rapidly in the first few seconds of operation at 1000 rpm, regardless of the injection system used. However, in the case of the induction-heated injector, the maximum NOx value is lower (24 ppm) compared to the conventional injector (28 ppm).

This suggests that preheating the AdBlue-gas mixture through induction contributes to a reduction in NOx emissions in the initial seconds of operation, which can be beneficial for compliance with emission standards and overall SCR system performance in low-temperature conditions.

Acknowledgments

This work was supported by Romania National Council for Higher Education Funding, CNFIS, project number CNFIS-FDI-2023-F-0579

4. References

1. Nicolas. (2023, 08 29). https://emitec.com/. Taken from car-enginee; https://www.car-engineer.com/emitecs-e-scr-system-for-nox-reduction/
2. Picus Claudiu Marian, Experimental Research on the Influence of Exhaust Gas Temperature on the Mechanisms of Solid Deposits Formation in AdBlue Injection for Selective Catalytic Reduction Systems, Paper within the Doctoral Thesis, Stefan cel Mare University Suceava, 50 pages, 2023.