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THE IMPACT OF VARIOUS FUELS ON PARTICULATE EMISSIONS FOR A COMPRESSION IGNITION ENGINE EQUIPPED WITH A DIESEL PARTICULATE FILTER

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ABSTRACT

The aim of this research was to highlight the impact of using different types of fuels on particulate emissions and also on the operation on particulate filters on diesel engines. For all the results obtained from the experimental tests, comparative studies were performed to find the optimal fuel mixture that can be used in order to obtain the optimal performance of the particle filter, without affecting the engine performance. Following the initial tests performed without DPF, the case with the highest smoke emission value (2000 1/min) was identified. For this case, continuous measurement tests were then performed. For this reason, a more detailed analysis was made only for this case.

KEYWORDS: particulate emissions, particulate filters, smoke emission

1. Introduction

One of the main issues of diesel engines is related to particulate emission which results from the combustion process. They are divided into several categories depending on their size. Thus, there are the so-called "TSPs" which represent all suspended particles in the air, PM10 are inhalable suspended particles so-called "coarse fractions" with a diameter between 10 µm and 2.5 µm, PM2.5 also called fine inhalable particles with dimensions less than 2.5 µm. Another category is ultrafine particles, which are denoted by PM0.1 and represent particles smaller than 0.1 µm. The last category are nanoparticles, their size is less than 0.05 µm [1, 2].

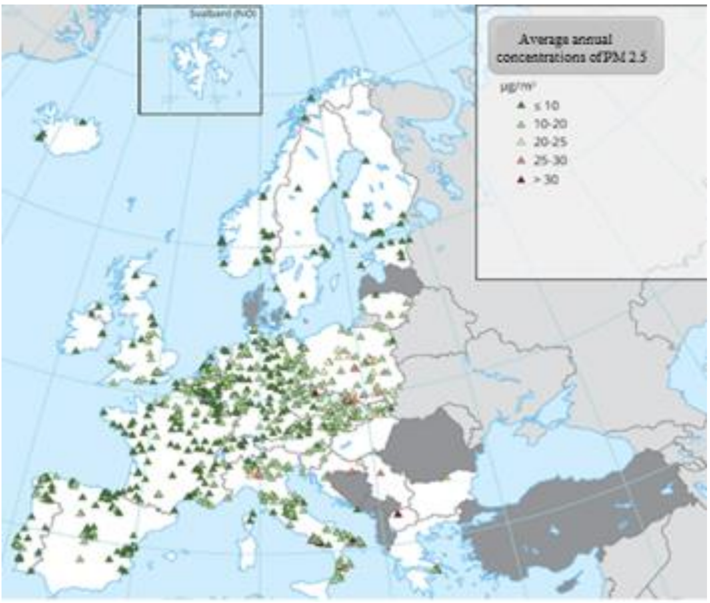

Fig. 1. *Average annual PM2.5 concentrations in Europe (2019)* [12]

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These PM emissions are continuously monitored by the emission monitoring stations. The highest concentration of PM is found in large urban areas or in industrial areas. The average annual concentrations of PM2.5 recorded by the European Environment Agency for 2019 in [μg/m^3] can be found in Figure 1.

The emission analysis was reduced for the cases in which biodiesel was used in the mixture at a speed of 2000 1/min. Experimental research has shown that the presence of oxygen in the fuel structure increases the supply of oxygen in the combustion process and has beneficial effects on smoke emissions.

2. Materials and methods

The experimental tests were performed on the single-cylinder engine AVL 5402 of the Testecocel laboratory, from The Department of Automotive Engineering and Transports of Cluj Napoca. The technical data of the engine can be found in Fig. 2. DPF loading with solid particles was monitored with a pressure sensor adapted before the diesel particulate filter. As the number of particles (PM1, PM2.5, PM10 or higher) in the filter increased, there was an increase of pressure before it. Because the sensor provided a relative pressure value, the impact of variations in atmospheric pressure was eliminated. To achieve this goal, a particle filter and a noise attenuator (Fig. 3). have been adapted to the exhaust system. Two particulate filters with asymmetrical square channels were used for experimental tests. The tests performed in this paper focused on determining the amount of soot loading of the particulate filter walls for several mixtures.

Parameter	Value	M.U.
Number of cylinders	1	[-]
Bore x Stroke	85 x 90	[mm]
Compression ratio	17.1	[-]
Maximum power	6	[kW]
Rated speed	4200	[min^{-1}]
Combustion system	4 valve	[-]
Displacement	510.7	[cm^3]

Fig. 2. *AVL 5402 Engine Technical Data*

In the first stage, measurements were made only with diesel (D100) at 3 different speeds and constant load to identify the least favorable point in terms of PM emissions. The second stage comprised performing tests with 20% biodiesel (B20) in the mixture and in the third stage experimental tests with 30% biodiesel (B30) in the mixture were performed. The formation of the mixture was performed by applying a formula for the exact calculation of the amount of fuel to be used in the mixture to reach the percentage of biodiesel of 20% and 30%, respectively. In order to determine the additional volume, it was taken into account that in D100 is already a percentage of 6.5% biodiesel. The soot load analysis was performed by continuous testing (engine operation without interruption) for 5 hours at 2000 rpm. The injection parameter values were taken from the injection map provided by the manufacturer of the engine (Table 1).

Fig. 3. *Diesel particulate filters mounted on the experimental engine AVL 5402*

Table 1. *Parameters used for experimental tests*

Fuels	Speed [1/min]	Ramp Pressure [bar]	Q_Pilot [mm^3]	Preinjection advance [°RAC]	Q_Main [mm3]	Main injection advance [°RAC]
D100, B20, B30	2000	700	2	22.125	21.6	8.625

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3. Results and discussion

There are multiple causes of the decrease in soot emissions as the oxygen content of the fuel increases. A first cause is that the presence of oxygen inhibits the formation of soot precursors in fuel-rich areas (by preventing carbon from entering the reactions that lead to their formation) and directly forms CO and CO_2, respectively, which makes a number of atoms available. for soot formation to decrease [3, 5]. Another cause is that oxygen leads to an increase in the temperature of the flame [6], which amplifies the oxidation of soot during the combustion process. If in the case of diesel, in the phase of diffusive combustion, an intense movement of the air is necessary to ensure the oxygen necessary for the oxidation of the soot, in the case of biodiesel this is compensated by the presence of oxygen in its structure. As a result, due to the fact that the testing was performed under the same conditions, soot emissions decreased as the percentage of biodiesel increased.

At the same time, it is highlighted that the stoichiometric ratio of biodiesel is lower, which under the conditions of the same air mass has the effect of reducing the rich regions during the combustion process [7]. In addition, it was found that, compared to the combustion of diesel, the combustion of biodiesel and diesel mixtures starts faster due to the reduction of the self-ignition delay caused by a higher cetane number, but also by an advance of the injection. Even if the higher viscosity disadvantages the mixture formation process (in this case, an advantage for biodiesel and diesel mixtures is that the load is reduced which negatively affects the self-ignition delay of diesel). This leads to more complete and uniform combustion of the fuel and thus to a decrease in soot emissions.

The decrease in PM is also due to the fact that biodiesel contains fewer aromatic hydrocarbons and does not contain Sulphur, the aromatic hydrocarbons being considered the precursors of solid particles [8]. The favourable factor for the formation of solid particles is a rich mixture followed by incomplete combustion resulting higher smoke emissions. The presence of oxygen in biodiesel also improves the combustion process through the chemical reaction that is achieved through the presence of oxygen, so oxygen molecules combine with soot molecules that are formed mostly of carbon resulting in CO_2.

For the analysed cases (Fig. 4) following tests performed, a relative decrease of the smoke emissions resulted after 5 hours of continuous operation with biodiesel mixture, at the speed of 2000 1/min as follows:

- the value of the differential pressure related to the charge of the particulate filter was 22.56% lower for B20 and 31.28% lower for B30 compared to D100;

- the value of the differential pressure was lower by 11.25% for B30 compared to B20.

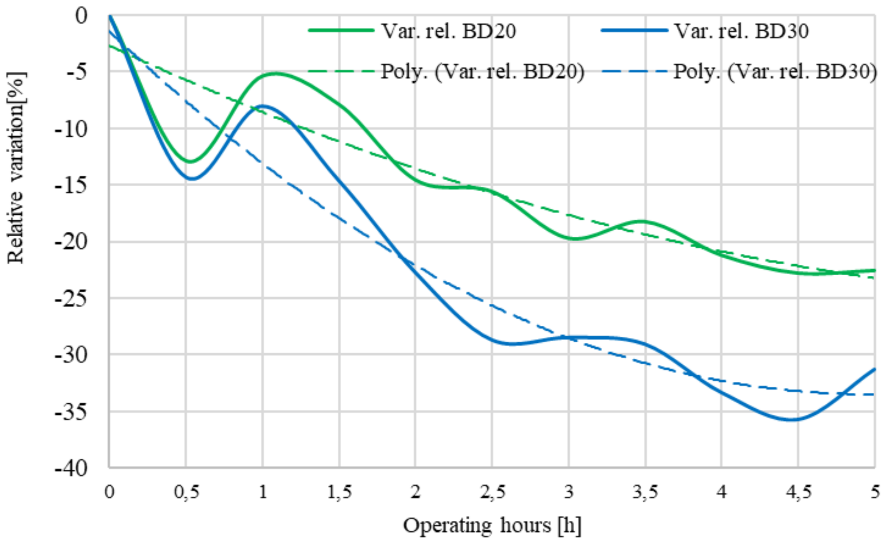

Fig. 4. *Relative polynomial variations of pressure drops for B20 and B30 related to D100 [%]*

The measured value of the pressure difference on the filter, after 5 hours of testing, was 19.5 mbar for D100, 15.1 mbar for B20 and 13.4 mbar (Fig. 5). Specialty literature confirms the results of experimental tests on the reduction of solid particulate emissions in direct proportion to the increase in the percentage of biodiesel in the mixture [9-11].

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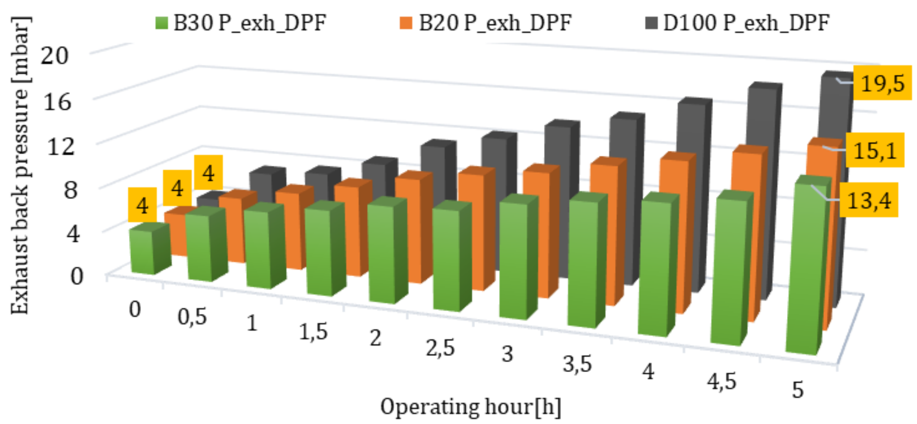

Fig. 5. *Variation of exhaust backpressure during 5 hours of continuous testing*

In order to be able to analyse in even more detail the load of the diesel particulate filters apart from the experimental test, a microscopic study of the particulate filter channels used in the experimental tests was performed. It was possible to analyse the channels of the diesel particulate filter in detail due to the high resolution that the device has and due to the fact that the optical zoom can be set up to 100 X. The images captured with the microscope were exported on an LED screen for a detailed analysis. In the first phase, the channel of the new particle filter was analysed and dimensioned (Fig. 6). As an element of analysis, the microscopically studied channel was chosen so as to be exactly in the same area of the DPF for all 3 cases studied as seen in Figure 6. The size of a cell following the measurements was 1.5 mm and the wall thickness was 0.225 mm.

Fig. 6. *Filter channels before the experimental tests and the area chosen for the microscopic study*

The objective of this microscopic research was to highlight the impact of various fuels on the loading of soot channels, but also to compare the results obtained experimentally with the results obtained by microscopic research. This impact was assessed by the effective measurement of the soot layer deposited on the channels with the help of Motic software.

The data obtained from microscopic measurements confirmed the results and the trend obtained in experimental tests. The first microscopic analysis was performed for D100 (Figure 7). From the detailed analysis that was transposed on a high-resolution LED screen it was observed that the maximum thickness for the soot layer deposited on the edge of the filter walls (referring to all 3 analysed cases D100, B20 and B30), was achieved for D100. Detailed microscopic analysis of the filter channel resulted in a thickness of 581 μm for the soot layer deposited in the filter. It is necessary to specify that these deposits were made without any regeneration during the entire experimental testing process. Microscopic analysis of the DPF channels for B20 led to lower thicknesses than the D100 for the soot layer, as can be seen in Figure 8. It is clear that with the increase of the percentage of biodiesel, the average thickness for the soot layer also decreased, having a maximum size for the soot layer of 441 μm. For the B30 case, the trend of decreasing soot mass-produced in the particulate filter is very pronounced. It can be seen from Figure 9 that the maximum layer size was up to 300 μm, which represent almost half of the soot deposited for B30 compared to D100.

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Fig. 7. *Microscopic analysis of DPF channels after experimental tests for D100*

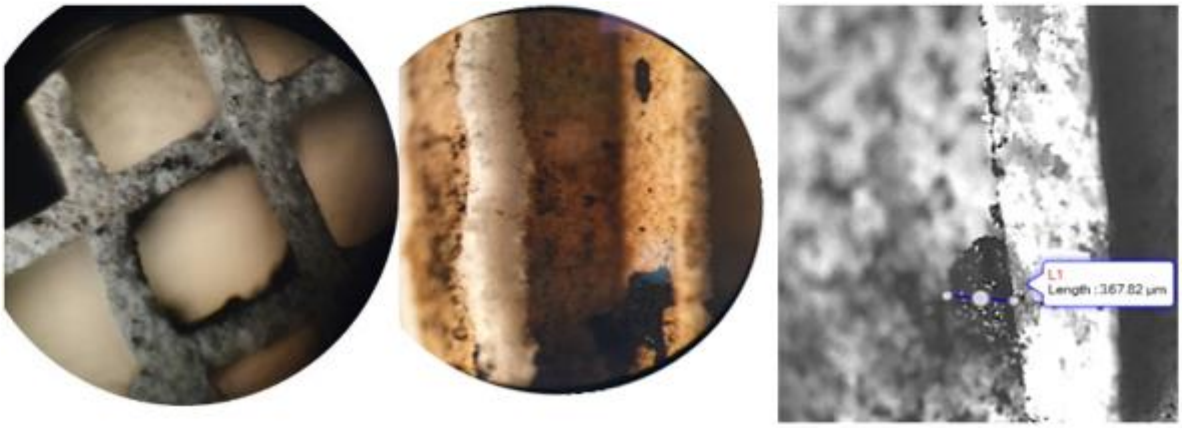

Fig. 8. *Microscopic analysis of DPF channels after experimental tests for B20*

Fig. 9. *Microscopic analysis of DPF channels after experimental tests for B30*

4. Conclusions

The main points and conclusions that emerge from this research, after the interpretation and analysis of data obtained from theoretical and experimental research are the following:

- for the cases analysed with DPF mounted on the exhaust, at a speed of 2000 1/min, for B20 the smoke emissions were 22.56% lower, respectively 31.28% for B30 compared to D100;

- soot emissions for B30 compared to B20 were lower by 11.25%;

- the measured value of the differential pressure on the particulate filter, after testing, was 19.5 mbar for D100, 15.1 mbar for B20 and 13.4 mbar for B30. Thus, it could be concluded that a higher percentage

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of biodiesel in the mixture leads to a slower soot loading of the particulate filter;

- the trend of soot emissions is directly proportional to the total pressure drop. Thus, for D100 there was an increase of 25.12% in soot emissions compared to B20, respectively by 47.5% compared to B30;

- the data obtained from microscopic measurements confirmed the results and the trend obtained in experimental and numerical research. Microscopic analysis of the DPF channels for B20 led to lower thicknesses than the D100 for the soot layer. It is obvious that with the increase of the percentage of biodiesel, the average thickness for the soot layer also decreased, having a maximum size for the soot layer of 441 µm. For the B30 case, the decreasing trend of the soot mass produced in the particle filter is very accentuated, the maximum size of the deposited layer being up to 300 µm.

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