INFLUENCE OF BIOFUELS ON SKODA RAPID 1.6 TDI ENGINE'S EMISSIONS AND FUEL CONSUMPTION

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Abstract
The road transportation increases all around the globe and bio-fuels become the forefront of public interest. The bio-fuels enable to replace completely or partially the existing energetic resources with their limited capacities. The usage of bio-fuels is particularly beneficial in terms of reducing dependence on fossil fuels (petroleum) and consequently negative environmental impacts. According to the Article 3, Directive 2009/28/EC, each member state has to ensure that an energy share from renewable sources in all forms of transportation reaches at least 10% of the final consumption of energy in transportation till 2020. This article analyses and compares selected bio-fuels and their influence on engine's emissions parameters. On diesel engine of Skoda Rapid 1.6 TDI were measured harmful emissions in the testing using the NEDC on chassis dynamometer. As fuels, were chosen pure diesel fuel, pure HVO and pure FAME. Furthemore, fuel consumption were monitored.

Key words: *driving cycle; HVO; RME.*

INTRODUCTION

The steep population growth over recent decades has led to a significant increase in demand for fossil energies. Most estimates present the world's oil reserves for the next 50 years, and although projections for relatively early depletion of fossil fuels are constantly delaying due to improvements in drilling technology and discovery of large shale gas stocks, efforts are being made to exploit and develop renewable sources such as fuels. The interest in their application and research is not only due to declining oil reserves but also many others, such as efforts to minimize harmful emissions and impact on the environment and human health, efforts to reduce dependence on oil suppliers *(Bae & Kim, 2017)*.
The consumption of fossil fuels keeps growing together with significant increase of sales of diesel vehicles in Europe. Emissions coming from these vehicles have an impact on both human health and the environment *(Dockery, Schwartz & Spengler, 1992; Pourazar, Frew, Blomberg, Helleday, Kelly, & Wilson, 2004; Goyal, Jaiswal, Kumar, Dadoo & Dwarakanath, 2010; Jacobson, 2001; Koch, 2011)*.
The European Union is increasingly focusing on the use of biofuels. At present, as a biofuel component in the Czech Republic, it is blended (according to legislation at least half of the sales network of the filling station operator up to 5% by volume, especially bioethanol or ethyl-tert-butyl ether (ETBE) produced from bioethanol. Bioethanol is therefore used as a component in conventional automotive gasoline fuels *(Mužíková, Pospíšil & Šebor, 2010)*. Fatty acid methyl esters (FAME) are used as the bio-component in diesel fuels. In the Czech Republic, rapeseed oil methyl esters (RME) are used in particular. At present, up to 7% FAME is added to the diesel fuel. The market also includes so called blended diesel fuels containing more than 30% by volume of FAME *(Šimáček, Vrtiška, Mužíková & Pospíšil, 2017)*.
The aim of the regulations of the European Union is to increase the proportion of renewable energy up to 10% by the year 2020 in order to reduce the production of greenhouse gases, especially CO_2 (Directive 28/2009/CE).

MATERIALS AND METHODS

In the experiment, the emissions and fuel consumption of the Škoda Rapid 1,6 TDI passenger car were measured on chassis dynamometer.
The car was placed on chassis dynamometer by a driven axle and secured by a parking brake and fixed with locking straps. A gas analyzer tube (FTIR) was introduced into the exhaust pipe. Engine speed, particle filter clogging, and other values were recorded and stored at a sampling rate of ± 1Hz using the VAG-COM system. The measured quantities from the FTIR gas analyzer and the VAG-COM system

were then synchronized. To the engine will be fuel transported by a fuel pump from an external fuel tank located on a laboratory scale. Using this scale fuel consumption was measured. 67/5000
Measurements were made with the engine warmed to its operating temperature. Car cooling was provided by a suction fan. Emission measurements and other operating parameters were measured during the New European Driving Cycle (NEDC) cycles.
The selected operating parameters selected the emissions and fuel consumption of a passenger car diesel engine using two biofuels - RME (rape oil methyl ester) and HVO (hydrogenated vegetable oil). The reference fuel served pure diesel. Measurements were made on the Škoda Rapid 1.6 TDI passenger car (see Table 1).

Tab. 1 Basic parameters of the Škoda Rapid 1.6 tdi

Engine type	compression ignition, turbo charged
Cylinders volume	1598 cm^3
Cylinders	4
Compression ratio	16,5:1
Injection	Common rail
Power	77 kW at 3000 rpm
Torque	250 Nm at 1500 rpm
Weight	1265 kg
EU norm	Euro 5

During measurement has been used, these devices:

- Chassis dynamometer
- Fan FILCAR AL - 1500 / C
- Gas analyzator MATRIX MG-5
- VIBRA AJ-6200CE Laboratory weight

The chassis dynamometer consists of two cylinders connected by a chain. To improve the adhesive properties, one cylinder is provided with an anti-slip surface. The cylinders are fitted on one side with adjustable flywheels designed to simulate the inertia of the vehicle. On the other side, a direct-current electric motor of 56 kW is connected to one cylinder. A 125 kW turbine brake is connected to the second cylinder for static power measurement purposes. Vehicle cooling during operation was provided by the FILCAR AL - 1500 / C suction fan. Then was used analyzer FTIR. FTIR is infrared spectrometer for automated, high-precision gas concentration monitoring in real time. It allows the detection and quantification of gas occurring in a concentration of only a few ppb (parts per billion) to one hundred percent. It measures up to 5 spectra per second at a spectral resolution of 0.5 cm -1 and up to 30 spectra per second at a spectral resolution of 4 cm^{-1}. For accurate measurement of fuel consumption was used laboratory weight, operating on the principle of a vibration cell that is highly resistant to electromagnetic and electrostatic interference and temperature changes (see Fig. 1).

Fig. 1 Connecting the scales to the vehicle

Pure RME and pure HVO (NExBTL from Neste Oil) were tested. The reference fuel was pure diesel. The properties of the individual fuels are described in Table 2.

Tab. 2 Basic properties of tested fuels

Parameter	Diesel	HVO	RME
Calorific value [MJ·kg^{-1}]	43,1	44,1	37,2
Density at 15°C [kg·m^{-3}]	833,5	778,6	882,5
Kin. viscosity at 40 °C [mm^2·s^{-1}]	2,66	2,89	4,63
Flesh Point [°C]	60	983	>120
Filterability - CFPP [°C]	-24	-38	-26
Cetan number [-]	555	>70.0	60
Cetan index [-]	552,2	793,1	58,5

RESULTS AND DISCUSSION

The results of emissions and fuel consumption measured during the NEDC driving cycle are described in the following text and their calculated averages from the individual measurements are shown in the graphs. These graphs include an error line based on standard deviations. For the same reason, the experiment was started and ended when running on the selected reference fuel - Diesel 1 (start) and Diesel 2 (terminating), see the following graphs for emissions. Emissions were measured according to the above mentioned methodology for the NEDC driving cycle. Three driving cycles (measurements) were performed for Diesel and HVO and 4 driving cycles were performed for RME. For illustration, Fig. 2 show the measured values of the instant CO_2 concentration when running a diesel car for 3 NEDC cycles.

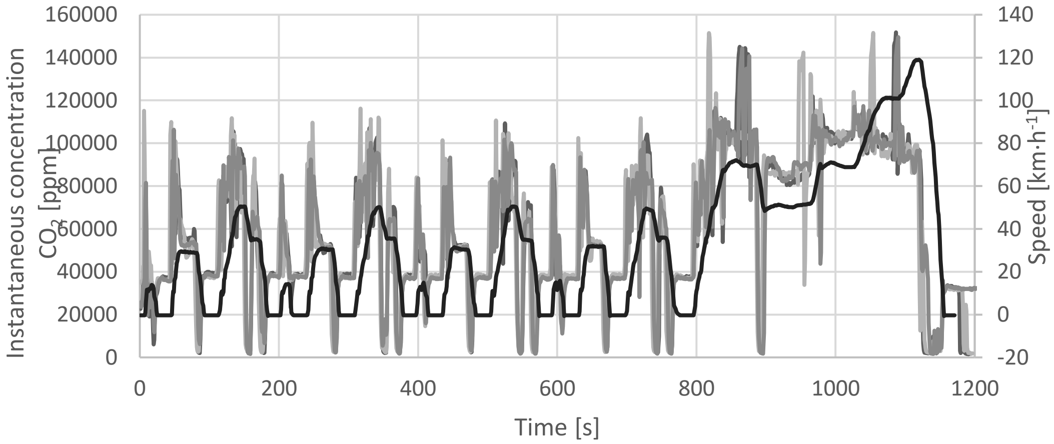

Fig. 2 Instant CO_2 concentration for 3 driving cycles NEDC

The lowest CO_2 emissions were measured during HVO operation. Compared to RME, an average of 10.2 g · km^{-1} is lower. CO_2 values for diesel were measured higher by 5.6 g · km^{-1} compared to HVO see on Fig. 3.

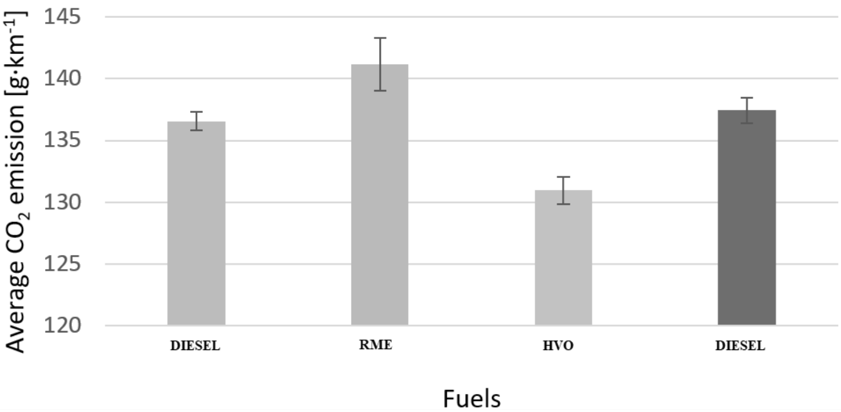

Fig. 3 Emission CO_2

These CO_2 values, as a product of high-quality combustion, correspond to the measured fuel consumption for each fuel. Higher levels of carbon dioxide can also be caused by oxygen, which contains much more fuel than oil and HVO.
The lowest and almost negligible CO emission values were measured at RME, with an average value of $7.710 \cdot 10^{-4}$ g · km^{-1}. This is probably due to the high content of oxygen in RME and therefore its high oxidation (CO_2 generation). Higher values were measured for diesel and HVO, which are probably due to the absence of oxygen in both fuels. The CO emission differences were very low when using diesel as compared to HVO see on Fig. 4. To the same conclusion was reached by the authors (*Millo, Debnath, Vlachos, Ciaravino, Postrioti & Buitoni, 2015*), in their publication they write: CO and HC specific emissions were significantly reduced with both RME and HVO blends. This behavior was more evident for the HVO, likely due to the better ignition quality of this fuel.

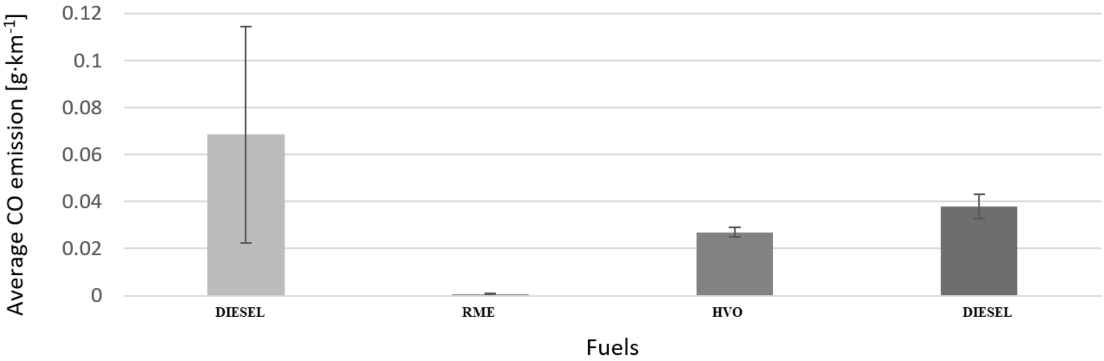

Fig. 4 Emission CO

However, the average CO emission value for diesel distorted one measurement during which the catalyst catalyst was regenerated. This phenomenon has dramatically increased the instantaneous concentrations of most measured emission gases, with the highest increase being measured for CO emissions, which is approximately 7 times the average of the measurable values.
Differences in NO_x production were recorded between HVO and diesel very small, averaging 0.009 g per cycle. Higher values were found for RME for which the average value of this emission was 0.224 g, ie about 0.06 g · km^{-1} more. This may be due to a higher rate of pressure wave propagation in RME than diesel, which typically causes earlier injections of conventional engines, and thus earlier ignition, which may be associated with higher oxygen content in fuel due to higher NO_X emissions, see on Fig. 5.
Authors (*Millo, Debnath, Vlachos, Ciaravino, Postrioti & Buitoni, 2015*) in their study report write that (Millo, Debnath, Vlachos, Ciaravino, Postrioti & Buitoni, 2015) NOx emissions of HVO fuel were generally comparable with of diesel fuel. Most studies for example *(Hajbabaei, Johnson, Okamoto, Mitchell, Pullman & Durbin, 2012)* have shown that HVO generally reduces NOx emissions compared to conventional diesel fuel and biodiesel.

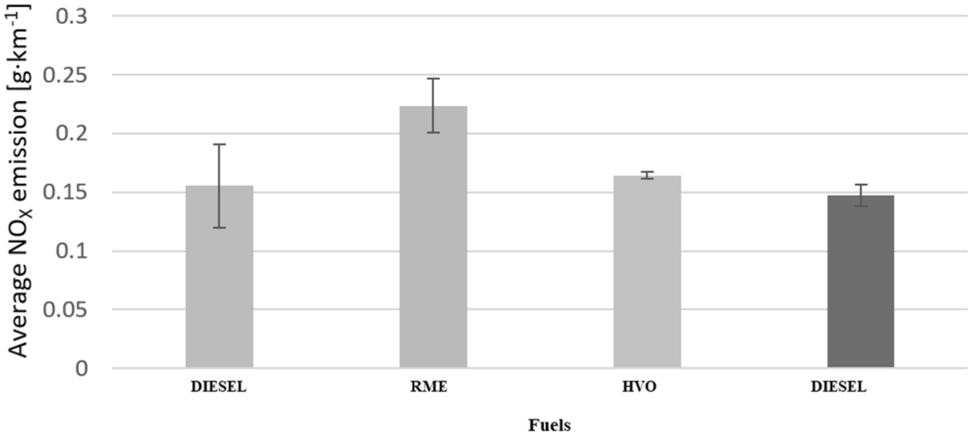

Fig. 5 Emission NO_x

The fuel consumption ratios correspond to their calorific values. Most fuel (540 g) per NEDC cycle was therefore consumed on average when the car is running on RME (calorific value 37.2 MJ · kg^{-1}) About 72 grams less consumed the vehicle while running on diesel (calorific value 43.1 MJ · kg^{-1}) and the lowest consumption was achieved with HVO (calorific value 44.1 MJ · kg^{-1}) by 86 g less than RME, see on Fig 6.

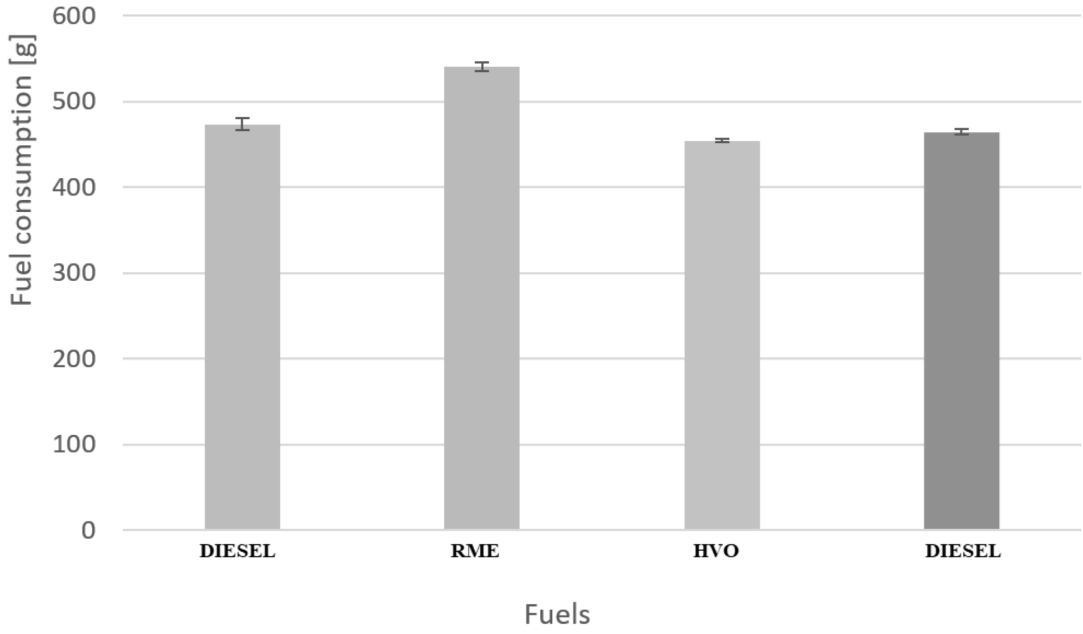

Fig. 6 Fuel consumption per NEDC cyklus

The review of the authors *(Chauhan, Singh, Cho & Lim, 2016)* shows that similar biofuels generally cause an increase in NOx emission and a decrease in CO emissions compared to diesel. HVO has potential advantages with respect to both petrodiesel and biodiesel in terms of production costs, exhaust emissions and adaptability to current engine designs. In the case of renewable diesel, all regulated emissions as well as fuel consumption can be reduced write *(Soo-Young No, 2014)*.

CONCLUSIONS

In the practical part, the effect of the rapeseed oil methyl ester (RED) and hydrogenated vegetable oil on the gaseous emissions and fuel consumption of the Škoda Rapid 1,6 TDI passenger car was evaluated, using diesel fuel as the reference fuel. In total, the smallest amount of the most significant greenhouse gases, CO_2, N_2O and CH_4, produced a test vehicle during the NEDC driving cycle when operating on HVO. Compared to RME, CO_2 emissions averaged about 10 g · km^{-1} were lower. Similar to slightly higher values than HVO were recorded when running on diesel fuel. In spite of the lowest measured N_2O values for RME, this biofuel appears to be least environmentally friendly in terms of greenhouse gas production. As far as fuel consumption is concerned, the lowest values (about 464 g · km^{-1}) were measured during HVO operation, again very similar to diesel operation (454 g · km^{-1}). With RME, fuel consumption was around 540 g · km^{-1}, which is probably due to its lower calorific value compared to the other two fuels tested.

From the point of view of emissions and fuel consumption, HVO appears to be a good substitute for petroleum naphtha, showing similar and somewhat better properties than this fossil fuel. Another advantage of HVO compared to RME is the possibility of its production from non-food raw materials, which does not affect food prices and does not require the cultivation of extensive monocultural areas degrading the quality of the soil. Some biofuels appear to be a good alternative, sometimes a substitute for fossil fuels. After the depletion of oil stocks, they are likely to play a major role in the transport sector, with transport being further shuffled between alternative drives than before, eg electric drives and hydrogen fuel cells.

The results of the study *(Pexa, Čedík & Pražan, 2016)* also show that biofuels are significantly affected by the combustion engine pollutants. Especially biofuels containing the HVO or butanol exhibit lower smokiness and up to 40% less NO_x production.

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