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Effect of different biofuels to particulate matters production

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Abstract. In recent years the European Union has exhibited a significant interest in the reduction of crude oil usage. Biofuels can be used in conventional engines but the biofuels should reduce the emissions produced by internal combustion engines. This article deals with analysis of particulate matters (PM) production in chosen biofuels burned in internal combustion engine Zetor 1505. The conventional emission analysers are capable to detect gaseous emission components but they are not able to classify PM. Analysis of PM was performed with a TSI Engine Exhaust Particle Sizer 3090 which is able to classify particles from 5.6 nm to 560 nm. The device analysed different blends of alcohol–based biofuels tested under NRSC cycle conditions. The given size of PM can be taken as an impact on human organism's cells consequently human health. PM create an ideal medium for polyaromatic hydrocarbons (PAH), their composition and structure. Analysis of PM should become a standard component of every emission parameter assessment.

Keywords: biofuels, particulate matters, emissions.

INTRODUCTION

The fast growth of the world population and industrial development is linked with an increasing consumption of fossil fuels. Fossil fuels, besides their benefits in terms of tradition and mastered processing technology, have many disadvantages as well. Among the major drawbacks include depletion and unstable price (Gumus et al., 2012). That is why all over the world are developing a new alternative fuels, with special emphasis on the renewable resources (Tashtoush et al., 2007). Diesel engines can possibly use various biofuels based on vegetable oils, fats and fatty acid esters etc. Many researches confirm the positive impact of biofuel production on harmful exhaust emission production (Altun et al., 2008; Pexa & Mařík, 2014; Obed et al., 2016). Another potential of biofuels application in diesel engines can be seen in the use of blended biofuels. In this case it brings more possibility used fuels on alcohol basis (methanol, ethanol, butanol, etc.). Many publications are showing a reduction of emissions and particulate matters (Hansen et al., 2005; Chotwichien et al., 2009). Especially in agriculture can expect significant use of biofuels through efficient access to the basic materials used for their production.

Diesel engines have dominant position in the agricultural utilisation. This is primarily due to their more advantages operating characteristics in the form of higher energy efficiency and lower production of emissions of CO, CO_2 and HC than gasoline engines. On the other hand, the operation of diesel engines is accompanied by an increased production of nitrogen oxides and particulate matters. (Ozsezen et al., 2008; Karavalakis et al., 2009). Exhaust emission from diesel engines has been associated with higher risks of asthma and other pulmonary diseases, heart attack and other chronic health problems (Lewtas, 2007; McEntee & Ogneva–Himmelberger, 2008; Balmes et al., 2009).

As particulate matter (or solid particle) according to the laws of the USA is referred to any substance which is normally contained in the exhaust gas as solid particle (ash, soot) or as a liquid. They consist of elemental carbon forming particles and organic compounds (condensed water, sulphur compounds and nitrogen compounds). Solid particle itself is not toxic, but on the solid particles are adsorbed substances with high health hazards. Lwebuga–Mukasa et al. (2004) found correlation between asthma and truck traffic volumes. Most of the emitted particles have a size from one to hundreds of nanometers (nano–particles). (Chien et al., 2009; Vojtisek–Lom et al., 2015)

This article deals with the issue of blended biofuels in terms of particulate matters production depending on the type of added biofuel. The measurement was aimed not only on the total production of solid particles but on their size distribution also.

MATERIALS AND METHODS

The tractor engine Zetor 1505 was used for measurement. This engine is a turbocharged four–cylinder engine with a volume of 4.156 dm^3. Detailed specifications are contained in Table 1. Engine on test bed is shown on Fig. 1. The engine falls under the classification of emission standard Tier III.

Table 1. Engine technical specification

Engine Z 1505	
Maximum power	90 kW
Maximum torque	525 Nm
Number of cylinders	4
Engine volume	4,156 cm^3
Bore	105 mm
Stroke	120 mm
Compression ratio	17
Rated speed	2,200 rpm
Fuel pre–injection	9° before TDC
	1 – 3 – 4 – 2
Specific fuel consumption	255 g kWh^{-1}

Classification of particulate matters 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 in the production of solid particles in the diluted exhaust gas were compared only relatively with the reference fuel.

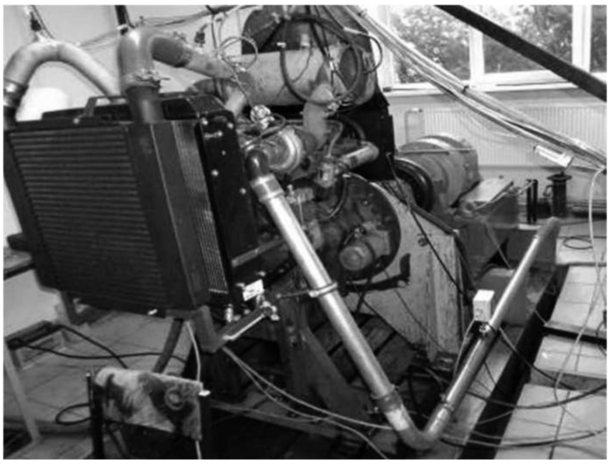

Figure 1. Engine on test–bed.

Table 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 min^{-1}
Dilution accessories	Rotation Disk thermodilution

Production of particulate matters was measured according to 8 – point test ISO 8178 C1 that is known as Non–road Steady Cycle (NRSC). Tractor engine methodology prescribes testing at 8 steady states of speed and load. The experiment was performed in all 11 measuring points with the addition of the 12th point in the form of higher idle. Stabilization of the engine for each point of measurement was carried out for 8 minutes. The measurement then lasted 6 minutes.

The aim of experiment was to test several blended fuels containing diesel fuel and additives (in the alcohol biofuel form). Ingredients of tested fuel blends are summarized in Table 3. The reference fuel was pure diesel without biofuels which conforms to EN 590.

Table 3. Used fuels

Fuel	Diesel ratio (weight, %)	Ratio of alcohol (weight, %)
Diesel – reference	100	0
Et10	90	10 ethanol
nBut16	84	16 n–butanol
iBut16	84	16 iso–butanol

The share of individual bio–components of the reference fuel was chosen on the basis of the common shares of bio–components (in this case, bio–diesel) in commonly used fuels in the EU.

RESULTS AND DISCUSSION

The production of PM in different size spectra for all researched fuels is shown in following figures. Operating modes of the engine were selected to see the differences in the production of particles between the individual fuels.

Fig. 2 presents the production of solid particles for full load at rated speed. Fig. 2 shows that the maximal production was achieved on diesel, the lowest production was achieved on an admixture of iso–butanol. In the case of n–butanol there is a shift of the spectrum producing particles to smaller size.

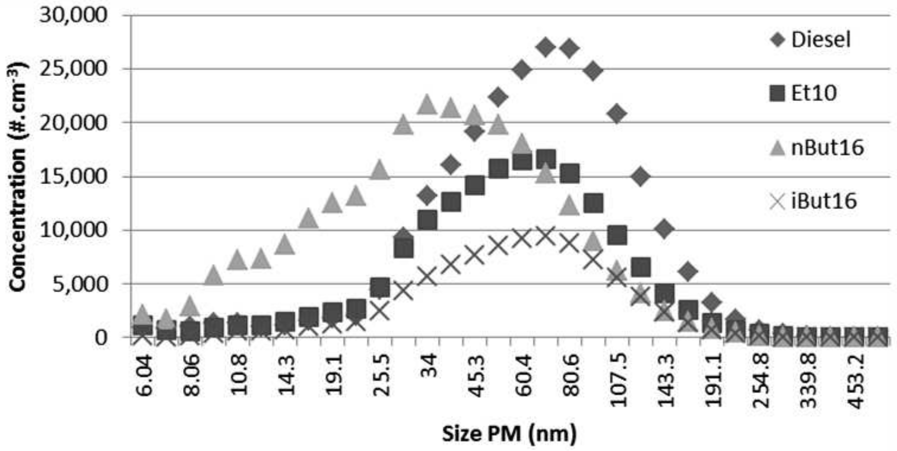

Figure 2. Particle concentration for point 1–100% torque, rated speed.

At 50% engine load at rated speed (see Fig. 3), it is again evident that the highest particle production was achieved when diesel fuel was used. The production of particulate matters from all monitored biofuels reached lower values than the reference fuel. The peak of all fuels has approximately the same size spectrum.

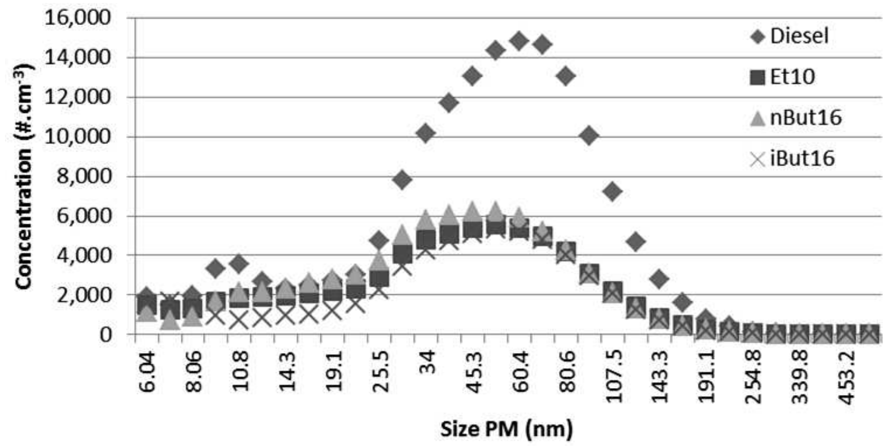

Figure 3. Particle concentration for point 3–50% torque, rated speed.

Fig. 4 shows the production of PM at 50% load and intermediate speed. It is evident that in most parts of the spectrum are all fuels balanced maximal particle production is shifted towards lower size spectra. The highest particle production reaches again the reference fuel.

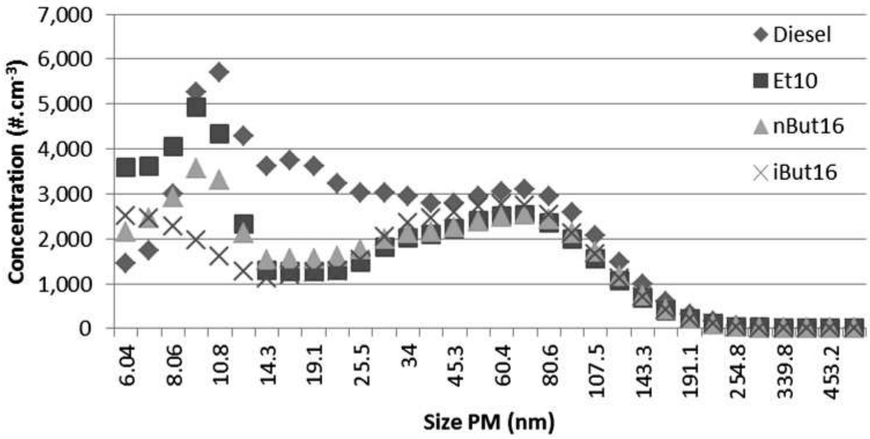

Figure 4. Particle concentration for point 8–50% torque, intermediate speed.

Fig. 5 shows particle production at 10% load and intermediate speed. At low loads, it is evident that the added biofuels causing increase in particle production. The highest production was achieved in the low size spectrum. The lowest total production reached the reference fuel.

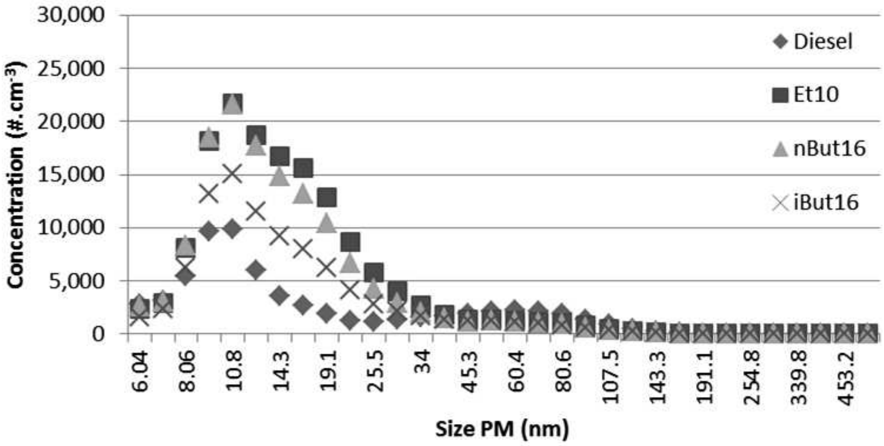

Figure 5. Particle concentration for point 10–10% torque, intermediate speed.

The following Fig. 6 shows the total quantity of particles produced for the entire duration of the measurement. The positive impact of added biofuels on the total production of particles is obvious.

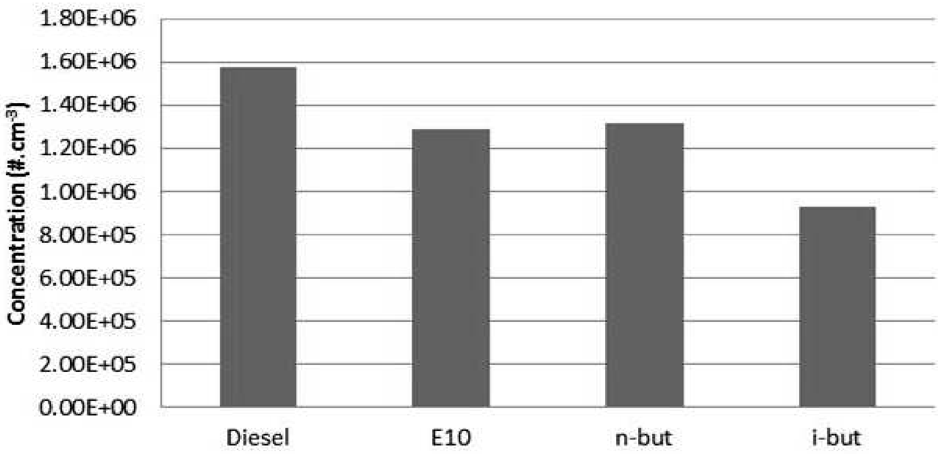

Figure 6. Total particle concentration for all tested fuels.

The achieved results correspond with the findings of other authors. Zhang & Balasubramanian (2014) tested several mixed fuels of similar composition and his findings confirm the positive effect of added butanol in the high engine load. Cheng et al. (2016) demonstrated the positive effect of adding butanol on engine smoke (smoke emission). Choi & Jiang (2015) highlights the positive impact of butanol in the area of higher magnitude spectra, while in the lower spectra was achieved better results to pure diesel.

CONCLUSIONS

Although only the production of solid particles was evaluated, the experiment's results demonstrate internal combustion engines' operability to use mixture of diesel and alcohol fuels. The engine used for tests was not additional modification specifically designed to operate with biofuels. The aim of experiment was to clearly demonstrate a different dependence of PM spectral distribution of each fuel. It can say that biofuels have a positive impact on the production of PM in the areas of higher loads and high engine speeds. Conversely, in low modes of load and speed was PM production higher than the reference fuel.

Pure alcohol biofuels using are not suitable for CI engines from their properties, because they have no optimal cetane number. The experiment results prove possibilities of appropriate use of alcohol fuels such as low blends in diesel. This can be seen a way for future in achievement to reduce a dependency on fossil fuels.

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