Agronomy Research **11** (1), 197–204, 2013

Impact of biofuels on characteristics of the engine tractor Zetor 8641 Forterra

M. Pexa[1,*], J. Mařík[1], K. Kubín[2] and K. Veselá[1]

[1]CULS-Czech University of Life Sciences Prague, Faculty of Engineering, Kamycka 129, 16521, Prague 6, Czech Republic;
[*]Correspondence: pexa@tf.czu.cz
[2]VUZT-Research institute of Agricultural Engineering p.r.i.; Czech Republic

Abstract: The European Union currently pays great attention to the possibilities for the use of biofuels to power mobile machinery. The main reasons for the promotion of biofuels is the effort of Member States to reduce dependence on oil imports, efforts to reduce emissions from internal combustion engines and also efforts to support agriculture. As the best substitute for diesel, promoting fatty acid methyl ester, namely in the Czech conditions rapeseed methyl ester (RME). Requirements for diesel fuel are the norm ČSN EN 590 and prescribes requirements for RME standard ČSN EN 14214. At present, based on the requirements of EU directives there is a mandatory addition of methyl ester in diesel of a maximum volume fraction of 7%. This blended fuel complies with ČSN EN 590 and can be used without any modification to existing diesel engines. Production of methyl ester of fatty acids is energy intensive and therefore offer, with the allowance made for the structural adjustment of the combustion engine, the possibility to use a mixture of diesel fuel and oil directly. In this paper they are compared on the basis of the complete characteristics of the engine performance parameters (torque and engine power) and minimum specific fuel consumption. Based on standardised test NRSC (non-road steady cycle) are also compared smoke and fuel consumption of the internal combustion engine of a Zetor 8641 Forterra tractor (tractor has worked less than 100 hours). As the fuel is a mixture of different ratios of selected diesel with rapeseed oil, jatropha curcas oil and rapeseed oil methyl ester.

Key words: biofuels, smoke, fuel consumption, non-road steady cycle.

INTRODUCTION

As the best substitute for diesel fuel, which covers most of the energy consumption of agricultural equipment, the **fatty acid methyl esters** (FAME) are currently being promoted. Specifically in the Czech Republic, the most common substitute for diesel oil is Rapeseed Oil Methyl Ester (RME). Although the RME is chemically different from petroleum products, its fuel properties such as density, viscosity, calorific value and combustion process, the diesel is very close (Table 1). Requirements for the diesel fuel are specified in the standard ČSN EN 590 (2010) and the RME requirements prescribes the standard ČSN EN 14214 (2010).

Another option is to use vegetable oil (**rapeseed oil**). The idea is to use it to drive machines originated in 1895 when Rudolf Diesel invented the diesel engine. Currently, mainly two views on propulsion engines using vegetable oil are widespread. Engine engineers and technicians refuse to address this issue (damage to both the pump and the motor). In their opinion, they are supported by enthusiasts who pour vegetable oil into the tank without any modifications or they use an unprofessionally rebuilt diesel engine. The vegetable oil is denser than the oil and its viscosity is higher (Table 1). There are basically two ways to reduce the viscosity:

- chemically – so do the manufacturers of the RME,
- by heating – by heating the vegetable oil a large increase in its fluidity can be achieved. (Gabrielová, 2010).

Similar to the rapeseed oil is the oil from the African plant **Jatropha Curcas**. Jatropha Curcas has the advantage that it is grown on agriculturally unsuitable soils, meaning it produces little or no carbon deficiency of the soil and thus provides an immediate advantage. The biodiesel made from Jatropha Curcas is very close to the biodiesel satisfying the ČSN EN 14214 standard. Properties of the oil, particularly its quality and density, are important for production of the biodiesel (Table 1). Generally, it is necessary to reach small oil contamination, low acid number, low levels of phosphorus, water and ash particles and to increase its oxidative stability. (Achten et al., 2008; Mazancová & Panáčková, 2011; Liu et al., 2012).

The raw oil can be poured directly into the diesel engines without major modifications. It has a higher viscosity than normal petrol, which doesn't cause a real problem when it is used in areas with a higher temperature. Thanks to the higher oxygen content, the engine has got more power under full load than that of diesel. Some systems can be divided into two fuel tanks. The motor is started and stopped using the mineral oil. There may be used a specially modified engine. Unlike the diesel, the biodiesel is very biodegradable (within 21 days the degradation is around 90%), contains almost zero of sulfur and heavy metals, and generally is low in emissions. (Huang et al., 2010; Chauhan et al., 2010; Mazancová & Panáčková, 2011; Varatharajan et al., 2011).

Table 1. Comparison of basic parameters of the diesel fuel (ČSN EN 590), RME (ČSN EN 14214), rapeseed oil and the oil from Jatropha Curcas

Request	Diesel	Jatropha oil	Rapeseed oil	RME
Density at 15°C (kg m^{-3})	820 to 860	919	915	860–900
Kinematic viscosity at 40°C (mm^2 s^{-1})	2.0–4.5	50	35	3.5–5.0
Freezing Point (°C)	-4 / -22	8		-8 / -20
Flash Point (°C)	over 55	240	246	over 120
Cetane number	min. 51	51	38	min. 51
Calorific value (MJ kg^{-1})	42,5	39.6	36	37.1–40.7
Carbon residue (%) by weight	0.10–0.30	0.64		max. 0.3

The aim of this paper is to compare the influence of different types of fuels containing bio-characteristics on the tractor engine (they were chosen different mixing ratios of the biofuel and the diesel). These characteristics were measured for fuel consumption and particulate matter (PM). As fuel for the engine of the Zetor 8641 Forterra tractor (less than 100 mth) blends of the diesel fuel with the bio fuel were used (the percentage indicates the proportion of the biocomponent and the rest is complemented by a clean diesel) – 5.5%, 19.7%, 33.9%, 48% and 100% RME, 5.5%

and 19.7% of the oil from Jatropha Curcas, 5.5% and 19.7% of the rapeseed oil (the higher share of oil can not be used due to a significant change in viscosity and density of the fuel).

MATERIAL AND METHODS

The fuel system of the tractor was not constructed for fuels containing FAME, Jatropha oil, canola oil. To the rear PTO of the Zetor 8641 Forterra tractor (Fig. 1) to, turbo-blower supercharged engine with direct-injection, engine capacity 4,156 cm^3, max. power 60 kW, max. torque 351 Nm, min. specific fuel consumption 253 g $(kW\ h)^{-1}$, rated speed 2,200 min^{-1} a hydraulic dynamometer AW NEB 400 was attached (Table 4 and the Fig. 1). To the fuel system was added a tractor fuel measuring device, which contains two flowmeters Macnaught MSeries FLOWMETER M2ASP-1R (1% accuracy).

Figure 1. Dynamometer AW NEB 400.

For smoke measurement purposes, the Brain Bee analyser was used (accuracy of opacity – 2%, temperature 2.5°C (Pexa & Kubín, (2012)).

Table 2. Basic technical parameters of the dynamometer AW NEB 400

Parameter	Value
Maximum torque on VH (Nm)	2,850
VH Maximum speed (min^{-1})	3,200
Maximum braking power (kW)	343
Maximum braking power at a speed of 540 min^{-1} VH (kW)	149

Table 3. Measuring points NRSC test

Mode number	Engine speed	Load (%)	Weighting factor
1	Rated	100	0.15
2	Rated	75	0.15
3	Rated	50	0.15
4	Rated	10	0.10
5	Intermediate	100	0.10
6	Intermediate	75	0.10
7	Intermediate	50	0.10
8	Idle	–	0.15

At first, the external rotation speed characteristic was measured. Some external speed characteristics were selected as measuring points for the NRSC tests that can be used in addition to assessing the technical condition of the internal combustion engine, also to examine the impact of emissions on human health. (Topinka et al., 2012) The NRSC test (2005/13/EC, 2000/25/EC, 2004/26/EC, 97/68/EC) consists of a series of eight modes of speed and torque measurements (Table 3):

- *rated speed* means the maximum rotation speed specified by the manufacturer, which allows the controller to operate at the full load,
- *intermediate speed* is the speed at maximum engine torque when the speed is in the range from 60 to 75% of the rated speed,
- *load shall* mean the percentage of the maximum available torque at the given engine rotation speed,
- *weighting factor* represents the weight of the calculation procedure when calculating the resulting fuel consumption.

After determining the measuring points of the NRSC test, the measurements of the fuel consumption and the smoke in the individual sections of the test were carried out. The specific fuel consumption or specific emissions (g (kW h)$^{-1}$), respectively, for the whole NRSC test were calculated according to the equation (1).

$$m_{NRSC} = \frac{\sum_{i=1}^{8} \left(M_{P,i} \cdot VF_i \right)}{\sum_{i=1}^{8} \left(P_{PTO,i} \cdot VF_i \right)} \tag{1}$$

where m_{NRSC} – the specific fuel consumption and the specific emissions over the NRSC test (g (kW h)$^{-1}$); $M_{P,I}$ – the weight of the hourly fuel consumption or emissions produced in the i (g h^{-1}); VF – the mode weighting factor i (–); $P_{PTO,I}$ – the engine power to the PTO in the i (kW).

Furthermore, based on the external speed characteristic (Fig. 2), the eligible measuring points for building a complete motor characteristic (Fig. 3) were chosen. The measuring points (about 35–40) are determined so that most of them belong to the engine working space. Measuring of the individual points is carried out in a similar way as in the case of the NRSC test.

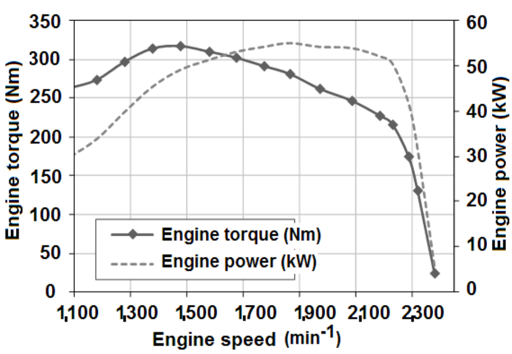


Figure 2. Example of the measured external speed characteristics – 5.5% RME.

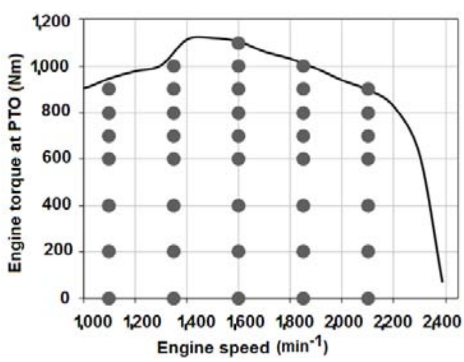


Figure 3. Example set of measuring points – 19.7% RME.

The torque values measured on the dynamometer PTO are converted – by using the appropriate gear ratio (3.543) – into the torque of the engine. To compare the impact of the fuel on the engine characteristics, the losses of the engine don't influence the PTO shaft, and therefore these are not considered. The resulting values of the specific fuel consumption and smoke therefore correspond to the engine power at the PTO shaft.

The measured values were then processed by using the MathCad program functions into the form of continuous surfaces. To create the continuous surfaces, the functions *REGRESS* and *INTERP* were used. The function *REGRESS* in conjunction with the interpolation function *INTERP* (2) approximates the preset polynomial fits of the measured points in the fuel consumption. The *PlochaZ* in the coordinates of the *PlochaXY* represents the coordinates of the rotation speed *om* and the torque *TM*. The result of the fitting is a continuous variable *Plocha(om,TM).* From this surface, the 41x41 square matrix (1,681 points) is created to be used for further processing. This matrix of the 1,681 points is then further processed using the interpolation function *SPLINE* (3), which interleaves the area precisely defined by the points in the 41x41 matrix. At the same time it is possible to get information on any point outside the matrix

$$R := \mathrm{regress}(PlochaXY, PlochaZ, 3)$$
$$Plocha(om, TM) := \mathrm{interp}\left[R, PlochaXY, PlochaZ, \begin{pmatrix} om \\ TM \end{pmatrix}\right] \tag{2}$$

$$Plocha(om, TM) := \mathrm{interp}\left[\mathrm{cspline}(PlochaXY, Plocha), PlochaXY, Plocha, \begin{pmatrix} om \\ TM \end{pmatrix}\right] \tag{3}$$

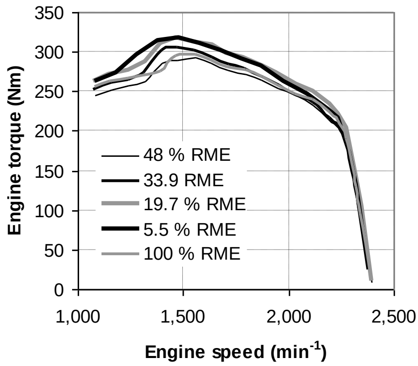
PlochaXY – matrix giving the coordinates of the speed om and the torque TM; PlochaZ – column of the data processed – variables (eg. fuel consumption) (g h^{-1}); 3 – polynomial of the 3rd degree (optional); Plocha (om, TM) – continuous variable area (g h^{-1}); Plocha – the matrix of the measured values in 1,681 points (g h^{-1}); om – coordinates of the rotation speed (min^{-1}); TM – coordinates of the torque (Nm).

RESULTS

Based on the methodology presented above, the external speed characteristics of the Zetor 8641 Forterra tractor were successively measured. The fuel composition in the engine tank was changed in these experiments. The measured data were processed and mathematically interpolated by the continuous function SPLINE (MathCad 14), to make available the motor torque value for any rotation speed.

From the waveform of the engine torque when running on biodiesel with-biofuels in Figs 4, 6 and 7 follows that the maximum torque values with the increasing proportion of the biofuel are – in general – reduced. The Figs 5, 6 and 7, which show the power of the engine with respect to the engine rotation speed, display the curves for the tested fuels. It is quite evident from these pictures that a higher proportion of the biofuel in the fuel causes – as a rule – the decrease in the engine power.

The complete engine characteristics are developed for all types of fuel. An example of the complete engine characteristic is shown in the Fig. 8, where the point of the minimum specific fuel consumption is indicated (Table 4).



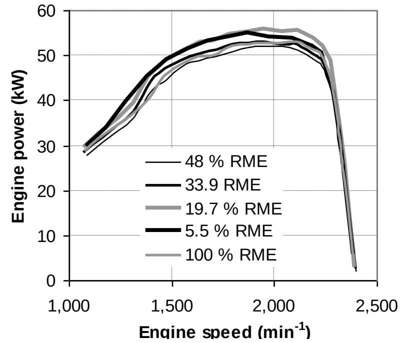
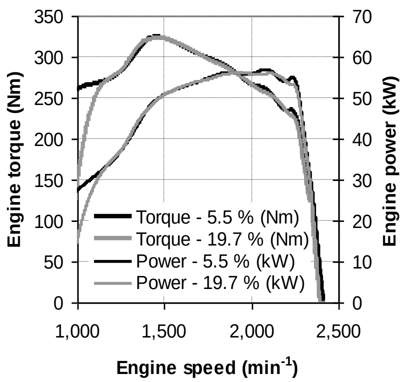


Figure 4. Dependence of torque on the rotation speed for different proportions of diesel and RME.

Figure 5. Dependence of the engine power on the rotation speed for different proportions of diesel and RME.



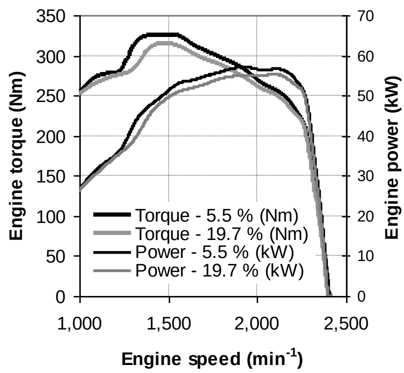


Figure 6. Performance parameters – jatropha curcas.

Figure 7. Performance parameters – Rapeseed oil.

An increasing share of the biofuels in the diesel is manifested by increasing specific fuel consumption. The lowest minimum specific fuel consumption (Table 4) 250.6 g $(kW\ h)^{-1}$ was achieved with the diesel fuel containing 5.5% rapeseed oil, while the highest minimum specific fuel consumption of 286.8 g $(kW\ h)^{-1}$ was achieved when the pure RME was used. The area of the low specific fuel consumption remained always the same. The engine rotation speed

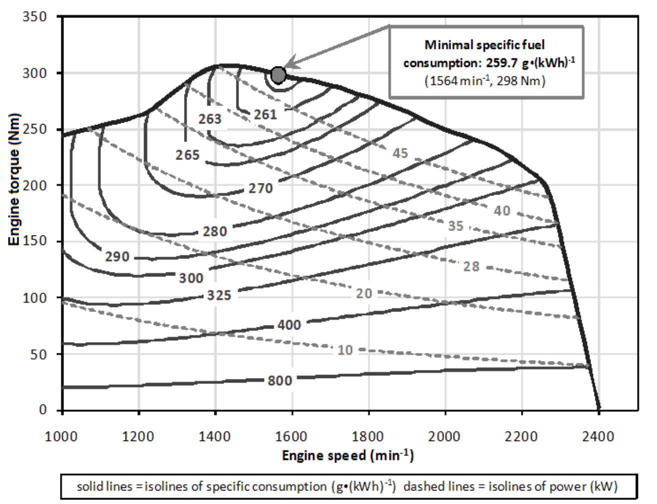


Figure 8. Complete characterisation of engine operating on RME 5.5%.

ranges from1,530 to 1,630 min^{-1} and the load can be found near the rated engine speed characteristics.

Table 4. Minimum specific fuel consumption

Biofuels	Share (%)	Minimum specific fuel consumption (g (kW h)$^{-1}$)	Engine speed (min^{-1})	Torque (Nm)
Jatropha Curcas	5.5	254.6	1,578	304
	19.7	255.4	1,624	312
Rapeseed oil	5.5	250.6	1,570	320
	19.7	256.6	1,552	296
RME	5.5	259.7	1,564	298
	19.7	262.6	1,612	311
	33.9	268.6	1,524	303
	48.0	274.0	1,548	289
	100	286.6	1,581	285

Other were, on the basis on the waveforms of the engine torque when running on the biodiesel, the various measuring points were determined for the NRSC test. The resulting values (fuel consumption, smoke) are presented in the Table 5.

Table 5. NRSC test results for selected types of fuel - Zetor Forterra 8641

Fuel	PM (g (kW h)$^{-1}$)	Specific Fuel consumption (g (kW h)$^{-1}$)
5.5% RME	0.365	325.6
19.7% RME	0.136	324.8
33.9% RME	0.094	339.7
48.0% RME	0.199	337.6
100% RME	0.048	367.0
5.5% Jatropha	0.175	319.3
19.7% Jatropha	0.105	337.3
5.5% Rapeseed oil	0.118	312.7
19.7% Rapeseed oil	0.117	318.8

CONCLUSION

For the measurements of the engine of the Zetor 8641 Forterra tractor with the attached PTO hydraulic dynamometer AW NEB 400 was used. By using the dynamometer, the individual points arising from the 8-point NRSC test points were fixed to create a complete engine characteristics. For recording the smoke level, the emission analyser BrainBee was used. To record the fuel consumption the fuel box with two fuel gauges Macnaught MSeries FLOWMETER M2ASP-1R was explored.

The results of the NRSC tests for smoke and fuel consumption are shown in the Table 5. The increasing share of biofuels is manifested by reduction of the smoke and on the other hand by an increase in the fuel consumption – this is confirmed by other authors Sahoo et al. (2009); Ong et al. (2011).

For each proportion of the biofuel in the diesel and for any variable (smoke and fuel consumption) the complete engine characteristics were created (an example presented in the Fig. 8). In these characteristics, the points of the minimum specific fuel consumption are evaluated. It can be concluded that the higher proportion of the biofuel in the fuel, the higher minimum specific fuel consumption (Table 4).

The disadvantage of the use of the fuels with a higher proportion of biofuels are mainly due to the higher maintenance demands put on the fuel system, lower engine power and greater fuel consumption. In contrast, the advantage of using biofuels is higher lubricity and reduction of emissions and very good biodegradability against the diesel.

ACKNOWLEDGMENT. The research carried out was supported by the grant project CZU 31190/1312/3139 – Comparison of the Impact of Biofuels on Emissions and Fuel Consumption by the NRSC Test of a Tractor.

REFERENCES

Achten, W.M.J., Verchot, L., Franken, Y.J., Mathijs, E., Singh, V.P., Aerts, R. & Muys, B. 2008. Jatropha bio-diesel production and use. *Biomass and Bioenergy*. **32**(12), 1063–1084.

Chauhan Bhupendra, S., Kumar, N., Jun, Y.D. & Lee, K.B. 2010. Performance and emission study of preheated Jatropha oil on medium capacity diesel engine. *Energy*. **35**(6), 2484–2492.

ČSN EN 14214+A1. 2010. *Automotive fuels – Fatty acid methyl esters (FAME) for diesel engines – Requirements and test methods*. ČSNI, 20 pp. (in Czech).

ČSN EN 590+A1. 2010. *Automotive fuels – Diesel – Requirements and test methods*. ČSNI, 16 pp. (in Czech).

Gabrielová, H. 2010 *Consumer issues, contributors,* '*Can a car run on vegetable oil?*' <http://www.ekoporadna.cz/wiki/doku.php?id=energie:muze_automobil_jezdit_na_rostlinny_olej&rev=1305581252>. in Czech [cit. 2011-07-13].

Huang, J., Wang, Y., Qin, J. & Roskilly, A.P. 2010. Comparative study of performance and emissions of a diesel engine using Chinese pistache and jatropha biodiesel. *Fuel Processing Technology*. **91**(11), 1761–1767.

Liu, K., Gao, S., Chung, T., Huang, C. & Lin, Y. 2012. Effect of process conditions on the removal of phospholipids from jatropha curcas oil during the degumming process. *Chemical Engineering Research and Design.* **90**(9), 1381–1386.

Mazancová, J. & Panáčková, B. 2011. *Využití jatropha sp k energetickým účelům*. Studie, Institut tropů a subtropů, Česká zemědělská univerzita v Praze. 24 pp. (in Czech).

Ong, H.C., Mahlia, T.M.I., Masjuki, H.H. & Norhasyima, R.S. 2011. Comparison of palm oil, jatropha curcas and calophyllum inophyllum for biodiesel: A review. *Renewable and Sustainable Energy Reviews.* **15**(8), 3501–3515.

Pexa, M. & Kubín, K. 2012 Effect of rapeseed methyl ester on fuel consumption and engine power. *Research in Agricultural Engineering*. **58**(2), 37–45.

Sahoo, P.K., Das, L.M., Babu, M.K.G., Arora, P., Singh, V.P., Kumar, N.R. & Varyani, T.S. 2009. Comparative evaluation of performance and emission characteristics of jatropha, karanja and polanga based biodiesel as fuel in a tractor engine. *Fuel*. **88**(9), 1698–1707.

Topinka, J., Milcova, A., Schmuczerova, J., Mazac, M., Pechout, M. & Vojtisek-Lom, M. 2012. Genotoxic potential of organic extracts from particle emissions of diesel and rapeseed oil powered engines. *Toxicology Letters*. **212**(1), 11–17.

Varatharajan, K., Cheralathan, M. & Velraj, R. 2011. Mitigation of NOx emissions from a jatropha biodiesel fuelled DI diesel engine using antioxidant additives. *Fuel*. **90**(8), 2721–2725.