ANALYSIS OF PARTICULATE MATTER PRODUCTION DURING DPF SERVICE REGENERATION

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Abstract
The reduction of particulate matter (PM) production generated by diesel engines is important topic of nowadays. One of possible ways to reduce of PM is the usage of diesel particulate filters (DPF). The basic function of DPF is a collecting of PM inside the filter. That is why that the functional DPF must be regularly regenerated and there are several methods of regeneration processes. This article deals with analysis of PM production during the service regeneration process of DPF.
The vehicle Skoda Rapid with turbocharged diesel common-rail engine equipped by DPF was used for the experiment. The results show high PM production during the process of DPF regeneration. The production was approximately 1.5 times higher than production of diesel engine without DPF at the maximum engine load. The summary of total PM concentration during the regeneration is equal to production of diesel car without the DPF during 1-hour normal drive.

Key words: *DPF; common rail; particulate matter; TDI; OBD.*

INTRODUCTION

Private car use is one of the biggest polluters of modern cities. The main impurities include carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3) and particulate matter (PM) (*Hea J., 2017*). It is becoming increasingly topical issue particulate matter in recent years.
PM in pure form (elementary and organic carbon) are not dangerous but they create conditions suitable for dangerous pollutant. The mutagenicity and carcinogenicity of PM initially was attributed primarily to polycyclic aromatic hydrocarbons (PAH) (*Lewtas, 2007;Vojtíšek-Lom, 2015*). PM may affect reproduction, cardiovascular system or may be involved in cancer (*Lewtas, 2007*). The main impact on health has a PM size. Particles less than tens of nanometres can penetrate through cell membranes into the blood and have a wide and detrimental effect on human health. (*Künzli, 2000*).
Currently there are several ways to reduce the production of PM. One possible way is a higher rate of biofuels use which has a positive impact on PM production. This trend was confirmed in several experiments of biofuel use in agriculture tractor engines (*Jindra, 2016; Pexa, 2014*) as well as in passenger cars (*Mařík, 2014; Kotek, 2015*).
Diesel Particulate Filter (DPF) have been widely used to remove harmful PM. The basic function of DPF is a collecting of PM inside the filter. Therefore DPF must be regularly regenerated to remove accumulated particulates such as soot and organic materials. Regeneration is initiated either actively by additional fuel injection or passively during higher engine load generating high exhaust temperatures. That is why that the large quantities of PM are emitted during regeneration (*Khalek, 2011*;*Barone, 2010*). This article deals with analysis of PM production during the service regeneration process of DPF like a one of possible way for maintain DPF efficiency.

MATERIALS AND METHODS

The vehicle Skoda Rapid Spaceback 1.6 TDI with 4 cylinder turbocharged compression ignition (CI) engine with diesel particulate filter (DPF) was used in this experiment. Before experiment DPF contained 12 grams of soot. The older vehicle Skoda Roomster 1.4 TDI was used for comparison of PM production of car with and without DPF. Technical specifications of cars are summarized in Table 1.

Tab. 1 Technical information of tested cars

Vehicle	 Rapid 1.6 TDI Spaceback	 Roomster 1.4 TDI
COMBUSTION ENGINE		
Design	compression ignition, turbo charged	compression ignition, turbo charged
Fuel system	common rail	unit injector system
Number of cylinders and valves	4, in row, 16 valves	3 in row, 6 valves
Fuel	diesel	diesel
Volume of cylinders	1,598 ccm	1,422 ccm
Power	85 kW at 4,400 rpm	59 kW at 4,000 rpm
Torque	250 Nm at 1,500 rpm	195 Nm at 2,200 rpm
EU limit	EU6	EU4
Manufacture year	2016	2006
CAR BODY		
Service weight	1,260 kg	1,240 kg
Total weight	1,740 kg	1,755 kg
DRIVE PERFORMANCE		
Max. speed	190 $km \cdot h^{-1}$	165 $km \cdot h^{-1}$
Acceleration 0-100 $km \cdot h^{-1}$	10.3 s	14.7 s
Fuel consumption	5.0/3.4/4.1 ($liter \cdot 100\ km^{-1}$)	5.1/3.76/4.26 ($liter \cdot 100\ km^{-1}$)

The diagnostic system BOSCH KTS 520 was used for communication with engine control unit (ECU). This device is able to activate special service function which allows to do so-called service regeneration of DPF. This process is primary intended for diesel particle filter regeneration if the standard processes of regeneration (passive or active regimes of regeneration) not passed. This can happen typically at the very short trips in town traffic. If the content of soot in DPF exceeds 20 g it is necessary to make the service regeneration.
Classification of particulate matter was made with the TSI analyser model EEPS 3090 whose detailed specification is shown in Table 2. The analyser enables detection of particle size and also monitors their number. The obtained data is then presented as a size range of particles produced. The measured sample is taken from the exhaust, and then is diluted by the device. Within the experiments were evaluated only relative changes in the production of particulate matter in the diluted exhaust gas.

Tab. 2 Specification of PM analyser TSI EEPS 3090

Particle size range	5.6 – 560 nm
Particle size resolution	16 channels per decade (32 total)
Electrometer channels	20
Time resolution	10 size distribution per second
Sample flow	10 $l \cdot min^{-1}$
Dilution accessories	Rotation Disk thermodilution

Production of CO_2 was measured using emission analyser Atal-AT-505. The analyser uses nondispersive infrared (NDIR) method to detect CO, CO_2 and HC emissions and electrochemical cell for O_2 and NO_X emissions. The technical data of the analyser are summarized in Table 3.

Tab. 3 Specification of ATAL AT-505

Measured Values	Measurement Range	Resolution	Accuracy
CO	0 ... 10 % Vol.	0.001 % Vol.	0 … 0.67%: 0.02% absolute, 0.67% … 10%: 3% of measured value
CO_2	0 ... 16 % Vol.	0.01 % Vol.	0 … 10%: 0.3% absolute, 10 … 16%: 3% m.v.
HC	0 ... 20, 000 ppm	1 ppm	10 ppm or 5% m.v.
NO_X	0 ...5 000 ppm	1 ppm	0 … 1000 ppm: 25 ppm, 1000 … 4000 ppm: 4% m.v.
O_2	0 ... 22 % Vol.	0.1 % Vol.	0 … 3%: 0,1% 3 … 21%: 3%

RESULTS AND DISCUSSION

The result of instantaneous values of PM total concentration during DPF regeneration is shown in Fig.1. Before start of regeneration process it was necessary to engine warm up to operating temperature. The regeneration process started at raised idling speed when ECU based on the command from KTS device started the increase in exhaust gas temperature inside DPF from 160°C up to 650°C. The additional burning was followed by increase in CO_2 production. The regeneration process took about 20 minutes (1205 s). The volume of soot decreased from 12 to 0 gram which demonstrates good DPF condition (according to car mileage it is expectable result). As is shown in Fig. 2 regeneration process has been splitted into 3 phases. First phase lasted from 100 to 180 seconds and has been characterized by fast high increase in PM production with size about some tens nm. The second phase lasted from 180 to 950 seconds and has been characterized by gradual increase in PM production caused by gradual burning of collected particles with size up to hundreds nanometers. The last third phase lasted from 950 to 1200 seconds and has been characterized by gradual decrease in PM production. As is shown in Fig. 2 the PM size distribution has been concentrated in two size groups (middle and big particles). The similar PM production during DPF regeneration process confirms (*Quirosa, 2014*).

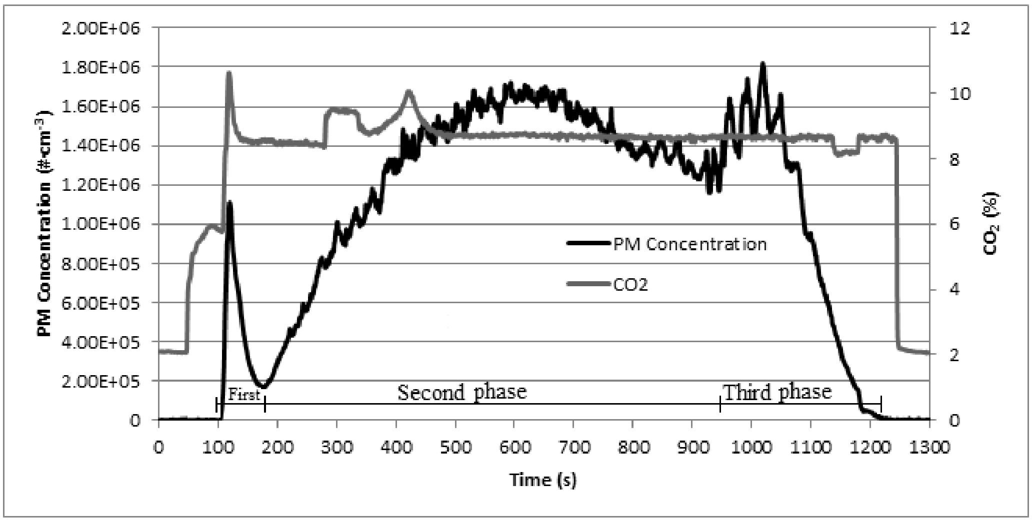

Fig. 1 PM and CO_2 production during service regeneration

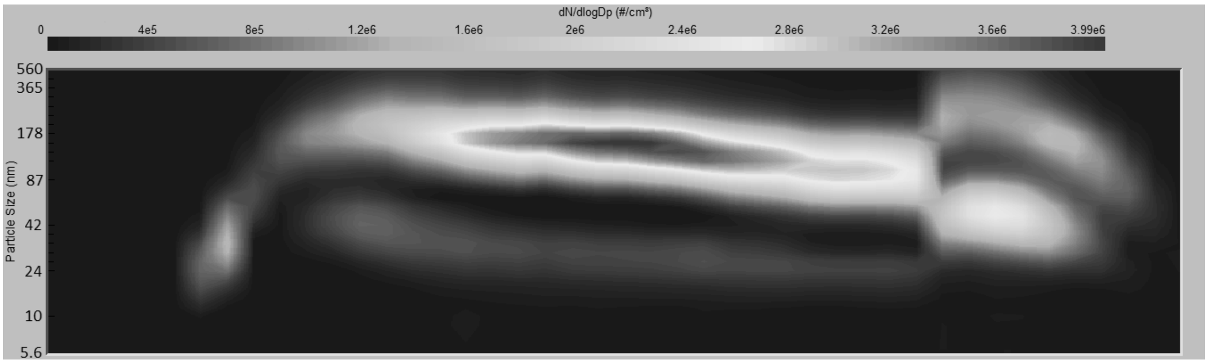

Fig. 2 Size distribution and the number of PM during regeneration

As is shown in Fig. 3, during the regeneration process were produced increased amounts of PM in compare of normal operating state of engine.

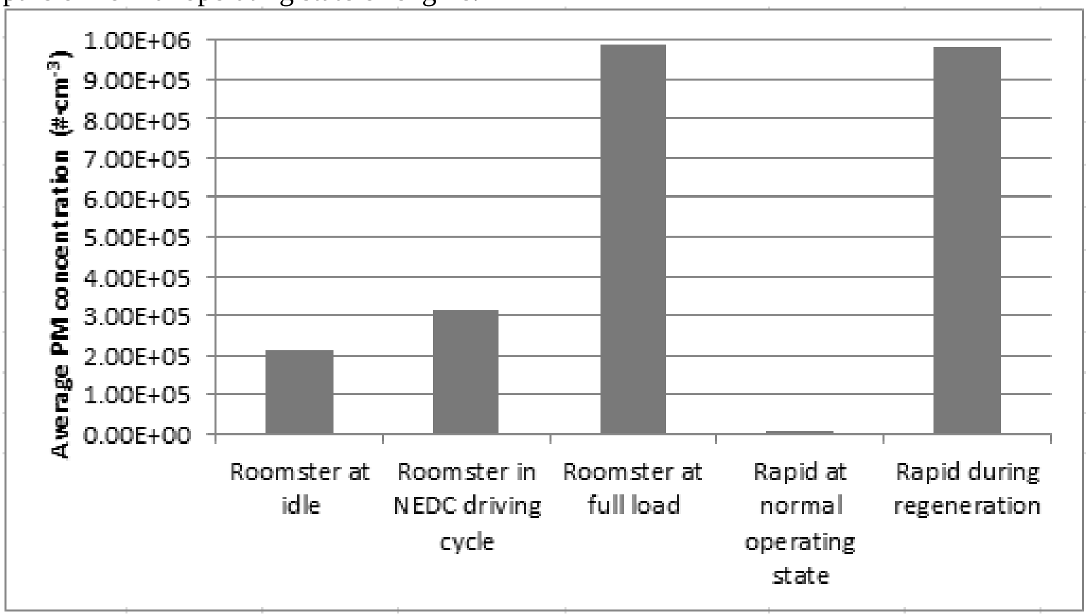

Fig. 3 Compare of average PM concentration of tested cars in various operating states

There is shown different PM production in depend on various operating states. PM production of Skoda Roomster was very dependent to engine operating state when already at idling speed produced substantially higher amount of PM and with increasing engine load the PM production grew. Skoda Rapid produced still very low PM amount independently to engine operating state while at active regeneration process of DPF was accompanied by increased PM production approximately equal to Roomster PM production at full load.

CONCLUSIONS

DPF is well known technology for PM reduction. The vehicles equipped by DPF produce provably minimally amount of PM compared to vehicles without DPF. Disadvantage of DPF is unfortunately necessary regeneration which is followed by big increase in PM production. This article showed immediate PM production during regeneration process which is almost equal to PM production of vehicle without DPF at full load. Although the temperature inside DPF is lower than inside combustion chamber the combustion conditions inside DPF are more stable and combustion process takes significantly longer time. Therefore use of DPF has very positive impact to the PM total concentration regardless to the immediate operation state of engine.

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