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NO_X AND CO EMISSION ANALYSIS USING OXYGENATED FUELS FOR A DIESEL ENGINE EQUIPPED WITH DIESEL PARTICULATE FILTER

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ABSTRACT

The automotive industry is responsible for a big part of the pollutant emissions, and the measures that are being taken to reduce these emissions are extremely important. Compared to 1990 emissions of nitrogen oxides from internal combustion engines decreased approximately by 39%, and for PM 2.5 by 37%. Even so, emissions concerns have increased in recent years, so the EU has taken a series of measures to continuously reduce emissions of nitrogen oxides and carbon monoxide related to transport sector. It is well known that the replacement, even partial, of fossil fuels with alternative fuels has a significant contribution to the decarbonisation of trans-European transport, which reduces the environmental impact of this sector. With a share of around 4.7% of all fuels used in EU transport, biofuels are the main type of alternative fuel. In addition, if produced sustainably, biofuels help reduce emissions of carbon monoxide and solid particles, but at certain operating intervals, the engine can produce more NO_x *emissions, which is why diesel engines must be equipped with additional* NO_x *emission treatment systems.*

KEYWORDS: NO_x emission, CO emission, Diesel particulate filter, biodiesel

1. Introduction

Compared to the combustion of gasoline engines, the combustion of diesel engines can be described by three successive processes: self-ignition delay, preformed mixture combustion and controlled mixing (diffusive) combustion. Depending on the operating point, the contributions of the three processes to the total duration of the combustion process change. Self-ignition delay defines the phase of combustion of the preformed mixture by the amount of fuel injected into the cylinder that has not yet burned. The longer the self-ignition delay, the greater the amount of preformed mixture. Combustion usually starts at the periphery of the fuel jet, where the fuel has mixed well with the air and therefore allowed the creation of optimal ignition conditions (temperature and λ). Exothermic reactions in these areas lead to temperatures above 2300 K [1], which allows the rapid oxidation of the preformed mixture by self-accelerating chain reactions. Compared to the petrol engine, the diesel engine runs on excess air ($\lambda > 1$), which is why the use of the catalyst is only beneficial for the oxidation of HC and CO with excess oxygen from the flue gases. For this reason, reducing internal emissions is important for diesel engines. In addition to the emissions of petrol engines (CO_2, H_2O, NO_x, HC and CO), soot and particulate emissions must also be taken into account for diesel engines.

A catalyst and a particulate filter are needed to treat the pollutant emissions from combustion. The basic part of the catalyst is a honeycomb-shaped ceramic monolith, which is composed of several small channels through which flue gases circulate. If the ignition temperature is reached, the oxidation in the DOC (Diesel Oxidation Catalyst) is almost complete. The ignition temperature varies between 170 and 200 °C, depending on the nature of the exhaust gases, the flow rate, and the catalyst composition. From this temperature, the conversion reaches 90%. For an optimal oxidation process in the catalyst, there must be a high residual oxygen content in the flue gases. Unburned hydrocarbons are the result of incomplete combustion. Nitrogen oxides are produced at very high temperatures in the combustion chamber in places where there is a surplus of oxygen. NO_x emissions cannot be reduced by the oxidation catalyst, but only in the three-way catalyst (Fig. 1).

Diesel Oxidation Catalyst has a carrier ceramic or metal structure and a substrate coating covered with noble metals. The major purpose of the substrate coating is to ensure that the noble metal is slowing down the sintering of the catalyst, which occurs at high temperatures and results in an irreversible reduction in the catalyst's activity.

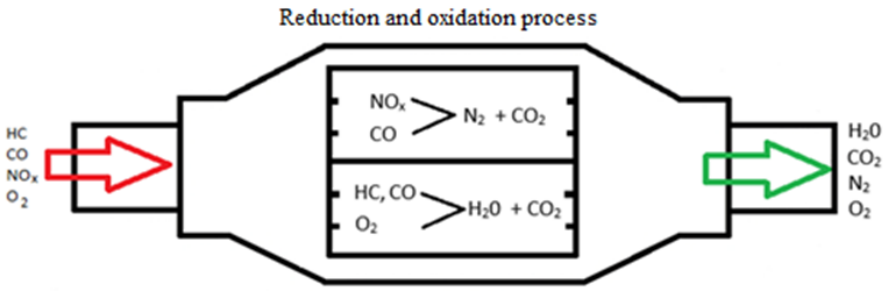

***Fig. 1.** Three-way catalyst (DOC)*

2. Materials and methods

The experimental research for the analysis of the operation of particulate filters with biofuels was carried out in the “Laboratory for testing, research and certification of internal combustion engines” within the Faculty of Road Vehicles, Mechatronics and Mechanics Cluj Napoca. The laboratory offers the possibility of testing internal combustion engines with different fuels. Therefore, comparative studies can be performed between the operation of conventional fuels, respectively biofuels in terms of pollutant emissions, performance and combustion processes.

The specific objectives were:

- CO emission analysis for Diesel engine using different blends;

- NO_x emission analysis for Diesel engine using different blends.

In order to obtain and process the data generated by the experimental tests performed in the Testecocel laboratory, in order to fulfil the objectives of the present doctoral thesis, the following were taken into account:

- modification of the input parameters of the electronic engine control system
- measuring the mass air flow;
- measuring NOx and CO emissions;
- fitting a particle filter to the exhaust system.

The experimental single-cylinder engine AVL 5402 with a maximum power of [6 kW] was used for experimental tests. The entire process was controlled from the command-and-control room (Fig. 2), which consists of computing equipment and process monitoring systems.

***Fig. 2.** Command chamber and AVL5402 engine used in experimental tests*

The TESTO 350 analyser (Fig. 3) was used to measure pollutant emissions (CO, NO_x), which is equipped with a modular probe that works at temperatures up to 1000 °C. After calibrating the device, the probe was introduced into the exhaust system to read NO_x and CO emissions (Fig. 4). The data acquisition was done in real time, by connecting the Testo unit to the PC using Bluetooth technology. The data was saved automatically every 5 seconds. The data used for the analysis were collected only after stabilization of temperature and NO_x and CO emissions. The change in values before collecting them had to be less than 1% within one minute.

Fig. 3. *Testo Analyzer: 1 - Testo 350 analysis unit, 2 - modular exhaust gas probe*

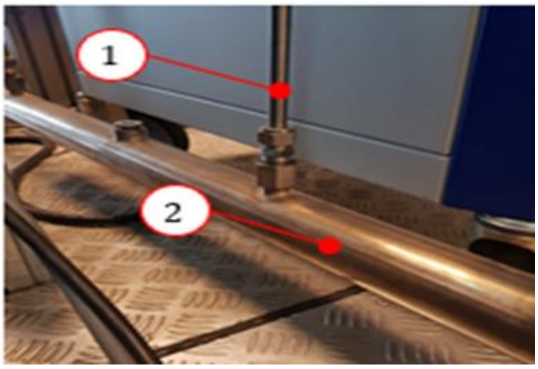

Fig. 4. *Adapting the modular probe to the exhaust system: 1 - modular probe, 2 - exhaust pipe*

3. Results and discussion

The working regime at which the experimental determinations were performed was 2000 1/min. The injection parameters were the same in all cases. For each fuel, 2 types of tests were performed:

1 - Tests without particulate filter;

2 - Tests with particulate filter.

The results obtained after the experimental tests performed with particulate filter and without particulate filter mounted on the exhaust are presented in Table 1. Three types of D100 fuel mixture were used - diesel, B20 - is a mixture of 20% biodiesel and 80% diesel and B30 - is a mixture of 30% biodiesel and 70% diesel. A first analysis of the results found that increasing the biofuel content from 6.5% v/v which D100 has to 20% and 30% v/v respectively has a beneficial effect on smoke and CO emissions, which can be justified by higher oxygen content. Instead, NO_x emissions increase, which is due to the local excess oxygen in the combustion chamber.

NO_x and CO emissions have been measured with the Testo device since the stabilization of the system, which was achieved when the engine oil and exhaust temperature fluctuated by less than 1% for a period of 1 minute. Another important aspect is that no gas recirculation system has been used to limit NO_x emissions. The NO_x and CO emission values were converted from PPM to g/kWh using the formula [2]:

$$EP_i = EV_{i,d} * \frac{M_i * \dot{m}_{Exh,d}}{M_{Exh,d} * P_{eff}} = EV_{i,w} * \frac{M_i * \dot{m}_{Exh,w}}{M_{exh,w} * P_{eff}} \quad (1)$$

Notes: EP_i - mass of pollutant "i" in relation to power in [g/kWh], EV_i - value of exhaust emissions "i" in [ppm], M_i - molar mass, M_{Exh} - molar mass of the exhaust gas, $\dot{m}_{Exh}$ - mass flow of the exhaust gas [kg/h], P_{eff} - effective power [kW], index d - dry exhaust gases without water vapor and index w - vapor exhaust gas.

Table 1. *Pollutant emissions at 2000 rpm - NO_X, CO*

Case nr.	Blend	NO_X [g/kWh]	CO [g/kWh]
1	Diesel_DPF	8.19	2.11
2	Diesel_noDPF	7.52	3.74
3	B20_DPF	10.41	1.91
4	B20_noDPF	8.43	3.60
5	B30_DPF	10.76	1.53
6	B30_noDPF	8.52	3.42

For the analysed cases (at a speed of 2000 1/min) (Fig. 5), the tests performed without a particulate filter showed an increase in NO_x emissions for B20 of 12.10% and 13.30% for B30 in the ratio with diesel. For DPF cases there is an increase in NO_x emissions for all mixtures. Thus, we have an increase

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of 8.91% for the Diesel_DPF case compared to the Diesel_No_DPF case, an increase of 23.49% for the B20_DPF case compared to B20_No_DPF and an increase of 26.30% for the B30_DPF case compared to B30_No_DPF. All these additional increases in NO_x emissions for a higher percentage of biodiesel in blend are confirmed by the specialty literature [3, 5].

The composition of biodiesel (oxygen content, length of molecules, unsaturated FAME, etc.) but also the effects of cetane number, viscosity and modulus of elasticity on the beginning of the combustion process, ensure conditions that favour the formation of nitrogen oxides. Higher flame temperatures [6], especially in regions where there is a high oxygen content coupled with the occurrence of dissociation reactions and sufficient residence time [7] lead to high NO_x emissions.

This is explained by the fact that the oxygen molecules in the mixture react with the existing nitrogen, increasing the maximum temperature during the combustion process, this being the main factor for increasing NO_x emissions. Although combustion is improved in the case of biodiesel blends, this has the consequence of increasing NO_x. Nitrogen oxides emissions can be reduced by applying temperature reduction measures: reducing the concentration of oxygen in the combustion zone or delaying the fuel injection, but also reducing the injection pressure.

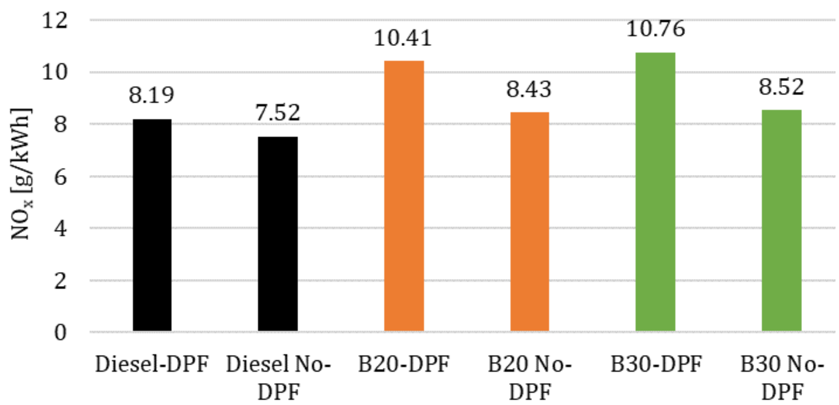

Fig. 5. *NO_x emissions at 2000 1/min*

CO emissions decreased in direct proportion to the addition of biodiesel to the mixture due to the presence of oxygen in the chemical composition of the biodiesel, resulting in a more complete combustion. Another reason why CO emissions fell was because biodiesel has a lower carbon content than diesel. For cases without exhaust particulate filter, the carbon emission decreased by 3.74% for B20 and by 8.56% for B30 compared to D100. Cases where particulate filter was used on discharge showed that the CO emission decreases by 43.58% for D100DPF compared to D100_No_DPF, by 46.94% for B20DPF compared to B20_No_DPF and by 55.26% for B30DPF compared to of B30_No_DPF (Fig. 6). The decrease in CO emissions for DPF cases is also confirmed by research conducted by Shao *et al.* [75].

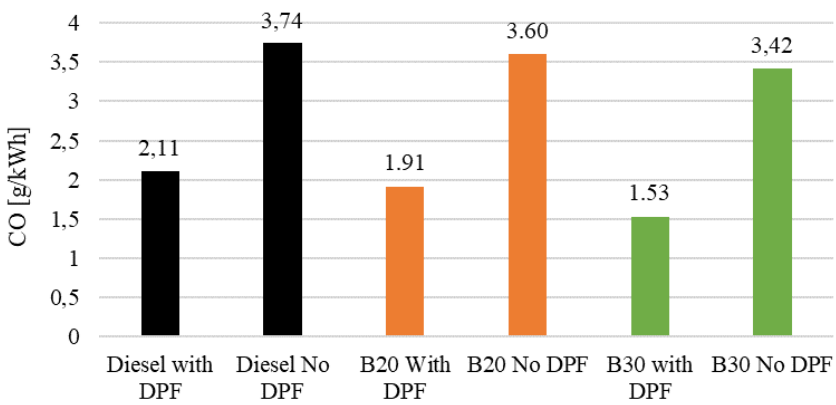

Fig. 6. *CO emissions at 2000 1/min*

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4. Conclusions

The main conclusions that can be drawn from this research are:

- for the analysed cases (at a speed of 2000 1/min), the tests performed without a particulate filter showed an increase in NO_x emissions for B20 of 12.10% and 13.30% for B30 compared to D100;

- for cases with DPF there was an increase in NO_x emissions for all mixtures. Thus, we have an increase of 8.91% for the Diesel_DPF case compared to the Diesel_No_DPF case, an increase of 23.49% for the B20_DPF case compared to B20_No_DPF and an increase of 26.30% for the B30_DPF case compared to B30_No_DPF;

- CO emissions decreased in direct proportion to the addition of biodiesel to the mixture, due to the presence of oxygen in the chemical composition of biodiesel, helping to burn more completely; in the cases without the exhaust-mounted particulate filter, the carbon emission decreased by 3.74% for B20 and by 8.56% for B30 compared to D100;

- the cases in which exhaust particulate filter was used showed that the CO emission decreases by 43.58% for D100DPF compared to D100NoDPF, by 46.94% for B20DPF compared to B20NoDPF and by 55.26% for B30DPF compared to B30NoDPF.

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