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EXHAUST GASES EMISSION TESTS OF TRACTOR ENGINE FUELED BY DIESEL AND BIOFUELS

Summary

This paper presents the methodology and results of comparative tests of tractor engine emission powered by diesel and two types of biofuels: rapeseed oil methyl esters and camelina oil methyl esters. Measurements of the CO_2 emissions, toxic exhaust gas components (CO, HC, NO_x) and mass, quantity, size of particulate matter (PM) are also included.
***Key words**: tractors, engines, biofuels, emissions, methods, comparative research*

BADANIA EMISJI SPALIN SILNIKA CIĄGNIKA ZASILANEGO OLEJEM NAPĘDOWYM I BIOPALIWAMI

Streszczenie

W artykule przedstawiono metodykę i wyniki porównawczych badań emisji spalin silnika ciągnika rolniczego zasilanego olejem napędowym i dwoma rodzajami biopaliw: estrami metylowymi oleju rzepakowego i estrami metylowymi oleju lniankowego. Przeprowadzono pomiar emisji CO_2 i toksycznych gazowych składników spalin (CO, HC, NO_x) oraz masy, liczby i wielkości cząstek stałych (PM).
***Słowa kluczowe**: ciągniki, silniki, biopaliwa, emisja spalin, metodyka, badania porównawcze*

1. Introduction

Exhaust gases emitted by internal-combustion engines cause a degradation of natural environment and also threaten human health. To prevent such disadvantageous effects, more and more restrictive standards of purity of gases [2] are implemented.

According to the U.S. Environmental Protection Agency, off-road vehicles are one of the main emission sources of OM and NO_x in U.S. Also in 27 countries of UE the emission of NO_x and PM_{10} from tractors and agricultural machines has significant participation in off-road vehicles group. According to the data [3] in 2005 and 2010 the NO_x emission from tractors and agricultural machines was about 40% of total emission from off-road vehicles and according to the prediction this level will be stable until 2020. In case of PM_{10} emission, in 2005 and 2010 this share was a little bit above the 50%, however it is anticipated that in 2020 this share will be reduced to about 45%.

In one of recent report [1, 4] International Agency for Research on Cancer has classified unambiguously the exhaust gases from diesel engine as the cause of cancer and place them in group 1. Thus, there has been a change in the classification of exhaust gases from the group 2A (probably carcinogenic) to the group clearly causing the disease.

Economic considerations and easy access to bio-fuels in agricultural cause that there are attempts to use them to power the engines of tractors and agricultural machinery. In view of the risks to human health and the environment caused by emissions from diesel engines there is a necessity to submit the bio-fuels for testing the full range of emission of harmful exhaust gas components.

2. Tests objects

During the comparative study to power an internal combustion engine used the following fuels: summer diesel (ON) and biofuels - Fatty Acid Methyl Ester (FAME). Two kinds of esters were used: rapeseed methyl esters (RME) and camelina methyl esters (Camelina seed).
Biofuels used in trials were produced in the apparatus and by technology developed in the Industrial Institute of Agricultural Engineering in Poznań.

Exhaust emission tests were conducted using a tractor Deutz-Fahr Agrotron X720 (Table 1) with modern diesel engine with turbocharger and charge air cooler. It meets the emission standards Stage IIIA. In addition, it can be powered by biofuel B100 instead the conventional diesel.

Table 1. Basic parameters of Deutz-Fahr Agrotron X720 engine [6]

Number of cylinders	6 / 4
Cylinders displacement	in-line
Sswept volume [dm3]	7,14
Maximum power output [kW/obr/min]	198 / 2350
Maximum torque [Nm / obr/min]	1052 / 1600
Injection	Common Rail
Injection pressure [bar]	1600
Exhaust gas cleaning systems	Exhaust gas recirculation Oxidizing catalytic converter

3. Instrumentation

Measurements of gaseous components concentrations of exhaust gases were conducted using mobile analyzer SEMTECH-DS (Table 2) from Sensors Inc. It allows to measure the concentration of compounds contained in the exhaust gas and fuel consumption, while measuring the exhaust gas mass flow.

To measure the emissions of particulate matter (PM) contained in the exhaust gas analyzer Semtech Laser Aerosol Monitor (LAM) from Sensors Inc. was used. The device

Table 2. Features of the mobile exhaust gas analyzer SEMTECH DS [7]

Parameter	Measurement method	Accuracy
Component concentration CO HC $NO_x = NO + NO_2$ CO_2 O_2 Sampling frequency	 NDIR – non-dispersive (infrared), range 0–10% FID – flame ionization, range 0–10 000 ppm NDUV – non-dispersive (ultraviolet), range 0–3000 ppm NDIR – non-dispersive (infrared), range 0–20% electrochemical, range 0–20% 1–4 Hz	 ±3% ±2,5% ±3% ±3% ±1%
Exhaust mass flow	Mass flow T_{max} do 700 °C	±2,5% ±1% of the range
Warm-up time	15 min	
Response time	T90 < 1 s	
Supported diagnostic systems	SAE J1850/SAE J1979 (LDV) SAE J1708/SAE J1587 (HDV) CAN SAE J1939/J2284 (HDV)	

Table 3. Technical data of Semtech-LAM analyzer [7]

The measuring range:	0 to 40 mg/m^3 0 to 700 mg/m^3
Particle size:	100 to 10 000 nm
Resolution:	0,01 mg/m^3
Drift:	<0,25mg/m^3 above 6 h
Sample flow:	1,5 dm^3/min
Sampling frequency:	5 Hz (internally to 100 Hz)
Output:	RS232 Analog 0 to 5 VDC option
Power supply:	12 to 24 VDC or 110 to 240 VAC
Temperature:	0 to 40 °C (104 °F)

Table 4. Technical details of the particle distribution analyzer 3090 EEPS [8]

The size of measured particles	5,6-560 nm
Number of channels	16 channels per decade (32 total)
Number of electrode channels	22
Sampling frequency:	10 Hz
Sample flow:	10 dm^3/min
compressed air flow	40 dm^3/min
input sample Temperature	10-52 °C
Operating temperature	0-40 °C

Table 5. Basic technical parameters of Eggers PT 301 MES dynamometer [9]

Breaking system	Retarder
Cooling medium	Air
Measuring range at 1000 1/min and 20°C	340 kW - 5 min 300 kW - 7 min 250 kW - 11 min 225 kW - 20 min
Max. Speer	3600 1/min
Max. Torque	7200 Nm
Rotation direction	Left/right

uses the phenomenon of laser-light scattering by particles suspended in the exhaust gases. Semtech-LAM can determine the concentration of PM in the exhaust gases in real time. It can be used as stationary equipment or to road tests. The basic parameters of the analyzer Semtech-LAM are presented in table 3.

Measurement of the particle matter size was performed using Engine Exhaust Particle Sizer Spectrometer (EEPS) 3090 (Table 4) from TSI Incorporated. It allows to perform continuous measurement of the size of particulates matter emitted by the engine of tested vehicle. EEPS spectrometer is a high performance device designed for the measurement of particulate matter emission from the fuel combustion inside the engine. It allows to measure the diameter of particulate matter from 5.6 to 560 nm.

Mobile electric dynamometer - Eggers Dynamometer PT 301 MES, which was connected to the tractor PTO, was used to load the tractor engine. Basic technical parameters of dynamometer shows the Table 5.

4. Test results and analysis

A comparative study was conducted on the test bench (Fig. 1) ensuring the same conditions for each fuel. The test characteristic (Fig. 2) was corresponding to registered during a previous field tests of Deutz-Fahr Agrotron X720 tractor with rotatable plow. The same tractor was used during the stationary tests.

Comparing the results obtained during the study of gaseous components emissions from the exhaust gas and particulate matter (Table 6) can be concluded that the emission of carbon dioxide, as well as proportional to this emission fuel consumption during the test, were the lowest for diesel.

The carbon emission, among the studied biofuels, was the lowest for camelina oil methyl esters.

Among the studied biofuel carbon emissions were lower for camelina methyl esters. However, the differences in values for the esters were less than 1%. The lowest emissions of carbon monoxide was recorded for camelina methyl ester (1.43 g/kW·h). It was lower than the emissions for diesel (2.83 g/kW·h) by 49% and by 37% for rapeseed methyl ester (2.27 g/kW·h). The lowest emission of oxides of nitrogen was obtained for the rapeseed methyl ester (5.37 g/kW·h). It was lower than diesel emissions by 13% (for rapeseed methyl esters) and 3% (for camelina methyl ester). However, in the case of hydrocarbons emission, the lowest level was recorded for camelina methyl ester (0.21 g/kW·h), and it was lower than diesel (0.56 g/kW·h) by 63% and lower than rapeseed methyl esters by 51%.

Fig. 1. The measuring stand of exhaust gas emission

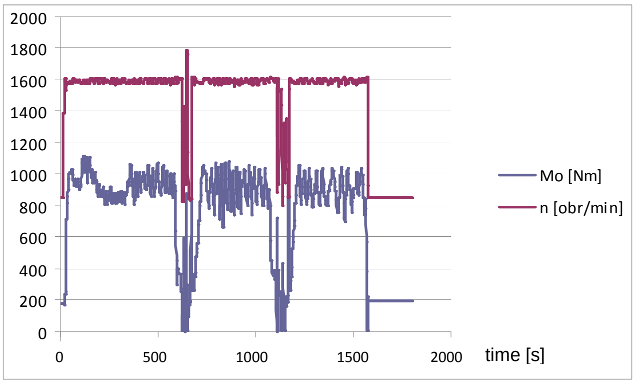

Fig. 2. Characteristic of comparison test

Table 6. The concentration of the gaseous components in the fuel

No.	Fuel type	Concentration [g/(kW·h)]				
		CO_2	CO	NOx	HC	PM
1	Diesel	621,23	2,83	6,23	0,56	0,52
2	Rapeseed oil methyl esters	634,17	2,27	5,37	0,43	0,46
3	Camelina oil methyl esters	629,76	1,43	6,03	0,21	0,45

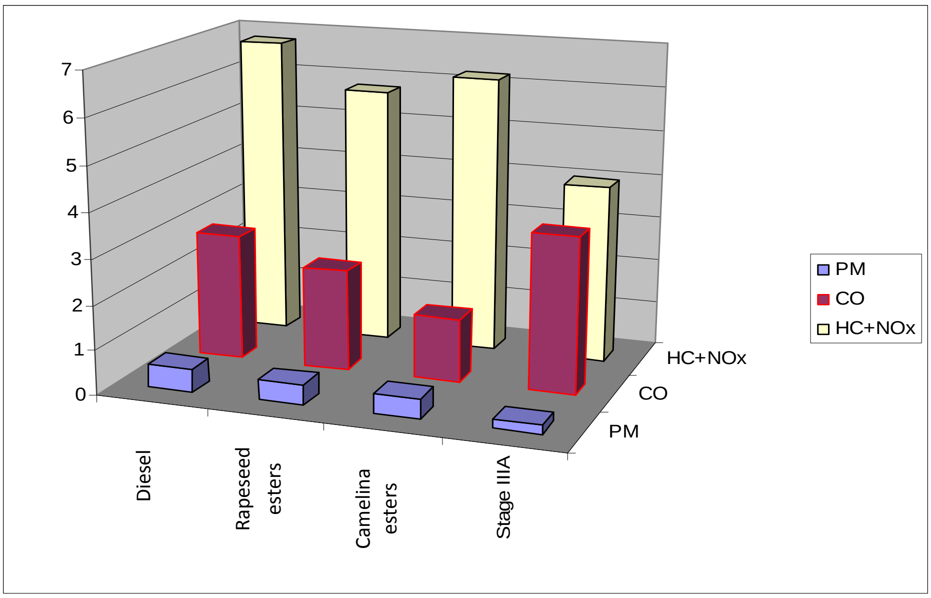

Fig. 3. Comparison of exhaust emissions with Stage IIIA standard

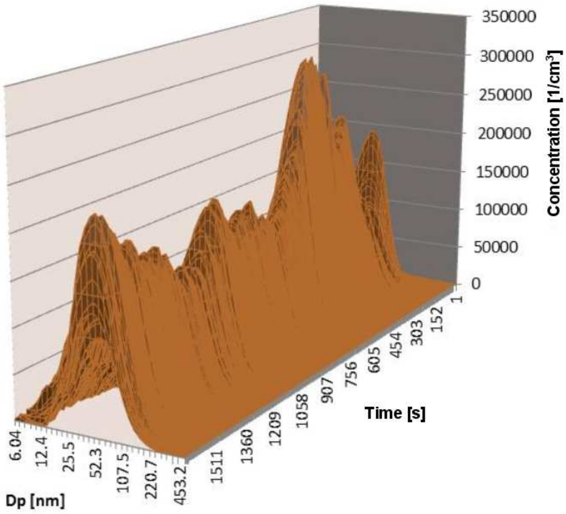

Fig. 4. The distribution of particulate matter size and concentration during the diesel oil test

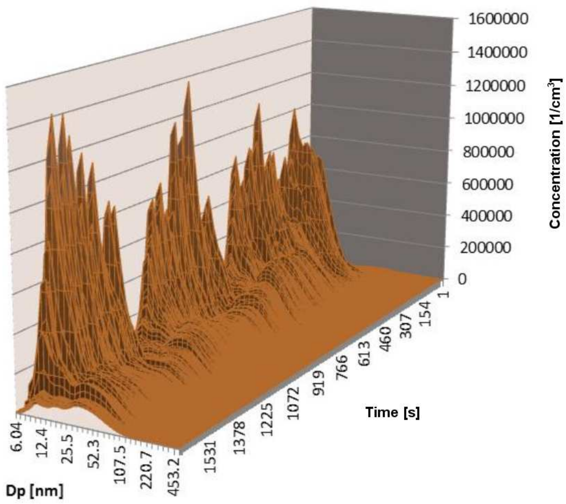

Fig. 5. The distribution of particulate matter size and concentration rapeseed methyl ester

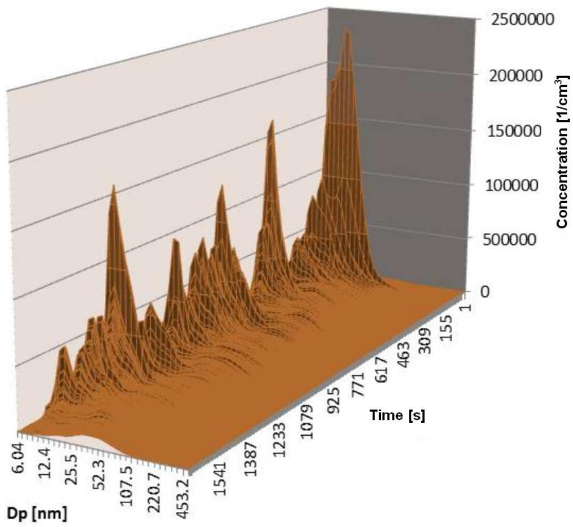

Fig. 6. The distribution of particulate matter size and concentration for camelina methyl esters

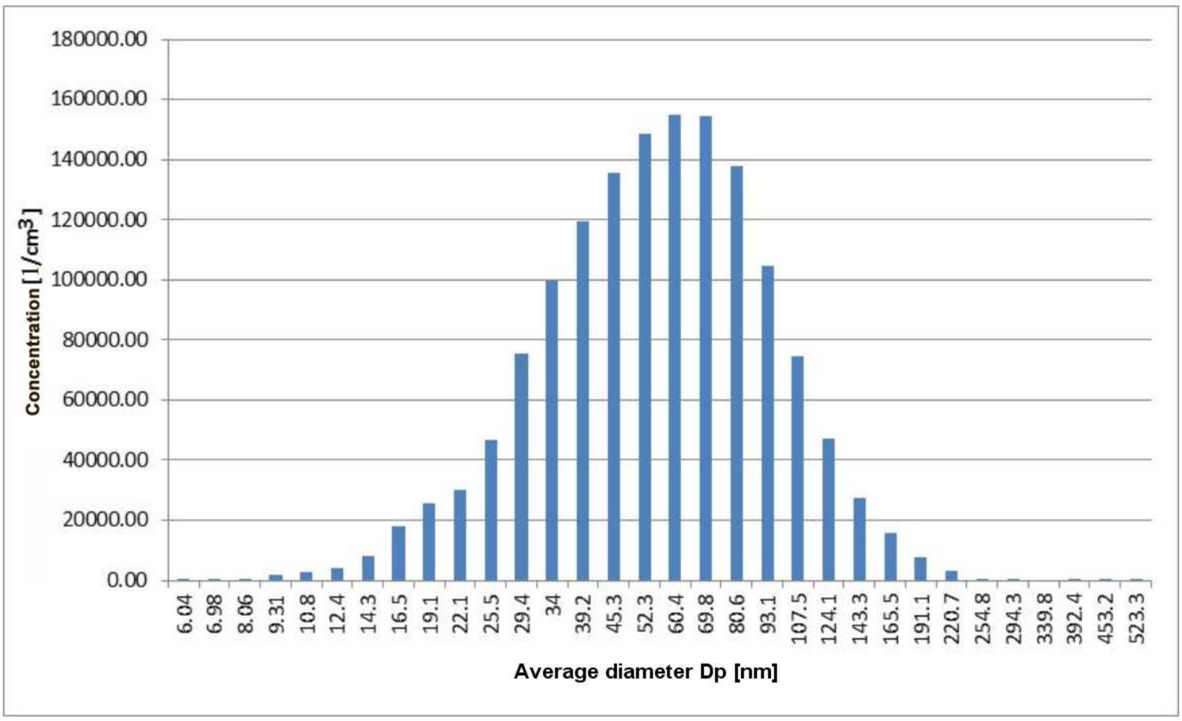

Fig. 7. The overall distribution of particulate matter size and the concentration for diesel oil

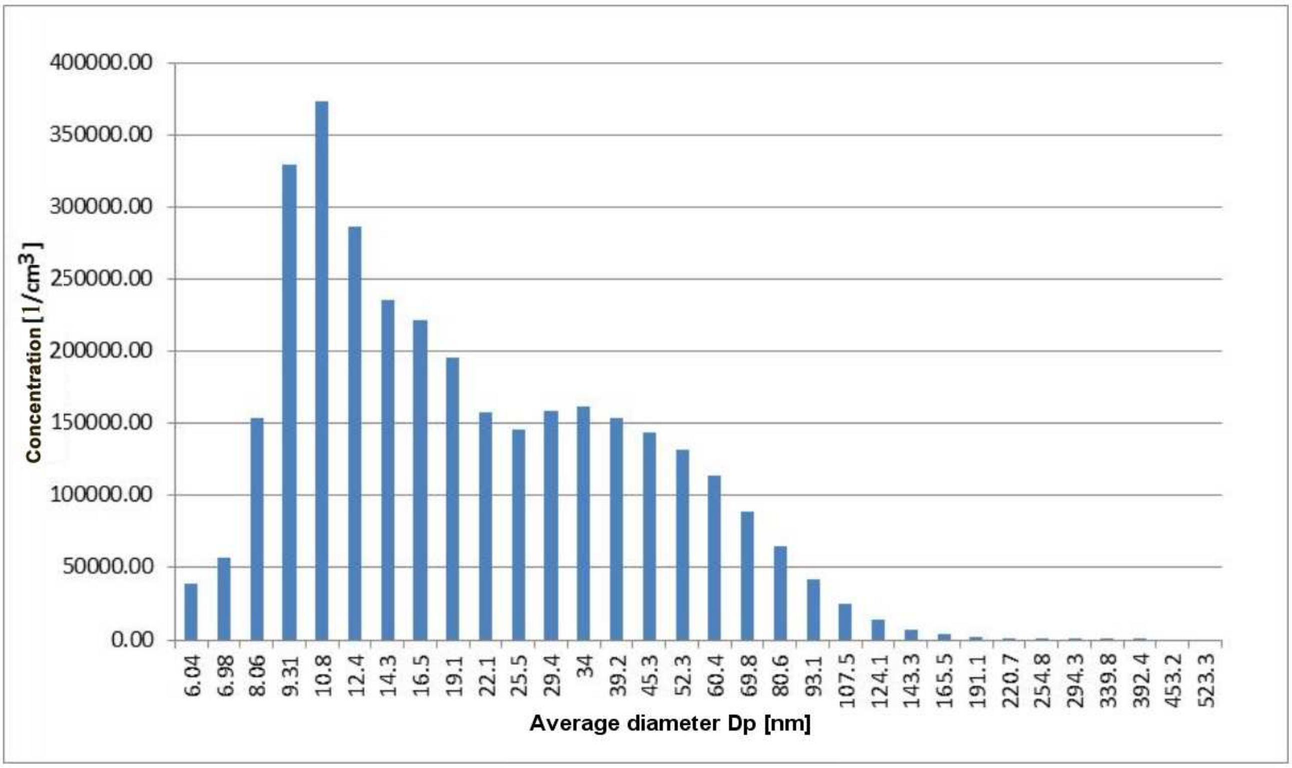

Fig. 8. The overall distribution of particulate matter size and the concentration for rapeseed methyl ester

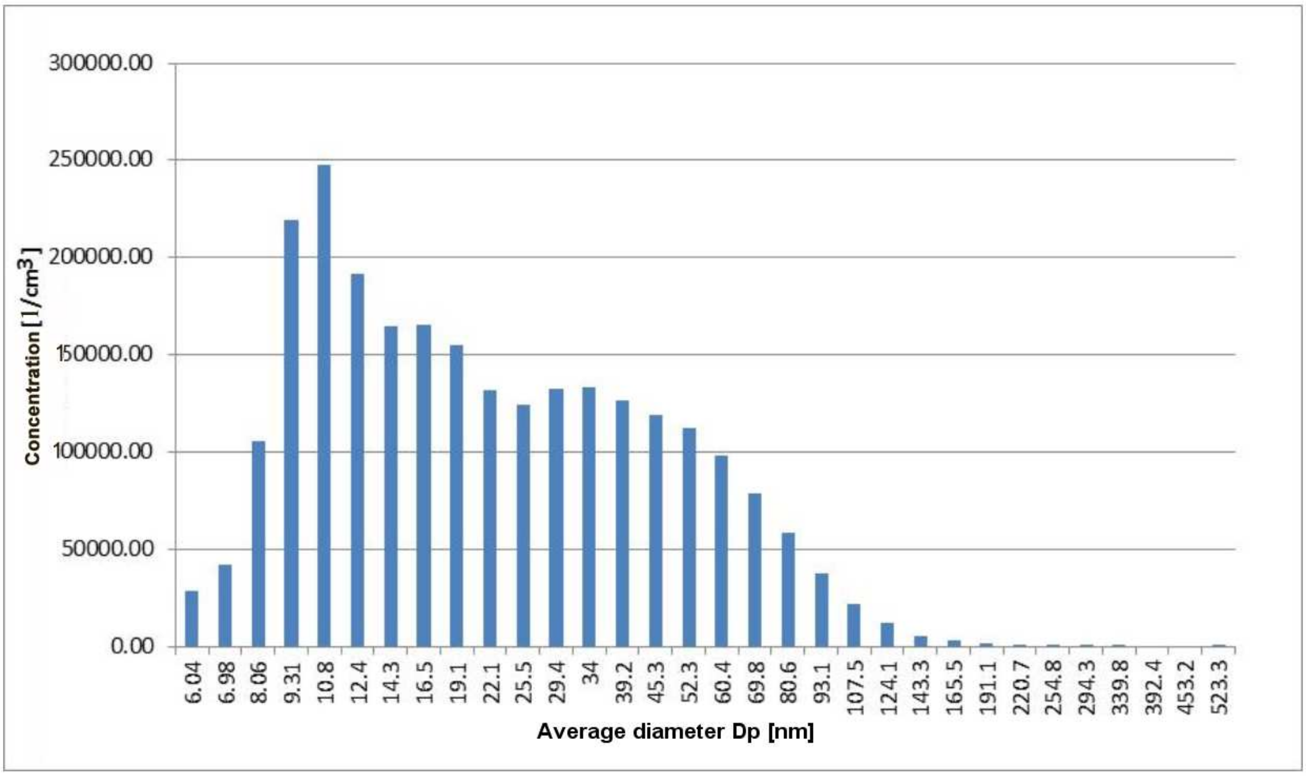

Fig. 9. Total distribution of particulate matter size and the concentration of the camelina methyl esters

The lowest average particulate emissions were registered for camelina methyl ester (0.448 g/kW·h), and it was lower than diesel emissions by 14% and 3% for rapeseed methyl esters.

With respect to the provisions of the standard Stage IIIA (applicable to the engines stationary homologation) carbon monoxide emissions (Fig. 3) for tested fuels was lower than the maximum limit (3.5 g/kW·h). However, the total emissions of nitrogen oxides and hydrocarbons significantly exceeded the maximum specified in the regulations (4 g/kW·h).

In the case of diesel fuel, it was 6.79 g/kW·h, and the 5.80 g/kW·h for rapeseed methyl esters and the 6.24 g/kW·h for camelina methyl esters.

Emissions of particulate matter (PM) for the test-fuels significantly exceeded the permissible average value

(0.2 g/kW·h) specified in the regulations of standards Stage IIIA. For diesel, this emission was the largest - 0.52 g/kW·h. The lowest average emissions were registered for camelina methyl ester (0.45 g/kW·h) - also higher than the limit.

Maximum concentration of PM for diesel oil (Fig. 4 and 7) occurred at average diameter and it was ranging 60.4 nm, the range above 50% of the maximum particle size concentration was 29.4 to 107.5 nm.

Maximum particle concentration for both types of esters (Fig. 5, 6, 8, 9) occurred at an average diameter 10.8 nm, for rapeseed methyl ester in a range above 50% of the maximum PM size concentration there ware ranged from 9.31 to 107.5 nm (Fig. 8). In the case of camelina methyl esters in a range above 50% of the maximum PM size concentration there ware ranged from 9.31 to 52.3 nm (Fig. 9).

Maximum PM concentration of ester was greater than diesel oil (150000 $1/dm^3$) (Fig. 7), where in the rapeseed methyl ester was 380000 1/dm3 (Fig. 8) and was greater than for the camelina methyl esters (250000 $1/dm^3$) (Fig. 9).

5. Conclusions

Based on the tractor engine survey, powered by diesel fuel and esters, it can be concluded that the carbon dioxide emissions for the ester is greater than for diesel fuel. For camelina methyl esters is lower than for rapeseed methyl esters.

Toxic exhaust emissions (carbon monoxide, hydrocarbons, nitrogen oxides and particulate matter) for the esters are lower than for diesel.

Among biofuels the carbon monoxide, hydrocarbons and average particulate matters emission is the lowest for camelina methyl esters. The greatest concentration of emitted particles average diameter was 10.8 nm for both esters and for diesel oil the average diameter was 60.4 nm.

According to the harmfulness of very small particle sizes (nanoparticles) to human health [1, 4, 5], these results gain particular significance. Maximum concentration of particulate matter for diesel is significantly smaller than the esters. For camelina methyl esters this ratio is smaller than in the case of rapeseed methyl esters, within the particle diameter range occurring above 50% of the maximum concentration is also lower for camelina methyl esters.

6. References

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