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Use of Waste Fats of Animal and Vegetable Origin for the Production of Biodiesel Fuel: Quality, Motor Properties, and Emissions of Harmful Components

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One of the ways to reduce the price of biodiesel fuel is to use waste fats of animal and vegetable origin. The objective of this work was to investigate the physical and chemical properties of the fatty acid methyl esters of animal and vegetable origin and their mixtures, to determine their motor characteristics, to choose the optimal composition of biofuel mixtures, and to perform comparative analyses of emissions of harmful components in exhaust gases. It was determined that pure fatty acid methyl esters of animal origin and linseed oil fatty acid methyl esters do not meet standard requirements and cannot be used directly in diesel engines. For diesel engines, three-component mixtures of rapeseed oil methyl esters (RME), pork lard methyl esters (PME) or beef tallow methyl esters (TME), and linseed oil methyl esters (LME) (where the proportion of LME and methyl esters of animal origin is 1:4) may be used as fuel. According to the comparative analyses of motor characteristics of three-component mixtures, they are practically equal to the certified RME and its mixtures with fossil diesel fuel. If these three-component mixtures are used for the high-speed diesel engine, CO emissions are reduced by 20%–50%, hydrocarbon (HC) emissions are reduced by 50%–60%, and the smoke opacity of the exhaust gases is reduced by 25%–70%. The increase in NO_x emissions does not exceed 13%; no significant changes in the CO₂ emissions have been noticed. When the mixtures with fossil diesel fuel that contained 30% of the aforementioned three-component biofuel mixtures were tested, CO emissions were reduced by 15%–40%, HC emissions were reduced by 30%–45%, and the smoke opacity was reduced by 25%–30%. The NO_x emissions increased ~6%; there were no notable changes in CO₂ emissions.

1. Introduction

The reduction of pollution by gases that cause the greenhouse effect is one of the most topical contemporary environment problems; many different measures for its solution have been undertaken. Having in mind that the main sources of air pollution are motor transport and energetic units, which use the nonrenewable resources of fossil diesel fuel, the fuel used in motor transport is changed into renewable biofuel, the leader of which is evidently biodiesel: fatty acid methyl esters (FAME), which are used as fuel in diesel engines. They may be used in pure form or as mixtures with fossil diesel fuel (D).¹ Vegetable oils of different types are used for the production of biodiesel fuel. Usually, the rapeseed oil fatty acid methyl esters (RME) are made. They form 85% of the biodiesel fuel that is

presently used. Then, following the ranking order of biofuel production, there is sunflower oil (which is dominant in southern European countries), soybean oil (which is the preferred biofuel fuel in the United States), and palm oil (which is popular in southern Asian countries). Individual countries, depending on climatic conditions and traditions, may use other types of oil for the production of biodiesel fuel (such as mustard, linseed, palm, coconut, etc.). The price of biodiesel fuel produced from edible vegetable oil is relatively high, so it is difficult for such biofuels to compete with fossil diesel fuel.² Therefore, research is being conducted for alternative ways to reduce the cost through the application of more-effective production technologies and the use of less-expensive vegetable oils and those which are unsuitable for food (due to the harmful substances they contain) for the production of FAME (such as castor oil, physic nut oil, etc.^{3,4}).

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Keeping in mind the fact that fatty wastes of the meat processing industry are characterized by low cost, interest in the possibilities to use fats of animal origin (beef tallow and pork lard) for the production of FAME recently has increased.^{5–7} It was determined that, while making FAME of animal origin, it is meaningful to apply a complex production process with two stages: (i) initial esterification of free fatty acids using acid catalysts and (ii) further transesterification of triglycerides using alkaline catalysts.⁸ However, FAME of animal origin has certain negative properties. Because of the high amount of saturated fatty acids, the clouding point (CP) and cold filter plugging point (CFPP) of such biofuels is higher, in comparison to FAME of vegetable origin; thus, it is not possible to use them in pure form during cold periods.⁹ On the other hand, methyl esters of animal origin also have positive properties. They are characterized by higher calorific value and cetane number (CN). To reduce the CP of FAME of animal origin, various methods are applied, such as the elimination of saturated fatty acids via winterization or the addition of specific additives (depressants) into methyl esters of animal origin. However, one of the simplest and most inexpensive methods is the production of mixtures with products that are characterized by better cold-temperature properties (usually fossil diesel fuel, D).¹⁰ The mixtures of methyl esters of animal origin with vegetable methyl esters are characterized by better cold-temperature behavior. Therefore, the producers of biodiesel fuel recently inserted a small amount of tallow into vegetable oil that has been used as raw material for transesterification. Nevertheless, if the traditional production technology is applied, the overall volume of the usage of animal fats is quite small.

Flax has been grown in Lithuania for ages. In earlier times, linseed oil has been used for food; however, now, exceptionally fibrous flax is grown for the textile industry. The oil of such flax is not suitable for making food, because of its high contamination by plant protection materials; however, it may serve as an additional raw material for the production of biodiesel fuel. Still, linseed oil fatty acid methyl esters (LME) are characterized by a high number of polyunsaturated fatty acids; they oxidize quickly, and, thus, such products cannot be used directly in diesel engines. LME could be mixed with FAME of animal origin, that has been produced from fatty waste, and RME in such a proportion to attain the optimal properties of biofuel. In such a way, it would be possible to use inexpensive fatty waste optimally and to reduce the cost of biofuel at the same time. However, such three-component mixtures of methyl esters have not been investigated very much. Besides an evaluation of the physical and chemical characteristics, it is very important to assess the operating and environmental motor properties of the new biofuel composition.

The characteristics of engine performance and harmful emissions have been widely investigated, although diesel engines are fuelled with common biodiesel fuel. An increase of fuel consumption (by 7%–13%) has been observed while fuelling

with soybean oil methyl esters (SME) and RME, if compared to fossil diesel fuel. According to almost all authors, when fuelling with common biodiesel fuel (RME, SME), the amount of nitrogen oxides (NO_x) in the exhaust gases is higher (by ~10%), if compared to fossil diesel fuel.^{11,12} This may be explained by the different amounts of oxygen, which is 11% higher in biofuel.¹³ Besides, it has been noted that, because of the better combustion of biofuel in the engine, the amount of CH and CO in the exhaust gases, as well as smoke emission, becomes significantly lower.^{14,15} There are almost no data that concern engine emissions of pure beef tallow (TME) and pork lard (PME) methyl esters. Some authors have analyzed the emissions of 5%–20% mixtures of the aforementioned esters with fossil diesel fuel. It was determined that if engine was fuelled with a 5% mixture, a positive effect is received for all pollutants, if compared to pure fossil diesel fuel. The amount of NO_x emissions decreases by 3%, the hydrocarbon (HC) emissions decrease by 11%, and the CO emissions decrease by 9%, while the smoke opacity decreases by 3%. If the amount of methyl esters of animal origin is increased in the mixture with fossil diesel fuel up to 20%, the concentration of all pollutants, except for NO_x, in the exhaust gases significantly decreases; however, the emission of NO_x is higher if compared to the mixture of 5%.¹⁶ The search for data about mixtures of methyl esters of animal origin with RME and LME was unsuccessful.

The tasks of this research were as follows: experimental analyses of the motor characteristics of new biodiesel fuel mixtures that contain methyl esters of vegetable and animal origin; setting of optimal proportions of components of biodiesel fuel mixture; and comparative analysis of the technical–economical and ecological parameters of the diesel engine while working with optimal three-component mixtures and a standard RME mixture with fossil diesel fuel.

2. Materials and Methods

Edible-grade linseed oil, beef tallow, and pork lard for the production of fatty acid methyl esters were purchased from the market. LME, PME, and TME were prepared following a standard procedure of two-step transesterification by methanol, using sodium hydroxide as a catalyst. Quality parameters of produced esters and their mixtures were checked according to the requirements of European standard EN 14214 (Automotive Fuels—Fatty Acid Methyl Esters (FAME) for Diesel Engines—Requirements and Test Methods). RME was purchased from the market. Its quality met the standard requirements of EN 14214. All FAME samples were stored in closed bottles, in a dark place, at a temperature of 18 ± 2 °C. Quality analysis of the FAME was made through the application of standard test methods.

Experimental analyses of motor characteristics were made on a certified stand, supported by modern automated measuring and registration devices of the main technical–economical (fuel consumption, temperature of exhaust gases, etc.) parameters regarding the emission of harmful components in exhaust gases.

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Table 1. Quality Parameters of Methyl Esters

parameter	Standard Limits		Methyl Ester			
	min	max	RME	LME	TME	PME
ester content (% , m/m)	96.5		98.7	98.1	97.8	97.2
density at 15 °C (g/cm ³)	0.860	0.900	0.888	0.896	0.867	0.866
viscosity at 40 °C (mm ² /s)	3.5	5	4.6	4.77	5.14	5.47
water content (mg/kg)		500	400	380	430	450
oxidation stability at 110 °C (h)	6.0		6.32	0.38	0.44	0.18
acid value (mg KOH/g)		0.5	0.40	0.50	0.40	0.45
iodine value (g J ₂ /100 g)		120	116.3	176.2	51.5	64.9
linolenic acid methyl ester (% , m/m)		12.0	9.50	48.0	n.d	0.8
methanol content (% , m/m)		0.2	0.15	0.1	0.18	0.17
alkaline metals (mg/kg)		5	3.5	4.0	4.2	4.3

Table 2. Iodine Value and Linolenic Acid Methyl Ester Content in LME Mixtures with TME and PME

LME content (%)	Mixtures with PME		Mixtures with TME	
	iodine value (g J ₂ /100 g)	linolenic acid methyl ester content (% , m/m)	iodine value (g J ₂ /100 g)	linolenic acid methyl ester content (% , m/m)
10	75.9	5.6	64.0	4.6
20	87.3	10.1	75.5	9.6
30	98.3	14.5	87.9	14.3
40	109.8	19.8	92.1	18.9
60	131.2	29.2	126.5	28.8
80	156.9	38.8	152.9	38.4
90	164.4	43.3	163.5	42.9

A hydraulic brake (Zöllner model 20LLNE3N19A (0–200 N, with a measurement error of $\pm 0.5\%$)) that was controlled by computer (models FIPS–S486/66-FTFT-635-ES/AT-08–4SER/TM-PLU) was used to regulate the load; the fuel consumption was measured by a fuel feeding rate gauge (model PLU 401–115W/116HR (0.3–63 L/h, with a measurement error of $\pm 0.5\%$)).

The emissions in the exhaust gases were measured using a model MIR 9000 analyzer, which was designed to register the harmful components of exhaust gases continuously, using the method of infrared absorption spectroscopy and gas-filter correlation. The lowest measured concentrations of the components are as follows: carbon dioxide (CO₂), 0–10 ppm, 0–20 mg/m³; carbon monoxide (CO), 0–30 ppm, 0–40 mg/m³; nitrogen monoxide (NO), 0–100 ppm, 0–200 mg/m³; and hydrocarbons (HC), 0–20 ppm, 0–25 mg/m³. The measurement error is within the limits of the smallest measurement scales of components. The smoke opacity of exhaust gases was measured using a Bosch analyzer. The measurement limits are 0–10.0 units, with a measurement error of 0.1 unit.

To guarantee that the testing conditions correspond the real operational conditions of diesel engines, the analyses were made while the engine was running in a wide range of loads (average effective pressure of $p_{me} = 0.2–0.7$ MPa) and rotation speeds ($n = 2000–3000$ min⁻¹).

3. Results and Discussions

Comparative analysis of the quality of FAME synthesized under laboratory conditions from animal and vegetable waste (Table 1) showed that pure methyl esters could not be used directly in diesel engines.

The biggest problems may be caused by low oxidation stability and high CFPP of methyl esters of animal origin, as well as high linolenic acid methyl ester content, high iodine value, and low oxidation stability of linseed oil fatty acid methyl esters.

The results of previous research show that the oxidation stability of FAME of animal and vegetable origin could be increased by adding 400 ppm of synthetic antioxidants, such as butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT) (with synergist citric acid (20% of antioxidant quantity) added).¹⁷ The mixtures, which contained 10%–20%

LME and 80%–90% TME or PME, were characterized by the highest oxidation stability in both cases, being pure, and having antioxidant additives.

LME is characterized by a high content of linolenic acid methyl esters (48%, which is 4 times greater than that allowed by the standard (12%)), whereas, in the case of PME and TME, this value is very small or is below the detection limits (see Table 1). The linolenic acid methyl ester content in FAME correlates with the iodine value; thus, the LME iodine value also exceeds the standard requirements and reaches a value of 176 g J₂/100 g, whereas the iodine value of FAME of animal origin is very low (51.6 J₂/100 g in the case of TME and 64.9 J₂/100 g in the case of PME). It is possible to make these indexes closer to the standard requirement if the FAME of animal origin are mixed with LME in appropriate proportions. Table 2 presents the dependence of the iodine value and the amount of linolenic acid methyl esters on the composition of the mixtures. Mixtures that contain no more than 20% LME meet the requirements for the linolenic acid methyl ester content, whereas the iodine value meets the standard requirements in any case. The received results correlate with the testing results of oxidation stability, where the established optimal proportion of LME and TME/PME was 1:4. Such mixtures could be mixed with pure RME without worsening its quality, relative to the previously investigated properties.

The bigger problems are encountered with regard to CFPP of FAME mixtures. It was determined that the CFPP of LME and TME/PME mixtures (in a proportion of 1:4) reaches $\pm (14–15)$ °C. However, in the case of 20% of the aforementioned ester mixtures with RME, the CFPP is reduced to -3 °C, and if effective depressants are added, the temperature may be reduced further to -10 °C.

Engine tests were performed on mixtures of RME, TME (PME), and LME in the volumetric proportions of 80:16:4, 60:32:8, and 40:48:12 (see Table 3). In such a way, the optimal set proportion for TME (PME):LME in all experimental mixtures of FAME was realized (4:1). For the comparative analysis, summer fossil diesel fuel that met the requirements of standard EN 590 and RME that met the requirements of standard EN 14214 were used. The physicochemical characteristics of fuel mixtures are presented in Table 3.

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Table 3. Physicochemical Characteristics of Tested Fuel Mixtures

fuel mixture (v/v)	density at 15 °C (g/cm ³)	viscosity at 40 °C (mm ² /s)	lower calorific value, H_u (kJ/kg)	cetane number, CN	stoichiometric constant, l_0 (kmol/kg fuel)
fossil diesel fuel	0.840	2.5	42 470	46.0	0.495
RME	0.890	4.7	37 200	51.6	0.433
RME/PME/LME					
80:16:4	0.890	6.3	37 440	53.6	0.434
60:32:8	0.883	6.7	37 410	55.6	0.433
40:48:12	0.881	6.9	37 370	57.4	0.433
RME/TME/LME					
80:16:4	0.886	6.0	37 380	52.7	0.433
60:32:8	0.889	5.1	37 290	53.8	0.432
40:48:12	0.890	5.4	37 170	54.8	0.430
B30 (fossil diesel fuel/RME)	0.854	3.8	40 950	47.7	0.476

All tested mixtures of the investigated FAME have similar values of density (0.881–0.890 g/cm³) and lower fuel calorific value ($H_u = 37\,170$ – $37\,440$ kJ/kg) (see Table 3), which is accordingly determined by similar chemical compositions. The essential differences are common to their cetane number (CN) and viscosity (ν). In the case of similar proportions of components, in the mixtures with PME, the viscosity is higher (from 5% to 22%) and the CN is higher (by 2.5 units), if compared to those of TME mixtures. The increase in the amount of PME in the mixture increases both the ν and H_u values, whereas in the case of TME mixtures, when H_u is increasing, the viscosity ν of the mixture is decreasing. It is meaningful to pay attention to the noticed regularity, not only when the optimal proportions of components of biodiesel fuel mixture are set,

according to the technical-economical parameters of diesel engine, but also when the operational problems in the cold climate are solved. Generally, the best results of fuel economy (specific consumption of fuel, b_e) and the lowest level of harmful components in the exhaust gases (NO_x, CO, HC, and smoke opacity (SE, Bosch)), were received for mixtures with PME (Figure 1).

It is evident that the change of mixtures composition in the case of PME mixtures has less influence on engine parameters, if compared to TME mixtures. Smoke opacity, e'_{NO_x} , and b_e remain practically unchanged at the same engine load p_{me} . It is supposed that the higher CN values, as well higher ν values, of the RME/PME/LME mixtures guarantee (in the case of same regulation of the diesel engine) an earlier start of the combustion

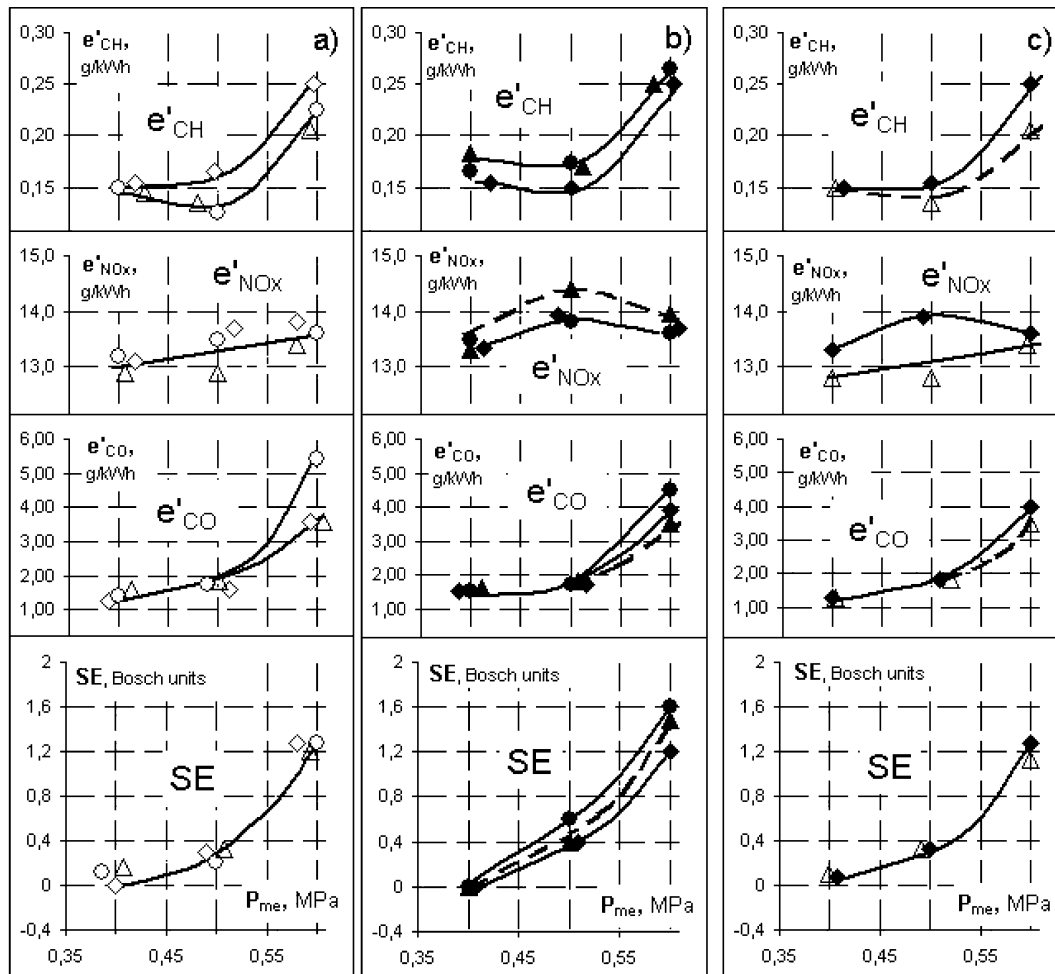


Figure 1. Performance parameters of diesel engine F2L511 ($n = 3000 \text{ min}^{-1}$) using biofuel mixtures: (a) RME/PME/LME (\circ) 80:16:4, (Δ) 60:32:8, and (\diamond) 40:48:12, (b) RME/TME/LME (\bullet) 80:16:4, (\blacktriangle) 60:32:8, and (\blacklozenge) 40:48:12, and (c) RME/PME/LME (\triangle) 60:32:8 and (\blacklozenge) 40:48:12).

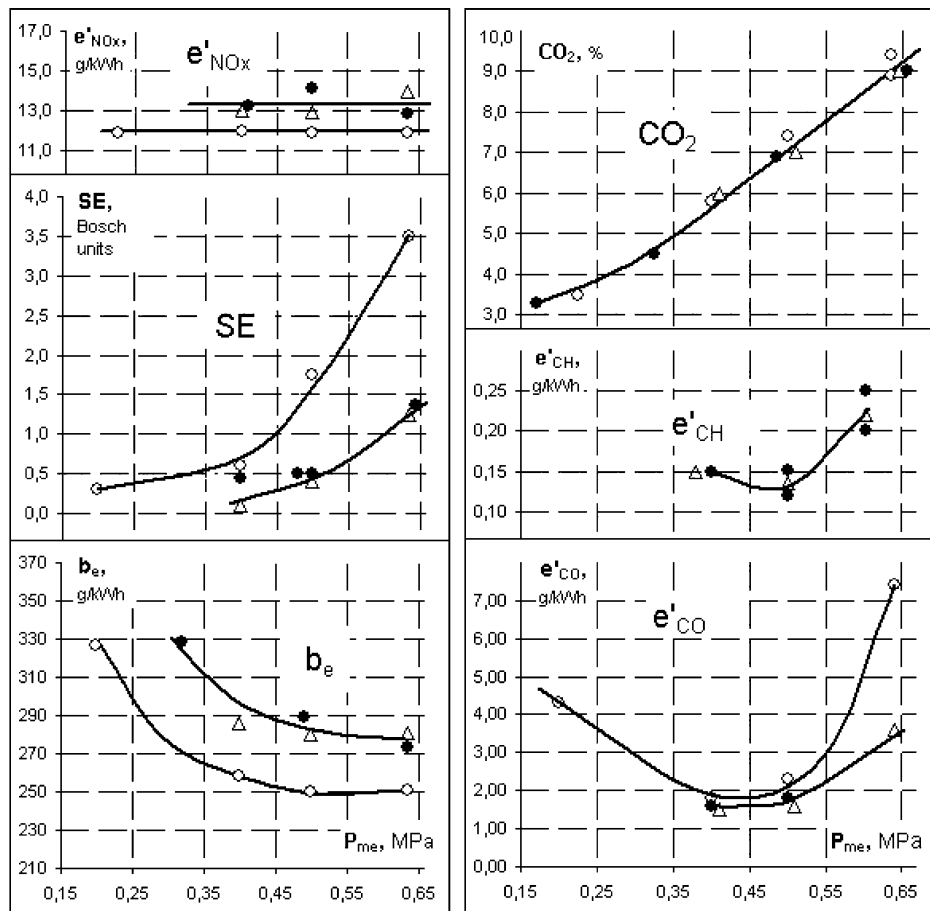


Figure 2. Performance parameters of diesel engine F2L511 ($n = 3000 \text{ min}^{-1}$) when a three-component biofuel mixture and certified RME are used as fuel: (O) D, (●) RME, and (Δ) RME/PME/LME (60:32:8).

process, because of the earlier fuel injection phase Φ_{fi} and shorter period of induction Φ_i (the period of fuel–air mixture formation for combustion in the cylinder of the diesel engine). As a result, the deflection of the burning process toward an expansion phase above the top dead center (TDC) guarantees better specific consumption of fuel (b_e) as well. Besides, a smaller Φ_i value positively influences the intensiveness of kinetic combustion phase and decreases the NO_x emissions. This hypothesis was substantiated by a fixed, sufficiently intensive decrease in the temperature of the exhaust gases (t_g): when the amount of PME in the mixture was increased from 16% to 48% (the $p_{me} = 0.6 \text{ MPa}$ regime), t_g decreases from $460 \text{ }^\circ\text{C}$ to $405 \text{ }^\circ\text{C}$ (see Figure 1a).

The best performance results of a diesel engine were attained using the RME/PME/LME 60:32:8 mixture as fuel. The increase in the TME amount in the RME/TME/LME mixture influenced the increase in CN value by a lower degree. As a result, when the parameters of the engine are constantly improving (b_e , D, HC), the best values were reached when the TME amount in the mixture was the largest, 40:48:12 (see Figure 1b). The performance parameters of a diesel engine, except for e'_{NO_x} emission, are insignificantly different for the optimal fuel mixture compositions of RME/PME/LME 60:32:8 and RME/TME/LME 40:48:12 (see Figure 1c), and their use in the mixtures with diesel fuel may be evaluated as invariant. The NO_x emissions from fuel mixtures that contain PME are lower by 5%, in comparison to TME mixtures.

The chosen optimal composition of biofuel—the RME/PME/LME, 60:32:8 mixture—and its performance parameters were

compared to those of standard RME in the next stage of the testing (Figure 2).

According to the received results, which were complemented by the data of earlier investigations with an analogous model of a diesel engine, the new mixture of biofuel is no worse than the certified RME, on the basis of ecological parameters. For the analyzed range of load ($p_{me} = 0.4\text{--}0.6 \text{ MPa}$ ($n = 3000 \text{ min}^{-1}$)), practically identical values of e'_{CO} , e'_{HC} , e'_{NO_x} , and smoke opacity were obtained. In the case of specific fuel consumption b_e , compared to RME, there was noticed certain tendency of improvement. The positive environmental effect of RME and new mixtures of biofuel is sufficiently significant if compared to fossil diesel fuel, and it correlates well with analogous results of other scientific research.¹⁸ The CO amount decreased by 20%–50%, the HC amount decreased by 50%–60%, and the smoke opacity (Bosch) decreased by 25%–70%. The higher values were received in the case of higher load on the engine. In such a way, the CO emissions in $p_{me} = 0.6 \text{ MPa}$ load conditions were reduced from 7.2 g/(kW h) down to 3.6 g/(kW h) , whereas the smoke opacity changes from 3.5 Bosch units down to 1.4 Bosch units. An $\sim 13\%$ decrease in the NO_x emissions in the exhaust gases is observed: e'_{NO_x} increases from 11.8 g/(kW h) up to 13.4 g/(kW h) . Practically no significant increase of CO_2 emissions in exhaust gases was observed. When the possibilities to use new types of biofuel are evaluated, initially, the characteristics of viscosity in low

(18) A comprehensive analysis of biodiesel impacts on exhaust emissions. Draft Technical Report No. EPA420-P-02-001, United States Environmental Protection Agency, October 2002, 118 p.

Table 4. Engine Emissions when Fuelled with 30% Fuel Mixtures of Fossil Diesel Fuel

fuel	Emissions ^a		
	$p_{me} = 0.4$ MPa	$p_{me} = 0.5$ MPa	$p_{me} = 0.6$ MPa
SE			
fossil diesel fuel	0.7 Bosch units	1.7 Bosch units	3.0 Bosch units
B30 (RME)	0.3 Bosch units	0.8 Bosch units	1.8 Bosch units
B30 (RME/PME/LME)	0.5 Bosch units	1.25 Bosch units	2.3 Bosch units
e'_{CO}			
fossil diesel fuel	1.8 g/(kW h)	2.3 g/(kW h)	5.1 g/(kW h)
B30 (RME)	1.6 g/(kW h)	1.95 g/(kW h)	3.0 g/(kW h)
B30 (RME/PME/LME)	1.8 g/(kW h)	2.0 g/(kW h)	3.0 g/(kW h)
e'_{HC}			
fossil diesel fuel	0.32 g/(kW h)	0.35 g/(kW h)	
B30 (RME)	0.21 g/(kW h)	0.19 g/(kW h)	0.22 g/(kW h)
B30 (RME/PME/LME)	0.23 g/(kW h)	0.19 g/(kW h)	0.22 g/(kW h)
e'_{NO_x}			
fossil diesel fuel	11.8 g/(kW h)	11.8 g/(kW h)	11.8 g/(kW h)
B30 (RME)	12.5 g/(kW h)	12.6 g/(kW h)	12.5 g/(kW h)
B30 (RME/PME/LME)	12.5 g/(kW h)	12.6 g/(kW h)	12.5 g/(kW h)
e'_{CO_2}			
fossil diesel fuel	5.8 g/(kW h)	7.4 g/(kW h)	8.4 g/(kW h)
B30 (RME)	5.9 g/(kW h)	7.1 g/(kW h)	8.3 g/(kW h)
B30 (RME/PME/LME)	6.0 g/(kW h)	7.2 g/(kW h)	8.3 g/(kW h)

^a For a rotation speed of $n = 3000 \text{ min}^{-1}$.

temperatures should be improved (cloudiness, freezing temperature, etc.). First of all, exactly for this reason, the mixtures of biodiesel fuel with fossil diesel fuel are used worldwide in the following volumetric proportion: 70:30.¹⁹ Therefore there was performed comparative motor testing of the diesel engine was performed, when fuelling with 30% biofuel mixture with fossil diesel fuel (B30), using RME and three-component new composition of biofuel (RME/PME/LME 60:32:8). Results are presented in Table 4.

As in the case of pure three-component mixtures of methyl esters, when their 30% mixtures with fossil diesel fuel (B30) were used, practically identical emissions of harmful components were observed in the exhaust gases: CO, HC, NO_x, as well as CO₂. In all analyzed ranges of load (p_{me}), smoke opacity increased by ~20%–25% when B30 that contained three-component mixtures of methyl esters were used as fuel, comparing to B30 that contained RME. While working in the nominal regime of $p_{me} = 0.62$ MPa, the smoke opacity value increases from 2.3–2.5 Bosch units (for B30 that contained RME) up to 2.8–3.0 Bosch units (for B30 that contained three-component methyl esters mixtures).

Specific fuel consumption at a rotation speed of $n = 2000 \text{ min}^{-1}$ is not changed, whereas, in the regime of $n = 3000 \text{ min}^{-1}$, it worsens by 2%–3% in all ranges of load, in the case of identical parameters of a diesel engine that is fuelled by pure RME and the RME/PME/LME 60:32:8 three-component mixture (see Figure 2). A presumption was made, that, in the case of a high cetane number of PME (CN = 63.6, compared to the CN of RME, 51.6) the work process (working with new biofuel mixture) is pushed toward the TDC zone, which has positive influence on the fuel economy and emission of products of incomplete combustion. CN differences using the 30% three-component mixture of biodiesel fuel with fossil diesel fuel decreased from 4 units down to 1.2 units. It is possible that this condition determines certain worsening of parameters b_e and D while working with new biofuel composition. Besides, the use of the 30% three-component mixture of esters with D,

if compared to fossil diesel fuel, allows a significant decrease in the emission of all harmful components, except for NO_x, in the exhaust gases (see Table 4): smoke opacity, decreased by 25%–30%, the CO amount decreased by 15%–40%, and the HC amount decreased by 30%–45%. The increase of e'_{NO_x} is ~6%; the amount of CO₂ is not changed.

Furthermore, an investigation of the mixtures of esters, which will contain biocomponents, characterized by high evaporation and the autoignition point (bioethanol included), is being planned. In the analysis of ester mixtures with fossil diesel fuel, an evaluation of the biofuel properties, relative to the increased amount of PME/TME components (above the optimal composition), which are characterized by higher CN, is planned. To improve the performance characteristics of the diesel engine while using innovative biofuel mixtures as fuels, an adjustment and optimization of the fuel supply system is planned.

4. Conclusions

(1) The price of biodiesel fuel can be reduced if fatty waste of vegetative and animal origin is used for its production. Potential waste materials in Lithuania are linseed oil (which is polluted by plant protective chemicals), waste tallow, and pork lard.

(2) Pure fatty acid methyl esters made from the aforementioned materials do not meet the standard requirements that are related to the amount of linolenic acid methyl ester, iodine value, oxidation stability, and cold filter plugging point (CFPP). Mixtures of linseed oil methyl esters (LME) and beef tallow methyl esters (TME) or pork lard methyl esters (PME) in 1:4 proportion are characterized by better-quality properties. Such mixtures can be used for the production of three-component mixtures with rapeseed oil fatty acid methyl esters (RME).

(3) According to comparative tests of motor characteristics of the new three-component biofuel composition, they are practically equivalent to those of certified RME and its mixtures with fossil diesel fuel.

(4) Use of the new three-component biofuel composition as fuel in the high-speed diesel engine allowed to the CO emissions to be reduced by 20%–50%, HC emissions to be reduced by 50%–60%, and the smoke opacity of exhaust gases to be

(19) Choi, C. Y.; Bower, G. R.; Retiz, R. D. *Mechanisms of Emissions Reduction Using Biodiesel Fuels*; final report for the National Biodiesel Board; Engine Research Center, University of Wisconsin: Madison, WI, January 1997; 31 p.

reduced by 25%–70%. The increase in NO_x emissions did not exceed 13%; no significant changes in the CO₂ emissions have been noticed. The use of the proposed 30% mixture of biofuel with fossil diesel fuel allowed the CO emissions in the exhaust gases to be reduced by 15%–40%, the HC portion to be reduced by 30%–45%, and the smoke opacity to be reduced by 25%–30%. An ~6% increase in the NO_x emissions is observed, and no significant changes in CO₂ emission have been noticed.

(5) The best improvement in the ecological parameters was obtained when the concentration of certified RME and new biocomponents was increased in the mixture with fossil diesel fuel, up to 30%, and that makes their practical exploitation

meaningful; little difference of low-temperature characteristics to compare with fossil diesel fuel was observed.

(6) Based on the performed tests, further investigation of the multicomponent mixtures of new biofuel compositions, which will contain biocomponents with high evaporation and self-ignition characteristics, is planned.

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