Periodica Polytechnica
Mechanical Engineering

59(3), pp. 120-125, 2015
DOI: 10.3311/PPme.7989

RESEARCH ARTICLE

Comparison Tests of Diesel, Biodiesel and TBK-Biodiesel

György Szabados[1*], Ákos Bereczky[2]

Received 18 February 2015; accepted after revision 15 April 2015

Abstract

The present article focuses on the properties of renewable bio fuels with relevance to ICE (Internal Combustion Engine) use. The diesel (EN (European Norm) 590) was used as referent fuel, that was compared with the standardized biodiesel (EN 14214) and a new type biofuel, the so-called TBK-biodiesel (Thész-Boros-Király) in a series of measurements. Data on the basic physical and chemical properties, as well as properties of combustion in ICE are presented in detail. Based on the results can be said, that biofuels don't have clear advantages compared to other fuel types. However, the disadvantageous physical and chemical properties of biofuels are partially compensated by a more favorable composition of exhaust gases due to their adherent oxygen content.

Keywords

new type biofuel, physical and chemical properties, exhaust gas analysis, indicator diagram, CI (Compression Ignition) engine

[1]Engine and Vehicle Emission Test Laboratory,
Centre for Environment Protection and Sustainability Research,
KTI Institute for Transport Science Nonprofit Ltd.,
H-1119 Budapest, Than Károly u. 3-5, Hungary

[2]Department of Energy Engineering,
Faculty of Mechanical Engineering,
Budapest University of Technology and Economics,
H-1521 Budapest, P.O.B. 91, Hungary

[*]Corresponding author, e-mail: szabados.gyorgy@kti.hu

1 Introduction, description of experimental methods and material

The demand of energy consumption in the transport sector is expected to increase in the coming years in the European Union as well as on a global scale [26,27,28]. It means also an increasing in environmental pollution and environmental load from transport sector. A wide range of alternative fuels is offered in the transport sector, among them, biofuels [29,30]. Biofuels were introduced for a number of reasons: (i) diversification of the energy sources, (ii) reducing the consumption of fossil fuels, and (iii) increasing energy security. Additionally, biofuels have a more favourable exhaust gas emission and greenhouse gas emission [30,31].

Diesel fuel is the traditional energy source of CI engines. Use of CI engines in on-road HDVs (Heavy Duty Vehicles; e.g. buses) and in other machines (e.g. non-road mobile machinery; e.g. excavators, bulldozers) is almost autocrat compared to the SI (Spark Ignition) engines thanks to their better efficiency and higher specific power. In the latest times an ever greater penetration of CI engines can be observed in passenger cars, due to the rapid development of technology [6,32]. For our comparison tests diesel fuel, corresponding to the standard EN 590:2013, was used as a reference fuel, which was purchased from a gas station.

Diesel engines can be propelled –besides conventional fuels-by different fuels derived from biomass. Among them the most frequently used are the Fatty-Acid-Methyl-Esters called biodiesel, which are produced from different basic stocks, as well as the other compounds with oxygen content (for example dimethyl-ether); the next-generation biodiesels (for example n- and i-paraffin mixture produced from triglycerides of vegetable oil); the synthetic diesels (mixture of synthetic n- and i-paraffins (for example the Fischer-Tropsch-diesel) and the bioparaffins produced from carbohydrate [4]. It was used for our tests the standardized biodiesel (EN 14214:2013), which is applied for blending the diesel sold in gas stations all over Europe.

The TBK (in English: TOMS (Triglycerides Of Modified Structure)) is a new type of biofuel. The main advantage of TBK is that during its production procedure no by-production of glycerine occurs, that is, the crude vegetable oil is wholly turned into fuel. This means that from the same volume of crude oil 15-20% more fuel is produced compared to conventional biodiesel. With retention of the glycerine-frame the internal oxygen content is 30 % higher than in the conventional biodiesel, which results in less harmful components in the exhaust gas than in the diesel [3,33]. The essential difference in the production procedure of TBK is that the crude vegetable oil is not transesterificated with alcohol, but with ester. Because of this the TBK fuel doesn't correspond to the standard EN 14214:2013, (the conventional biodiesel). For our tests we used TBK based on rapeseed oil, transesterificated with methyl acetate. It is very important to highlight that the TBK biodiesel is a pure material; it doesn't have any additive contrary to the two other standardized fuels, which contain many additives in order to improve their physical and chemical properties and making them suitable for using in internal combustion engines. It is also important to mention that the production procedure of TBK is an invention of three Hungarian engineers (János Thész, Béla Boros, Zoltán Király), from this follows the Hungarian name of this new type biofuel. The above-described production procedure essentially differs from the so-called green diesel production [17] known previously.

The three fuels were tested for the following basic physical and chemical properties with relevance to ICE use: density, kinematic viscosity, lower heating value, flash point with open and closed cup method, and evaporability. Evaporability was determined with the help of thermogravimetry (TG) and differential thermogravimetry (DTG) curves.

Disadvantages of bio fuels in point of view of physical and chemical properties [15,16,25] can be compensated by decreasing in exhaust gas emission in point of certain components like CO (Carbon monoxide), HC (HydrogenCarbon) because of their adherent oxygen content [18,20,21,24].

In point view of combustion (recorded with helping of indicator diagrams) and ignition delay the results until now [16,19,22,25] show not too much difference between commercial diesel and biodiesels.

2 Tested engine and used method

The fuel tests were carried out in engine type RÁBA D10 UTSLL 160, as this is the most commonly used engine in the Hungarian bus fleet. The main properties of the engine are shown in Table 1.

Table 1 The main properties of the tested engine

bore	120,5 mm
stroke	150 mm
number of cylinder	6
engine layout	inline
compression ration	15,2
displacement	10350 cm^3
injection	direct injection
Fuel supply system	Bosch
charging	yes
emission approval	EURO II
rated power	160 kW / 1900 rpm
rated torque	920 Nm / 1300 rpm

Three points were chosen for the tests from the speed-load range of the engine as follows:

- 1300 rpm; 50% load
- 1900 rpm; 25% load
- 1900 rpm; 75% load

The above three test points were chosen in relation to the emission of particulate matter. In these three test points the properties of the particulate matter emitted by the engine are very different. (Measuring more than three points did not seem justified and was avoided in order to prevent damages to the engine or the measurement system during the 30 to 50 minutes' test runs under high fuel load.) At low rotational speed the charger works with little power and the in-cylinder rotation (tumble and swirl) is also lower which results in poorer mixture formation, besides the greater air-fuel ratio at mean load. This can be a characteristic point in the emission of particulate matter in „mean" quantity. Lower quantity of particulate emission can be obtained at rated speed, and less load, where a greater mixing velocity and better air-fuel ratio results in better mixture formation. As regards the previous conclusions at rated speed and larger load one can expect a larger scale of particulate emission.

3 Results and discussion– regarding the physical and chemical properties of the fuels

In first step of the test series the main parameters of fuels was determined, which have an effect on use in ICE. These were density, kinematic viscosity, lower heating value, flash point with open and closed cup method, as well as evaporability. The physical and chemical properties of the investigated fuels are listed in Table 2.

Table 2 Main parameters of the tested fuels [14]

Fuel	Density [kg/dm^3] 15°C	Kin. viscosity [mm^2/s.] at 40°C	Lower heating value [MJ/kg]
Diesel	0.837	2.98	42.12
Biodiesel	0.877	5.05	36.29
TBK	0.905	6.43	34.81
Fuel	**Flash point (open cup method) [°C]**	**Flash point (closed cup method) [°C]**	
Diesel	90	70	
Biodiesel	189	201	
TBK	185	221	

Measures of fuel density were carried out with the help of areometer and weighing-machine [5]. The density of TBK is proved to be higher than the density of biodiesel and diesel. From the higher density comes a higher viscosity which leads to poorer atomization, less complete mixture formation and less efficient combustion in comparison with the biodiesel [2]. Although the density of TBK exceeds just slightly the upper limit value of density of biodiesel standing in the relating standard.

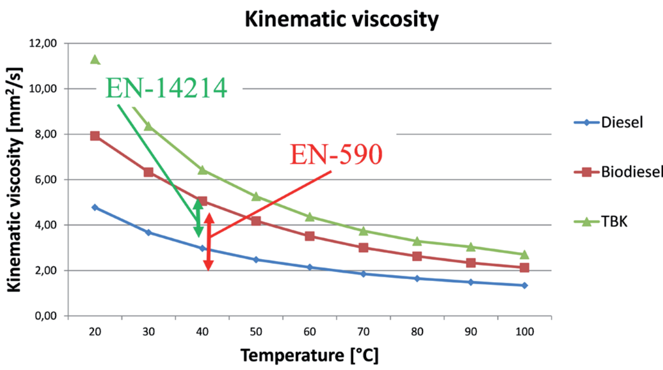

Fig. 1 The kimenatic viscosity in function of temperature of the tested fuels

Measurements of fuel viscosity were carried out with the help of Ostwald-Fenske viscometer [11], in the temperature range of 20 – 100 °C in 10 °C steps. The results are shown in Fig. 1. In Figure 1 the limit values in the relating standards are marked [12,13]. The kinematic viscosity of TBK is the highest in the whole temperature range tested. The value of TBK at 40 °C exceeds significantly the value of 5 mm^2/s, which is the upper limit value of biodiesel in the relating standard.

Another option to calculate the lower heating value of the fuel, in case its elemental composition is known, is to determine the LHVs (Lower Heating Values). The details of LHV determination are fixed in the relevant standards [9,10]. Analysis of the elemental composition of the fuels as regards the four elements, namely C, H, N, S [9,10,14], determined according to the standardized method, resulted in the approximation that the residue was the oxygen. Comparing the two renewable fuels can be stated that TBK has a 30 % higher oxygen content, which can have a beneficial effect on certain emission components derived from the engine.

From the elemental composition the lower heating value is derived using the Boie formula [2]. The Boie formula is suitable both for solid and liquid fuels. The results show that the LHV of TBK and biodiesel is less than that of the diesel; the respective values are: 14% (biodiesel) and 17% (TBK).

The power of engine is proportional to the heating value of the fuel. If a fuel with less heating value is used and at the same time the dose is kept on the same value, the power of the engine will decrease. It follows that in order to reach the same power the fuel consumption will increase.

To determine the flash points of the fuels the relating standards [7,8] was used [14]. The flash point is a key property in Diesel engine as regards the ignition delay. Because of the use in an internal combustion engine the results from the closed cup method are competent. The data listed in Table 1 clearly show, that the flash point of the two biofuels is almost identical in the open cup method, and in the closed cup method the TBK has a higher flash point, ergo the ignition delay will be a longer time period in case of a Diesel engine running on TBK.

It is worth to mention, that in the indoor method there is a higher sensitivity to fire; that is the temperature range with the open air method is circa 100 °C (between 90-185 °C) compared to the temperature range with the indoor method which is circa 150 °C (between 70-221 °C); in other words in the latter the differences in flammability are amplified. The TBK sample shows the largest difference between the two methods. It can be assumed that the higher oxygen content is responsible for this phenomena. The oxygen makes the molecule polar, and the polarity decreases the evaporative tendency.

The lower part of the thermogravimetry and the differential thermogravimetry curves give information about the evaporation properties of the fuels as well. Evaporation is affected by many things, for example the weight distribution of the molecules, the polarity of the molecules, their chemical saturation, and the phenomena of polarization.

The results can be seen in Fig. 2. The diesel is built up of molecules with nonpolar bonds that is: soft bonds, and thanks to this the intensive evaporation begins sooner compared to the renewable fuels, which have molecules with polar, strong bonds and are heteronuclear (oxygen). The measurements were carried out in aerob environment favouring polarization in the biofuels and thereby decreasing the evaporative tendency.

The upper part of Fig. 2 shows the weight losses (%) in function of the temperature. The intensive evaporation of renewable fuels begins at a temperature which is about 100 °C higher compared to the fossil one. Figure 2 shows the velocities of the weight losses in function of the temperature. The maximum velocity of weight losses of the renewable materials appear approximately at the same temperature, which is 40-45 °C higher than the same parameter of diesel. While the fossil fuel quickly reaches the maximum point, the biofuels run at a lesser value. By the time the diesel is almost fully evaporated, only half of the biodiesel and the TBK are evaporated.

4 Results and discussion of achieved results – Engine tests

Indicator diagrams are created from data derived from engine tests, and enable us to calculate the rate of the heat release rate and to analyse the process of combustion. The measurement system used to record the indicator diagrams can be seen in Fig. 3. In case of indicator diagrams pure fuels were also tested in order to analyse the effect of the above mentioned parameters of combustion technology.

Indicator diagrams obtained at 1300 rpm rotational speed and 50% load are presented in Fig. 4. As 1300 rpm is the speed which belongs to the rated moment therefore this point means a

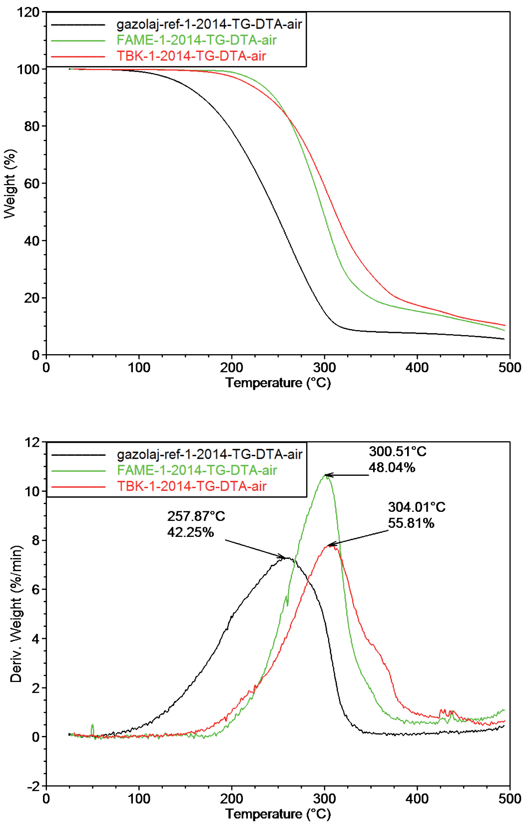

Fig. 2 TG and DTG curves of the three tested fuels [14] (black: diesel, green: biodiesel, red: TBK)

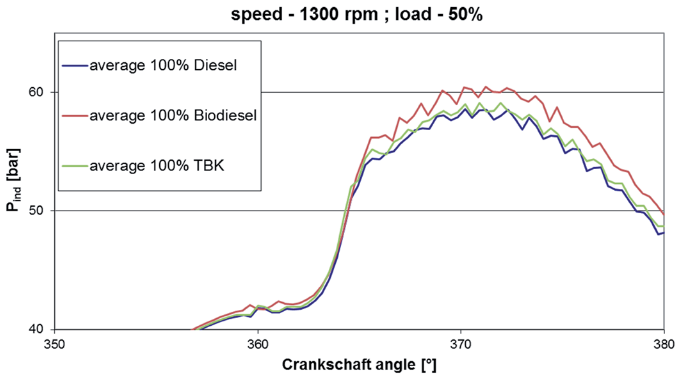

Fig. 4 Indicator diagrams of the three tested fuels at speed 1300 rpm and 50% load (black: diesel, red: biodiesel, green: TBK)

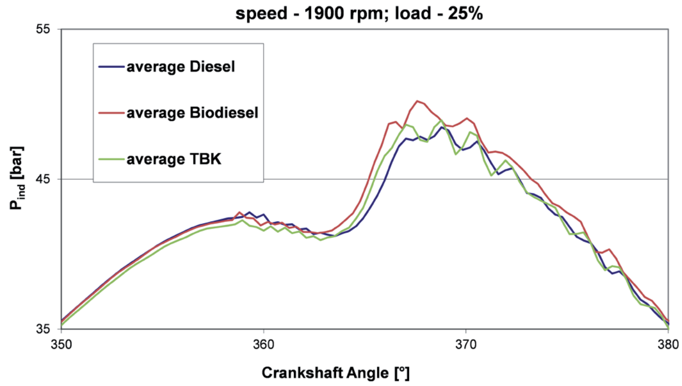

Fig. 5 Indicator diagrams of the three tested fuels at speed 1900 rpm and load 25% (black: diesel, red: biodiesel, green: TBK)

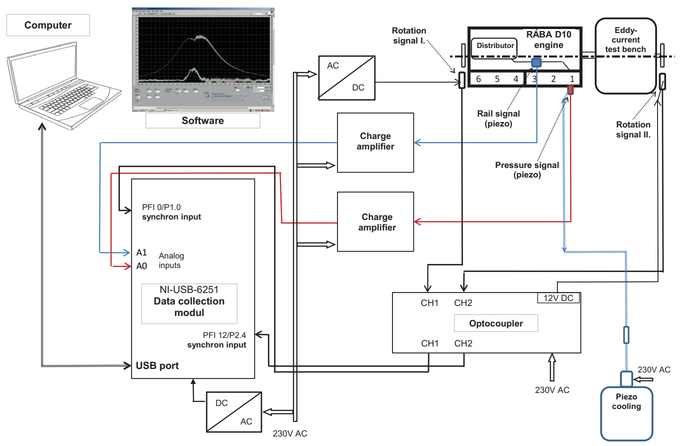

Fig. 3 Experimental set up recording the indicator diagrams

low speed and a mean load. In this engine running point the differences caused by the fuels are easy to observe. The injection start is the same at every fuel: exactly 1 CA (Crankschaft Angle) BTDC (Before Top Dead Center) based on rail signal of the fuel distributor. The biodiesel dose is risen by 13.3%, the TBK dose is risen by 8.1%, which is a little (biodiesel) or , much (TBK) lower than the scale of decrease of the heating value (14% and 17%, respectively). Based on the assessment of 100 indicator diagrams the peak pressures are established as follows: biodiesel 60.5 bar; TBK 59.1 bar; and diesel 56.6 bar. Figure 4 can also be noted, that the combustion is more intensives in the first section of combustion in case of the renewable fuels.

Indicator diagrams at 1900 rpm and 25% load are presented in Fig. 5. As 1900 rpm is the rated speed therefore this point means a high speed and a low load. In this engine running point there are obvious differences between the fuels. The injection start is the same at every fuel exactly 10 CA BTDC based on rail signal of the fuel distributor. Biodiesel dose is risen by 13.6%, TBK dose is risen by 18.5%, which is in case of biodiesel little lower, in case of TBK higher than scale of decreasing of heating value (14% and 17%). Based on the assessment of 100 indicator diagrams it can be noted that the peak pressure is at biodiesel 51.8 bar, at TBK 51.6 bar, and at diesel 51.1 bar, which deviation in not competent. Based on Fig. 5 it can also be noted, that the combustion is more intensive in the first section of combustion in case of the renewable fuels.

Figure 6 shows the indicator diagrams at 1900 rpm rotating speed and 75% load. At this speed and load the differences between the fuels are insignificant. Injection start is the same for all the fuels, based on the rail signal is 7 CA BTDC. Increase in dose is 13.9% in the case of biodiesel, and 19.4% in the case of TBK. It is by biodiesel little lower, by TBK higher than scale of decreasing of heating value (14% and 17%). Based on the assessment of 100 indicator diagrams it can be noted that the peak pressure is 65.8 bar in biodiesel, the highest: 66.4 bar in TBK, and 64.6 bar in diesel. Figure 6 also shows that the combustion is more intensive in the first section, primarily in the case of biodiesel, because of its specific composition.

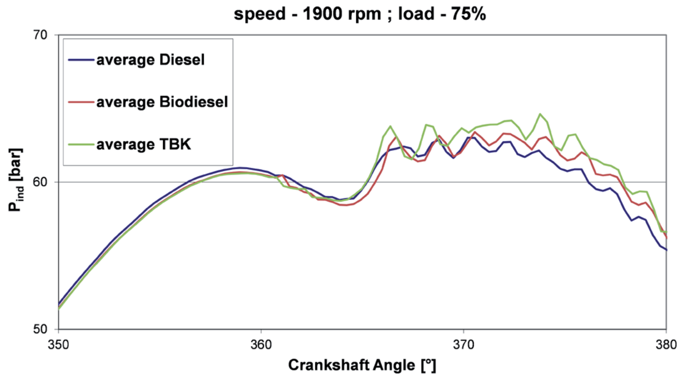

Fig. 6 Indicator diagrams of the three tested fuels at speed 1900 rpm and 75% load (black: diesel, red: biodiesel, green: TBK)

5 Conclusion

Parameters of a Diesel engine are influenced predominantly by the characteristics of the fuel used in the engine. These have an effect among others on the atomization process, on the range and size of fuel drops, and consequentially, on the composition of the exhaust gas, and finally on the engine efficiency. One of these parameters is density. The density of TBK is higher than that of biodiesel. A similar difference exists in kinematic viscosity as well. This property can result in a poorer atomization and, subsequently, a less effective combustion process. As regards density and kinematic viscosity the combustion process in the case of the biofuels leads to higher exhaust emission as compared to diesel but this increase regarding certain components can be compensated by the higher oxygen content of renewable fuels.

Work is done during the expansion stroke so the moment and power of the engine is proportional to the heating value of the fuel. Based on the results above it can be predicted that an engine running on TBK will have the least power and the highest specific fuel consumption.

Regarding the results obtained on flash point TG, and DTG it can be stated that the higher flash point of biofuels changes the characteristic of the combustion process. Ignition delay resulting from the higher flash point has to be controlled by measurement of cetane number. The oxygen content of the transesterificated molecules have an antinomic role: although the exhaust gas emission is reduced, the heating value and the evaporative tendency are reduced as well.

In our present article the emission measurement and the heat release rate were not mentioned. Furthermore, we would like to introduce, analyse, and assess the base emission and supplement it with the data of detailed particulate measurements and combustion simulation.

Acknowledgement

We are especially thankful to Dr. Zsuzsanna KEREKES (Szent István University, Ybl Miklós faculty of Architecture, Institute for Fire and disaster management), to István BÁCSKAI (National Agricultural Research and Innovation Centre – Institute of Agricultural Engineering) and to Dr. János MADARÁSZ (Budapest University of Technology and Economics, Department of Inorganic and Analytical Chemistry).

References

[1] Beda, L., Kerekes, Zs. "*Combustion and quenching theory II.*" Budapest: Tankönyvkiadó. 2006.

[2] Laza, T., Bereczky, Á. "Basic fuel properties of rapeseed oil-higher alcohols blends." *Fuel*. 90 (2). pp. 803-810. 2011. DOI: 10.1016/j.fuel.2010.09.015

[3] Thesz, J., Kondor, L. "Triglycerides of modified structure." *Biofuels Issue*. Available from: www.oilsandfatsinternational.com [Accessed: 7th August 2014] 2014.

[4] Hancsók, J., Krár, M., Baladincz, J., Vuk, T. "Bio origin components of diesel fuels – Fatty-Acid-Methyl-Esters." *Magyar Kémikusok Lapja*. 61 (7). pp. 228-235. 2006.

[5] Petz, A. "*General chemical practices*." Budapest. 2005.

[6] MOL "Diesel Product Broschure 2011-1 - MOL diesels." Available from: www.mol.hu [Accessed: 12th June 2014] 2011.

[7] Hungarian Standard Institution *MSZ EN 22592:1996, Petroleum products. Determination of flash and fire points. Cleveland open cup method (ISO 2592:1973)*. Budapest. 1996.

[8] Hungarian Standard Institution *MSZ EN 22719:1995, Petroleum products and lubricants. Determination of flash point. Pensky-Martens closed cup method (ISO 2719:1988)*. Budapest. 1995.

[9] Hungarian Standard Institution *MSZ EN 15104:2011, Solid biofuels. Determination of total content of carbon, hydrogen and nitrogen. Instrumental methods*. Budapest 2011.

[10] Hungarian Standard Institution *MSZ EN 15289:2011, Solid biofuels. Determination of total content of sulfur and chlorine*. Budapest. 2011.

[11] Hungarian Standard Institution *MSZ 3256-1:1980, Viscometers. Ostwald-Fenske capillary viscometer*. Budapest. 1980.

[12] Hungarian Standard Institution *MSZ EN 590:2013 Automotive fuels. Diesel. Requirements and test methods*. Budapest. 2013.

[13] Hungarian Standard Institution *MSZ EN 14214:2012+A1:2014, Liquid petroleum products. Fatty acid methyl esters (FAME) for use in diesel engines and heating applications. Requirements and test methods*. Budapest. 2014.

[14] Szabados, Gy., Kerekes, Zs., Bácskai, I., Bereczky, Á. "Determination and comparison of biofuel properties with relevance to ICE use." *Proceedings of ENELKO Conference*. Székelyudvarhely. 2014.

[15] Lujaji, F., Bereczky, A., Janosi, L., Novak, C., Mbarawa, M. "Cetane number and thermal properties of vegetable oil, biodiesel, 1-butanol and diesel blends." *Journal of Thermal Analysis and Calorimetry*. 102 (3). pp. 1175-1181. 2010. DOI: 10.1007/s10973-010-0733-9

[16] Laza, T., Kecskés, R., Bereczky, Á., Penninger, A. "Examination of burning processes of regenerative liquid fuel and alcohol mixtures in diesel engine." *Periodica Polytechnica Mechanical Engineering*. 50 (1). pp. 11-29. 2006.

[17] Calero, J., Luna, D., Sancho, E. D., Luna, C., Bautista, F. M., Romero, A., Verdugo-Escamilla, C. "An overview on glycerol-free processes for the production of renewable liquid biofuels, applicable in diesel engines." *Renewable and Sustainable Energy Reviews*. 42. pp. 1437-1452. 2015. DOI: 10.1016/j.rser.2014.11.007

[18] Guarieiro, L. L. N., de Almeida Guerreiro, E. T., dos Santos Amparo, K. K., Manera, V. B., Regis, A. C. D., Santos, A. G., de Andrade, J. B. "Assessment of the use of oxygenated fuels on emissions and performance of a diesel engine." *Microchemical Journal*. 117. pp. 94-99. 2014. DOI: 10.1016/j.microc.2014.06.004

[19] Ushakov, S., Valland, H., Æsøy, V. "Combustion and emissions characteristics of fish oil fuel in a heavy-duty diesel engine." *Energy Conversion and Management*. 65. pp. 228-238. 2013. DOI: 10.1016/j.enconman.2012.08.009

[20] Lapuerta, M., Armas, O., Rodriguez-Fernandez, J. "Effect of biodiesel fuels on diesel engine emissions." *Progress in Energy and Combustion Science*. 34 (2). pp. 198-223. 2008. DOI: 10.1016/j.pecs.2007.07.001

[21] Mrad, N., Varuvel, E. G., Tazerout, M., Aloui, F. "Effects of biofuel from fish oil industrial residue–Diesel blends in diesel engine." *Energy*. 44 (1). pp. 955-963. 2012. DOI: 10.1016/j.energy.2012.04.056

[22] Varuvel, E. G., Mrad, N., Tazerout, M., Aloui, F. "Experimental analysis of biofuel as an alternative fuel for diesel engines." *Applied Energy*. 94. pp. 224-231. 2012. DOI: 10.1016/j.apenergy.2012.01.067

[23] Ogunkoya, D., Roberts, W. L., Fang, T., Thapaliya, N. "Investigation of the effects of renewable diesel fuels on engine performance, combustion, and emissions." *Fuel*. 140. pp. 541-554. 2015. DOI: 10.1016/j.fuel.2014.09.061

[24] Lapuerta, M., Armas, O., Hernández, J. J., Tsolakis, A. "Potential for reducing emissions in a diesel engine by fuelling with conventional biodiesel and Fischer–Tropsch diesel." *Fuel*. 89 (10). pp. 3106-3113. 2010. DOI: 10.1016/j.fuel.2010.05.013

[25] Zhou, L., Boot, M. D., Johansson, B. H. "Comparison of emissions and performance between saturated cyclic oxygenates and aromatics in a heavy-duty diesel engine." *Fuel*. 113. pp. 239-247. 2013. DOI: 10.1016/j.fuel.2013.05.018

[26] *BP World Energy Outlook*. London, 2012.

[27] *Shell energy scenarios to 2050*. Shell International BV. 2012.

[28] EUROPEAN COMMISSION Directorate-General for Energy in collaboration with Climate Action DG and Mobility and Transport DG. "*EU energy trends to 2030 — UPDATE 2009*." European Union. 2010. DOI: 10.2833/21664

[29] International Energy Agency "*World Energy Outlook 2013 Renewable Energy Outlook*." 2013.

[30] European Commission Joint Research Centre Institute for Energy "*EU renewable energy targets in 2020: Analysis of scenarios for transport*." European Union. 2011. DOI: 10.2788/74948

[31] Official Journal of the European Union "*DIRECTIVE 2009/28/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC*." 2009.

[32] ACEA-European Automobil Manufacturer's Assotiation "Diesel Penetration" Available from: http://www.acea.be/statistics/tag/category/diesel-penetration [Accessed: 3rd March 2015] 2014.

[33] Thesz, J., Kondor, L. "*EU's EN 590 welcomes new fuel blends - Out with the old. Biofuels international november/december 2014*." 2014.