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Test of used certified biofuels and their blends with diesel fuel of tractors in conditions of agricultural practice

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They are described two blend fuels with a high hydrotreated vegetable oil (HVO) share and two sustainable biofuels of the fatty acid methyl ester and HVO types of the ZETOR 9540 tractor in the framework of a long-term operational test. Compared to standard fossil diesel, the results of measuring performance parameters and characteristics for the assessment of the use of these fuels tractors and other agricultural machinery are mentioned. It was specified the quality, manufacturer, emission factors and greenhouse gas savings of clean certified biofuels and their high percentages of fossil diesel. For samples from all tested fuels, comprehensive fuel analysis was performed in accordance with the technical standards.

Keywords: Biodiesel; Fatty acid methyl ester; Hydrotreated vegetable oil; Renewable paraffinic diesel; Emission factor; External speed characteristic.

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Introduction. In the next decades combustion engines will continue to be the key drive technology for agricultural tractors and machinery.

The compression ignition engines use diesel as a fuel according to the standard EN 590 (2013) which reduces the content of Fatty acid methyl esters (FAME) to 7% (V/V). The following fuels are used as well FAME EN 14214 (2012+A1) at 100% concentration: high FAME diesel fuel (B20 and B30) according to the standard EN 16709 (2015), diesel fuels blends containing FAME B30 according to the standard ČSN 65 6508 (2013).

One of the possible alternatives how to meet the required reduction of CO_2 emission greenhouse gas is use of paraffinic diesel fuel from synthesis or hydrotreatment (synthesized hydrocarbons), including hydrotreated vegetable oil (HVO), hydroprocessed esters and fatty acids (HEFAs) and biomass to liquid (BtL). It is possible to use them separately or add them to diesel in such amount so that the final mixture complies with the requirements of the standard EN 590.

The issue of production and use of HVO/HEFAS is widely discussed at an international level [1-6]. Commercially hydrogenation process for processing vegetable oils is operated by the company Neste Oil and their products are labelled NExBTL [6, 7]. The quality requirements for these paraffin-based fuels intended for compression ignition engines with regard to their needs are recorded in the technical specification of the standard EN 15940 [8]. More than 98% of this fuel consists of paraffins, max. 1% consists of aromatics and max. 0.1% consists of polyaromatics and olefins. HVO/HEFAs are characterized by lower density and viscosity in comparison with fossil fuel and biodiesel. The products have ultra low sulphur content, high cetane number and high net calorific value which is suitable for the combustion engines [9]. With regard to the above presented qualitative indicators, using HVO/HEFAs and their mixtures with diesel and FAME results in significant saving of GHG emissions [10]. Results of biodiesel or FAME, pure rapeseed oil, HVO/HEFA, bio-methane, hydrogen and fully electric powered evaluation for different driving concepts and fuels for agricultural tractors were described [11].

Materials and methods. Within the solution of project National Agency for Agricultural Research of the Ministry of Agriculture of the Czech Republic there are realized the tests of tractors ZETOR 9540 (year of production 1992) with nominal output 67.5 kW and ZETOR 10540 (year of production 1998) with nominal output 75.5 kW in conditions of livestock production of the agricultural cooperative POOSLAVÍ Nová Ves. During the performance tests there are monitored the fillings of engine oils M 7ADSII, class of viscosity 15W/40. Both of tractors works in the same conditions. Tractor ZETOR 9540 uses as diesel fuel blend SMN R31 containing 25% V/V HVO + 6% V/V FAME + 69% V/V diesel fuel (MN) and diesel fuel blend SMN HVO 30 containing 30% V/V HVO + 70% diesel fuel (MN). Tractor 10540 uses as fuel only diesel fuel. The aim of diesel fuel analyse is to monitor continuously state and degradation of oil filling and ensure the effect of a fuel on oil filling.

In order to measure the speed characteristics of tractors there were used diesel fuel as standard, SMN R31, SMN HVO 30, SMN HVO 100 and FAME on the basis of rapeseed oil (FARME) and used cooking oils (UCOME). Biofuel supplies was documented by certificates of quality and sustainability containing emission factors in g CO_{2eq} (*table 1*).

Fig. 1. Measurement with mobile dynamometer AW NEB 400 of external speed characteristics and consumption of tested fuels in tractor ZETOR 9540

Fig. 2. System of connection of fuel box with flowmeter Macnaught M2ASP-1R to the fuel system of tested tractor ZETOR 10540

Table 1

Quality, producer, emission factors and savings of emissions of GHG fuels used during the operational tests of tractors ZETOR 9540 and ZETOR 10540

Fuel		Quality	Producer/ salesman	Emission factors (g CO_{2eq}/MJ)	Savings of GHG emissions (%)
Diesel fuel	without FAME (<0.30 % V/V)	ČSN EN 590	Slovnaft, a.s., Bratislava	95.1[1]	–1.06[2]
	with FAME (6.8 % V/V)			91.24	3.04[2]
HVO		ČSN EN 15940	Neste Renewable Fuels, Inter Terminals Mannheim	41.9	50[3]
FAME	FARME	ČSN EN 14214	Primagra, a.s., Milín	30.95	63.1[3]
	UCOME			5.88	93[3]
SMN R31 (25 % V/V HVO, 6 % V/V FAME, 69 % V/V diesel fuel)		ČSN EN 590	Preparation in cooperative	78.79[4]	16.27[2]
SMN HVO 30 (30 % V/V HVO, 70 % V/V diesel fuel)		ČSN EN 590	Preparation in cooperative	79.77[4]	15.2[2]

[1]Standard value of emission factor of diesel fuel according to the Council Directive (EU) 2015/652 from 20. 4. 2015
[2]Related to basic standard for fuels 94.1 g CO_{2eq}/MJ according to the Council Directive (EU) 2015/652 from 20. 4. 2015
[3]Related to fossil fuel comparator with emission factor 83.8 g CO2eq/MJ according to the European Parliament and Council Directive 2009/28/ES from 23. 4. 2009
[4]Converted from emission factors of particular components of mixed fuel

Measurement was carried out in the workshop of agricultural cooperative POOSLAVÍ Nová Ves and it was determined the fuel temperature 15 ± 0.5°C (*fig. 1 and 2*).

Results and discussion. The summary results physical and chemical properties of tested fuels are shown in the *table 2*.

Oil filling in tractor ZETOR 9540 has greater number of operating hours by 30% and lower level of degradation, it means content of impurities and CCT and considerable lower level of wear expressed by content of abrasive metals - iron, copper, silicon, than in case of tractor ZETOR 10540. Decrease of oil viscosity is also considerably lower and doesn´t surpass 10%. It is also possible to say, that, composition of fuel SMN R31 with lower content of aromatic hydrocarbons influences favourably state of engine oil, especially during the comparison of carbonization of oil, formation of soots and content of mechanic impurities. Infrared spectrum of oil sample with drawed in the course of operating test shows slight decrease of antiwear and antioxidation additive of type ZnDDTF (strip in zone 1000 cm^{-1}), detergent additives (in zone 1130 cm^{-1}), in zone 1745 cm^{-1} is bond C=O from FAME, which indicates small penetration of fuel.

For diesel fuel as reference fuel there was the highest power output 69.1 kW in the speed range 2207, 2105, 2009 min^{-1} and specific consumption of fuel at rated speed 245.51 g/kWh. On the *fig. 3 – 6* there are shown graphically the results of measurements of particular fuels with reference fuel.

Conclusions. From these results it is obvious, that in case of fuel SMN R31 there was measured the highest power output of engine in the whole range of measured speed. Maximum power output of engine with this fuel made 70.4 kW (at 2260 revolutions/min). At this fuel there was also recorded lower unit consumption of fuel compared to diesel fuel (242.93 g/kWh). In case of fuel SMN HVO 30 there was measured by 0.3 kW higher maximum power output of engine compared to reference

Table 2

Physical and chemical properties of tested fuels

Property	Unit	Standard	Fuel sample				Standard
		Diesel EN 590 temperate climates	Diesel	Diesel blends 30 % HVO	Diesel blends 25 % HVO, 6 % FAME	Neat 100 % HVO	Paraffinic diesel fuel EN 15940 temperate climates
Start of distillation	°C	–	177.2	183.7	181.3	187.9	–
Distillation:							
at 250°C recovered	% (V/V)	<65	40.1	30.6	29.5	2.8	<65
at 350°C recovered	% (V/V)	min. 85	96.9	–	96.2	–	min. 85
95 % (V/V) recovered at	°C	max. 360	343.7	326.6	345.3	291.0	max. 360
Total distillation volume	% (V/V)	–	98.3	99.9	99.1	98.1	–
End of distillation	°C	–	350.2	344.9	349.1	298.1	–
Flash point in closed cap	°C	above 55	67.5	68.0	66.5	69	above 55
CFPP	°C	<(+5 to –20)	–24	–27	–22	–39	<(+5 to –20)
Cloud point	°C	–	–7	–11	–10	–34	–
Polycyclic aromatic hydrocarbons	% (m/m)	max. 8.0	5.0	3.6	3.7	<0.1	max. 1.1
Fatty acid methyl esters content	% (V/V)	max. 7.0	6.8	<0.3	5.5	<0.3	max. 7.0
Water content	mg/kg	max. 200	50	40	45	30	max. 200
Sulphur content	mg/kg	max. 10.0	8.5	6.1	6.4	<3.0	max. 5.0
Ash content	% (m/m)	max. 0.01	<0.01	<0.01	<0.01	<0.01	max. 0.01
Total contamination	mg/kg	max. 24	<6.0	<6.0	<6.0	<6.0	max. 24
Carbon residue on 10% distillation residue	% (m/m)	max. 3.0	0.03	0.01	0.02	0.01	max. 30
Copper strip corrosion	rating	class 1	class 1	class 1	class 1	class 1	class 1
Lubricity, wear scar diameter (wsd) at 60°C	μm	max. 460	178	195	206	423	max. 460
Viscosity at 40°C	mm^2/s	2.000-4.500	2.621	2.650	2.822	2.855	2.000-4.500
Total insoluble sediment	g/m^3	–	1.0	1.0	1.0	1.0	–
Oxidation stability Rancimat (110°C)	h	min. 20	21.1	30.1	27.3	min. 20	57.2
Oxidation stability PetroOxy	min	–	96.3	96.5	88.1	67.8	–
Cetane number	–	min. 51	51.1	55.1	61.7	74.9	min. 70
Cetane index	–	min. 46	49.6	59.6	58.6	91.6	–
Density at 15°C	kg/m^3	820-845	840.1	822.1	826.3	779.6	765-800

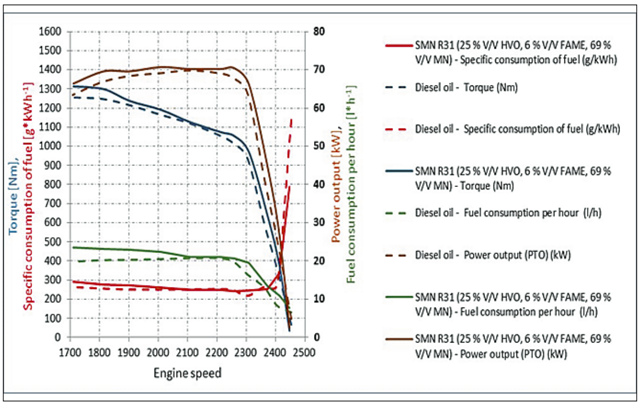

Fig. 3. External speed characteristics of engine measured through the PTO of tractor ZETOR 9540 fuel SMN R31 (25% V/V HVO, 6% V/V FAME, 69% V/V diesel fuel) with reference fuel – diesel fuel

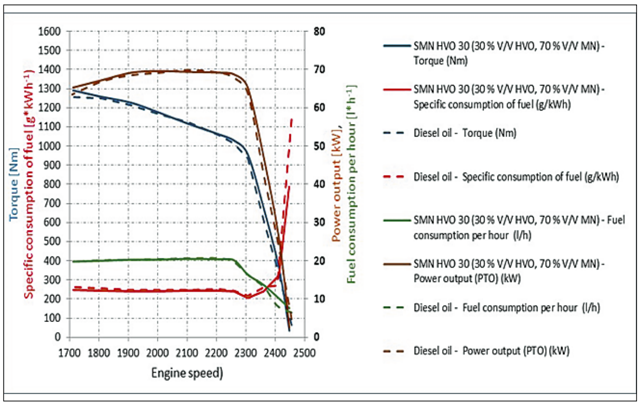

Fig. 4. External speed characteristics of engine measured through the PTO of tractor ZETOR 9540 fuel SMN HVO 30 (30% V/V HVO, 70% V/V diesel fuel) with reference fuel – diesel fuel

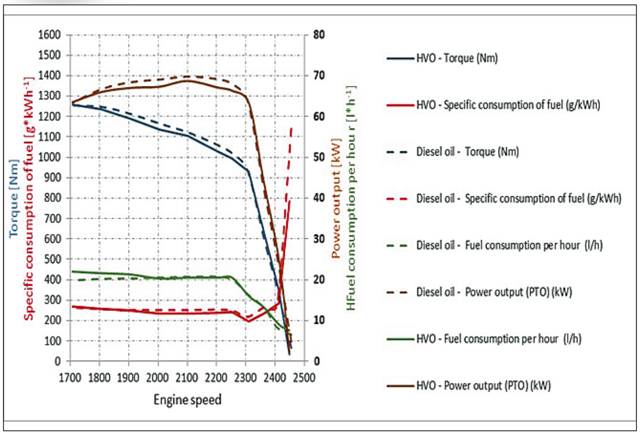

Fig. 5. External speed characteristics of engine measured through the PTO of tractor ZETOR 9540 fuel HVO 100 with reference fuel – diesel fuel

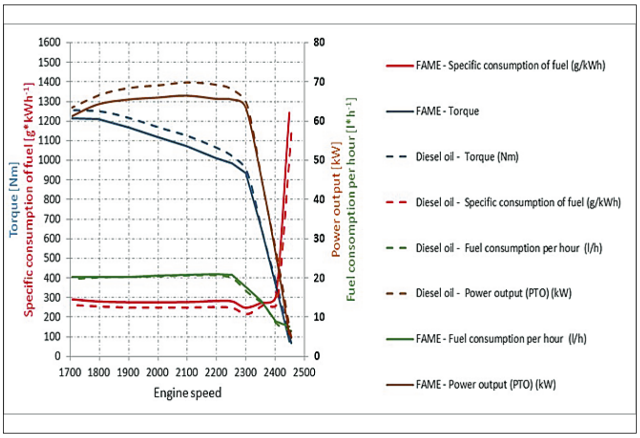

Fig. 6. External speed characteristics of engine measured through the PTO of tractor ZETOR 9540 fuel FAME with reference fuel – diesel fuel

fuel. At this fuel there was measured and calculated the lowest specific consumption of fuel (240.59 g/kWh) at rated speed of engine. At use of HVO 100 the maximum power output of engine decreased by 0.4 kW compared to diesel fuel, however specific consumption of fuel at rated speed of engine was the lowest from all of measured fuels and was 241.05 g/kWh. The lowest maximum power output of engine was measured at the FAME fuel. This performance was lower by 2.6 kW compared to the reference fuel and also specific consumption of fuel at rated speed of engine was the highest and was 280.22 g/kWh.

The proportion of HVO in the fuel has a slightly positive effect on the indicated power and specific fuel consumption. HVO as paraffinic diesel fuel and FAME can also offer a meaningful contribution to the target of increased non-petroleum and or renewable content in transportation fuel pool

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