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Common rail diesel tractor engine performance running on pure plant oil

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HIGHLIGHTS

- ▶ A study on raw rapeseed oil (PPO) and its performance in a common rail diesel engine.
- ▶ The torque and power drop is a direct consequence of the oil's lower energy content.
- ▶ The overall fuel consumption, as well as the engine energy efficiency, is comparable to diesel.
- ▶ A power drop of 12–14% was observed in the engine fueled with PPO as opposed to the one fueled with diesel.
- ▶ The alternate fuel had no impact on the energy efficiency.

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ABSTRACT

Many studies have been carried out on raw rapeseed oil (PPO) and its performance in a common rail diesel engine. In this study the PPO had characteristics within the DIN V 51605 norm. The engine, model 6068HL481 rated at 103 kW and installed in agriculture tractor John Dear 6830, was studied after working for 230 h and then for 1000 h. Full characteristic of the engine fueled with PPO was obtained for both tests and was then compared with the characteristic of the engine fueled with diesel. A power drop of 12–14% was observed in the engine fueled with PPO as opposed to the one fueled with diesel. The alternate fuel had no impact on the energy efficiency.

1. Introduction

Combustion diesel engines play an important role in transport, industry and agriculture. The limited supply of crude oil and its high costs of extraction and processing make the search for renewable fuels important, both for commercial and environmental reasons. Thus, biofuels, especially the rapeseed oil are becoming more popular in Europe.

Biodiesel can be obtained from various types of biomass [1,2]. Vegetable-based, waste frying or animal fat based oils are put through a process of esterification and trans-esterification in order to enhance their physical and chemical characteristics [3–6]. Stable emulsions of fats and oils can also be obtained with use of surfactants, as well as alcohols and water [7,8]. Such methods use less energy, but the final products are of lower quality.

The production of biofuels using a simple apparatus and technology based on low-temperature trans-esterification [9,10] has been considered for implementation on Polish agricultural farms. However, for environmental reasons due to toxic byproducts, such a solution has not worked in practice.

The many studies that have been conducted over the last few years of diesel engines fueled with alternate fuels [11] included fuels such as methyl esters, various ethyl derivatives, vegetable oils [12–17]. This study summarizes tests conducted over the last five years using pure rapeseed oil in trucks and agriculture tractors. It included 38 one and two tank installations in tractors representing nine brands [18].

Published analysis of the internal combustion engine parameters as a function of biofuels (rapeseed and animal fat based oils) as opposed to diesel, indicate that in all cases the internal cylinder pressure is lower and the engine energy efficiency comparable [19,20]. The generated power is lower and unit fuel consumption greater. In addition, use of rapeseed oils results in increased emission of NO_x and lower Stoke Number. In cases where Poon oil is

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used, an opposite phenomena was observed, i.e. reduction in NO_x emissions, Stoke Number increase, and fall of engine heat efficiency [21,22].

The main goal here is to draw conclusions on performance and efficiency of the John Deere 6830 agricultural tractor, adjusted for combustion of pure raps oil as a function of the fuel type and length of test.

2. Description of the test site

The tests were conducted on a John Deere 6830 agricultural tractors equipped with six cylinder, 24 valve engine model 6068HL481, with a turbocharger generating power of 103 kW (140 kM), a high-pressure fuel injection system "Common Rail", 620 Nm torque at 1400 rpm, 6790 cm^3 displacement, and an operating range of 1300–2100 rpm, Table 1. The engine was connected to a mobile engine brake PT 301 MES and to a fuel intake meter AMX 212F, as shown in Fig. 1. The engine break was connected through a main reducing gear followed by a power transmission shaft (WOM). The exact efficiency of the reducing gear was not important in this study and was assumed to be $\eta = 1$.

The engine brake (dynamometer) PT 301 MES consists of two air cooled retarding electromagnetic breaks. The power losses due to cooling and friction in ball bearings have been taken into account by the test software. The fuel meter consisted of a strain scale with a 1 dm^3 cylinder fueled through a solenoid valve. The control system for the above setup was a programmable AMX 212F system set to display instantaneous fuel consumption in kg/h.

3. Test methodology

The raw rapeseed oil used in this study was cold pressed with screw press, no preheating, in temperature range below 70 °C. The oil temperature right after press was in the vicinity of 32 °C. The pressed oil was next homogenized with montmorillonite to absorb out phospholipids. The resulting emulsion was put through filters to obtain what is called pure plant oil (PPO) and defined as pre-filtered raw rapeseed oil.

The test started by warming up the engine to the operating temperature of 85 ± 2 °C. Afterwards the engine was set to operate at max. rpm of about 2250. The engine break was set to slow the engine rpm from 2200 to 1300, i.e. the engine's operating range. The data consisting of torque and fuel use were recorded at every 100 ± 5 rpm drop, with more measurements taken around the maximum power point at around 1750 rpm. The test was repeated three times for each fuel. The results presented in this paper span two years, and include two tests. Test 1 of 230 h of operation represents a reference set of measurements, and the other, Test 2, provides the results after 1000 h of operation.

Table 1
6068HL481 engine parameters.

Engine type	6068HL481
Max. engine power in accordance with 97/68/EC	103 kW
Intelligent power management (momentary power)	121 kW
Max. torque	620 Nm at 1400 rpm
Number of cylinders	6
Cylinder diameter/piston travel	106.5 mm/127 mm
Displacement	6790 cm^3
Nominal revolution	2100 rpm
Range of operating revolutions	1300–2100 rpm
Size and type of injection system	PowerTech, 4 valves
Air intake system	Turbocharger with active air cooling system
Fuel injection system	High-pressure "Common Rail"
Combustion chamber	Swirl chamber

Fig. 1. Test station.

Prior to our study the test tractor ran on PPO with characteristic parameters as shown in Table 2. The tests were conducted using PPO, followed by one using summer diesel fuel (parameters within the EN 590 norm) with a density of 830 kg/m^3 at 15 °C, and an energy density of 45.4 MJ/kg. Fuels used for both tests came from the same large fuel storage tanks. The possible fuel contaminations, outside of shortening the useful life of fuel filters, did not seem to have observable influence on the engine operation and were not included in analysis.

The measured parameters in our tests were: engine torque (M_o), engine power rating (N_e), overall fuel consumption (G), unit fuel consumption (g_e), unit energy consumption (g_e^*), and engine energy efficiency (η_e). The test results were analyzed with the help of the statistical analysis method ANOVA to evaluate dependence of the measured parameters on time length of engine operation and type of fuel. The error probability (p) is used to indicate above dependence. The threshold of 5% (i.e. $p > 0.05$) indicates insignificant dependence.

4. Test results

The chemical structure of the rapeseed oil is significantly different than diesel fuel. The vegetable oil molecules contain more of both carbon and oxygen than hydrocarbon fuels. As a result they differ in viscosity and calorific value. The high viscosity, especially in traditional mechanical fuel injection systems, influences the injector's needle operation, accounts for pressure increase in high pressure lines, and increase in fill time of injector pumps. The design of a common rail injection system, as in the engine used in this study, helps to alleviate above problems. Precise volumes of fuel are injected under constant pressure to combustion chamber by computer controlled electro-valves. Such an approach allows for multiple fuel injections within each engine work cycle. In addition, preheating of fuel to about 70 °C improves the quality of fuel mixture in the combustion chamber. The long term engine operation analysis, in this study, confirmed effectiveness of such approach.

In terms of power and torque generated, the following differences were observed. The engine torque characteristics were obtained for two tests, each as an average of three repetitions. The type of fuel and the time length of the engine operation had a visible influence, as shown in Fig. 2. The peak M_o was registered for diesel at 1500 rpm. A drop of M_o by 12 ± 2% was observed for PPO in Test 1, and by 15 ± 2% in Test 2. The above difference in M_o performance is due mainly to the tractor engine being constructed and optimized for diesel fuel.

The peak N_e was registered at 1700 rpm. As with the M_o, a N_e drop of 12 ± 2% was observed for PPO in Test 1, and of 14 ± 2% in Test 2, as illustrated in Fig. 3.

The M_o had an insignificant dependence on the type of fuel used ($p_1 = 0.11$, $p_2 = 0.17$, for Tests 1 and 2, respectively) and the time