Scientific quarterly journal ISNN 1429-7264

Agricultural Engineering

2014: 3(151):49-56

Homepage: http://ir.ptir.org

DOI: http://dx.medra.org/10.14654/ir.2014.151.056

FACTORS THAT INFLUENCE SOLID PARTICLES EMISSION AND METHODS OF THEIR LIMITATION

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ARTICLE INFO

Article history:
Received: May 2014
Received in the revised form: September 2014
Accepted: September 2014

Keywords:
engine
fuel
DPF filter
NEDC test

ABSTRACT

Renewable energy constitutes an effective tool in the struggle with a danger of global climate warming. The next solution in this fight is development of the construction of combustion engines and exhaust gas purification systems such as new catalysts and particulate filters (DPF). The paper presents the author's own research results of the measurement of toxic components of exhaust gas emission, in particular (NOx and PM) in delivery trucks which meet the requirements of environmental protection Euro 4, which were propelled with diesel oil – petroleum – derived and with biofuel B10. The above vehicles were operated in a horticultural farm. Measurement of toxic components emission NOx and PM from the operated vehicles was carried out pursuant to the European standards i.e. the New European Driving Cycle with the use of a dynamometer Schenck 500G S60. The obtained results proved that the efficiency of the particulate filter and the operation of the catalytic converter for both types of fuels were comparable

Introduction

Significant changes of the structure of combustion engines of the automotive industry and agricultural sector within the last decade is an aspect which is related to natural environment protection. At the constant increase of the number of vehicles and farm tractors, the process of consequent and intelligent purification of exhaust gases seems to be indispensable. The EURO standards introduced by the European Union force taking up more and more radical steps in order to limit emission of toxic components of exhaust gases, in particular particulate matter (PM) by drive units equipped with the self-ignition engines.

Meeting the future requirements of EURO 6 (presented in table 1) will require the use of new technologies and modern solutions concerning construction of drive units, including advanced methods of controlling the combustion process and modern fuels and additional packets, which refine these products (Jakóbiec et al., 2008a; Jakóbiec et al., 2008b.) In case of engines of non-road vehicles, which include machines and farm tractors, diversification of operational conditions and limits of emission of toxic components of fumes determined with standards Stage IIIA and Stage IIIB is significant. Diversification of approval tests, during which measurements of emissivity of road vehicles are carried out. Emission standards for non-road vehicles refer to the regulations included in the Tier standards (EPA Non-road Regulation USA): 40 CFR 89; 40CFR1039; 40 CFR 1068) with the European references in the EU directive - EU-Nonroad Directive 97/68/EC (2004/26/EC). In case of farm tractors, measurements of emissivity are carried out in the determined steady state cycles (WOM) as ISO 8178, ECE R49, ESSC (European Steady State Cycle).

Table 1
Border values of emission of Euro standards for self-ignition engines

C	Date:	Test	CO ($g \cdot kWh^{-1}$)	HC ($g \cdot kWh^{-1}$)	NOx ($g \cdot kWh^{-1}$)	PM ($g \cdot kWh^{-1}$)	Exhaust smoke (m^{-1})	NH_3 ($mg \cdot kg^{-1}$)
Euro I	1992, <85 kW	ECE R-29	4.5	1.1	8.0	0.612		
	1992, >85 kW		4.5	1.1	8.0	0.36		
Euro II	1996.10	ESC & ELR	4.0	1.1	7.0	0.25		
	1998.10		4.0	1.1	7.0	0.15		
Euro III	1999.10, tylko EEV	ESC & ELR	1.5	0.25	2.0	0.02	0.15	
	2000.10		2.1	0.66	5.0	0.10 0.13*	0.8	
Euro IV 0.02	2005.10		1.5	0.46	3.5	0.02	0.5	
Euro V	2008.10		1.5	0.46	2.0	0.02	0.5	
Euro VI	2013.01		1.5	0.13	0.5	0.01		10

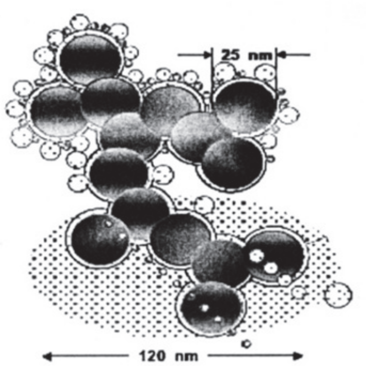
*For engines of swirl volume per a cylinder below 0.75 dm^3 and rated speed exceeding 3000 m^{-1}

Source: Stanik and Jakóbiec, 2012

Mechanism of formation of particulate matter emission

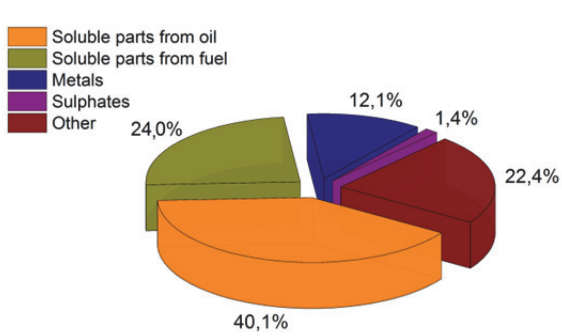
Particulate matter means products coming out of the exhaust system of the engine (self-ignition) of liquid or solid state which include particular number of carbon particles, sulphur and nitrogen, metals and heavy hydrocarbons. A typical form of the particulate matter was presented in figure 1, whereas a percentage participation of various components which form particles and their agglomerates are presented in figure 2.

The increased participation of light fractions in the diesel oil influences the decrease of its viscosity, affecting thus the improvement of the combustion process effectiveness. Presence of fractions with a high temperature of boiling (value of temperature of de-distillation of 90 and 95% fuel and temperature at the end of distillation) causes the increase in the emission of particulate matter and increase in the exhaust smoke, but does not decrease the content of nitric oxide.



Source: Jakóbiec, 2012

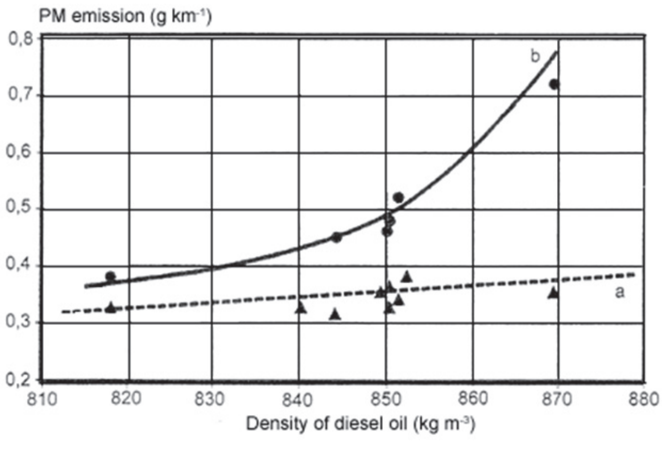
Figure 1. Typical particulate matter of PM emission



Source: Jakóbiec, 2012

Figure 2. Percentage share of various components of particulate matter emission (PM)

Presence of the heavy fractions also indirectly influences emission, because carbon deposit is more easily formed on sprayers' ends and the combustion chamber. The carbon deposit changes the course of the combustion process leading to deterioration of its effectiveness, increase of the emission of the non-combusted hydrocarbons, carbon monoxides and the particulate matter. Density of diesel oil plays a significant role in shaping the emission of the particulate matter (fig. 3).



Source: Jakóbiec, 2012

Figure 3. Relation of emission of particulate matter to density of diesel oil - a self-ignition engine direct injection charged with cooled air

It should be emphasised that emission of particulate matter is related to the combustion of hydrocarbon fuels and FAME biofuels in varied conditions determined with the injection process and phases of fuel combustion. Intense works tend in the direction of knowing the mechanism of formation of the particulate matter emission and their limitation. Motor oil, in particular a type of the base (physical and chemical properties) and the use of performance chemicals play a significant role in the process of formation and composition of the PM. Moreover, conditions of the engine operation play a significant role, where at low rotational speed and low load, non-combusted engine oil constitutes high percentage participation in the composition of the formed PM (Dowling, 1992). It is related to a low temperature of combustion of the load in the engine chamber, which influences incomplete combustion of oil which gets there. With the increase of the engine load, and thus the increase of the temperature in the combustion chamber of the engine, combustion of oil takes place in a more complete manner and participation of oil in the composition of the formed PM decreases (Stępień and Oleksiak, 1992). The increase of the rotational speed shortens the time of oil formation in the combustion zone of the engine, which caused incomplete combustion of oil and increase of the participation in the composition of the formed particulate matter (PM).

Methods of reduction of the particulate matter (PM) emission

Reduction of the particulate matter emission from self-ignition engines is one of the most difficult problems which lead to development of the particulate matter filter (DPF) (Mayer, 2001; Blanchard et al., 2002). Considerable progress has been made concerning improvement of the construction solutions on various planes of the DPF regeneration processes due to the advanced systems of Common rail fuel injection and also through development and spreading of new materials for filtration monoliths such as silicon carbide, ceramic metals (including aluminium - titanic filters) along with development of additives for FBC fuels (Stępień and Oleksiak, 2009).

The most popular solution of passive regeneration of the DPF filter is electronic control of fuel injection at the use of the Common Rail system (Rokosch, 2007). The concept of natural regeneration (without catalytic support) of the particulate matter filter (DPF) may be carried out within temperatures ranging from 600 to 700ºC of initiation of the carbon black oxidization process. Support of regeneration with the use of covering walls of the filtration monolith with the layer of catalyst - usually a platinum one, decreases temperature of carbon black oxidization to approx. 400ºC, whereas by the use of the additives FBC (Fuel Born Catalyst) type, the temperature may be reduced to approx. 300-500ºC. Catalytic impact of ash additives (organic in particular) on oxidization (afterburning of particulate matter) PM is very well documented in the literature (Eastwood, 2000; Novel-Cattin, 2000).

The basic assumption of passive regeneration of the DPF filters is lowering the temperature of carbon black oxidization to the level, which is obtained by exhaust gases in conditions of operation. Additives for fuels, which contain metals, constitute catalytic structure for carbon black oxidization (Bllom et al., 1997; Daly et al., 1993). Presently, the most popular additives for fuels which are used for support of the regeneration process DPF are: Fe, Ce, Mn, Zn, Pt and Cu. To sum up the issue of the FBC additives with catalytic activity, the basic requirements, which have to be met, should be emphasised:

– initiation of the DPF regeneration must include the temperature of exhaust fumes in the exhaust system of an engine which results from the engine structure as well as from the manner of its operation;
– regeneration of the filter must take place completely and evenly in its full volume - too high local increase of the temperature will cause defects of materials, of which the filter is made;
– ashes from burning of the additive should not chemically damage the material, of which DPF monolyth is constructed i.e. ceramic body and its metal casing;
– products of the combustion process of the FBC additives and ashes accumulated in the DPF filters should not generate secondary emission of exhaust fumes components i.e. NO_2, furans, dioxines, PAH (polycyclic aromatic hydrocarbons) and other gas components.

Evaluation of the process of passive regeneration of the DPF filter of a delivery vehicle

Research included measurement of the particulate matter emission and concentration of nitric oxides (NOx) in delivery trucks used in the horticultural farm. The vehicles had the same type of an engine of 2.0 dm^3 displacement equipped with the Common Rail injection system and the particulate matter filter (DPF) of the exhaust gases purification system which meets the requirements of Euro 4. Three vehicles were used in the research including one which was propelled by diesel oil and the remaining two with B10 biofuel. Measurements were carried out after the following mileage: 10,40, 80 thousand km with the use of a dynamometer SCHENCK 500g s60 according to the European NEDC (UDC+EUDC) presented in figure 4.

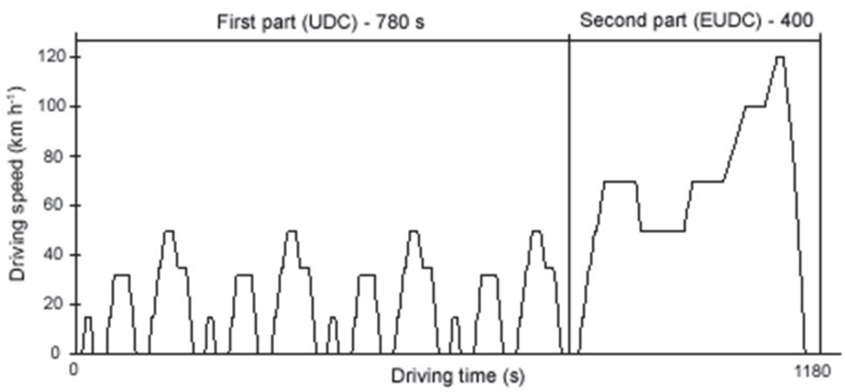


Figure 4. European driving cycle NEDC (UDC + EUDC)

During the research each time the analysis of the operational parameters of the engine with a diagnostic device was carried out, mainly in order to check a degree of regeneration of the particulate matter filter (DPF) and changes of of correction of fuel doses in the CR system for the needs of determination of the technical condition features change of particular engine cylinders and technical condition of the electromechanical injectors of the 2nd generation. An exemplary list of the selected working parameters (table 2) for the correct scope of the Smooth Running Control - SRC along with the record of the regeneration condition DPF can be read out with the use of the external diagnostic testing device. Modern filters of the particulate matter which use ceramic filtration monoliths of Cordieryt type, SiC or Sintermetal characterize with efficiency reaching 95-99% in the scope of total mass of stopped PM, including 95-99.9% concerning stopping particles of elementary carbon (carbon black) and 60-90% concerning decrease of SOF emission (Soluble Organic Fraction) and 50-70% of limitation of the WWA amount (Automotive Division, 1999).

Table 2
Exemplary list of the selected working parameters of the engine during the diagnostic process OBD II

Control parameter	Measured value	Nominal value
Rotational speed	830 rot·min^{-1}	The scope of rotations: up to 1,500 rot·min^{-1}
Correction of a dose	96% 104% 109% 92%	Admissible deviation 20%
Cylinders injectors 1, 2, 3, 4		
Difference of pressures for DPF	34 hPa	230 hPa
Atmospheric pressure	980 hPa	600-1080 hPa
Mass intensification of air flow	280 mg·cycle^{-1}	300 mg·cycle^{-1}
Charging pressure	106 kPa	Value of reference 100 kPa
Dose of injection	7.2 mg·cycle^{-1}	6.8 mg·cycle^{-1}

Research results acc. to the European test NEDC (UDC + EUDC) was presented in figure 5 and 6.

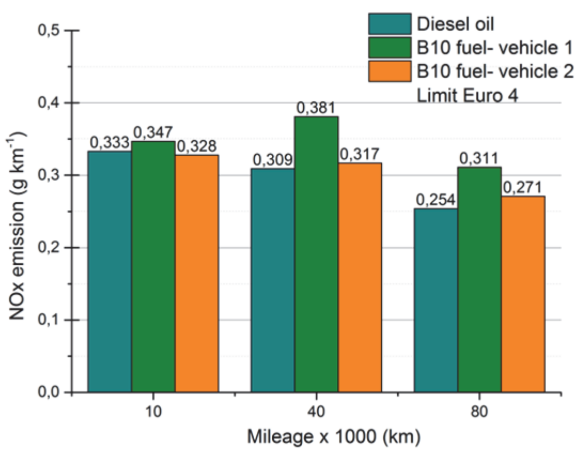


Figure 5. Average concentration of nitric oxide (NOx) in the European test NEDC (UDC + EUDC) for the researched delivery trucks propelled with diesel oil and biofuel B10 during operation

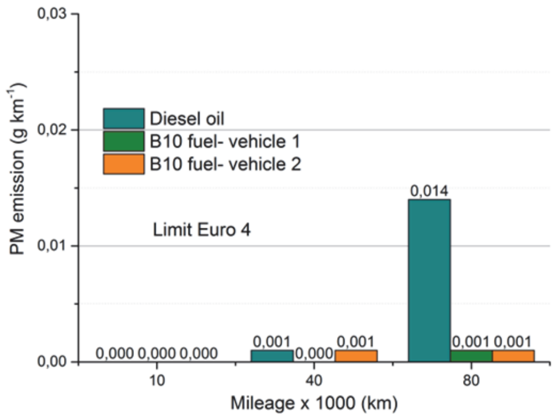


Figure 6. Average concentration of particulate matter emission in the European test NEDC (UDC+EUDC) for the researched delivery trucks propelled with diesel oil and biofuel B10

Conclusions

The obtained results allow formulation of the following conclusions:

1. Deterioration of catalytic converter operation efficiency with regard to the concentration of nitric oxide (NOx) for both fuels was reported, where in case an engine was propelled with diesel oil it was approx. 19.5%, whereas for B10 biofuel it was respectively approx. 38.5% and 22.1%.
2. Results obtained in vehicles propelled with biofuel B10 were comparable and slight difference may be assigned to slightly different conditions of operation.
3. Efficiency of the particulate matter filter for both fuels was comparable and was on a high level above 95%.
4. In the vehicle propelled with diesel oil after mileage of 80 thousand km, blockage of particulate matter filter caused by human factor (exceeding the conditions of vehicle operation) was reported.

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CZYNNIKI WPŁYWAJĄCE NA EMISJĘ CZĄSTEK STAŁYCH ORAZ METODY ICH OGRANICZENIA

Streszczenie. Energia odnawialna stanowi skuteczne narzędzie w walce z niebezpieczeństwem globalnego ocieplania klimatu. Kolejnym rozwiązaniem w tej walce to rozwój konstrukcji silników spalinowych i układów oczyszczania spalin jak nowe katalizatory i filtry cząstek stałych (DPF). W pracy zamieszczono własne wyniki badań pomiaru emisji toksycznych składników spalin zwłaszcza (NOx i PM) w samochodach dostawczych spełniających wymagania ochrony środowiska Euro 4, które były napędzane olejem napędowym (ON)- paliwo ropopochodne i biopaliwem B10. Powyższe pojazdy eksploatowano w gospodarstwie sadowniczym. Pomiar emisji toksycznych składników NOx i PM z eksploatowanych pojazdów przeprowadzono według standardów europejskich tj. europejskiego cyklu jezdnego NEDC z wykorzystaniem hamowni podwoziowej typu Schenck 500G S60. Uzyskane wyniki wykazały, że sprawność filtra cząstek stałych oraz pracy reaktora katalitycznego dla obu rodzajów paliw były porównywalne.

Słowa kluczowe: silnik, paliwo, filtr DPF, test NEDC