INVESTIGATION IN TRACTOR CLAAS ARES 557ATX OPERATING PARAMETERS USING HYDROTREATED VEGETABLE OIL FUEL

Kristaps Sondors, Aivars Birkavs, Ilmars Dukulis, Vilnis Pirs, Zanis Jesko
Latvia University of Agriculture
kristaps.sondors@gmail.com, aivars.birkavs@llu.lv, ilmars.dukulis@llu.lv, vilnis.pirs@llu.lv, zanis.jesko@gmail.com

Abstract. Hydrotreating of vegetable oils, animal fats, waste cooking oils and algae is an alternative process to esterification for producing bio-based diesel fuels. Hydrotreated vegetable oil (HVO) belongs to the second generation BTL (biomass-to-liquid) biofuels group. Investigation of tractor *CLAAS ARES 557ATX* was carried out determining the engine power, torque, fuel consumption and exhaust gas content running the engine on two different fuels – hydrotreated vegetable oil and fossil diesel fuel. Power take-off dynamometer *MAHA ZW-500*, *AVL KMA MOBILE* fuel consumption meter, and *AVL SESAM FTIR* multi-component exhaust gas measurement system were used during these experiments. It was established that the average effective power and torque reduction using HVO fuel was about 5.0 % in comparison with fossil diesel fuel. The hourly fuel consumption using HVO was by about 1 % lower comparing to diesel fuel, but the increase of specific fuel consumption was in average by 4.1 % higher. Running the tractor on HVO the average reduction of NO_x in comparison with fossil diesel was 11.8 %. Decrease of total unburned hydrocarbons, CO and CO_2 was accordingly 26.4, 14.5 and 5.2 %.

Keywords: biofuels, hydrotreated vegetable oil, effective power, effective torque, fuel consumption.

Introduction

A lot of different EU directives and regulations are dedicated to decrease greenhouse gas emissions, to increase the share of renewable energy, and to improve energy efficiency. One of the latest documents – communication of the European Commission “A policy framework for climate and energy in the period from 2020 to 2030” states that greenhouse gas emissions in 2012 decreased by 18 % relative to emissions in 1990 and are expected to reduce further by 24 % in 2020, but the share of renewable energy has increased to 13 % in 2012 as a proportion of final energy consumed and is expected to rise to 21 % in 2020 [1]. The use of biofuels can promote to reach both of these targets.

Liquid biofuels commercially available today are mainly the so called first generation biofuels. The first generation biofuels are commonly derived from oil, starch or sugar containing plants that can be used in food. In order to mitigate against possible impacts of some biofuels, the European Commission has proposed to limit the amount of the first generation biofuels towards the 5 %, and to increase the incentives for advanced biofuels such as those made from ligno-cellulosic biomass, residues, waste, and other non-food biomass, including algae and microorganisms. After 2020 only the next, i.e., second, third and even fourth generation biofuels should receive public support. Communication of the European Commission “Clean power for transport: a European alternative fuels strategy” notes that there is no single fuel solution for the future of mobility and all main alternative fuel options have to be pursued, with a focus on the needs of each transport mode. A strategic approach for the EU must therefore build on a mix of alternative fuels without giving preference to any particular fuel [2].

Hydrotreated vegetable oil (HVO) that can be produced from triglycerides based biomass such as vegetable oil, animal fat, waste cooking oil and algae is one of the most perspective next generation biofuels in nearest future. Sometimes instead of the term “hydrotreated vegetable oil” researchers are using “hydrogenated vegetable oil”, “hydroprocessed vegetable oil” etc. A number of manufacturers around the world, i.e., *Neste Oil* (Finland), *Conocophillips* (USA and Ireland), *Syntroleum* (USA), *Universal Oil Products (UOP)-Eni* (UK and Italy), *Nippon Oil* (Japan) and *SK Energy* (Korea) have developed HVO refining processes and tested them in commercial trials. Some of these fuels acquired their own trade names, for example, NExBTL (an acronym for “next generation bio-to-liquid”) is the trade name of the HVO produced by *Neste Oil Corporation*, “Green Diesel” – produced by *UOP-Eni*, HBD (hydrogen-treating biodiesel) – produced by *SK Energy* [3].

During HVO processing three reactions take place – hydrogenation of double bonds present in unsaturated chains of bonded fatty acids, removal of oxygen atoms from carboxylic group in the form of water (hydrodeoxygenation), and elimination of carboxylic group in the form of carbon dioxide (hydrodecarboxylation) [4].

The main fossil diesel and HVO properties are compared in Table 1 [3-10].

Table 1

Fossil diesel fuel and HVO properties

Parameter	Fossil diesel fuel	HVO
Density, kg·m^{-3}	820 … 850	775 … 785
Viscosity, mm^2·s^{-1}	2.2 … 3.5	2.5 … 3.5
Cloud point, ºC	-5 … -30	3 … -30
Lowest heating value (LHV_{mass}), MJ·kg^{-1}	42.5 … 43.0	43.8 … 44.0
Lowest heating value (LHV_{volume}), MJ·l^{-1}	34.9 … 36.6	33.9 … 34.5
Cetane number	51 … 60	80 … 99
Sulphur content, mg·kg^{-1}	<12	≈0
Oxygen content, mg·kg^{-1}	≈0	≈0

HVO like fossil diesel is not oxygenated fuel and density for it is lower than that of fossil diesel fuel. HVO has ultra-low sulphur content, high cetane number and heating value that is beneficial for use in compression ignition engines. Analysis of investigations of HVO application shows that most of the standard parameters are similar to or better than those of fossil diesel fuel, but low-temperature properties are worse [3; 4]. Most of the studies are devoted to determine the changes of physiochemical properties of HVO using different catalysts and reaction conditions (for example, temperatures and pressures) during fuel production. However, only few studies have been conducted on the engine power and torque measurement, and fuel consumption determination [3].

Testing a turbocharged 8.4 liter 6-cylinder 4-stroke direct injection heavy duty diesel engine in Finland it was established that the use of hydrotreated vegetable oil enables reductions in CO, total hydrocarbon, and NO_x emissions without any changes to the engine or its controls [5]. A 1.5 liter DOHC (double overhead camshaft) diesel engine was used in the Republic of Korea to evaluate the differences of performance using biodiesel and HVO blends with fossil diesel fuel. The investigation results show decreases in the power – the more biodiesel or HVO is blended, the more power decreased, for example, blending 2 % of biodiesel to fossil diesel the power loss was approximately 1.4 %, blending 20 % – about 2.5 %, but blending 50 % – more than 5 %. Blending the same volume of HVO to fossil diesel fuel the power loss was accordingly 0.7, 1.8 and 1.2 %. Biodiesel blended diesel shows the increase of fuel consumption when the blending ratio goes up (approximately from 1 to 8 %), but for HVO blends a small decrease of fuel consumption was observed (up to 1 %) [10].

Most of the studies investigating the use of HVO fuel are realized testing engines on the benches, but rarely – the car or tractor in general. Since agriculture is one of the main branches in Latvia, but tractors consume a great part of diesel fuel the aim of this research is to determine the main operating parameters (power, torque, fuel consumption, and emissions) of the tractor *CLAAS ARES 557ATX* running it on two different fuels – pure hydrotreated vegetable oil and fossil diesel fuel.

Materials and methods

The main fuel parameters were determined in an independent certified laboratory (See Table 2).

Table 2

Main parameters of tested fuels

Parameter	Fossil diesel fuel	HVO
Density at 15 ºC, kg m^{-3}	836.3	778.9
Viscosity at 40 ºC, mm^2 s^{-1}	2.6	2.9
Lowest heating value (LHV_{mass}), MJ kg^{-1}	43.5	44.2
Lowest heating value (LHV_{volume}), MJ l^{-1}	36.4*	34.4*
Cetane number	52.4	74.7

* – LHV_{volume} in MJ l^{-1} is calculated form measured LHV_{mass} in MJ kg^{-1} and density

The test object – tractor *CLAAS ARES 557ATX* – is equipped with a 4.5 liter 4-cylinder direct injection cooled turbo diesel engine (year of production – 2007, maximum engine power in accordance with ISO TR 14 396 – 77.5 kW at 2100 min^{-1}, maximum torque – 421 Nm at 1400 min^{-1}, specific fuel consumption – 218 $g \cdot kWh^{-1}$ at 1700 min^{-1}).

The tractor power was determined from the power take-off (PTO) using dynamometer *MAHA ZW-500* (See Fig. 1a). Simultaneously the hourly fuel consumption and exhaust emissions were measured, accordingly using *AVL KMA MOBILE* fuel consumption meter and *AVL SESAM FTIR* multi-component exhaust gas measurement system (See Fig. 1b and 1c).

Fig. 1. **Test object and measuring equipment:** a – *CLAAS ARES 557ATX* and *MAHA ZW-500*; b – *AVL KMA MOBILE*; c – *AVL SESAM FTIR*

The maximum power to be measured from PTO using *MAHA ZW-500* is 500 kW, the maximum torque – 6600 N·m, the maximum PTO speed – 2500 min^{-1}, and the measurement accuracy ±2 %. The measured parameters can be determined at the entire revolution range, setting the measurement program (PTO revolutions range, step, and holding time) on the hand-held terminal. The *AVL KMA MOBILE* system measures the volumetric fuel consumption within very short measurement times. The measurement is possible up to 150 $l \cdot h^{-1}$ fuel flow with 0.1 % accuracy of reading. The *AVL SESAM* multicomponent exhaust gas measurement system is based on the FTIR (Fourier Transform Infrared Spectroscopy) optical measurement method that can diagnose up to 25 different exhaust gas components (for example, CO_2, CO, SO_2, NO, NO_2, CH_4 etc.) simultaneously. In addition, some collective components can be calculated, for example, NO_x and total hydrocarbons (THC).

Taking into account the nominal engine crankshaft frequency (2200 min^{-1}) of the test object and the PTO transmission ratio (3.67), the power determination was performed at PTO revolutions range from 300 to 625 min^{-1} with 25 min^{-1} step. The holding time at each measuring point was set to 15 seconds. Five repetitions were performed for each fuel. Examples of raw data – a printout from the *MAHA ZW-500* hand-held terminal and a fuel consumption graph – are shown in Figure 2.

To calculate the corresponding engine crankshaft revolutions n (min^{-1}), the following formula was used:

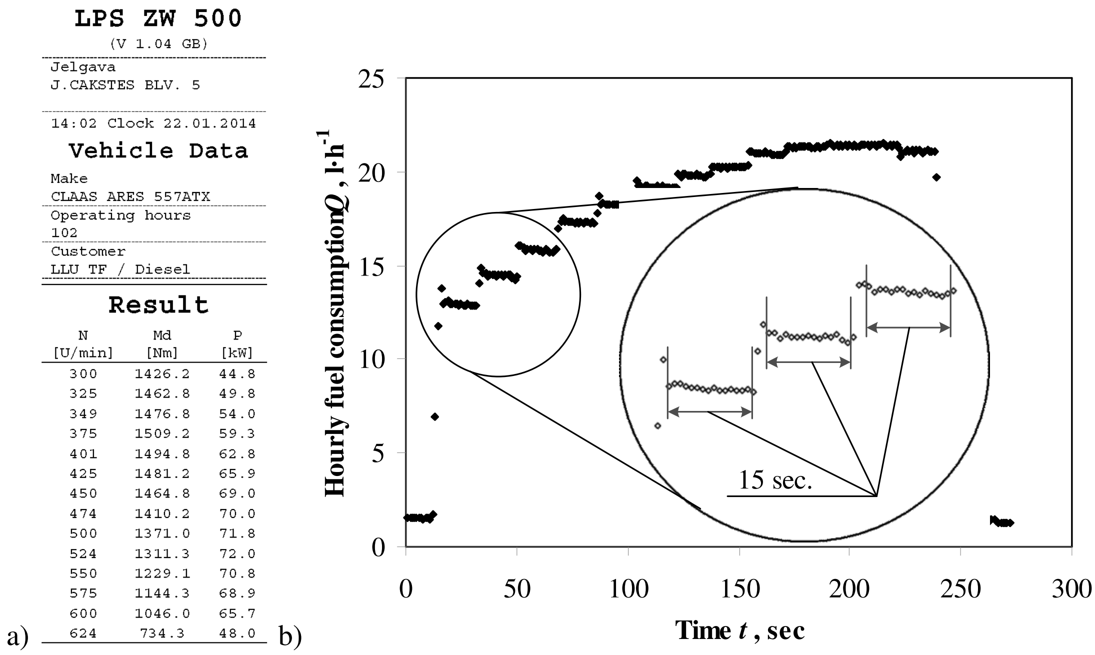
$$n = n_{PTO} \cdot i , \tag{1}$$

where i – PTO transmission ratio, 3.67;
n_{PTO} – PTO revolutions, min^{-1}.

The effective power of tractor engine N (kW) was calculated by formula:

$$N = \frac{N_{PTO}}{\eta} , \tag{2}$$

where η – PTO transmission efficiency, 0.95;
N_{PTO} – power measured from PTO, kW.


LPS ZW 500
(V 1.04 GB)
Jelgava
J.CAKSTES BLV. 5
14:02 Clock 22.01.2014
Vehicle Data
Make
CLAAS ARES 557ATX
Operating hours
102
Customer
LLU TF / Diesel
Result

N [U/min]	Md [Nm]	P [kW]
300	1426.2	44.8
325	1462.8	49.8
349	1476.8	54.0
375	1509.2	59.3
401	1494.8	62.8
425	1481.2	65.9
450	1464.8	69.0
474	1410.2	70.0
500	1371.0	71.8
524	1311.3	72.0
550	1229.1	70.8
575	1144.3	68.9
600	1046.0	65.7
624	734.3	48.0

Fig. 2. **Examples of raw experiment data:** a – printout from the *MAHA ZW-500* hand-held terminal; b – raw fuel consumption graph

The effective torque of the tractor engine M (N m) was calculated using the relationship:

$$M = \frac{M_{PTO}}{i \cdot \eta}, \tag{3}$$

where M_{PTO} – torque measured from PTO, N m.

As the 15 seconds loading on certain PTO revolutions starts only when the revolutions become stable (after approximately 3 seconds) for further analysis the raw fuel consumption data have to be cut out (See Fig. 2b). Similarly to raw fuel consumption data look also individual exhaust emission components measuring graphs, but, due to the specifics of exhaust gases and the measuring device, stabilization of a certain component amount takes longer time and it is very difficult to cut out 15 seconds data intervals like for the fuel consumption. That is why it was decided to calculate an average amount of each emission component in all PTO revolutions range from 300 to 625 min^{-1}.

Since both diesel injection systems and fuel dispensing systems deliver fuel by volume, the specific fuel consumption g_e was calculated not in g·kW^{-1}·h^{-1} as usually, but in l kW^{-1}·h^{-1}:

$$g_e = \frac{Q_{(l \cdot h^{-1})}}{N_e}. \tag{4}$$

Results and discussion

The experimental results after data processing (confidence level – 95 %) are shown in Fig. 3-5.

The engine effective power and torque using HVO were decreased relatively to fossil diesel fuel – the average power and torque reduction in all PTO revolutions range was about 5.0 % (See Fig. 3). This value is close to the difference in the volume-based lowest heating values LHV_{volume} (accordingly 36.4 and 34.4 MJ l^{-1}), i.e., to 5.5 % (see Table 2).

Despite the fact that the hourly fuel consumption using HVO was approximately by 1 % decreased comparing to diesel fuel, lower developed engine effective power with this fuel is the reason for the increase of the specific fuel consumption in average by 4.1 % (See Fig. 4).

In comparison with fossil diesel, running engine on HVO the average reduction of NO_x was 11.8 %. The amount of other important components influencing environment – total unburned hydrocarbons (THC), CO and CO_2, using HVO was also decreased – accordingly by 26.4, 14.5 and 5.2 % (See Fig. 5).

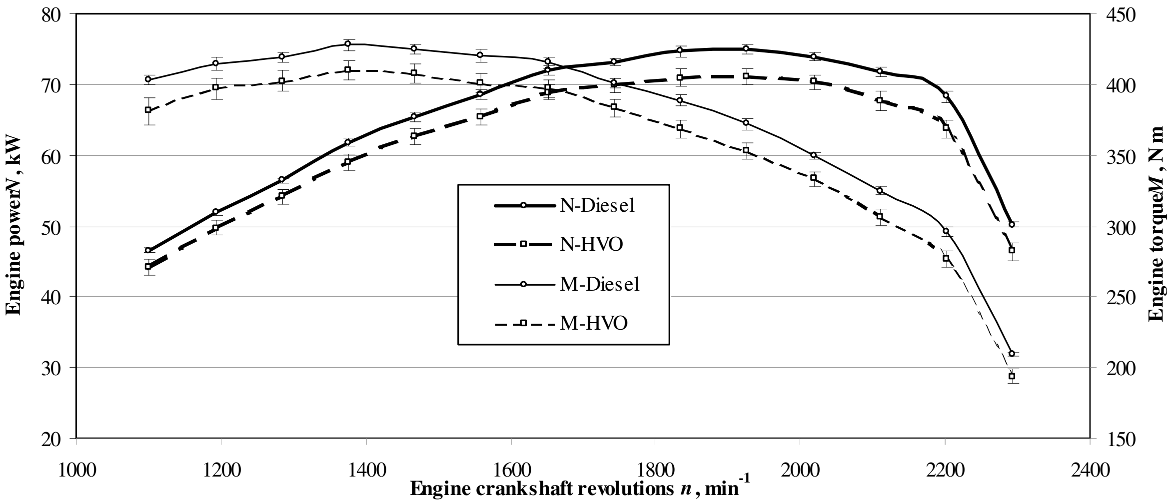


Fig. 3. **Engine effective power and torque characteristics**

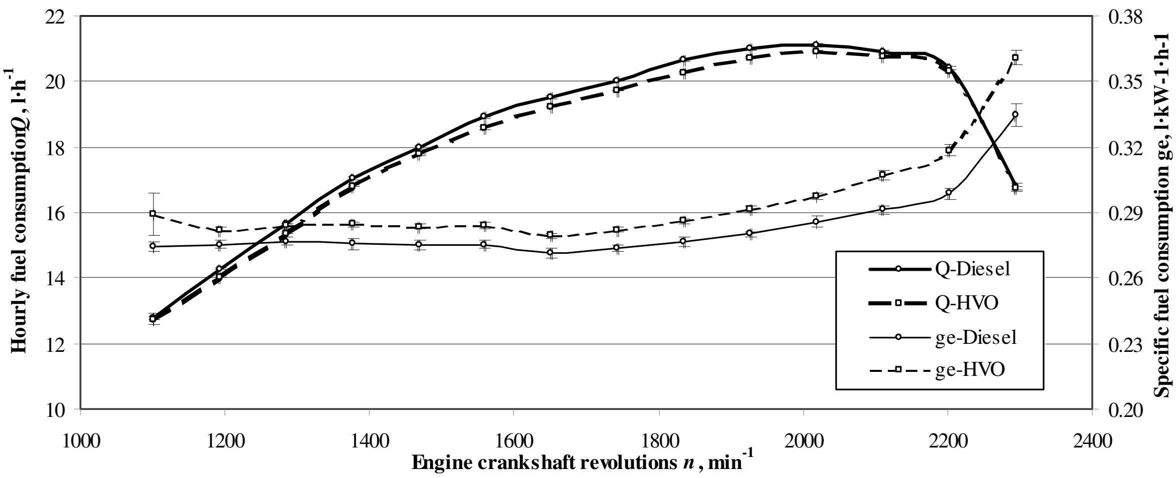


Fig. 4. **Fuel consumption characteristics**

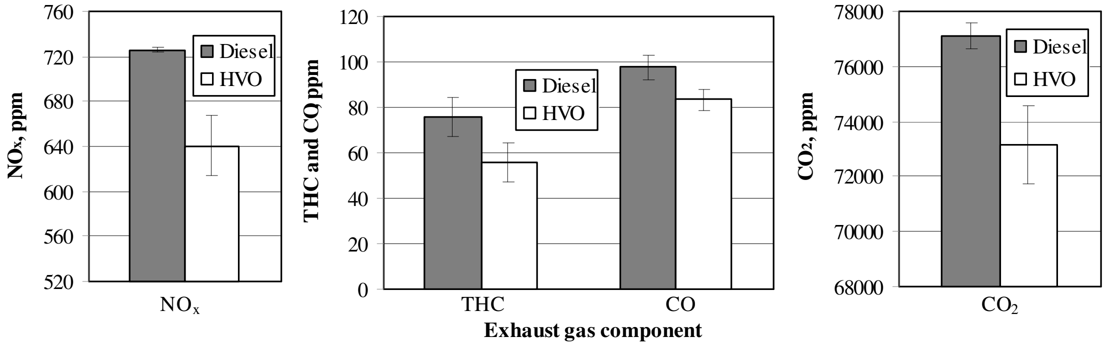


Fig. 5. **Content of NO_x, THC, CO and CO_2 in exhaust gases**

Summarizing the obtained data it can be concluded that HVO is environmentally friendly fuel with a small hourly fuel consumption economy, but the user has to be ready for power and torque reduction, close to the difference in HVO and fossil diesel fuel lowest volume-based heating values.

Since the results of the investigation "Key properties and blending strategies of hydrotreated vegetable oil as biofuel for diesel engines" carried out in Spain, Colombia and the USA show that a compromise between lubricity, cetane number, and cold flow properties, especially in colder regions, like in Latvia, leads to a recommendation for low or medium HVO concentrations, and blends with HVO content above 50 % are not recommended in unmodified diesel engines [7], the power and torque reduction using blends would not be so considerable. It is approved by studies performed in different countries, for example, in the Republic of Korea [10]. Of course, it has to be considered that testing biofuels the results are strongly dependant on the quality of fuel and raw materials used for their production, test vehicle and fuel injection system type, etc. That is why in future investigations it is necessary to test other type vehicles, for example, passenger cars and trucks, using HVO in pure form and in blends, especially in proportions that are most realistic implementation scenarios in nearest future, i.e., low content (up to 30 %) HVO blends with fossil diesel fuel.

Conclusions

1. Performing research of the tractor *CLAAS ARES 557ATX*, it was established that the engine effective power and torque using HVO fuel decreases relatively to fossil diesel fuel. The average power and torque reduction in PTO revolutions was about 5.0 %. It can be explained by the 5.5 % difference in the volume-based lowest heating values of both fuels.
2. The average hourly fuel consumption in PTO revolutions range from 300 to 625 min^{-1} using HVO was by about 1 % lower comparing to diesel fuel, but due to the lower developed engine power the increase of the specific fuel consumption was in average by 4.1 % higher.
3. Running the tractor on HVO the average reduction of NO_x in comparison with fossil diesel was 11.8 %. The amount of total unburned hydrocarbons (THC), CO and CO_2 was also decreased – accordingly by 26.4, 14.5 and 5.2 %.
4. In future studies it is necessary to test other vehicle types, for example, passenger cars and trucks, using HVO in pure form and in low content HVO blends with fossil diesel fuel, that are most realistic implementation scenarios in nearest future.

Acknowledgements

Funding support for this research is provided by Europe Social Fund program "Support for doctoral studies in LUA", agreement Nr. 2009/0180/1DP/1.1.2.1.2/09/IPIA/VIAA/017.

References

1. A policy framework for climate and energy in the period from 2020 to 2030. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. European Commission, Brussels, 22.01.2014, COM(2014) 15 final, 18 p.
2. Clean Power for Transport: A European alternative fuels strategy. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. European Commission, Brussels, 24.01.2013, COM(2013) 17 final, 11 p.
3. No S.-Y. Application of hydrotreated vegetable oil from triglyceride based biomass to CI engines – A review. *Fuel*, No. 115, 2014, pp. 88-96.
4. Šimáček P., Kubička D., Šebor G., Pospíšil M. Fuel properties of hydroprocessed rapeseed oil. *Fuel*, No. 89, 2010, pp. 611-615.
5. Aatola H., Larmi M., Sarjovaara T. Hydrotreated Vegetable Oil (HVO) as a Renewable Diesel Fuel: Trade-off between NO_x, Particulate Emission, and Fuel Consumption of a Heavy Duty Engine. *SAE International Paper 2008-01-2500*, 2008, 12 p.
6. Arvidsson R., Persson S., Fröling M., Svanström M. Life cycle assessment of hydrotreated vegetable oil from rape, oil palm and Jatropha. *Journal of Cleaner Production*, No. 19, 2011, pp. 129-137.
7. Lapuerta M., Villajos M., Agudelo J.R., Boehman A.L. Key properties and blending strategies of hydrotreated vegetable oil as biofuel for diesel engines. *Fuel Processing Technology*, No. 92, 2011, pp. 2406 –2411.
8. Bezergianni S., Dimitriadis A. Comparison between different types of renewable diesel. *Renewable and Sustainable Energy Reviews*, No. 21, 2013, pp. 110-116.
9. Pinto F., Martins S., Gonçalves M., Costa P., Gulyurtlu I., Alves A., Mendes B. Hydrogenation of rapeseed oil for production of liquid biochemicals. *Applied Energy*, No. 102, 2013, pp. 272-282.
10. Kim D., Kim S., Oh S., No S.-Y. Engine performance and emission characteristics of hydrotreated vegetable oil in light duty diesel engines. *Fuel*, No. 125, 2014, pp. 36-43.