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Influence of biodiesel on the performances of farm tractors: Experimental testing in stationary and non-stationary conditions

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This paper demonstrates the results of testing the performance of tractors using fossil diesel, biodiesel, and blends of biodiesel and fossil diesel. The results of tests conducted in stationary and non-stationary conditions indicate that, in contrast to fossil diesel, the use of biodiesel and blends of biodiesel and fossil diesel reduce the power of engine and drawbar power, and increase specific fuel consumption. Thermal efficiency slightly improves with biodiesel blends. The differences become notable with bigger share of biodiesel in the blend. However, the changes are less notable regarding the differences in heating value, which is the result of complete combustion. Use of different fuels, compared to use of fossil diesel only, reduces the CO emission and temperature of exhaust fumes, and increases the CO_2 emission and NOx. At maximum load, the difference between the parameters measured in stationary and non-stationary conditions is minimal. On the other hand, at lower loads, the load variable formed in non-stationary conditions of testing becomes noticeable which results in greater differences. However, decrease in engine power and increase in fuel consumption using biodiesel significantly deteriorated the exploitation characteristics of plowing tractors (production efficiency was reduced by 12.87% and fuel consumption per unit of cultivated area was increased by up to 21.63%).

1. Introduction

Variable and unpredictable price of oil, its limited availability, as well as its negative impact on the environment, health and safety, indicate the importance and necessity of developing alternative domestic fuels that are available, renewable, and environmentally friendly. Over the last decade, biodiesel has become the best-known renewable liquid fuel because it satisfies these criteria. Also, an advantage of biodiesel is that its use does not require any particular adjustments of engine or fuel injection system [1], as well as the fact that it is a non-toxic and biodegradable fuel [2].

Biodiesel represents methyl esters of fatty acids of vegetable oils or animal fats. In commercial production, it is obtained through the process of transesterification in alcohol (most commonly methanol) using suitable catalysts [3]. Transesterification of vegetable oils can be catalyzed by bases, acids and enzymes. Homogenous base catalysts (NaOH or KOH) or heterogeneous catalysts are typically used [4]. The reaction time, yield, and quality of the product depend on the type and quality of raw material, as well as the process parameters (molar ratio of oil and methanol, the catalyst amount, reaction temperature, reaction time, blending speed and alike [5]). Nevertheless, homogenous catalysts cause a series of problems relating to relatively expensive and complex procedures of neutralization, washing and separation. On the other hand, heterogeneous catalysts partially solve the problem of difficult separation of the end product [6]. Still, the problem of methanol insolubility in oil remains (this requires intensive mixing), as well as the negative effect of water and unsaturated fatty acids in oil, and a relatively long reaction time. In order to find the solution to these problems, contemporary research has been focused on the development of technologies and equipment for performing transesterification in supercritical conditions. This involves high temperatures and pressures necessary for the reaction (over 240 °C and 8.09 MPa) [7].

Biodiesel has also attracted a lot of attention over the last decade

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Abbreviations

ED	Fossil diesel characteristics in line with EN590:2010 standard without added biodiesel
B20	Mixture of ED and biodiesel in a ratio of 80:20% v.v-1
B40	Mixture of ED and biodiesel in a ratio of 60:40% v.v-1
B60	Mixture of ED and biodiesel in a ratio of 40:60% v.v-1
B80	Mixture of ED and biodiesel in a ratio of 20:80% v.v-1
B100	Pure biodiesel; SFC - Specific fuel consumption
PDE	Power delivery efficiency
DBP	Drawbar power
DPU	Drawbar pull

as a component in a mixture with fossil diesel (hereinafter as ED) [8]. Blends of biodiesel with ED are called BXX, where XX stands for the amount of biodiesel in the blend. In commercial sales, biodiesel is most commonly available in ED blend with a share of 20% (B20) or less [9]. According to the European standard EN 590:2010 and based on the Directive 98/70/EO [10], 7% (v/v) of biodiesel can be mixed with ED. In this respect, biodiesel used for blending has to comply with the standard EN 14214:2012.

In the past, a large number of studies were conducted with the aim of determining the engine performances by using biodiesel and biodiesel and ED blends [1,11–14]. The research results showed a decrease in values of effective power and torque, and an increase in the specific fuel consumption (SFC). The decrease in power and torque and the increase in SFC were higher with an increase of biodiesel share in the blend with ED. The greatest change was observed with the use of fuel B100 at the mode corresponding to the maximum operating power (up to 10%). The reasons for deterioration in engine performance were the following: lower heating value, higher viscosity and fuel density compared to ED [1,15–18]. The change in pressure and injection time also had effects on engine performances [17,19,20]. A large number of studies have shown that engine performances (increased power and torque) can be improved by mixing 20% of biodiesel in ED [1,19,23].

Biodiesel is efficient in reducing friction. It has good lubrication properties compared to ED, especially in relation to ED with considerably lower content of sulfur [24]. By adding up to 1% of biodiesel to fossil diesel, lubrication properties of ED required by standard ED590 are ensured [25]. Biodiesel and ED blends have higher cetane number compared to pure ED, which is a result of higher cetane number of biodiesel [1].

Biodiesel does not contain benzene or other aromatic compounds. The flash point of biodiesel is about 150 °C, which makes it safe for storage and handling [26]. The use of biodiesel and its blends with fossil diesel reduces CO emissions (30–50% depending on the share of biodiesel in the blend) because biodiesel has higher content of oxygen and lower content of hydrogen and carbon [11–13,27–29]. The use of biodiesel, as well as its blends with ED, also reduces smoke by 30–70% [11,22,28,30–32] and particulate matter (PM) by 50–70% [32,33]. On the other hand, the studies conducted on engines with installed Common Real injection systems indicate that the use of biodiesel and blends of biodiesel with ED leads to increased NOx content in the combustion products [19,21–23,27]. Besides the increased NOx emission, another problem relating to the use of biodiesel and blends of biodiesel and ED is high temperature CFPP (Cold filter plugging point) and low oxidative stability.

The common feature of almost all the tests mentioned in the literature is that they were performed in the stationary mode of engine operation (laboratory conditions), primarily on low power test engines with up to 10 kW. Some researchers have obtained their results by testing the tractor engines in stationary (laboratory) conditions [1,25,34]. However, a few tests were conducted in non-stationary conditions. Namely, in stationary (laboratory) test conditions, the engine is not expected to be adapted to dynamic working conditions, as it is the case in real life. One can find contradictory results in available literature on the influence of biodiesel on drawbar efficiency of tractors. Some researchers, for example, claim that the use of biodiesel and its blends with ED (B20, B40, B60) does not have particular influence on the force and drawbar power, but it does affect the fuel consumption significantly [35,36]. On the other hand, research conducted on single axle tractors showed that by using B20, B60 and B80 fuels force and drawbar power decreased compared to ED [37]. Therefore, there is a need for a more in-depth research on the influence of biodiesel on tractor traction properties. The aim of this paper is to obtain objective facts on the changes in the performance of farm tractors using biodiesel and its blends with ED, and to compare them with the results from stationary (laboratory) testing.

2. Material and methods

2.1. Fuels

During the test, biodiesel produced from sunflower oil (national hybrid 'Somborac') was used. Sunflower was selected as raw material because it is the most common oilseed in the Republic of Serbia. The sunflower is grown on the land covering an area of 178,000 ha with an average yield of 2.54 t/ha^{-1} [38]. Serbia is the country with the highest yields of sunflower in Europe due to favorable climate and soil conditions (e.g. in 2010–2015, the average yields per ha in Germany, France, Spain were 2.1 t, 2.27 t and 1.1 t, respectively [39]) The previously mentioned fact can be supported with a long tradition that enabled mastering the production technology and development of a large number of domestic hybrids. Domestic sunflower hybrids contain high oil content in the grain (35–55% [40]). Biodiesel was produced by classical homogeneous basis transesterification in methyl alcohol. NaOH was used as the catalyst. Prior to testing, the analysis of compliance of biodiesel with EN 14214 standard was performed. The results below show that the used biodiesel was in compliance with EN 14214 (Table 1).

Biodiesel was mixed with ED produced in Oil Refinery in Pančevo, Serbia. Table 2 shows the properties of used ED fuel.

During the tests, biodiesel was mixed with ED in the ratio of 20:80 (B20), 40:60 (B40), 60:40 (B60) and 80:20 (B80)% (v/v). Table 3 shows basic physical-chemical properties of biodiesel and ED blends.

2.2. Engine and instruments

Tests were conducted on John Deere 6820 tractor. It is a standard wheeled tractor with four -wheel drive (MWFD). John Deere 6820 tractor is a universal tractor designed to carry out a large number of agricultural operations (basic tillage, pre-sowing preparation, sowing, mechanical and chemical treatments of crops, transport …) on small and medium-size farmsteads which are most common in the agriculture of the Republic of Serbia. Tractor specifications are given in Table 1.

Testing was conducted in the registered OECD (Organization for Economic Co-operation and Development) Laboratory for Power