Influence of exhaust gas temperature on treatment of harmful pollutants

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Abstract: This paper describes the influence of exhaust gas temperature on treatment of harmful pollutants on truck engine equipped with 2 generation SCR technology. First part devotes to the clarification of second generation of SCR technology. Advantages and disadvantages are mentioned. Subsequently the experiment in truck transport is mentioned. With usage of CAN-BUS data reading, specific parameters of the engine and exhaust gases were obtained during the duty cycle in truck transport. Dependencies between AdBlue injection and temperature of exhaust gases with taking account the engine load were observed. Text devotes to obtaining of the parameters and subsequent evaluation of results. Activation parameters of SCR technology were declared. The influence of engine load and exhaust gases temperature on quantity of AdBlue injection were confirmed.

Key-Words: - SCR, nitrogen oxides, exhaust gas temperature

Introduction

With an increase of emission limit standards after treatment systems of exhaust gases are evolving. For removal of the harmful pollutants from exhaust gases selective catalytic reduction was developed for about 24 years [1]. Problematic of fundamental problems and challenges of urea-SCR utilization in automobile industry was handled by many authors. Urea-SCR used as reducing agent is a well-established technique for $DeNO_x$ of stationary diesel engines [2]. It is presently considered as the most promising way to reduce NO_x emissions from trucks and tractors [3]. This solution brings advantages but also risks in form of secondary emission ammonia slip. This is a major problem when ammonia is used directly as a reducing agent [4].

With EURO 6 engines comes second generation of selective catalytic reduction. Main goals of this solution are efficiency boost in NOx reduction and fuel savings with high level of engine performance. With a usage of NOx sensors located in front of SCR catalyst and behind of it, ECU monitors NOx level during the harmful pollutants treatment. Main goal of SCR is to remove the harmful pollutants of the exhaust gases in the exhaust system. This gives maximum performance and optimum fuel economy of the engine with fulfilling of strict emission limits. Exhaust gases are treated with a fluid called AdBlue.

$$4\,NO + 4\,NH_3 + O_2 = 2\,N_2 + 6\,H_2O \quad (1)$$

$$NO + NO_2 + 2\,NH_3 = 2\,N_2 + 3\,H_2O \quad (2)$$

As they passed through exhaust system a catalytic converter converts the harmful nitrogen oxides into harmless nitrogen and water vapor. These changes are at molecular level. Firstly the maximum performance and torque are gained by optimized fuel injection and timing with minimize of fuel consumption. Subsequently harmful exhaust gases are treated by the injection of AdBlue into exhaust system. Nowadays SCR systems dynamically control the quantity of AdBlue by monitoring of the NOx level and temperature before and after the treatment. This leads to maximizing of the efficiency and minimizing of absolute use of AdBlue. SCR system consists from several parts. AdBlue tank is located beside the main fuel tank for convenient filling and insulation against cold weather. Supply module pumps the AdBlue up to the AdBlue injectors. Dosing module injects the AdBlue behind the DOC. Reduction of NOx is achieved by injecting AdBlue into the exhaust gas flow before SCR catalyst. Adblue is decomposed to ammonia and carbon dioxide due to heat of the exhaust gases. Formed ammonia and exhaust gas flows to SCR catalyst where ammonia reacts with NO and NO2 molecules converting the NOx molecules to harmless nitrogen and water vapor. Catalytic reduction of NO runs according to the equation 1 and reduction of NO_2 runs according to equation 2.

Temperature and NOx sensors at the end of the exhaust system monitors the exhaust gases after

passing through the catalyst to ensure that the AdBlue injection is optimized at all engine loads. SCR system is electronically controlled by ECU which regulates amount of injected AdBlue based on these parameters: engine RPM, actual torque, temperature of exhaust gases, amount of NOx and intake air humidity. Injection is realized after fulfilling these specific conditions: coolant temperature above 45°C, temperature of SCR catalyst over 180°C, 1000 engine revolutions and 20% of torque load of the engine. Without fulfilling of these parameters, AdBlue is not injected due to inability of initialization of chemical reaction. These variables are classified as activation parameters.

Following text is devoted to reading of CAN-BUS data and obtaining of specific parameters of engine like exhaust gases temperature, fuel consumption and torque load for observing of AdBlue injection timing. Main goal is to point out on influence of exhaust gas temperature on treatment of harmful pollutants directly connected with AdBlue injection.

Material and Methods

Structure of measurement chain

Measurement chain for monitoring of observed parameters was designed especially for the road test on highway. Portable computer with data acquisition card with OBD connector placed on board of IVECO truck was used. OBD connector was connected directly on SAE J1962 16 pin connector. For online reading from CAN-BUS specific code was programmed with a usage of LabView software. This approach brought the possibility to read the data from already fitted sensors on the engine. Data logging was realized during the whole transport duty cycle for variety of engine loads.

Transport duty cycle

The main testing subject was an IVECO STRALIS 420 EEV truck with second generation of SCR technology exhaust gas treatment system. Truck was equipped with engine with 313,2 kW nominal power and 1900 Nm torque at 1050÷1550 RPM. Engine was also fitted with a variable geometry turbocharger for heavy duty transport. Engine was warmed up to operating temperature. Mean value of atmospheric pressure was 98,6 kPa. Ambient air temperature was in range between -3 and 11 °C. Automatic transmission was activated during whole measurement. For proper engine workload specific track was scheduled. Transport duty cycle was realized on transport road between Vyškov and Prostějov. Total distance was 28 km consisting of city traffic in the first and the last part and speed way in the middle. During the duty cycle different engine loads were achieved. This had a direct influence on fuel consumption and exhaust gas temperature. Also AdBlue injection was influenced due to exhaust gas temperature fluctuation.

Results and Discussion

Exhaust gas temperature and engine load course

First part of results is devoted to monitoring of dependencies between basic parameters like engine load, exhaust gas temperature and fuel consumption. Individual engine states were selected from entire transport duty cycle.

Fig. 1 Engine load, EG temperature and fuel consumption in 800 – 880 time range.

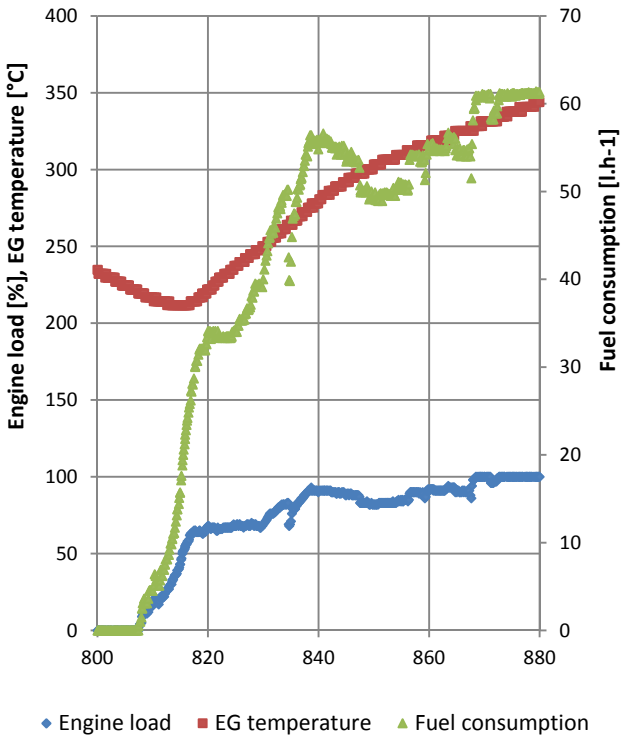
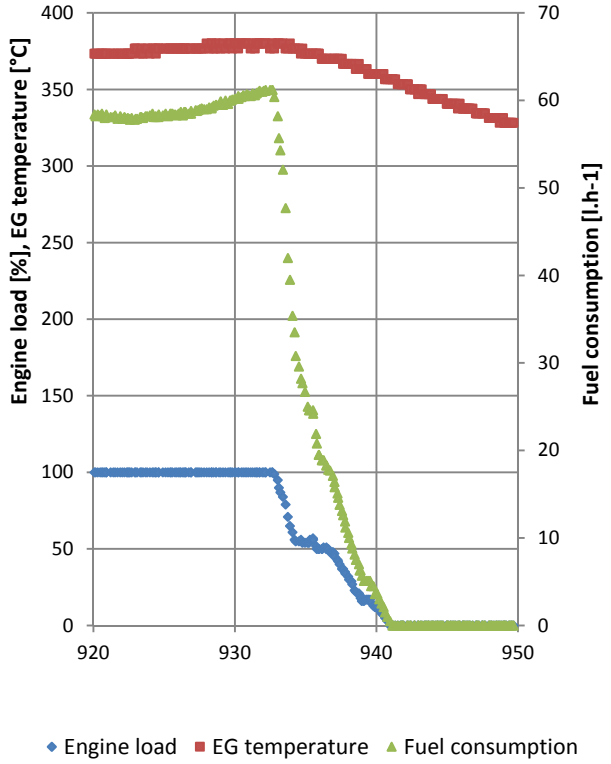


Figure 1 presents gradual increase in engine load up to 100%. This state represents hill climbing. As can be seen, increase of engine load goes hand in hand with increase of fuel consumption. These two states are interrelated with the temperature of exhaust gases. With more burned fuel, temperature of exhaust gases increase due to the combustion process. Another state describes deceleration process when engine load decrease. This brings the sharp drop in fuel consumption due to termination of fuel supply. Without fuel supply there is no combustion in the cylinder resulting in decrease of temperature of exhaust gases (see fig. 2).

Fig. 2 Engine load, EG temperature and fuel consumption in 920 –950 time range

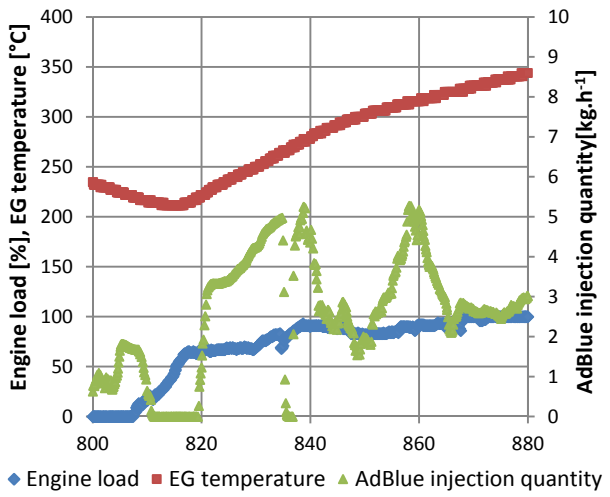


These two states represent behavior of engine basic parameters with regard to operating load caused by difficulty of the road, workload of the truck and weather conditions. Exhaust gas temperature has a major impact on AdBlue injection process. Also engine load plays a crucial role in treatment of harmful pollutants.

AdBlue injection process

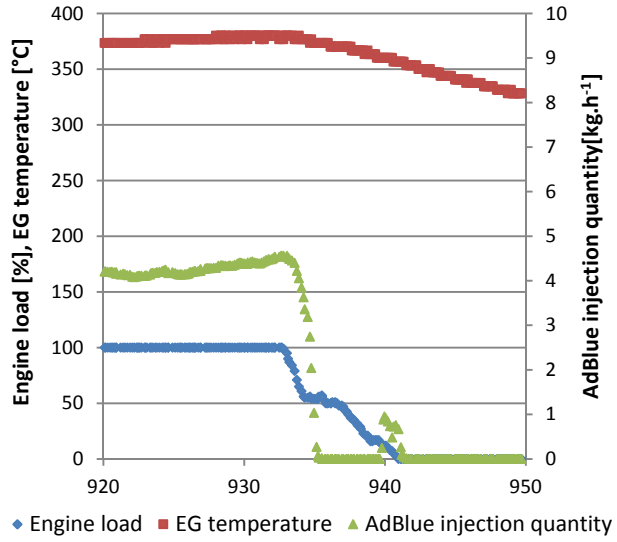
For a proper function of selective catalytic reduction, AdBlue injection process is very essential part. During the transport duty cycle different engine loads were achieved. Control unit of the SCR system evaluates input parameters required for proper function of NOx reduction. Figure 1 represents injection process of AdBlue during the engine load increment. As can be seen from figure 1 AdBlue liquid is not injected continuously. Reason is supply of SCR catalyst with ammonia and carbon dioxide. SCR catalyst stores specific amount of ammonia and chemical reaction needs time for NOx reduction. Ammonia level with exhaust gas flow through SCR catalyst decrease and additional dosage is required. Also excessive AdBlue injection leads to ammonia leakage directly into the atmosphere which causes undesirable and toxic pollution. At full and medium engine loads the most of NOx is formed.

Fig. 3 AdBlue injection process in 800 – 880 time range



During the deceleration, quantity of AdBlue injection is significantly restricted. This is caused by combustion process cessation due to fuel supply termination. During the stable and full engine load amount of AdBlue injection remains almost constant due to high exhaust gas flow through the SCR catalyst. These phenomena are presented on figure 4. The beginning of characteristics represents full engine load with high injection of AdBlue followed by eminent decrease of engine load accompanied by AdBlue injection shutdown.

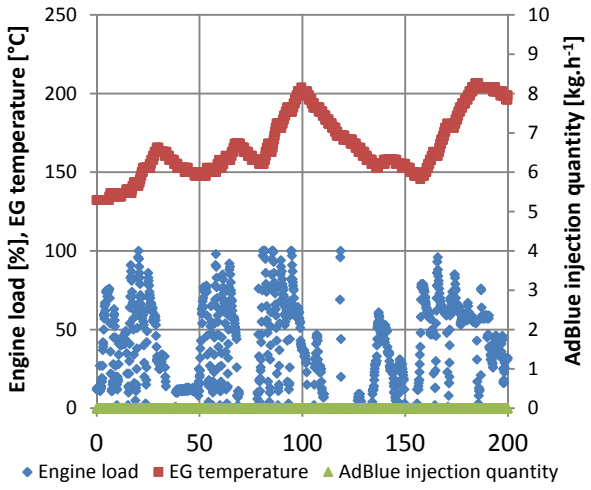
Fig. 4 AdBlue injection process in 920 – 950 time range



Demonstration of the importance of exhaust gas temperature is presented in figure 5. This diagram shows an injection process at the beginning of the measurement. Although all of the engine liquids achieved their operating temperature, due to variety in engine loads, temperature of exhaust gases

fluctuated between 130 – 205°C. This temperature is not in appropriate level for start of chemical reactions in SCR catalysts. If there would be an injection of AdBlue directly to the main flow of exhaust gases, decomposition of AdBlue to ammonia and carbon dioxide could not be realized. It would result in high content of urea in exhaust gases and subsequent environmental pollution.

Fig. 5 AdBlue injection process in 0 – 200 time range



Conclusion

Based on results with usage of the CAN-BUS as a source of data collection, temperature of exhaust gases is one of the major factors affecting the whole selective catalytic reduction process. Activation parameters must be fulfilled for a proper function of SCR technology. Temperature of exhaust gases inside of SCR catalyst must reach beyond 190°C with a torque load at least 20%. This research also confirms the basic dependencies between fuel consumption, engine load and temperature of exhaust gases.

The results also indicate that second generation of selective catalytic reduction taking account the NOx levels in front of and behind the SCR catalyst. This phenomenon was observed from achieved diagrams obtained from transport duty cycle.

During the truck engine deceleration quantity of AdBlue injection is significantly restricted due to lack of NOx levels contained in the exhaust gases. This is the moment when the output from NOx sensor informs the control unit. Subsequently the injection of AdBlue is suspended. Secondary emission of ammonia slip is taken account [4] due to NOx sensors located in front of and behind the SCR catalyst.

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EDIT: axis description was mismatched during copying of graph with fuel consumption. Units were not adjusted for AdBlue injection. Now are units of AdBlue shown correctly.