Experimental studies regarding the thermal operating regime for SCR catalysts of heavy-duty commercial vehicles

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Abstract. SCR, selective catalytic reduction, is the most efficient method for treating nitrogen oxides – one of the main pollutants of internal combustion engines. The SCR system involves the injection of a reductant (the solution AdBlue) in the exhaust gas flow, the reduction of the oxides being achieved in the catalyst's interior [1,4,6]. The operating limits of the SCR system are given by need to maintain the temperature conditions for the injected solution as well as the catalyst and its internal components (oxygen and temperature sensors, reductant injector) [2]. Overheating the AdBlue injectors may have a major influence for the operation of the SCR system, the deposits of the decomposed solution within the injectors leading to the system's out of use. Thus, maintaining an optimum thermal regime by cooling the AdBlue injectors becomes a required solution for a good functioning of the entire system. The paper presents experimental studies in relation to the thermal evolution of SCR catalysts on heavy-duty commercial vehicles in different turnover situations as well as an analysis of the measured values.

1. Introduction.

The heavy-duty commercial vehicles that fulfill the polluting norm Euro 6 use two combined methods for treating the evacuation gases; EGR for treating the nitrogen oxides and a complex system of catalysts which reduces the particles, carbon monoxide as well as nitrogen oxides, up to their entire neutralization. The two methods operate independently, EGR uses the evacuation gases that are partially collected and returned to the engine's admission gallery, while the catalysts system is set on the engine's evacuation path and treats those gases before they are sent out to the atmosphere [5,8,9].

The system for treating subsequent gases is made out of an assembly of catalysts: DOC, the oxidation catalyst that transforms CO in CO_2 respectively NO in NO_2; the particles filter that retains the particles from the evacuation gases; the SCR system that treats the emissions of NO_x, respectively the ammonia catalyst that prevents the evacuation of ammonia into the atmosphere [7,8,9].

The exhaust gas recirculation system, EGR, can be activated and becomes functional shortly after starting the engine, in comparison to the post-treating system that needs to reach a certain thermal regime to be activated. The starting temperature for the post-treating exhaust gas system is around 250^0C and the efficiency of the transformation processes within the catalysts improves with the increase of its internal temperature. There is also a superior limit for temperature, considered to be over 600^0C, a temperature at which the efficiency of the transformation in the catalysts is extremely diminished and the danger of the catalysts' deterioration becomes a real issue. Thus, we can actually talk about a working window of the catalysts between 250-450^0C, according to the materials used for their manufacturing, an interval that insures maximum efficiency and a safe exploitation of their components [3].

The proposed experimental studies have been focused of the determination of the thermal operating regime of the catalysts in different exploitation conditions for the commercial trucks. Also, the way in which the temperature within the SCR catalysts might influence the thermal regime of the reductant injectors has also been pursued. Thus, there is a link between the temperature within the SCR catalyst and the deposits of the decomposed reductant on its injector as well as on the catalyst's interior walls. The partial obstruction of the reductant injector's nozzle supplies the perfect conditions for creating these deposits, and not cleaning them leads to the total blocking of the injector and the put out of use of the subsequent gases treating system.

2. The experimental installation, the equipment used and the progress of the experiments:

The thermal experimental determinations have been achieved on Volvo trucks, model FH(4), manufactured in 2018, endowed with 13 liters engines (D13K of 500CP). The catalysts group DOC, DPF, SCR is compact, while three temperature sensors placed on the direction of the exhaust gases flow monitor the thermal operating regime of these catalysts. The placement of the temperature sensors is being done before the oxidation catalyst, thus having information on the entrance temperature into the catalysts group for the exhaust gases; between the oxidation catalyst and the particles filter for information regarding the temperature of gases before the particles filter; between the particles filter and the catalyst of selective catalytic reduction for measuring the exhaust gases temperature at the entrance into the SCR catalyst.

The monitorization and registration of the temperature values obtained by the three sensors have been achieved with the diagnosis computer Volvo TechTool by selecting the proper parameters, thus obtaining temperature values for each second of the engine's operation.

A mixed route – highway-national road – has been achieved in order to simulate a transport for general goods, 28 km, respectively a route on a temporary work side in order to simulate a construction transportation regime, 7.5km.

Figure 1. Montage temperature sensor

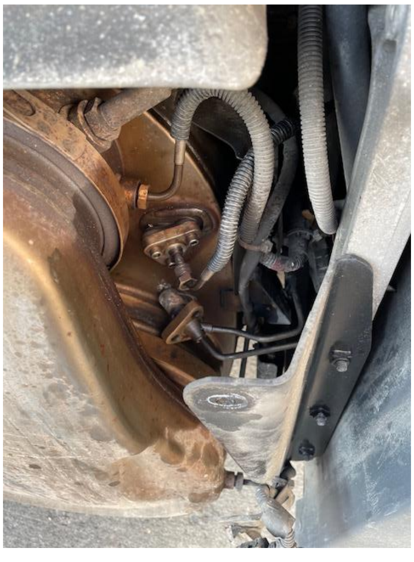

Figure 2. Montage assembly sensor on catalyst

The determinations for the temperature of the reductant injector have been achieved statically, by using a crafted montage and introducing a temperature sensor within the injector on the reductant's flow, as it can be noticed in figure 1. The information on the temperature within the injector have been measured with the diagnosis computer Volvo TechTool, by connecting the temperature sensor to the electric installation of the truck – figure 2, instead of the temperature sensor placed at the entrance into the catalysts group.

Heating up the catalysts for the static determinations has been achieved with the regenerating tests SCR, the maximum temperature within the catalyst being 400^0C, followed by a slow cooling at 550rot/min, down to a temperature of 160^0C in the catalyst.

3. The analysis and the interpretation of the results:

In order to determine the temperature values recorded by the three sensors placed into the catalysts assembly for post-treating exhaust gases system, there have been achieved road tests in conditions closed to the exploitation ones.

Thus, the road tests for the general merchandise running mode has been accomplished at an average load of 15t, and the route included a mixed plan, including plan road and significant gradients of slope or ramp (figure 3)

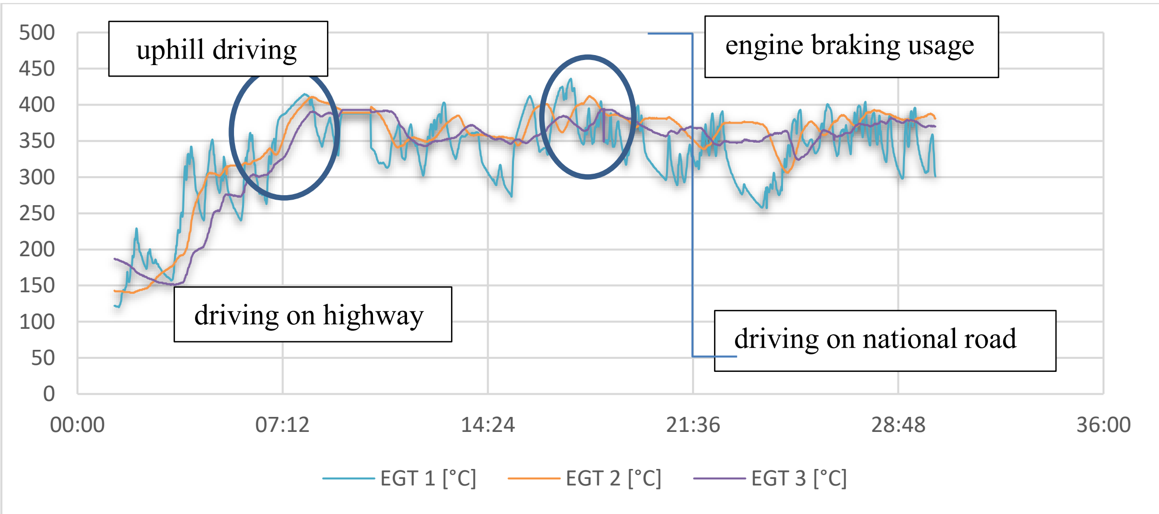

Figure 3. The registered temperatures for highway/national road

By analyzing the registered values for highway/national road, it can be noticed that there is a maintenance in temperature for the SCR catalyst between $350\text{-}380^0$C, with tops reaching 400^0C when the engine is maximum loaded; when uphill driving the ramp or using engine brake. It can also be noticed the fact that the temperature within the catalysts (EGT2, EGT3) changes less with respect to the temperature of the exhaust gases measured at the catalysts' entrance (EGT1). The phenomenon is due to the fact that temperature is being kept within the catalysts group well enough, the heat loss through the thermal transfer towards the catalysts' walls or the exhaust gases within them being relatively small. The catalysts efficacy is due to their working thermal regime, so that the higher the temperature within the catalysts is (up to a limit), the ore transformations happen within them.

The decrease in temperature within the SCR catalyst are given by the free rolling of the vehicle or going down small slopes without using engine brake.

Repeated speeding periods, typical for driving on national road, lead to an increase in temperature on the SCR catalyst, its working value being much higher compared to driving on a highway.

The measurements for the construction sector have included highway constructions with loads and unloads at certain points and a mixed route of national road, off road, suppling for highway construction (figure 4). Loading the vehicles has been done at an average of 23 t.

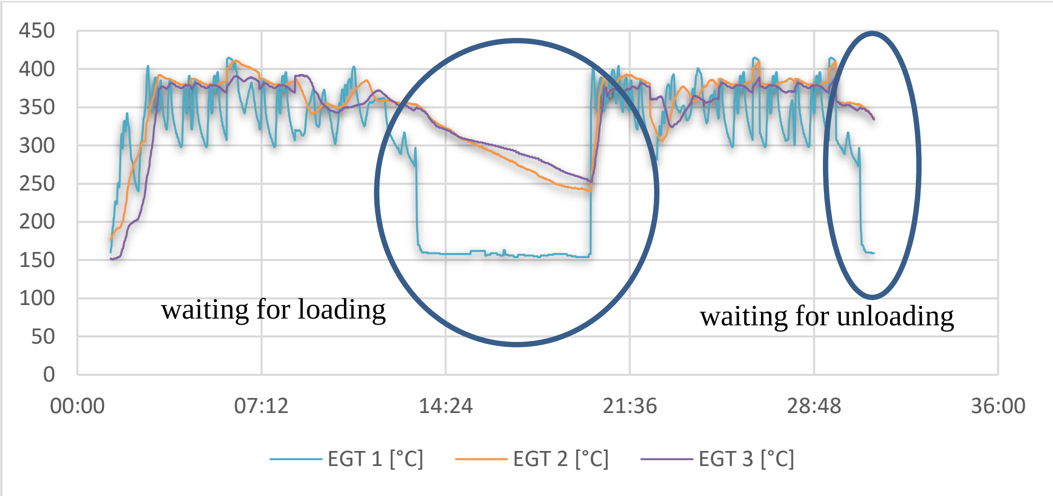

Figure 4. The registered temperatures for construction regime

The thermal operating regime for SCR catalysts for the construction segment is higher than driving on highway/national road, the average value being 370^{0}C. The major disadvantage is the jerky use of the vehicles, the alternation between driving and stops at the loading-unloading points having a major impact on the temperatures measured in the SCR catalysts.

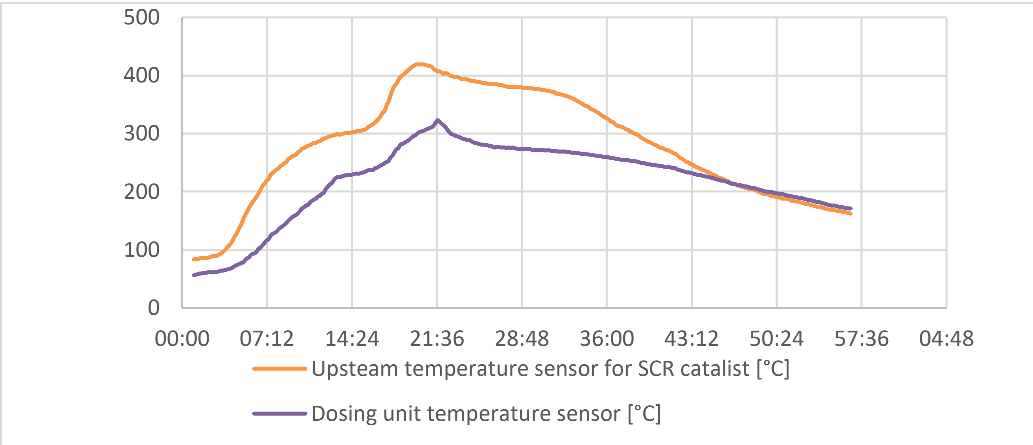

Figure 5. Static measurements of the temperature of the reductant injector

The measurements for the thermal regime of the reductant injector (figure 5) reveal a delay in its heating in comparison to the temperature of the SCR catalyst, a delay due to its placement outside the direction of the flow of the exhaust gases. It can be noticed a relatively constant difference, of about 80^{0}C, between the temperature of the SCR catalyst and the temperature of the injector during the heating phase, a difference that is being lost during the cooling phase. It can also be noticed that the temperature of the SCR catalyst decreases under the value that has been measured on the reductant injector at the end of the catalyst's cooling.

4. Conclusion regarding the achieved experimental studies:

Driving on highway or on national road offers a relatively constant plane for the temperature measured before the SCR catalyst, the average temperature being 375^{0}C. The top points correspond to driving on slopes and going down on ramps with using the engine brake when the temperatures of the SCR catalyst reach 400^{0}C.

The thermal stress on the reductant injector corresponds to the maximum temperature values registered in the SCR catalyst, the effect being more pronounced as the distance is higher.

There can also be issues of overheating the reductant injectors when there are stops in the vehicle's exploitation after an increased thermal exploitation of the SCR catalyst.

For the construction regime, an extreme variation of the thermal regime that has been measured in the SCR catalyst can be noticed. This variation is due mainly to the exploitation regime of the vehicles, thus longer the stop when loading/unloading are, higher is the possibility of creating decomposed reductant deposits around the injector. The situation can be worsened even more if the routes between the loading/unloading areas are short and the thermal regime in the SCR catalyst does not reach the required temperatures for the decontamination of the internal deposits.

Cooling the reductant injectors is extremely required for both regimes for commercial trucks, while active regeneration of the catalysts for driving in constructions needs to be done more often.

The protection of the reductant injector by placing it outside the exhaust gases flow, or by putting it into a thermal cover is a required condition in order to avoid the deposits on the reductant's nozzle.

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