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Ecological aspects of using mixtures of canola oil with n-hexane in diesel engine

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The article discusses the results of research on the use of canola oil and canola oil with the addition of n-hexane in a compression-ignition engine. An engine with a Common Rail injection system was tested in real traffic conditions on the road and on a chassis dynamometer. The tested fuels were fed to the engine by an additional fuel supply system. An analysis of the effect of the addition of n-hexane on the emission of the main components of toxic exhaust gases was carried out. The proposed solution may contribute to extending the service life of currently used compression ignition engines due to the improvement of the ecological properties of this type of drive sources.

Key words: *Diesel engine, nitrogen oxides, hydrocarbons, carbon dioxide, combustion, canola oil, n-hexane, common rail*

1. Introduction

Today, thecombustion engine is widely used to drive means of transport [1]. The main problem of the use of means of transport is greenhouse gas emissions, which affect among others climate change observed in the world. It is believed that the main reason for this phenomenon is the use in vehicles of internal combustion engines powered by non-renewable petroleum-based fuels [2]. Therefore, it is particularly important to reduce carbon dioxide (CO_2) emissions into the atmosphere. Despite the increase in the number of electric vehicles used, there is still a significant number of vehicles with internal combustion engines in widespread use. The tightening of standards for the emission of toxic exhaust compounds forces work to be carried out in the field of searching for new types of fuels to power internal combustion engines. With regard to diesel engines, this work was carried out mainly in the field of obtaining fuels not from the refining of crude oil, the so-called alternative fuels (mainly biofuels) [3, 4]. The use of biofuel made from oilseeds (among others canola oil) brings significant benefits. It can be assumed that CO_2 emitted during the combustion of fuels of plant origin is quantitatively balanced by CO_2 taken up by plants in the process of photosynthesis during the period of plant growth (closed circuit CO_2) [5,6]. Despite the advantages of vegetable fuels, there are also problems associated with the use of canola oil (*Co*) as a fuel. The basic problems in the use of *Co* as a fuel include different physicochemical properties in relation to diesel fuel, such as density, viscosity, surface tension, cloud point, fractional composition. Canola oil also has a high temperature of blocking the cold fuel filter, approx. +12^{o}C (CFPP – cold fuel plugging point). The use of vegetable oil can also lead to operational problems because it contains glycerine, which at high temperatures can change into acrolein (CH_2=CH–CHO). Acrolein can form carbon deposits (polymers, soot) in the engine and fuel lines [7–9]. The authors of the work dealing with this issue, conducted a number of studies on the engine dynamometer in static and dynamic conditions, during which the research diesel engine was powered by, among others, canola oil with various additives. The physicochemical properties of fuels have a direct impact on the course of the injection and combustion process, and indirectly on the ecological parameters of the exhaust gases [10–13]. Therefore, additives are being sought to change the physicochemical parameters of Co, so that they are close to the properties of diesel fuel. (Df). One of the proposed ways is to use a mixture of Co with n-hexane [14–18]. Due to the legal regulations on the level of emissions of toxic exhaust gas components, which force the control of emissions in dynamic conditions, measures have been taken to assess the ecological parameters of a diesel engine powered by mixtures of canola oil with n-hexane in these conditions. The article presents the results of diesel engine tests in real operating conditions reflected on the chassis dynamometer, as well as in road conditions.

2. Test stand and research methodology

The research was carried out at the Center for Innovation and Technology Transfer of the Lublin University of Technology, in the Laboratory ofthe Department of Motor Vehicles, equipped, among others, with a Dynorace chassis dynamometer, designed for vehicles with two-axle drive type DF4FS-HLS. The research stand is presented on Fig. 1. The engine of the test vehicle had a turbocharger with a discharge valve (without variable geometry), a common rail storage injection system, an EGR exhaust gas recirculation system and a DPF particulate filter. To measure ecological parameters in road driving conditions, the Herman HGA400 mobile exhaust gas analyzer was used, whose probe was located in the exhaust system, i.e., behind the diesel particulate filter (DPF). During the tests, CO_2 and O_2 as well as the main components of toxic exhaust gases (CO, HC, NO_x) were measured. The concentration of toxic compounds in the exhaust gases was also measured using the MAHA exhaust gas analyzer (in the conditions of movement on the chassis dynamometer, exhaust gas consumption before the catalyst). In addition, the engine of the test vehicle was identified using AVL's INDIMICRO 602 engine indication system. The signals recorded by the AVL system are the pressure waveform inside the cylinder, the signal of the position of the engine crankshaft, the injection pressure. To analyze the operating parameters of the engine controller, a diagnostic interface designed to work with the Bosch KTS system was used.

Fig. 1. Test stand consisting of: 1 – Fiat Qubo test car with 1.3 Multijet engine, 2 – computer with installed AVL Indicom V2.7 software, 3 – Indimicro 602 engine indicator system, 4 – DF4FS-HLS chassis dynamometer, 5 – additional fuel system tank, 6 – KTS Bosch – Diagnostic module, 7 – diagnostic exhaust gas analyzer and dymometer MET 6.3 by Maha, 8 – mobile exhaust gas analyzer Herman HGA400

Table 1. Basic physicochemical parameters of the tested fuels [12]

Fuel type	Density 20°C [kg/m^3]	Kinematic viscosity 20°C [mm^2/s]	Surface tension 20°C [mN/m]	Calorific value [MJ/kg]
Co	916.00	34.89	34.15	37.10
90%Co10%Hex	895.43	19.64	30.08	30.77
85%Co15%Fex	887.60	15.20	30.10	30.95
Df	840.00	2.70	29.15	43.84

Diesel fuel (Df) meeting the requirements of EN590, commercial canola oil (Co), non-reactive solvent n-hexane were used for testing. N-hexane (C_6H_{14}) is an organic chemical compound from the group of alkanos. N-hexane isomers are very little reactive and often used as solvents in organic reactions because they are highly non-polar. On the basis of canola oil (Co) two mixtures with n-hexane were made in proportions of 10% (90%Co10%Hex) and 15% (85%Co15%Hex). The main physicochemical properties of the tested fuels are presented in Table 1.

The tests were carried out under the driving conditions of the vehicle on the chassis dynamometer (case 1) and in real traffic, on the road (case 2), with the vehicle being loaded with rolling resistance and air resistance force. The researchwas carried out to determine the effect of the n-hexane additive on the operating parameters of the diesel engine and on the exhaust gas composition. The measurements were carried out in the fourth gear of the vehicle, at fixed engine speeds: 2000, 2500, 3000, 3500, 4000 rpm. The results obtained were related to the results achieved with diesel fuel. The studies concerned the exhaust gas composition of gases down the catalytic converter (this exhaust gas composition was measured in case 2) and before the catalytic converter (this exhaust gas composition was measured in case 1).

3. Research results

Figures 2 to 5 show the results of the obtained tests of ecological parameters of engine operation in selected conditions. Concentration of nitrogen oxides (NO_x), carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbons (HC) and oxygen (O_2) were analysed. The studies carried out concerned two types of engine operating conditions (see cases 1 and 2).

a)

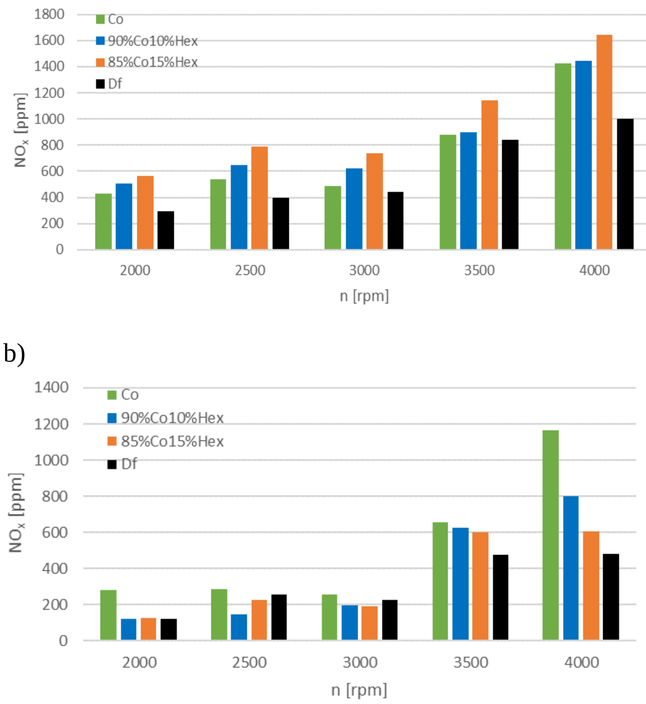
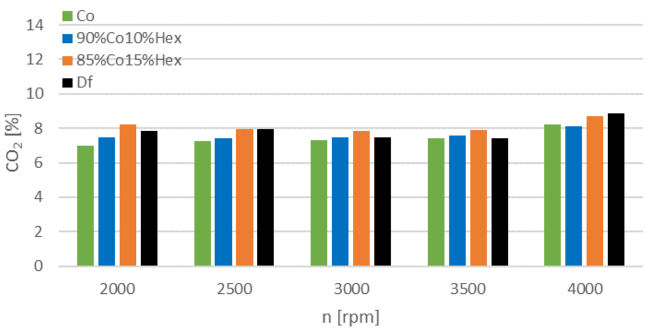


Fig. 2. The course of the concentration of nitrogen oxides (NO_x) in the exhaust gases depending on the rotational speed, for the operation of the Diesel engine powered by the tested fuels, a) case 1 (measurement before catalytic converter), b) case 2 (measurement after catalytic converter)

An analysis of the exhaust gas composition (before the exhaust after-treatment system) emitted during the operation of an engine running on vegetable fuels under the vehicle on the chassis dynamometer (Fig. 2a, case 1) showed that over the entire engine speed range, concentration of nitrogen oxides (NO_x) were higher than when using diesel (Df). The biggest relative difference occurred at a speed of

2500 rpm when powered by canola oil with the addition of 15% n-hexane (about 50%). For case 2 (Fig. 2b – driving the vehicle in real traffic, on the road), the differences in nitrogen oxides (NO_x) concentration when powered by canola oil with the addition of 15% n-hexane were no longer as large as for case 1. In the range of lower rotational speeds (2000–3500 rpm), the addition of n-hexane caused the no_X concentration to be lower or at a comparable level to Df. The biggest relative difference when powered by canola oil with the addition of 10% n-hexane compared to diesel (Df) occurred at a speed of 2500 rpm (about 75%). As the rotational speed increased, the trend was reversed. The observed quantitative difference in NO_x concentration between the cases under consideration is mainly related to the operation of the exhaust aftertreatment system (catalytic converter, particulate filter).

a)



b)

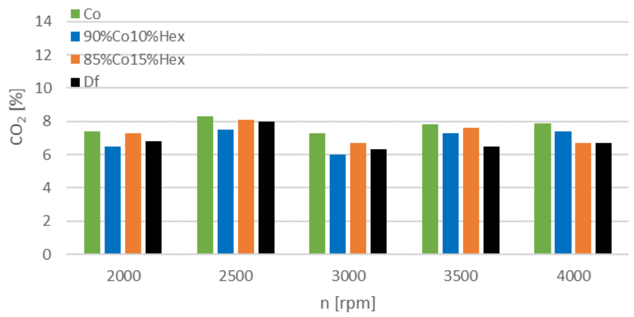


Fig. 3. The course of the concentration of carbon dioxide (CO_2) in the exhaust gas depending on the rotational speed, for the operation of the Diesel engine powered by the tested fuels, a) case 1 (measurement before catalytic converter), b) case 2 (measurement after the catalytic converter)

Figure 3 item A shows the results of the carbon dioxide (CO_2) concentration emitted during the operation of the engine running on the tested fuels (exhaust exhaust gas composition before the exhaust after-treatment system) under the chassis dynamometer (case 1).The analysis showed that over the entire speed range, CO_2 concentration were almost comparable to the use of diesel (Df). The differences were on the order of several percent. For case 2 (Fig. 3 item B – driving the vehicle in real traffic, on the road), the concentration of carbon dioxide (CO_2) when supplying the engine with canola oil over the entire speed range was higher compared to diesel (Df). The largest relative difference was 16% at 3500 rpm when powering the Co motor relative to Df. By supplying the engine with canola oil with the addition of n-hexane (10% and 15%), a lower CO_2 concentration was observed in relation to canola oil (Co) while in relation to diesel oil the largest relative difference was at a speed of 3500 rpm (about 14%) for 15% of the n-hexane additive.

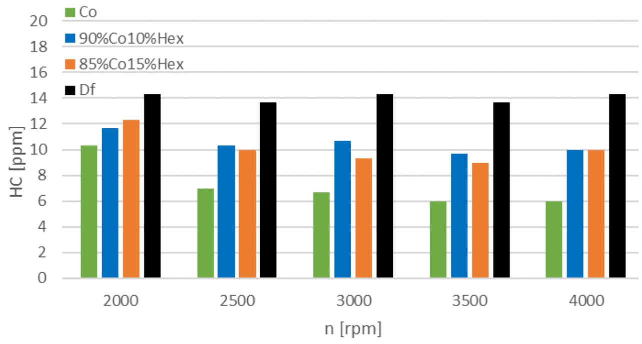


Fig. 4. The course of hydrocarbon concentration (HC) in the exhaust gas depending on the rotational speed, for the operation of the Diesel engine powered by the tested fuels (case 1)

The case studies carried out for case 2 (driving in real traffic, on the road) concerned the exhaust gas composition of gases behind the catalytic converter and the particulate filter. In this case, a trace amount of carbon monoxide (CO) and hydrocarbons (HC) in the exhaust gases was recorded. The operation of an engine powered by vegetable fuels (exhaust gas composition before the exhaust aftertreatment system) under the vehicle's driving conditions on the chassis dynamometer (Fig. 4 – case 1) showed higher HC concentration when powered Df relative to Co over the entire engine speed range.

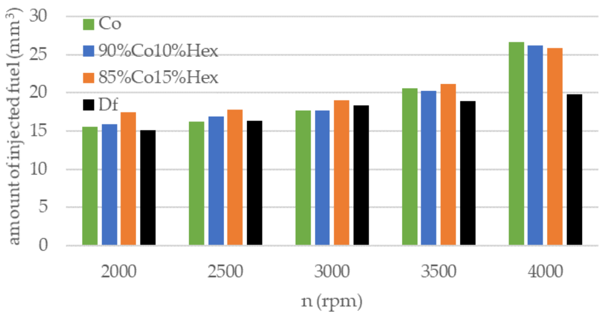


Fig. 5. Amount of fuel injected depending on the rotational speeds, for the operation of the Diesel engine powered by the tested fuels (case 1)

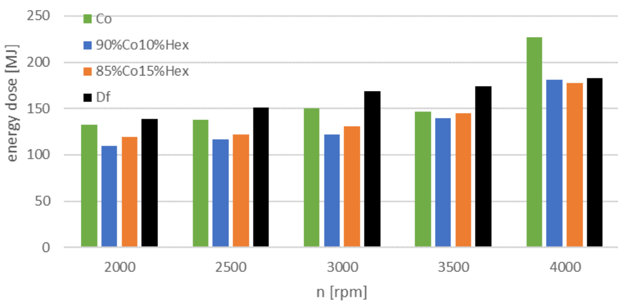


Fig. 6. Energy dose of the test fuels, depending on the rotational speeds, for the operation of the Diesel engine powered by the tested fuels (case 2)

Obtaining the same engine operating point determined by its rotational speed and load required the supply of a different volumetric dose of the tested fuels – as shown in

Fig 5. This was related to the different physicochemical properties of the fuels, which influenced the injection strategy implemented by the controller. At the same time, the tested fuels had different calorific values, which translated into the energy dose of injected fuels, which can be defined as the product of the calorific value of the fuel and the mass of the injected fuel (Fig 6). It seems that the above had a decisive impact on the observed ecological parameters obtained during the research.

4. Conclusions

Supplying a diesel engine with unprocessed canola oil is difficult due to its physicochemical properties, which are different from diesel fuel. This is especially true for viscosity and density, especially at low ambient temperatures. The high viscosity of canola oil is significantly reduced with the addition of n-hexane. Observation of the ecological parameters indicates that for pure canola oil (Co) and canola oil with the addition of n-hexane (10% and 15%), the level of NO_x concentration relative to diesel oil (Df) was higher for both cases (measurement before and after the catalytic converter), which is also confirmed by the conducted research described in the available literature [19–21]. The observed quantitative change between the investigated cases was mainly due to the operation of the haust gas cleaning system. When fueling the diesel engine with vegetable fuels, no significant differences were observed from Df in terms of carbon dioxide (CO_2) concentration. This leads to the conclusion that the use of canola oil with the addition of n-hexane may be a pro-ecological effect due to the absorption of carbon dioxide during plant growth. Therefore, it is possible to operate the tested engine when powered by canola oil and a mixture of canola oil with n-hexane in real vehicle traffic conditions. The only problem in terms of ecological conditions is the increased concentration of nitrogen oxides – further scientific considerations of the authors of the work will be devoted to limiting this phenomenon.

Nomenclature

CI	compression ignition
Co	canola oil
Df	diesel fuel
DI	direct injection
CR	common rail

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