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The impact of biofuels and technical engine condition to its smoke – Zetor 8641 Forterra

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Abstract: The large number of vehicles necessitated the introduction of rules that focus in addition to traffic safety on the ecology of operation of the engine especially. Over time, the emission limits in amendments to regulations tightened, and this also applies to agriculture. One of the efforts of the EU is the introduction of biofuels precisely because, among other things, they have an impact on reducing emissions from the operation of internal combustion engines. Fatty acid methyl ester is promoted as the best substitute for diesel fuels, in the Czech conditions, namely rapeseed methyl ester (RME – Rapeseed Methyl Ester). The requirements for diesel fuel are established with the standard EN 590 and the requirements for RME with the standard EN 14 214. Efforts are made to promote replacement of the old fleet with the new. A large percentage of obsolete vehicles in poor condition still remain in use in small farms. In this paper, a comparison of a smoke combustion engine tractor Zetor 8641 Forterra when using fuels with different ratios of diesel and RME is provided. For comparison, a common test is performed in the technical emission (measurement of smoke on the principle of free acceleration). In order to assess the influence of the technical condition of an internal combustion engine and rapeseed methyl ester on smoke, gradually simulated faults of turbochargers, opening pressure and spray of pre-injection fuel injectors on a selected motor are used. The result showed that deteriorating technical condition of an internal combustion engine decreases the positive effect of rapeseed oil methyl ester blended into the fuel on smoke.

Key words: biofuel, smoke, technical condition of the engine.

INTRODUCTION

In recent years, the European Union has devoted increasing attention to the possibility of using biofuels to power mobile machinery. The main requirements for biofuels include requiring similarity of its chemical and physical properties to conventional fuel.

Fatty acid methyl esters (FAME – Fatty Acid Methyl Ester) are currently promoted as the best substitute for diesel fuel, which covers most of the energy consumption of agricultural equipment. Specifically, in the Czech Republic, the most widespread substitution for diesel is Rapeseed Methyl Ester (RME) (Jokiniemi & Ahokas, 2013). The requirements for diesel fuel are established in the standard EN 590 (2010) and the requirements for RME in the standard EN 14214 (2010) (Table 1).

Based on the requirements of EU directives, it is mandatory to add RME (or other methyl esters) into diesel fuel with a maximum volume fraction of 7%. This blended fuel complies with DIN EN 590 (2010) and can be used without modification in the existing diesel engines.

Table 1. Comparison of the basic parameters of diesel fuel (ČSN EN 590) and RME (ČSN EN 14214)

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

In the agricultural and forestry tractors which are mainly driven by diesel engines, the exhaust pipe releases large amounts of gaseous emissions and particulate emissions into the air. These are mainly carbon monoxide (CO), carbon dioxide (CO_2), unburned hydrocarbons (HC), nitrogen oxides (NO_x), and particulate matter (PM). The negative impact of the emissions on the environment has proved the necessary for legislation to limit the amount of pollutants produced by the engine (Brožová & Růžička, 2009, Jasinskas et al., 2011). Therefore, the tractors currently marketed in the EU comply with all regulations regarding exhaust emissions.

The currently applicable legislation is based on Directive 97/68/EC (1997) and the related Directives 2004/26/EC (2004), 2000/25/EC (2000) and 2005/13/EC (2005). These Directives establish gradual tightening of the emission limits for agricultural and forestry tractors in the period from 2001–2014 in several stages (Bauer et al., 2006).

During certification, verification of compliance with the above emission limits for agricultural and forestry tractors are used in two different test cycles. NRSC (Non-Road Steady Cycle) is a measurement of the emission parameters of an engine at a steady state (Lijewski et al., 2013; Pexa et al., 2013). NRTC (Non-Road Transient Cycle) is used to measure the engine transient mode when the rotational speed and the engine load vary throughout the test cycle (Kotus et al., 2013; Pexa et al., 2013).

Emission certification ensures that no new tractor new startup exceeds the emission limits. Using a tractor, however, causes wear to all its parts, including the engine. This is reflected in the gradual increase in fuel consumption and increased emissions.

The aim of this paper is to compare the effect of different types of fuels containing biofuels and the technical condition of an engine on its smoke. For motor fuels, a 1204 Zetor 8641 Forterra (less than 100 hrs) was used successively with several mixtures (usually 6) from 100% diesel fuel to 100% rapeseed oil methyl ester. Various technical states of the internal combustion engine are simulated by changing the opening pressure of the injectors (20, 22, and 25 MPa), by change of pilot injection (7, 12, and 17°), by replacing the injectors for drain off, and a change of control of the turbocharger.

MATERIALS AND METHODS

Measurements were carried out on the tractor Zetor Forterra 8641 with the engine 1204. The engine power at rated speed is 60 kW, the maximum torque is 351 Nm, and the specific consumption at the rated speed of 2,200 1 min^{-1} is 253 g kWh^{-1}. In terms of design, they are inline engines with turbocharging in which the manufacturer has the fixed smoke limit of 63.5%. Fuel is supplied into the engine combustion chamber with a transported line injection pump in the form of a single injection initiated 12° before top dead center of the piston (factory setting).

The smoke combustion engine was measured by free acceleration. This method is defined in a regulation on technical emission for assessing the technical condition of an internal combustion diesel engine. The regulation stipulates repeating of four consecutive free accelerations. In the same experiment, a smoke free acceleration method was always repeated after each 10 measurements. Usually, the first measurement was not included in the evaluation because it served to purge the exhaust system. The smoke measurement analyzer used was Brain Bee (accuracy – 2% opacity).

In our analysis of the impact of the technical condition of an internal combustion engine, the type of biofuel-using motor 1204 (motor B) located in the laboratory was used due to the ease of simulating the selected faults. Motor B serves students in practical examples and measurement. Currently, the injector, turbocharger, and tightness of the combustion chamber are mainly damaged. A 1204 motor (motor A) located in the tractor Zetor Forterra 8641 (Fig. 1) that has less than 100 hours was chosen for comparison.

Figure 1. Combustion engine A.

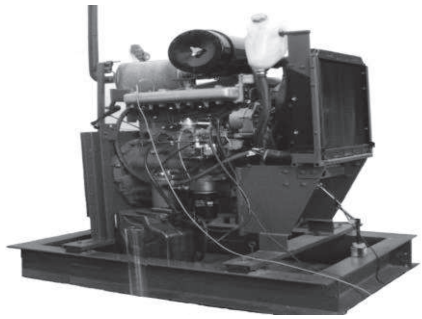

Figure 2. Internal combustion engine B.

The basic parameters were the engine's fuel injector's opening pressure of 22 MPa and the pilot injection angle of 12°. In order to monitor the change in smoke due to the technical condition of the internal combustion engine, the combination of parameters given in table 2 was gradually established.

Table 2. Changes in parameters of the combustion engine

Designation	Opening pressure injectors	Fuel injection	Note
1	22 MPa	12°	Engine A
2	22 MPa	12°	Engine A – damaged injectors of the engine B
3	22 MPa	7°	Engine B – damaged with leaking injector assembly
4	22 MPa	12°	Engine B – damaged with leaking injector assembly
5	22 MPa	17°	Engine B – damaged with leaking injector assembly
6	20 MPa	12°	Engine B – damaged with leaking injector assembly
7	25 MPa	12°	Engine B – damaged with leaking injector assembly
8	22 MPa	12°	Engine B – damaged injector with a tight fit

The damaged injectors of the engine B (Fig. 2) are in such a state that two of the four do not have clean spray cone, but a significantly drip. The difference between tight and leaky assembly is in the use and non-use of the prescribed brass mat under the mounted injector.

Fuels were selected with the mixing ratio of 100% diesel fuel with rapeseed oil methyl ester. The mixing ratios were chosen so as to cover the entire spectrum from 100% diesel fuel to 100% rapeseed oil methyl ester.

RESULTS

All eight changes in the condition of the combustion engine were measured for particular fuels used in the range from 100% rapeseed oil methyl ester in 100% diesel fuel 12 times. The first two measurements were always excluded from the evaluation, because there was a clean exhaust system of an internal combustion engine tractor (Table 3).

Table 3. Example of the measured values of smoke – 100% fuel, diesel fuel, and technical condition 1

Order of measurement	Smoke (%)	Order of measurement	Smoke (%)
1 – exclude	39.6	7	32.6
2 – exclude	34.4	8	30.0
3	30.9	9	30.4
4	30.0	10	26.5
5	28.8	11	28.0
6	33.2	12	32.0
		Ø	**30.2**

For the final graphic design in Fig. 3, the average value has always been used. The smoke limit value specified by the manufacturer is also shown in the Figure and it reaches 63.5% smoke.

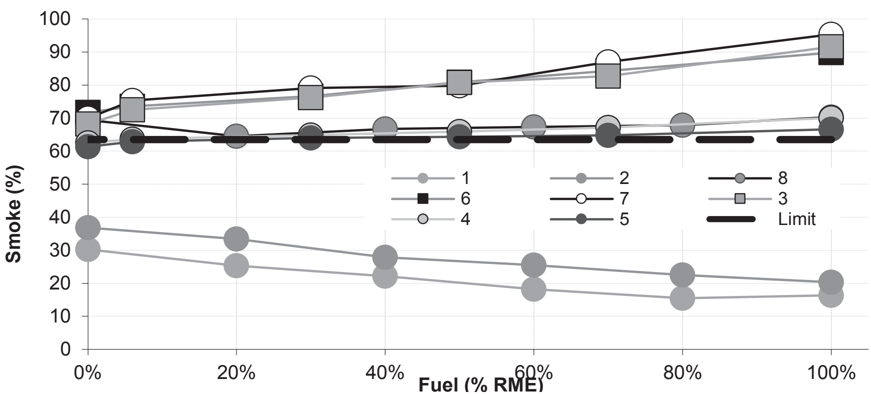

Figure 3. Progress of smoke depending on the technical condition of a combustion engine and the type of fuel used.

Fig. 3 shows that a combustion engine with worsened technical condition exhibits increased smokiness. Generally, however, it demonstrates that increasing share of biocomponents in the fuel reduces smoke. This was confirmed by the engine in good condition. With the deteriorating technical condition of the internal combustion engine, the positive impact of biofuels is gradually limited to a significantly degraded condition reflected in the deterioration of smoke. This is illustrated using linear interpolation on the slope of the line in Fig. 4. The slope gradually changes from negative for engine A (-14 to -17) and is moved by the gradually worsened technical state into positive territory for motor B (+ 17 to + 23).

In terms of the limit values specified by the manufacturer, smoke 63.5%, it can be stated that the motor upheld the measurement 1 and 2. In contrast, motor B essentially failed at almost any point. Only when using fuel with 100% of diesel fuel when measured, 4 and 5 were upheld by the manufacturer as specified smoke.

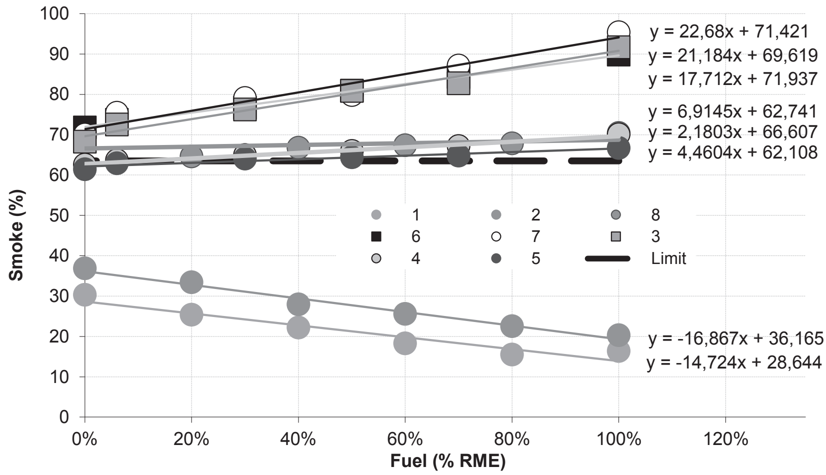

Figure 4. Course of smoke – the slope.

CONCLUSIONS

We used an internal combustion engine 1204 tractor Zetor 8641 Forterra, the operating conditions of which were gradually modified in order to simulate a malfunction (the owner of engine A did not allow changes in the parameter settings and even the use of the components in engine B). At the same time, this engine used biodiesel from 100% diesel fuel to 100% biofuel (RME). The smoke of the combustion engine is the determined at each point. Originally, it was assumed that smoke of the combustion engine would decrease with a higher proportion of biofuel.

This hypothesis was confirmed only for the engine in good condition (motor A). In contrast, with the engine in poor condition (motor B – Measurement 3–8), the smoke deteriorated (Figs 3 and 4) with a higher proportion of biofuel. Increasing engine smoke was caused by damaged injector 5 to 10%, changing the opening pressure of the injectors 10 to 20%, reduction by pilot injection at 7° 10 to 20%. Most significantly, however, the increase in smoke was due to defect of the turbocharger, which caused an increase in engine smoke of about 30–60%. The initial slope of the line of the motor in good condition in the range (-14 to -17) is moved by the gradually worsened technical state into positive territory for motor B (+ 17 to + 23). It can be expected that older engines in deteriorated condition will produce more particles using a biofuels combustion engine more than they would if they were an internal combustion engine run on clean diesel.

The disadvantage of using fuels with a higher proportion of biofuels is mainly due to the higher maintenance the fuel system (especially the removal of water from the system), lower engine performance and higher fuel consumption, based on the calorific values presented in Table 1. In contrast, the advantage of using biofuels is the higher lubricity and very good biodegradability against diesel.

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