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Comparison of the operating characteristics of the internal combustion engine using rapeseed oil methyl ester and hydrogenated oil

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Abstract. The issue of the use of alternative fuels in diesel engines is discussed in this paper. The purpose is to reduce the dependence of EU Member States on fuels of petroleum origin. One of the possibilities is the use of oils from biological materials. The use of the oil in standard engines is not usually possible. The engine modification or the fuel modification is necessary. Esterification or hydrogenation of oils can be used as the fuel modification. Impact of these changes on the operational characteristics of a turbocharged internal combustion engine is observed in the paper. The internal combustion engine of the tractor Zetor Foretrra 8641 was used for testing. This engine was burdened using a dynamometer to the PTO. Performance and fuel consumption of the engine were monitored during measurement. As fuels the 100% rapeseed methyl ester and 100% hydrogenated oil was elected. Based on the results we can say that the operating parameters of the internal combustion engine does not change significantly when using these fuels.

Key words: biofuels, power, fuel consumption, combustion engine, vegetable oil, RME, HVO.

INTRODUCTION

In an effort to reduce the amount of the greenhouse gases emitted into the atmosphere, to reduce the dependency on the fossil products and their import and to support local production, the liquid biofuels are used, such as vegetable oils and their products. Oil from a variety of plants with suitable oil characteristics can be used (Vanichseni et al., 2003; Sidibé et al., 2010; No, 2011).

Vegetable oil may be used in several ways while the modification of fuel or the fuel system is always required. Raw vegetable oil can be added into the diesel oil in ratio 20% oil and 80% diesel oil and it can be burned without modification of the engine (Yilmaz & Morton, 2011), some sources state 30% of oil (Masjuki et al., 2001). Another possibility is to use pure vegetable oil but it requires modification of the fuel system because it is necessary to preheat the oil to reduce viscosity (Pexa et al., 2014). The recommended heating temperature varies significantly, the values range from 70 °C (Kumar et al., 2005) to 135 °C (Pugazhvadivu & Jeyachandran, 2005).

Another possible use of vegetable oil is its chemical processing such as transesterification, micro-emulsions, cracking or hydrogenation (No, 2011; Shambhu et al., 2012; Pexa et al., 2013a).

FAME (Fatty Acid Methyl Ester) is produced by transesterification and it may be produced from the vegetable and animal fat (Sirviö et al., 2014). The main disadvantages of FAME are high price of the input feedstock and low storage and oxidation stability. In comparison with diesel oil, generally FAME has lower mass calorific value, higher density and higher viscosity (Hönig & Hromádko, 2014; Rahman et al., 2014). Rapeseed methyl ester (RME) is currently the most widely used substitute for the diesel oil in Europe (Jokiniemi & Ahokas, 2013; Pexa & Mařík, 2014). Concerning RME the studies revealed approx. 5–10% lower engine performance and higher fuel consumption and approx. 3.5% lower average thermal efficiency, yet approx. 3% higher thermal efficiency at maximum load (No, 2011; Imran et al., 2013; Pexa et al., 2013b).

HVO (Hydrotreated Vegetable Oil), also called renewable diesel or green diesel, is fuel obtained by hydrodeoxygenation of vegetable oil. It consists of paraffinic hydrocarbons with a linear chain, it is free from aromatics, oxygen and sulphur, it has a high cetane number, lower density than diesel oil and comparable calorific value. Thus there are no problems usually connected with bio diesel (FAME), such as increased NO_X emission, deposit formation, storage stability problems, faster aging of engine oil or high cloud point (Aatola et al., 2008; Kučera & Rousek, 2008; No, 2014; Knothe, 2010; Naik et al., 2010; Hartikka et al., 2012). HVO has lower fuel consumption, lower loss of power and higher motor efficiency than conventional bio diesel (Duckhan et al., 2014; Kim et al., 2014).

The goal of the measurement was to compare performance parameters of the engine and specific fuel consumption of two differently processed fuels based on vegetable oil (HVO, RME). On the basis of the previous scientific work it is possible to assume that HVO will have better performance parameters of the engine as well as specific fuel consumption.

MATERIALS AND METHODS

The measurement was done using the tractor engine Zetor 1204 prefilled by means of turbocharger and placed in the tractor Zetor Forterra 8641. It is in-line 4 cylinder engine, its volume is 4.156 and rated power 60 kW (it is 53.4 kW on PTO according to the measurement made by Deutsche Landwirtschafts-Gesellschaft), the maximum torque is 35l Nm, the nominal specific fuel consumption is 253 g kWh^{-1} and the rated speed is 2,200 min^{-1}. The fuel is delivered to the engine by means of mechanical in-line injection pump, injecting is done by one injection with pressure 22 MPa, 12° before top dead center. The operating time of the mentioned engine does not exceed 100 operating hours.

The engine was loaded by the dynamometer AW NEB 400 connected to PTO, torque was recorded by the torque sensor MANNER Mfi 2500Nm_2000U/min with accuracy 0.25%. The torque values recorded by the sensor placed on PTO are converted to the engine torque by means of appropriate gear ratio (3.543). The losses in the gearbox have no effect on the comparative measuring of the influence of fuel on the external speed characteristics of the engine and therefore they are not taken into consideration. The fuel consumption was recorded by means of the flowmeter AIC VERITAS 4004 with measurement error 1%. Data were saved on the hard disk of the measuring computer (netbook), with the use of A/D converter LabJack U6 with frequency 2 Hz, in the form of text file. The programmes MS Excel and Mathcad were used for data evaluation.

The following fuels were chosen for the test: rapeseed methyl ester and hydrotreated vegetable oil. Their basic characteristics are presented (Table 1).

Table 4. Basic parameters of the measured fuels

Fuel	Density at 15 °C (kg m^{-3})	Heating value (MJ kg^{-1})	Viscosity at 40 °C (mm^2 s^{-1})	Cetane number
HVO	750	44*	2.5–3.5*	80–99*
RME	880	37.5*	4.5*	51*

*(Aatola et al., 2008)

The external speed characteristics of the engine were measured for both tested fuels. Based on these characteristics, the measuring points were determined for the complete characteristic of specific fuel consumption. Subsequently, these points were connected by the polynomial function of the third degree with two unknown variables, using the method of least square error. Then the measuring points of the eight-point NRSC (Non-Road Steady Cycle) test were determined according to ISO 8178-4 (type C1) (Fig. 1). The points of the test are defined by rotation speed (idle, at max. torque and rated) and load in percentage (0, 10, 50, 75 and 100%). The test was used for measuring the specific fuel consumption. Specific fuel consumption for the whole NRSC test was calculated according to the equation (1). In every predetermined measurement point the measured parameters were stabilized.

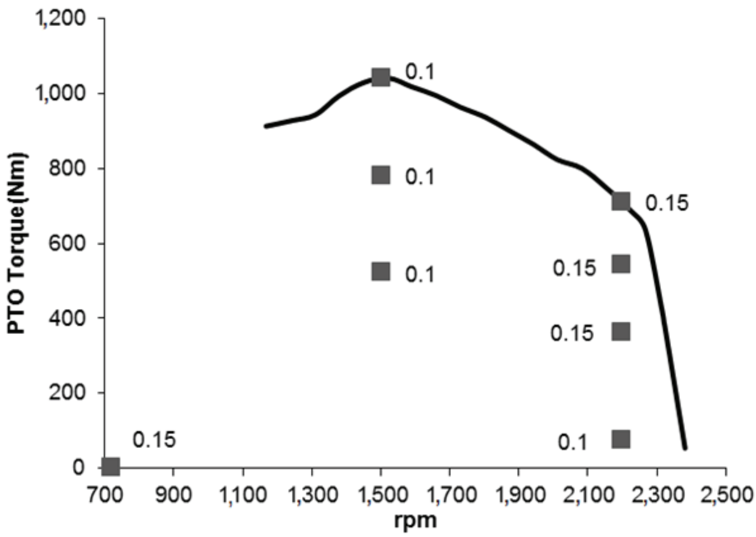

Figure 6. Measurements points for the NRSC test for HVO with weight factors.

$$m_{NRSC} = \frac{\sum_{i=1}^{8}\left(M_{Pi} \cdot WF_i\right)}{\sum_{i=1}^{8}\left(P_{PTO,i} \cdot WF_i\right)} \quad (1)$$

where: m_{NRSC} – Specific fuel consumption for whole NRSC test (g kWh^{-1}); $M_{P,i}$ –hourly fuel consumption (g h^{-1}); WF_i – weight factor (–); $P_{PTO,i}$ – power on the PTO (kW).

RESULTS AND DISCUSSION

The external speed characteristic for both tested fuels was created (Fig. 2). It is obvious that during the operation of the HVO engine, the maximum torque is reduced by approx. 0.9% and the maximum performance is reduced by approx. 6%. The specific fuel consumption of the HVO fuel is reduced in comparison to the RME fuel almost in the whole speed range. This is caused mainly by lower density of HVO in comparison with RME (Table 1). Increase of the specific fuel consumption of HVO from approx. 2,000 min^{-1} is caused by decrease of the torque or rather by performance in this speed range in comparison with RME.

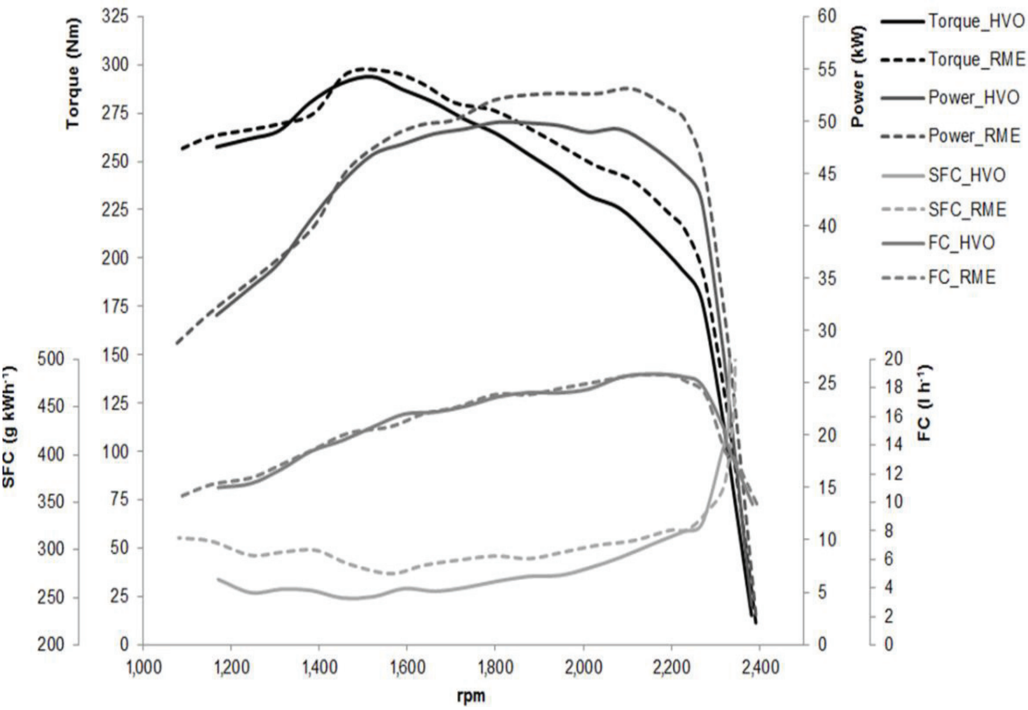

Figure 2. The external rotation speed characteristics for HVO and RME (SFC – specific fuel consumption, FC – fuel consumption).

From the presented results (Table 2, Fig. 2) it is obvious that the torque and performance are reduced by approx. 9.9% during rated speed of the engine. It is also obvious that the specific fuel consumption of HVO fuel is reduced by 1.9% during the rated speed. This is caused by lower engine performance during use of this fuel.

Table 5. Results of the measurement

Fuel	Max. Torque (Nm) rpm	Max. Power (kW) rpm	Min. SFC (g kWh^{-1}) rpm	Rated Torque (Nm)	Rated Power (kW)	Rated SFC (g kWh^{-1})	Torque Backup (%)
HVO	293.8 1,521	49.9 1,803	247.4 1,516	199.9	46	314.7	47
RME	296.5 1,559	53.1 2112	275.1 1,559	221.8	51.1	320.9	33.7

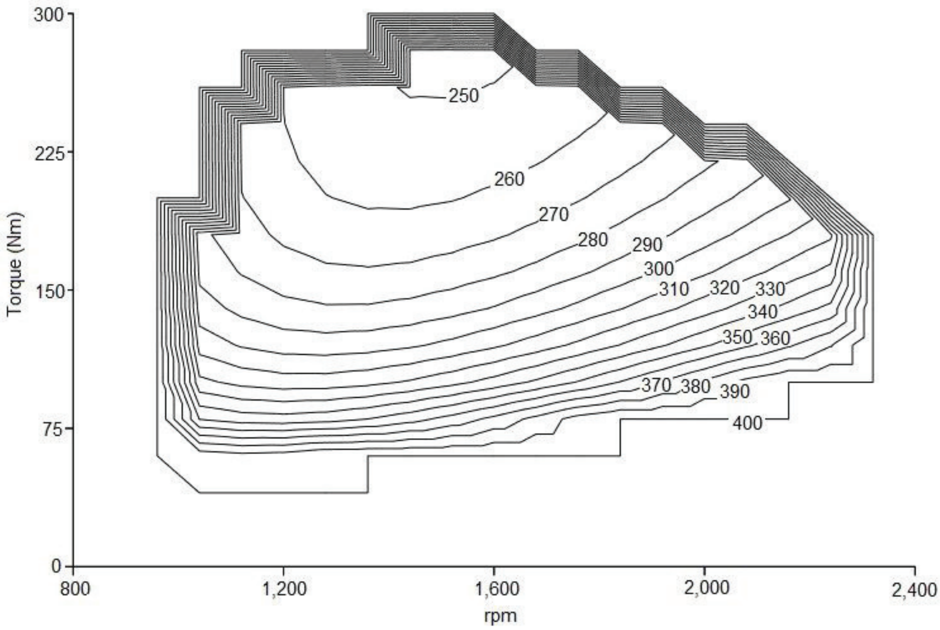

Figure 3. Complete characteristic of specific fuel consumption for HVO (g kWh^{-1}).

The complete characteristics of specific fuel consumption for HVO and RME were created (Figs 3, 4). For both variants minimums of specific fuel consumption were assessed from the complete and the external rotation speed characteristics. From the obtained results (Table 2, Figs 3, 4) it is evident that minimum of the specific fuel consumption of HVO fuel is approx. by 10.1% lower in comparison with the RME fuel and it is located at the similar rotation speed. It is also obvious that in case of HVO the specific fuel consumption is lower within the speed and load range than in case of RME.

The specific fuel consumption measured by means of NRSC test was 328.69 g kWh^{-1} for HVO fuel and 366.3 g kWh^{-1} for RME fuel, which is approx. 11% more.

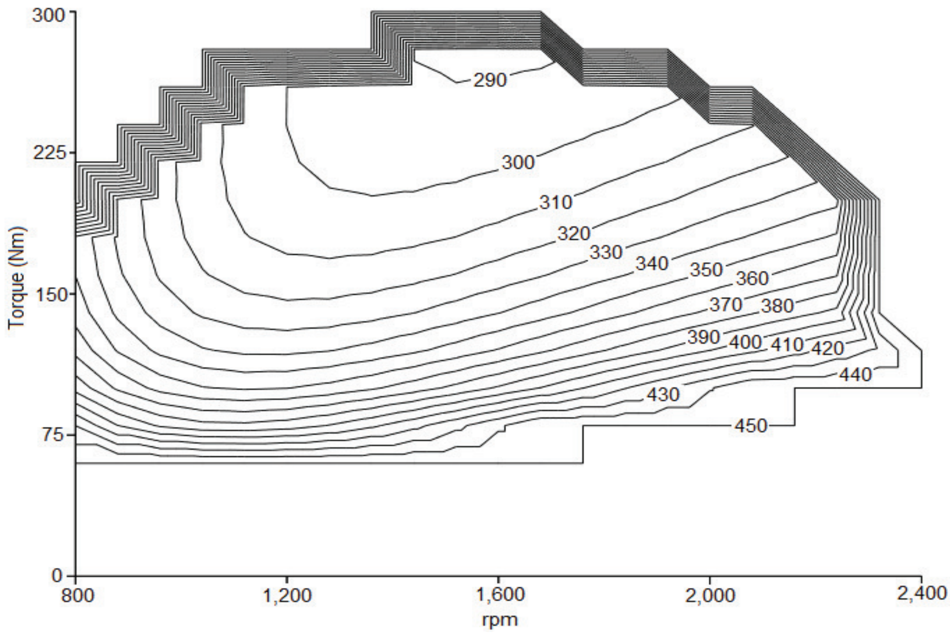

Figure 4. Complete characteristic of specific fuel consumption for RME (g kWh^{-1}).

CONCLUSIONS

Both tested fuels are based on vegetable oil and they differ only in production technology. Decrease of torque and performance during higher speed in case of use of HVO fuel can be attributed mainly to low density of this fuel because both the mass calorific value and the cetane number are higher than in case of RME. Therefore it can be assumed that if the amount of fuel is increased it would be possible to reach similar maximum performance as in case of RME.

Based on the results it is possible to state that the engine reached lower performance parameters when using HVO fuel than in case of RME, so the above mentioned assumptions were not confirmed. However, decrease of maximum performance was only 6.4% and the maximum torque was almost identical when accuracy of performance parameters was included.

The results also indicate that in comparison with RME the specific fuel consumption of HVO was lower. This proved to be the case within all measurements (external speed characteristics, complete characteristics and NRSC), which confirms the above mentioned assumptions and makes this oil modification interesting.

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