305.21

# Analysis of an automotive thermoelectric generator coupled to an electric exhaust heater to reduce NOx emissions in a Diesel-powered Euro VI Heavy Duty vehicle

A. Massaguer[1], E. Massaguer[1], J. Ximinis[1], T. Pujol[1], M. Comamala[1], L. Montoro[1], J.R. Gonzalez[1], P. Fernández-Yañez[2], O. Armas[2]

[1] Department of Mechanical Engineering and Industrial Construction
E.P.S., Universitat de Girona Campus de Montilivi – C/ Universitat de Girona, 4, 17003 Girona (Spain)

[2] Universidad de Castilla-La Macha. Escuela de Ingeniería Industrial y Aeroespacial de Toledo.
Av. Carlos III, s/n. 45071. Campus Fábrica de Armas, Toledo (Spain).

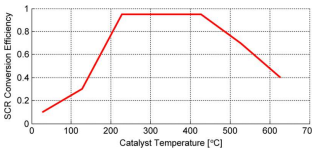
## Abstract

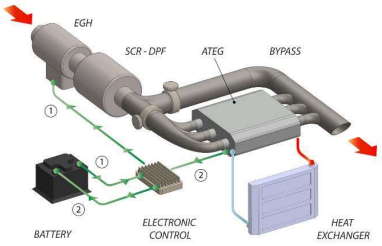
This study presents a new approach to minimize the amount of NOx emitted by diesel engines of Heavy-Duty Vehicles during low engine regimes and low gases temperature conditions. We propose the addition of an electric Exhaust Gas Heater (EGH) to make the SCR system inject the urea solution at low engine regimes. The second part of this study focuses on the viability to use an Automotive Thermoelectric Generator (ATEG) to generate the energy required by the EGH and thus avoiding the need to consume electrical energy from the vehicle's system. This EGH-ATEG system is designed to be energetically closed, so there is no extra consumption of fuel. Experimental results show that NOx emissions reduce up to 80% when an EGH is added to a standard diesel-powered Euro VI Heavy Duty truck configuration. Simulations show that an ATEG installed downstream of the aftertreatment system can produce the energy required by the EGH. This system can improve SCR efficiency up to 55% during low engine regimes.

## Introduction

SCR works as an advanced active emissions control that converts nitrogen oxides (NOx) into diatomic nitrogen (N2) and water (H2O) with the aid of a catalyst. A reducing agent, a solution of urea (32.5%) and distilled commonly known as AdBlue, is needed to achieve this conversion reaction. This urea solution is decomposed into water vapor and ammonia that is adsorbed on the catalyst substrate as it is injected before SCR. Finally, adsorbed ammonia reacts with NOx and is reduced into harmless water vapor and nitrogen.

Recent research has remarked that this process strongly depends on temperature. Ammonia process reaction generally starts from 180°C, reaching its maximum reaction rate around 350°C. When exhaust gas temperature is lower than 180°C, urea decomposition reaction can generate derivatives such as cyanuric acid, biuret, melamine, ammelide and ammeline as deposits on pipe wall, which are highly undesired. In order to avoid by-products, urea injection generally starts when exhaust gas temperature is higher than 180°C. Figure below (left) shows a static map of SCR efficiency. In order to achieve maximum de-Nox efficiency (around 0.95) the catalyst requires temperatures over 230°C.




## System proposed

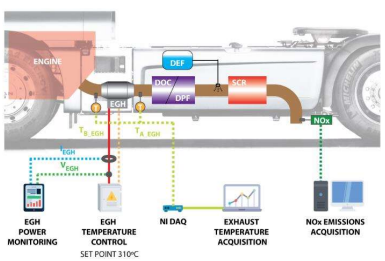
This system is designed to work in two different stages illustrated in the above figure (right).

Heating stage (1): this first step consists on rising the exhaust gas temperatures using the EGH. This device, an electrical resistance, consumes power from an dedicated electrical battery. The goal of this phase is to increase the exhaust gas temperature at SCR inlet. The beginning of this stage is when the engine starts as exhaust gases are on its lowest temperature level. The duration of this stage is determined by the target temperature (= 180ºC), being around 12 minutes at idling in this tested vehicle using its standard exhaust system. Reaching this target temperature (=180°C) is crucial because at this point urea solution is dosed into the system and its catalyst reaction is made properly, obtaining a faster and more efficient NOx reduction.

Recovery stage (2): this second step is related to ATEG conversion of thermal energy from exhaust gases into electricity. This electrical power is managed by the electronic control that stores it into the dedicated battery. This step starts when the engine is turned on and it can last up to 240 minutes (by assuming a maximum continuous driving time limited to 4 hours). The objective of this second phase is to maximize the amount of electrical energy stored for its later use by the EGH under low engine regime conditions.

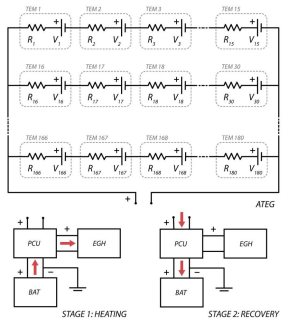
## Experimental setup

The system used consisted of an EGH located upstream of the standard aftertreatment system. The EGH is a Watlow ECOTEG unit with 12kW of power. This device contains an electric heating coil controlled by a temperature regulation system designed specifically for this application. The whole system was disposed as seen in the following figure.




## ATEG system

In order to validate the previous exposed idea, a simulation model of an ATEG is launched with relevant data gathered during the experimental test described in section 3. The idea is to explore the theoretical capabilities of commercial Thermoelectric Modules (TEM) disposed in a particular array that guarantees enough power to supply electrical energy to the EGH, see right figure. Focusing on this goal, a 1500 rpm regime is chosen as it contains the highest tested exhaust gas temperatures without surpassing the TEM maximum working temperature (230°C). ATEG benefits from these conditions to convert thermal energy into electricity for a future use in a low regime (for example 1000 rpm).




## Results

This section presents a comparative analysis of NOx emitted by a standard HDV, with and without the use of a 12kW EGH (see Table I). In all regimes, the target temperature of the EGH was set to 300ºC.

As it can be seen in Figure 4, at 1000 rpm, the NOx ppm values are the highest of the two regimes (Figures 5 and 6). NOx emissions, considering that EGH was disabled $NOx_{EGH_OFF}$ , achieved 578 ppm when the FTPP was at 60%. At the same conditions, NOx measured with the EGH enabled $NOx_{EGH_ON}$ was about 87 ppm. This was the maximum reduction achieved in all tests. In absolute numbers, it represented a NOx reduction of 508 ppm. In relative terms, however, the greatest reduction was achieved at 50% FTPP with 97.2% of ppm reduction.

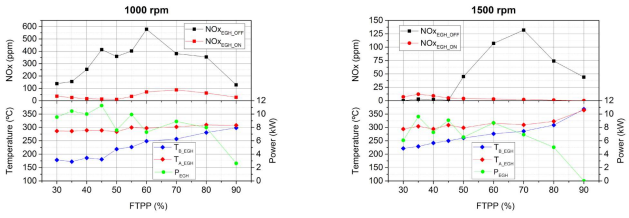
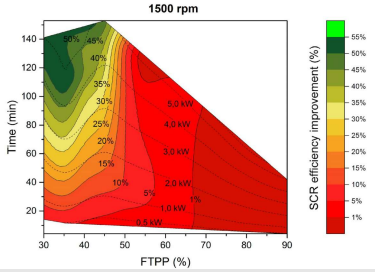



Figure 7 quantifies the SCR efficiency improvement of the proposed EGH+ATEG system respect to the standard aftertreatment system of the HDV tested, both cases compared at 1000 rpm regime. Y-axis (time values in minutes) represents the duration of the recovery stage performed by the ATEG at 1500 rpm regime. These results confirm that EGH is required in lower or medium FTPP values, where major improvements are achieved, especially at high power demand of EGH (4 kW - 5 kW).




## Conclusions

This study experimentally demonstrates that the use of an EGH can reduce the NOx emissions more than 80% in a Diesel-powered Euro VI Heavy Duty truck working at low engine regimes. The highest reductions were achieved at 1000 rpm and medium FTPP values. It also has been demonstrated that, at low engine regimes, EGH power higher than 5kW does not produce a significant impact on NOx reduction. A conventional catalytic device heated using an EGH of 5 kW could improve the SCR efficiency from 65% to 95%. Consequently, exhaust gas heaters are a potential solution to the high emitting low engine regimes issue.

The viability of energy supply during a cold start scenario (1000 rpm during 12 minutes) is positively demonstrated by time figures not exceeding of 155 minutes in the worst conditions (5 kW of EGH demand and generation at 45% FTPP). The EGH-ATEG allows the aftertreatment system to start dosing urea solution sooner. In consequence, the SCR efficiency is improved up to 55% using a proposed EGH of 5 kW, which is powered exclusively by an ATEG.

International Conference on Renewable Energies and Power Quality (ICREPQ'14)
Almeria (Spain), 28th to 30th July, 2021
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, No.19, September 2021