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THE ANALYSIS OF THE MOTOR CHARACTERISTICS OF D–RME–E FUEL BLEND DURING ON-FIELD TESTS

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Abstract. A detailed analysis of the characteristics of D–RME–E (diesel-rapeseed methyl ester-ethanol) was carefully performed fuelling an 18 kW capacity tractor unit equipped with the four-stroke D21A1 diesel engine (combustion chamber consists of a dished piston). The conducted on-field test demonstrated a positive effect on the dynamic and ecological characteristics of the tractor unit while fuelling the engine with biodiesel blend 70% D+30% RME (hereinafter – B30) admixed with dehydrated ethanol additive (5% (v/v)). This compound did not affect a decrease in the diesel engine power, and in the range of experiment error, showed a tendency of ~2% fuel economy compared to pure B30. A dramatic decrease in PM (40%), HC (25%) and CO (6%) emissions comparing to fossil diesel was observed when operating the tractor unit at maximum traction power which is a characteristic operating mode of the heavy duty transport means of agricultural purpose. NO_x emission of the proposed D–RME–E blend showed a tendency to decrease to 4% compared to B30.

Keywords: D–RME–E, fuel consumption, exhaust emission, ethanol additive, dehydrated ethanol.

1. Introduction

This publication continues the presentation of complex experiment (stand and on-field tests) results on the diesel engines of direct injection (combustion chamber consists of a dished piston). The experiment was carried out using a blend of mineral diesel (D) and rapeseed methyl ester (RME) with dehydrated ethanol (E) additives as a fuel.

Stiffening requirements regarding the toxicity of exhaust emission by diesel engines necessitate the further development of both engines and fuels. Tractors driven by the diesel engines (combustion chamber consists of a dished piston) of direct injection are mainly used in Lithuania (Department of Statistics to the Government of the Republic of Lithuania, *www.stat.gov.lt/en*, 2008). The major part of those does not comply with the permissible exhaust emission rates of the engines of heavy duty diesel transport means applicable in the EU countries. Diesel-fuelled engines have a disadvantage of producing soot, particles and nitrogen oxides and are now subjected to increasingly severe legislation following the revision of standards. The required levels are difficult to achieve through engine design only. Introducing the oxygenated compounds such as rapeseed methyl ester and ethanol into diesel fuel is presently the best way to achieve the required results in case of pollution (see Table 1).

Table 1. A comparison of exhaust emissions for ethanol/biodiesel/fossil diesel fuel blends (v/v). Fossil diesel exhaust emissions are accepted equal to 100%.

Authors	CO	HC	NO_x	PM
5:20:75 (ethanol: biodiesel: diesel fuel)				
Shi *et al.* (2006)	–	–	+5.6... +11.4	–30
Pągowski (2003)	–11	–15	–7	–50
Lebedevas *et al.* (2006)	–30... –37	–20... –25	+10... +12	–50... –55
4:16:80 (ethanol: biodiesel: diesel fuel)				
Shi *et al.* (2005)	–19... –20	–21... –23	+25	–48

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Thus, as far as the exploitation of diesel engines fuelled with D/RME blends is well-known, the fact-findings of the influence of ethanol additives on engine characteristics presented in the scientific papers are still discussed by many researchers (Shi *et al.* 2005 and 2006; Pągowski 2003; Lebedevas *et al.* 2006, 2007 and 2009; Pikūnas *et al.* 2006; Labeckas 2005; Hansen *et al.* 2001; Raslavičius 2009; Raslavičius and Markšaitis 2007; Mittelbach and Remschmidt 2004; Kwanchareon *et al.* 2007; Bazaras and Raslavičius 2008; Török 2009; Al-Hasan and Al-Momany 2008). These facts have encouraged initiating research on the characteristics of the diesel engine fuelling it with blends consisting of mineral diesel and bio–based fuel additives.

There are two possible approaches to use ethanol in the diesel engine. First, diesel could be injected in the normal way using a carburettor added to atomize ethanol, stored in the self-contained feed-tank (Pikūnas *et al.* 2006). Second, ethanol could be blended with diesel or MD/RME compound (Shi *et al.* 2005 and 2006; Lebedevas *et al.* 2009). The simplest way is to use the prepared fuel blends because this approach requires no engine modifications.

In general, diesel engines run well with cetane number ≥ 46 (Raslavičius 2009). Fuels with a higher cetane number (eg. biodiesel) having shorter ignition delays provide more time for the fuel combustion process to be completed (Lebedevas *et al.* 2009). This can result in changing the operating characteristics of the engine (Pągowski 2003; Raslavičius 2009). On the purpose to bypass it, 5% and 10% (v/v) ethanol additives were used to reduce a cetane number of 70%D+30%RME (B30) fuel blend.

Studies at the Institute of Agriculture Engineering of Lithuanian University of Agriculture show that D–RME–E blend can be burnt in the diesel engine with no modifications of operating parameters (Raslavičius 2009). It is recommended replacing certain hoses, gaskets and fuel tank cap, for example, with products that resist degradation (Raslavičius 2009; Mittelbach and Remschmidt 2004; Kwanchareon *et al.* 2007).

Research results have paved the way to formulate a biofuel blend from renewable material that has energy values comparable to those of fossil fuels (Raslavičius 2009), superior lubricity (Kwanchareon *et al.* 2007) and environmentally friendly characteristics (Shi *et al.* 2005 and 2006; Pągowski 2003; Lebedevas *et al.* 2006 and 2009; Hansen *et al.* 2001; Raslavičius 2009; Kwanchareon *et al.* 2007).

Immediately discussing the purpose of bio–based fuels with farmers and a manual on preparing D–RME–E exploitation, we deal with a lack of scientific data about on-field tests. Thus far stand experiments were extended by test drives.

The aim of research is establishing the energy and emission characteristics of the 18 kW capacity tractor unit operating on D–RME–E fuel under field conditions at variable load and torque rotational speed.

2. Objects and Methods

On-field tests were performed working on a tractor having 18 kW capacity (see Fig. 1). The specification of technical parameters is summarized in Table 2.

Tractor unit traction force resistance R_m was identified using tensometric equipment including 1.5–3.0 t traction catenary and EMA–PM register. Fuel consumption was identified measuring the weight of volume with fuel before and after the experiment with the help of electronic waterproof scale IPC–WP (class IP65, error ±0.5 g). Research on the same type of fuel and engine load was repeated 8 times. The experiment was performed at four different working speeds (four gears) at 1.5–2.7 m/s. Specific fuel consumption was identified at variable engine loads. Tractor unit operating speed and the slip of driving wheels was fixed with the help of wheel rotation sensors across the length of the field the total distance of which was 500 m. All experimental data was obtained fuelling the tractor with the investigated types of fuel (see Table 3). The collected data was compared with the obtained information when fuelling the tractor with pure diesel.

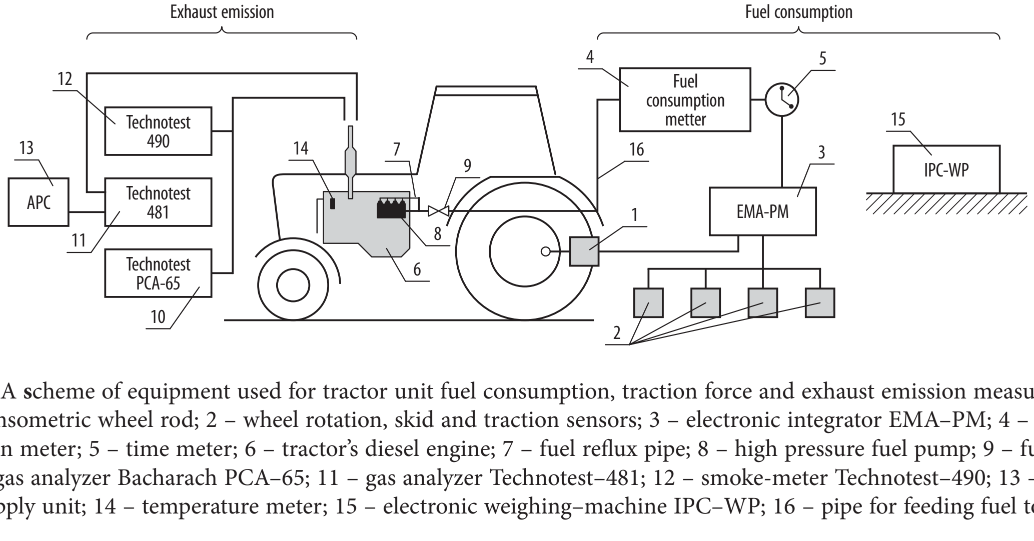

Fig. 1. A scheme of equipment used for tractor unit fuel consumption, traction force and exhaust emission measuring: 1 – tensometric wheel rod; 2 – wheel rotation, skid and traction sensors; 3 – electronic integrator EMA–PM; 4 – fuel consumption meter; 5 – time meter; 6 – tractor's diesel engine; 7 – fuel reflux pipe; 8 – high pressure fuel pump; 9 – fuel supply valve; 10 – gas analyzer Bacharach PCA–65; 11 – gas analyzer Technotest–481; 12 – smoke-meter Technotest–490; 13 – reserved power supply unit; 14 – temperature meter; 15 – electronic weighing–machine IPC–WP; 16 – pipe for feeding fuel to pump

Table 2. Tractor technical parameters

Technical parameters	Tractor
Mark	T25A
Engine	D21A1
Engine size, cm^3	4100
Nominal power, kW	18
Number of cylinders	2
Cylinders operating order	1–2–0–0
Cylinder diameter, mm	105
Stroke, mm	120
Compression ratio	16.5
Cooling system	Air–cooling
Chassis drive arrangement	rear–wheel drive (RWD)
Gears	forward 8, backwards 6
Fuel	mineral diesel, (LST EN 590)
Mass, kg	1780

Table 3. Investigated fuel blends

Basic fuel	Dehydrated ethyl alcohol additive, %		
	0	5.0	10.0
B30	+	+	+

Table 4. Emission measuring equipment

Parameter	Measurement error	Equipment
PM	0 – 100 % (error ±0.2 %)	Technotest–490
CO	0 – 9.99 % (error ±0.01)	Technotest–481
CH	0 – 1995 ppm (error ±2 %)	Technotest–481
NO$_x$	0 – 1000 ppm (error ±2 %)	Bacharach PCA–65

Emission tests were performed using smoke-meter Technotest–490 certificated at the public office *Vilnius metrology centre* and exhaust gas analyzer Technotest–481 (see Table 4).

3. Results and Discussion

When analyzing the data collected while the tractor was working in the field, according to the observations of tractor speed and stoppages, it was possible to distinguish between time the tractor was travelling to or between the fields and time it was working in the field. In order to make useful comparisons between the types of fuels, it was necessary to focus on the operation of tractors in the field. Therefore, only on-field work segments were selected for further analysis.

Other factors such as work rate and implementation settings also affected loading on the engine. With regard to implementation settings, the tractor driver had considerable experience of driving tractors and setting up implements and made a special effort to ensure that the implements on test drives were adjusted so that they had the same settings with particular reference to shank depth in the soil.

Analysis of the fuel consumption of the tractor unit. During the on-field tests, specific fuel consumption (SFC) rates were achieved (see Fig. 2).

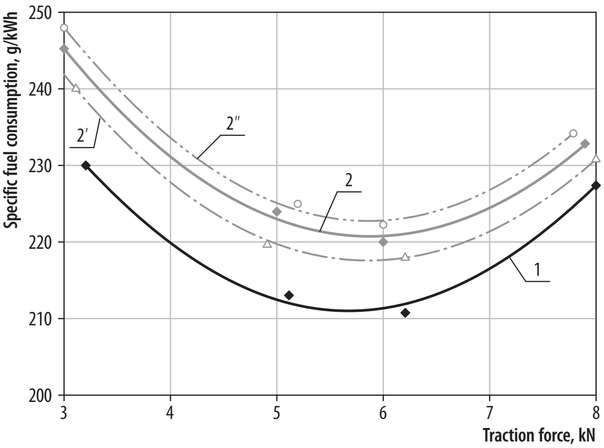

Fig. 2. Comparative fuel consumption dependence of the 18 kW capacity tractor unit on traction force and the type of fuel: 1 – MD, 2 – B30, 2′ – B30 with 5% ethanol additive, 2″ – B30 with 10% ethanol additive

The fuel consumption of the 18 kW capacity tractor unit working at maximum tractor's traction force $P_{\max}$ and nominal engine revolution speed under the same conditions with mineral diesel and B30 with 5% and 10% ethanol additives was established. SFC and exhaust emission were established while loosening stubble. Soil moisture in the stubble was 17%, hardiness – 810 kPa.

The lowest SFC of the used tractor unit was achieved at the average revolution speed of the engine's crankshaft (1200–1600 min^{-1}) and at full load often near the maximum torque mode. It was established that the highest specific fuel consumption was achieved when the engine operated at high frequency of crankshaft revolutions and at slimed down engine load. During the on-field tests, it was established that the optimum amount of ethanol to the basic fuel was 5%.

The comparisons of engine performance between D–RME–E blends and standard diesel in the unmodified engine generally show reductions in power when fuelling the engine with compound having 10 % of ethanol.

As would be expected, comparative fuel consumption increases with increasing the concentrations of ethanol in the blend because of the reduced energy content (Hansen *et al.* 2001). Improvements in SFC were small but consistent for B30+5%E and were assumed to be the result of improving the efficiency of the thermal cycle (Hansen *et al.* 2001).

Analysis of the exhaust emission of the tractor unit. In order to achieve better emission characteristics of the diesel engine, fatty acid methyl esters are mixed into pure mineral diesel fuel distilled from oil. However, due to the different origin and chemical-physical characteristics of these two types of fuel, in the mixture of those, the duration of ignition delay time inevitably decreases. Short ignition delay characteristics of biodiesel fuelled-engines lead to early fuel ignition (Mittelbach and Remschmidt 2004). In most diesel engines, early ignition causes high combustion pressures and maximum temperatures, and thus results in increased NO_x emissions (see Fig. 3).

Investigations carried out under operating conditions showed that the 18 kW capacity tractor unit fuelled with B30 blend had a higher amount of NO_x in exhaust gases. One of the methods to avoid this negative effect is the use of a 5% dehydrated ethanol additive in the above mentioned blend.

The effect of oxygenated fuel blends on NO_x emissions is complex and is not conclusive. Aromatic fuel composition, fuel density and cetane number can influence NO_x emissions (Shi *et al.* 2006; Hansen *et al.* 2001; Mittelbach and Remschmidt 2004; Kwanchareon *et al.* 2007). Therefore, adding 5% of ethanol as a cetane number improver to B30 blend causes a small decrease in NO_x quantity in exhaust emission. Ethanol has oxygen participating in the combustion process, the atoms of which are of a much lesser mass compared with hydrocarbon compounds which conditions a better combustion reaction and a lesser amount of open-ended combustion products is emitted. It can be observed that all fuel blends reduced NO_x emissions at the medium load conditions and increased NO_x significantly at small and full load modes.

Oxygenated diesel fuel blends are known as reducing the total PM emissions. However, the mechanisms of reducing PM by oxygenate addition have not been fully explained. It is commonly assumed that oxygenates blended with diesel fuel effectively deliver oxygen to the pyrolysis zone of the burning diesel spray resulting in reduced PM generation (Shi *et al.* 2006).

The highest decrease in PM (see Fig. 4) was established when the diesel engine developed maximum traction force. A 5% ethanol additive to B30 fuel blend reduced PM emission by 40% compared to mineral diesel.

Variations in CO emissions with respect to fuels and engine loads are shown in Fig. 5. The carbon monoxide emissions of the blends were not much different from those of conventional diesel. The addition of oxygenates into diesel fuel resulted in only a slight effect on CO emissions at low, medium and high loads.

It was also observed that the blends containing a higher percentage of biodiesel would have lower HC emission (see Fig. 6). These findings are attributed to the oxygen content of fatty acid methyl esters which leads to more complete combustion (Shi *et al.* 2006). In the case of unburnt or partially oxidized hydrocarbons, also a cetane number is considered to contribute to low emissions.

At a small load of tractor diesel engine, B30 blends with ethanol had higher HC emissions than those emitted from medium or higher loads.

Fuelling the 18 kW capacity tractor with D–RME–E blends, the emission of hydrocarbons was reduced by 24–26% (see Fig. 6).

In addition, data on comparative emissions is influenced by a number of factors that may have caused greater differences than those brought by fuel. These

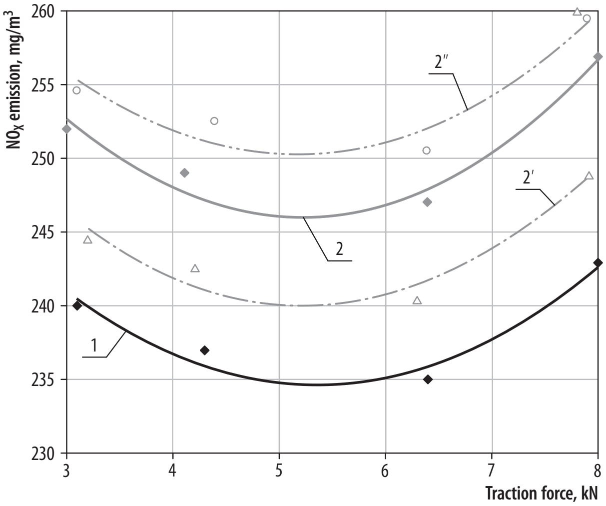

Fig. 3. NO_x emission dependence on traction force and the type of fuel: 1 – MD, 2 – B30, 2′ – B30 with 5% ethanol additive, 2″ – B30 with 10% ethanol additive

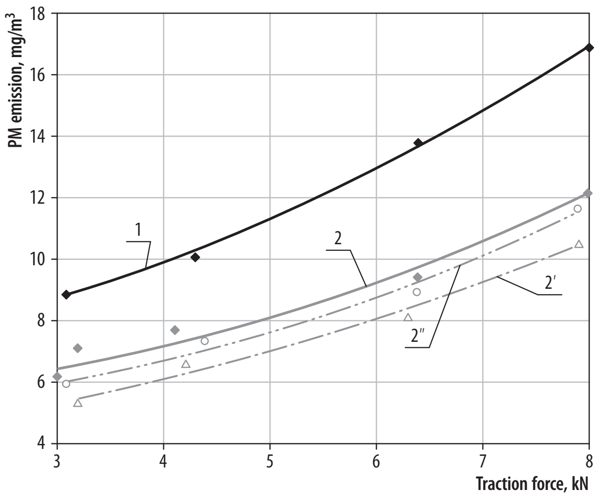

Fig. 4. PM emission dependence on traction force and the type of fuel: 1 – MD, 2 – B30, 2′ – B30 with 5% ethanol additive, 2″ – B30 with 10% ethanol additive

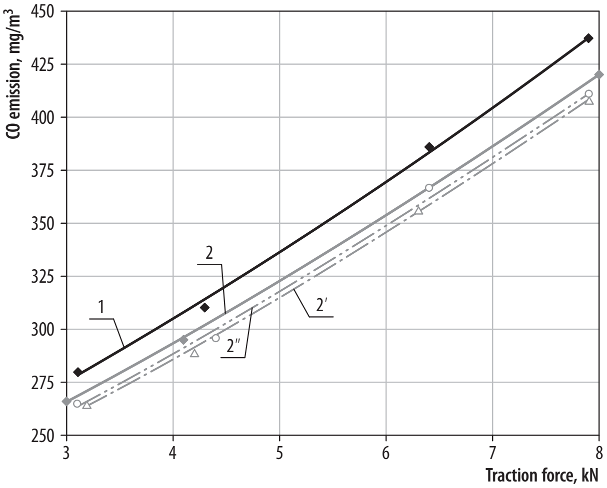

Fig. 5. CO emission dependence on traction force and the type of fuel: 1 – MD, 2 – B30, 2′ – B30 with 5% ethanol additive, 2″ – B30 with 10% ethanol additive

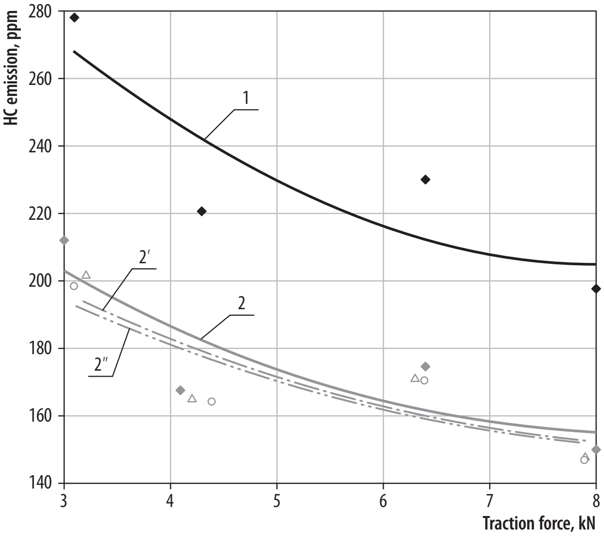

Fig. 6. HC emission dependence on traction force and the type of fuel: 1 – MD, 2 – B30, 2′ – B30 with 5% ethanol additive, 2″ – B30 with 10% ethanol additive

factors include engine fuel metering technology, exhaust control technology, the age of the vehicle, maintenance history, testing procedure and test conditions. Nevertheless, these tests provide a means of gauging the relative benefits of introducing these blends as a substitute for traditional diesel fuel.

The proposed fuel blends B30 with a 5% ethanol additive are expedient to be used in the areas especially sensitive to environmental pollution (forestry, ecological farms etc.).

4. Conclusions

1. It was established that having added 5% of ethanol to B30 fuel blend, the exploitation characteristics of the tractor unit were analogous within the total range of loads as operating on pure mineral diesel. Modifications in D21A1 diesel engine operating parameters are not required.
2. Using a 10% ethanol additive is not recommendable due to uneven engine operation and increased emission level in the exhaust gases.
3. Operating the tractor unit at full load, frequently near the maximum torque mode, SFC rates fuelling the diesel engine with D–RME–E and pure diesel were in the range of the margin of error.
4. The oxygen content of the chemical composition of RME and ethanol positively influenced the combustion process by dramatically reducing solid particles and hydrocarbon emission – 40% and 25% respectively as well as marginally decreasing CO concentration in the unburnt gases by 6%. High combustion temperatures resulted slightly (2%) with the number values close to the margin of error.
5. Due to the more aggressive chemical behaviour of bio–based additives to rubber and plastic parts of the fuel supply system, gaskets and fuel tank cap, it is recommendable to replace them with those resisting degradation.

References

Al-Hasan, M. I.; Al-Momany, M. 2008. The effect of iso-butanol-diesel blends on engine performance, *Transport* 23(4): 306–310. doi:10.3846/1648-4142.2008.23.306-310

Bazaras, Ž., Raslavičius, L. 2008. Investigation of three-component biodiesel fuels using a single droplet technique, in *Proceedings of the 7th International Conference Vibroengineering 2008*, October 9–11, 2008, Kaunas, Lithuania, 109–112.

Hansen, A. C.; Hornbaker, R. H.; Zhang, Q.; Lyne, P. W. L. 2001. On-farm evaluation of diesel fuel oxygenated with ethanol, *American Society of Agricultural and Biological Engineers, Paper No 016173*.

Kwanchareon, P.; Luengnaruemitchai, A.; Jai-In, S. 2007. Solubility of a diesel–biodiesel–ethanol blend, its fuel properties, and its emission characteristics from diesel engine, *Fuel* 86(7–8): 1053–1061. doi:10.1016/j.fuel.2006.09.034

Labeckas, G. 2005. *Aplinkai žalingos deginių emisijos mažinimas tobulinant dyzelinių variklių darbo procesą.* Habilitacijos procedūrai teikiamų mokslo darbų apžvalga: technologijos mokslai T000, aplinkos inžinerija ir kraštotvarka (04T) [Reduction of environmentally harmful exhaust emissions by improving the performance process of diesel engines. Summary of the review of scientific works presented for Dr Habil procedure: technological sciences T000, environmental engineering and landscape management (04T)]. Lithuanian university of agriculture. 34 p. (in Lithuanian).

Lebedevas, S.; Lebedeva, G.; Makarevičienė, V.; Janulis, P.; Sendzikienė, E. 2009. Usage of fuel mixtures containing ethanol and rapeseed oil methyl esters in a diesel engine, *Energy & Fuels* 23(1): 217–223. doi:10.1021/ef800512z

Lebedevas, S.; Vaicekauskas, A.; Lebedeva, G.; Janulis, P.; Makarevičienė, V. 2006. Research into operational parametersof diesel engines running on RME biodiesel, *Transport* 21(4): 260–268.

Lebedevas, S.; Vaicekauskas, A.; Suškov, P. 2007. Presumptions of effective operation of diesel engines running on RME biodiesel. Research on kinetics of combustion of RME biodiesel, *Transport* 22(2): 126–133.

Mittelbach, M.; Remschmidt, C. 2004. *Biodiesel: a Comprehensive Handbook*. Graz, Austria. 330 p.

Pągowski, Z. T. 2003. New perspectives for biofuels in aviation, *Journal of KONES* 10(3–4): 4 p. Available from Internet: <http://www.ilot.edu.pl/KONES/2003/3-4/28.pdf>.

Pikūnas, A.; Pukalskas, S.; Bureika, G.; Grabys, J. 2006. Investigation of efficiency of consuming ethanol of diesel engine, *Journal of KONES* 13(2): 381–386. Available from Internet: <http://www.ilot.edu.pl/KONES/2006/02/39.pdf>.

Raslavičius, L. 2009. *Research into three-component combustible mixture application for fuelling diesel engines*. Summary of Doctoral Dissertation. Kaunas: Technologija. 32 p.

Raslavičius, L.; Markšaitis, D. 2007. Research into three-component biodiesel fuels combustion process using a single droplet technique, *Transport* 22(4): 312–315.

Shi, X.; Pang, X.; Mu, Y.; He, H.; Shuai, S.; Wang, J.; Chen, H.; Li, R. 2006. Emission reduction potential of using ethanol–biodiesel–diesel fuel blend on heavy-duty diesel engine, *Atmospheric Environment* 40(14): 2567–2574. doi:10.1016/j.atmosenv.2005.12.026

Shi, X.; Yu, Y.; He, H.; Shuai, S.; Wang, J.; Li, R. 2005 Emission characteristics using methyl soyate–ethanol–diesel fuel blends on a diesel engine, *Fuel* 84(12–13): 1543–1549.

Török Á. 2009. Theoretical estimation of the environmental impact of biofuel mixtures, *Transport* 24(1): 26–29. doi:10.3846/1648-4142.2009.24.26-29.