TRANSPORT
2009
24(1): 58–65

THE PROBLEMS OF USING ALCOHOL BIOFUEL MIXTURES IN THE LITHUANIAN TRANSPORT SYSTEM

Sergejus Lebedevas[1], Galina Lebedeva[2]

Klaipėda University
[1] Maritime Institute, I. Kanto g. 7, 92123 Klaipėda, Lithuania
[2] Faculty of Natural Science and Mathematics, H. Manto g. 8, 92294 Klaipėda, Lithuania
E-mails: [1] Sergejus.Lebedevas@ku.lt; [2] galina@ik.ku.lt

Received 25 January 2008; accepted 12 January 2009

Abstract. The article presents the technological aspects of the problems aimed at using alcohol biofuel mixtures in diesel engines kept in operation in Lithuania concerning a gradual replacement of fuel oils with biofuels. It is shown that three-component fuels such as D-RME-E possess the motor characteristics close to mineral diesel fuel. The use of the EC standardized rapeseed oil methyl esters RME as a solvent allows compensating the unfavorable motor characteristics of ethanol E and increasing the number of biocomponents in the fuel at the same time. The key aspects of research on the indicator process and the operating characteristics of diesel engines running on alcohol biofuel mixtures are substantiated.

Keywords: alcohol diesel fuels, ethanol, physical-chemical properties, motor characteristics, biofuels.

1. Introduction

Methanol, ethanol and esters made of vegetable oils and animal fats are the main components of the most useful renewable alternative fuels (Al-Hasan and Al-Momany 2008; Lingaitis and Pukalskas 2008a, b; etc.) the expansion in use of which nowadays is regulated by international standards, agreements, programms and directives approved by the EU Parliament.

In accordance with Directive 2003/30/EC issued by the European Parliament, the use of diesel biofuel and ethanol to be increased up to 5.75% of the total fuel balance in the transport field of application within the EU member states till the year 2010. It should be mentioned that starting from the year 2000, the production of ethanol in the USA has increased more than 300%.

Since decade 3 of the 20th century, alcohol fuels as a type of fuel for cars have been in use in the countries of South America. The production of the above mentioned fuels was based upon the well developed basis of raw materials. Nowadays, ethanol totals 20% in the fuel balance of Brazil. Recently, the importance of using alternative fuels, along with the energy saving factors of the limited crude oil resources is dictated by the actual purposes of the world society concerning the decrease of the environment pollution by internal combustion engines.

Bioethanol used as a fuel is neutral in respect of hotbed gases emission. It has a zero balance of carbon dioxide as the quantity of the same substances during the process of producing biofuel by means of fermentation and carbon dioxide obtained by the following combustion of the introduced type of biofuel equals to the quantity of carbon dioxide taken by the plants (vegetal resources to produce biofuel) from the atmosphere (i.e. circulation of carbon dioxide CO_2 in the environment). If compared with the fuels of mineral oil origin, a high content of oxygen in alcohol promotes the appreciable decrease of the incomplete combustion products such as carbon monoxide and particulate matter and nitric oxides having the highest toxic index. At the same time, within the combustion of alcohol fuels, the formation of low temperature zones in the cylinder increases the number of aldehydes in Otto internal combustion engines and the emission of hydrocarbon in the exhaust gases of diesel engines 2–3 times.

Besides, the problems of using alcohol fuel in diesel engines are caused by the following factors:

- poor inflammability owing to a low cetane number of alcohol which in case of being combined with a high point of ignition temperature and high heat of vaporization, is resulted in the high dynamics of the indicator process that in turn actuates the mechanical overload of cylinder and piston assembly;
- poor lubricating properties and weak interaction with luboils causing a higher service wear of cylinder and piston assembly and the precision pairs of the fuel supply system;

- aggression on polymers connected with a necessity to re-equip the fuel feeding system.

The principal disadvantage of the multi component alcohol fuels application is the basic instability of these owing to poor solubility of alcohols in diesel fuel.

One of the basic scientific trends in Lithuania is the use and application of biofuels in the field of transport. In recent years, Lithuanian Government have decided on making the technological units of different subjects such as Universities, industry and business (so called technological platforms) to create the new kinds of biofuels and to prove its value production and the efficient use of the same in the transport field. On the basis of Universities, scientific centers and laboratories to train specialists and create special programmes for training are formed. By mutual efforts taken by the scientists from Kaunas Lithuanian Agricultural University and Klaipeda University Maritime Institute, the efficient technologies of producing and using biofuels in transport were elaborated including rapeseed methyl esters (LST EN 14214:2009) and its mixtures with mineral diesel fuel standardized in the EU and the new kinds of diesel biofuels based on waste fats and oils of agriculture and live-stock farming (Lebedevas *et al.* 2006a, b; 2007a, b).

The characteristic indices of fuel feeding, biofuel combustion, operational efficiency, fuel saving and toxicity of diesel engine exhaust gases are researched on the basis of complex experimental results and simulated mathematically by means of computer. The principal propositions of technological aspects are formed to convert the acting fleet of diesel engines to operate on diesel biofuel.

Nowadays, the production capacity of diesel biofuel reaches 200 000 tons per year in Lithuania and is capable to fulfill the EU total prospective quota and in case of necessity to export the above discussed biofuel to any economically developed region in Europe. At the same time, vegetal resources to produce RME viz. the rape seed in Lithuania will reach its limits, and thus the sown area for those to be many times increased (Janulis 2006; Smailys and Lebedevas 2008).

Besides, to make the production of biofuels profitable, it is very important to integrate the indices of the effectiveness of all technological links including raw materials, work in process and finished products. Nowadays, the average crop capacity of the rape seed in Lithuania is 1.7–1.8 tons per hectare and the index of energy effectiveness R_1 of the *RME* vital production cycle is below 1.0, which makes the production of biofuel made of rape seed low efficient and expensive. R_1 is the relation of chemical energy potential in the unit of *RME* to the total quantity of energy spent to produce *RME* within its vital cycle (Janulis and Zakarevičienė 2004; Janulis 2006).

Therefore, scientific researches are the real current problems and tend to the expansion of the raw materials base to produce the new kinds of biofuels in Lithuania. The before mentioned researches are also important for developing the technological process of biofuel production to fulfill the standard LST EN 14214:2009 and to use biofuels efficiency in transport taking into consideration the technical data of diesel engine fleet still operating in Lithuania. It should also be emphasized that the use of several kinds of biofuels especially those of alcohol origin increases the engine cycle energetic efficiency which conforms to the normative demands of the EU directions COM(2003) 739 final. 2003/0300 (COD) (Naeser and Bennett 1980; Adelman and Pefley 1980; Lebedevas *et al.* 2006a, b; 2007a, b).

Within the bounds of the international scientific program *EUREKA*, Lithuanian University of Agriculture, Lithuanian Agricultural Institute, Klaipėda University Maritime Institute, one of the most modernized enterprises in Europe viz. producer of diesel biofuels – JSC *Mestila* and the colleagues from Poland started implementing the project *E!4018CAMELINA-BIOFUEL* 'Development of technology to manufacture biofuels using camelina sativa oil as new raw material base' (yrs. 2008–2010). The researches are financed by *EUREKA* agency in Lithuania.

This project is a logical continuity of the previous scheme '*BIOWASTEFUEL E3234*' (*EUREKA*, 2004–2006) successfully fulfilled by Lithuania. A scientific potential was made within this project and necessitated to be continued. The object of the new project researches are multi-component biofuels made on the basis of camelina sativa oil. Within the above described components, the use of alcohol is expected.

This article is a commencement of the series of published researches into producing the new kinds of biofuels containing alcohol and technologies efficiently used in diesel engines operating in Lithuania. The purposes of these researches are tended to reach the decision about the universal character that provides its purposeful development of the new kinds of biofuels having the specified engine performance and the efficient use of the introduced biofuels in a wide number of diesel engines. To provide the use of different fuels in diesel engines viz. to conserve the availability of using diesel fuel, it is decided to minimally modernize the design of diesel engine tending to the optimization of control characteristics.

2. Comparative Analysis of Physical - Chemical Properties and Motor Performance of Different Diesel Fuels

The expansion of the range of fuel products in modern diesel engines of high operating economy expects mutual adaptation as the construction and control parameters of diesel engine itself and as the purposeful formation of the motor properties of diesel fuels for efficient ecological and safe use in diesel engine.

A comparative analysis of the physical-chemical properties of alcohol fuels such as methanol and ethanol and its main motor performances when using alcohol fuels by diesel engines is given below.

The commercial reserves of methanol-methyl alcohol – CH_3OH are usually produced by means of the hydrogenation of carbon monoxide under high pressure. The above introduced carbon monoxide can be obtained from such raw materials as coal, natural gas, limestone, raw waste lumber etc (Льотко *и др.* 2000).

However, coal consists of the low content of hydrogen that is one of the main energy sources and of the high content of nitrogen and oxygen which makes coal an unfavorable raw material to produce biofuel being compared with crude oil.

Methanol can also be made of wood pulp but in this case, the process of production is less effective and its cost is much higher being compared with that of methanol made of coal. Therefore, methanol (marketable methanol) cannot be considered as an alternative diesel biofuel made of the restored raw materials in contrast to ethanol.

Ethanol-ethyl alcohol – C_2H_5OH made by means of ethylene hydration or by the well known method of fermentation and ethanol is an impure water-alcohol mixture contaminated with impurities. The main production sources of ethanol are such restored raw materials as sugar-cane, sugar-beet, potato corn etc. allowing to call it 'bioethanol' while being used as diesel biofuel.

A traditional way of distillation provides the possibility of producing concentrated ethanol of 95.6% rectified alcohol that consists of 4.4% water only. By means of distilling alcoholic solution, the absolute alcohol can be produced, i.e. anhydrous alcohol can be produced (Janulis and Zakarevičienė 2004).

Nowadays, positive experience is sufficiently accumulated concerning the use of ethanol as a fuel for automobile internal combustion engines viz. gasoline-Otto engines and diesel engines. This mostly concerns to the countries available to widely cultivate corn, sugar-cane etc.

The world leaders in producing ethanol and using it as a type of automobile fuel are Brazil and USA. As per statistical data in the year 2006, ethanol production was about 20 000 and 17 000 million litres respectively. A wide use of ethanol as an alternative of automobile fuel in Brazil began in 1920s. Up to 1983, the use of pure ethanol (fuel E100) for automobile transport (vehicles of any kind) reached 11.2% and the use of petrol-ethanol mixture (petrol mixed with 20% of ethanol), i.e. fuel E20 reached 14.8% in the total use of the light fuel in the country. On the whole, the part of ethanol in the balance of fuel use in Brazil reached 20% in 2005. Following the requirements imposed by the Government, biofuel E24 is used in internal combustion engines, whereas diesel engines run on mineral fuel with 2% ethanol addition.

In the USA, an intensive development of ethanol production as restored fuel for transport was stipulated by the 'Energetic Bill' signed by president Bush in 2005 and up to 2012, a large quantity of biofuels will be annually produced viz. 8 billion tons of ethanol made of grain and 1 billion tons of that made of wood pulp, corn stalks, rice straw, raw waste lumber etc.

If compared with the USA, the production and use of alcohol for transport needs in Europe is considerably decreased. According to directive 2003/30/EC 2003 issued by the EU Parliament, the total use of alcohol and diesel biofuel will reach 5.75% in 2010. The mixtures of that with petrol are mostly used as alcohol increases octane number (Bio-ETBE, MTBE).

Presently, interest in using ethanol for diesel engines as a part of multi-component fuels is shown (Плотников *и др*. 2003; Li *et al.* 2005; Shi *et al.* 2005; Agarwal 2007). Exactly these trends of complex research carried out by Klaipeda University are emphasized in the field of applying biodiesel fuels in transport sector.

A comparison of data on the physical-chemical properties of different fuels available in Europe is given below in the Table: methanol and ethanol alcohols and well known and widespread types of diesel biofuel including rapeseed oil methyl esters (*RME*), rapeseed oil (*RO*), diesel fuel (*D*) of mineral origin, i.e. made of

Physical and chemical properties of different diesel fuels (biofuels and fuel of mineral origin)

Parameters	Methanol	Ethanol	Rapeseed Oil (RO)	RME	Diesel Fuel
Elementary chemical composition, %					
• carbon	37.5	52	77.5	77	87
• hydrogen	12.5	13	11.5	12	13
• oxygen	50.0	36	11.0	11	–
Molecular mass, kg/kmol	32	46	890	300	180–200
Density at 20 °C, kg/m^3	791	789	910	883	840
Theoretical quantity of air necessary for full combustion of 1 kg of fuel, kg air/kg fuel	6.4–6.5	9.0–9.07	12.5	12.5	14.6
Volumetric lower calorific value, MJ/dm^3	15.78	21.16	34.2	32.5–33.4	35.7
Mass lower calorific value, MJ/kg	20.0	26.8	37.60	36.8–37.8	42.5
Calorific value of stoichiometric mixture (pressure 1 bar, temperature 20 °C), KJ/ m^3	3175	3318	3595	3107–3193	3475
Heat of evaporation at pressure 1 bar, KJ/kg	1104	841	–	–	~250
Electrical conductivity at 20 °C, m^{-1}	4.4×10^{-5}	1.35×10^{-7}	–	–	10^{-13}
Cetane number	3	8	37.5	48-62	45–55
Temperature of ignition, °C	436	363	300	–	200–220
Flash point, °C	11	21	198	150	75
Viscosity kinematic at 40 °C, $\times 10^{-6}$ m^2/s	0.5	1.07	37.3	4.83	2.74
Mixing with water	good	good	poor	poor	poor
Mixing with hydrocarbon fuels	poor	poor	good	good	good
Surface tension at 20 °C, N/m	22.7×10^{-3}	22.4×10^{-3}	33.2×10^{-3}	30.7×10^{-3}	27×10^{-3}

crude oil (Хачиян 1984; Ваграфтик 1963; Carpetis 1982) are presented.

Hereinafter, ethanol will be marked – *E* in the text. The comparative analysis of the above-mentioned fuels explains the characteristic properties observed in practice, the use of fuels mixed with alcohol and the influence of those on diesel engine operational indices.

Elementary chemical composition. Alcohols are characterized by two aspects: a lower content of carbon and a higher content of oxygen being compared with other fuels, viz. diesel fuel contains 87% of carbon and diesel biofuels – *RME* and *RO* – contain 77% of carbon respectively and alcohols contain 37.5–52% of that. Oxygen is almost absent is diesel fuel but its content in alcohols makes 50–36% and the content of oxygen in *RME* and *RO* is 11.0%. As a result, alcohols and especially methanol are characterized by a considerably low value of energy emitted within its combustion. This in turn is characterized by ***mass low calorific value*** – (H_{um}) and ***volumetric low calorific value*** – (H_{uv}). H_{um} of methanol and ethanol are 2.1 and 1.6 times less than H_{um} of *RME* and *RO* respectively. As the density of alcohols is much less than the same of *RME* and *RO*, i.e. 790 kg/m^3 of alcohol against 910 kg/m^3 of *RME* and 883 kg/m^3 of *RO* and 840 kg/m^3 of *D* mass, the low calorific values of these differ considerably. To obtain the equal quantity of heat into the cylinder of diesel engine, as per data given in the Table above, volumetric methanol feed will increase 2.1 times more than that of *RME* and 2.3 times more than that of *D*, whereas the figures of ethanol will rise 1.6 times more than that of *RME* and 1.7 times more than that of *D*.

Within diesel engine direct injection timing, the above circumstance necessitates revising the construction and controlled parameters of the fuel injection system embracing a high pressure fuel pump, high pressure piping, an injector and fuel tanks capacity of long run vehicles. It should be mentioned that similar figures of the volumetric low calorific values viz. 2.3–3.5 MJ/m^3 of ***stoichiometric mixture*** composition for the examined types of different diesel biofuels including mineral one prove the fact that its use does not have a big influence on diesel engine power indices, despite of much lower values of alcohols H_{um} and H_{uv}. It means that naturally aspirated diesel engine operating on alternative alcohol contained fuel does not necessitate increasing the piston displacement volume, as for turbocharged diesel engines, which in turn does not necessitate to considerably increase the supercharged air parameters (P_k and T_k).

Due to a considerably large content of oxygen in alcohols, the theoretically essential quantity of the air necessary for completing the combustion of the mass unit of methanol (stoichiometric constant L_o) is 2.3 times less for methanol and 1.6 times less for ethanol if compared with mineral diesel fuel.

As a result, the local conditions of fuel air mixing and the completeness of combustion are improved and these aspects promote to increase diesel engine indicated efficiency for 3–5%. Decreasing the probability to emerge the local zones of overreach mixture into diesel engine cylinder reduces the hydrocarbons cracking up to 30–50% and prevents soot, particulate matter and incomplete combustion emission (Hansen *et al.* 2001; He *et al.* 2003).

The below presented properties are different physical-chemical components of diesel fuels contained in alcohol ***and having influence on such characteristics as injection timing, fuel atomization and combustion:***

- lower temperature of alcohols boiling but considerably higher heat of vaporization;
- lower viscosity especially being compared with diesel biofuels;
- higher pressure of saturated vapor;
- bad self-ignition of alcohols characterized by a low cetane number of those.

Because of much lower surface tension, the density and viscosity of alcohols comparatively with mineral diesel fuel is expected to improve several characteristics of fuel such as atomization (fineness, homogeneity of fuel spray cone), fuel mixing (more homogeneous thermal field in cylinder) and heat release that increases the cycle indicated efficiency.

The density of alcohols at 20 °C is less than that of *D*, *RO* and *RME* for 6%, 10.5% and 13% respectively. The viscosity of ethanol at 40 °C 2.7; 4.8 and 37 times less than that of *D*, *RO* and *RME*. As for methanol, difference between *D*, *RO*, *RME* and methanol is twice more if compared with ethanol. Because of this destruction of alcohol, fuel spray into drops occurs a little bit earlier. This is evaluated by the Weber criterion:

$$We = \frac{\rho w^2 d}{\sigma}, \quad (1)$$

where: ρ – gas medium density, w – the velocity of fuel spray in gas medium; d – fuel spray diameter on the outlet of injector nozzle; σ – fuel surface tension). As per test data (Плотников *и др.* 2004), the velocity of diesel fuel spray destruction was 132 m/sec, whereas that of methanol made 115 m/sec. This circumstance explains an increase in the fuel spray cone angle and the best filling of combustion chamber volume by fuel mixing. The homogenous fuel distribution increasing in the air medium should promote faster oxidation of soot particles and carbon oxide CO, i.e. the incomplete products of oxidation. The reduction of intensive NO_x, i.e. nitric oxides formation, due to the equalization of the working mixture thermal field into diesel engine cylinder followed by a simultaneous decrease of maximum temperatures. To be considered a possible deviation in the parameters of fuel spray cone formation can activate troubles in realizing efficient fuel mixing into the limited displacement of combustion chamber while diesel engine is running at partial loads.

Considerably low viscosity of alcohols and its functional dependence upon temperature $\upsilon = f(t)$ (where: υ – viscosity of alcohols) guarantee an advantage of alcohol application for diesel engine in cold climate (see Fig. 1 – viscosity-temperature diagram).

As usual in practice, the temperature coefficient of viscosity $\upsilon = f(t)$ is used to evaluate the slope of a curve:

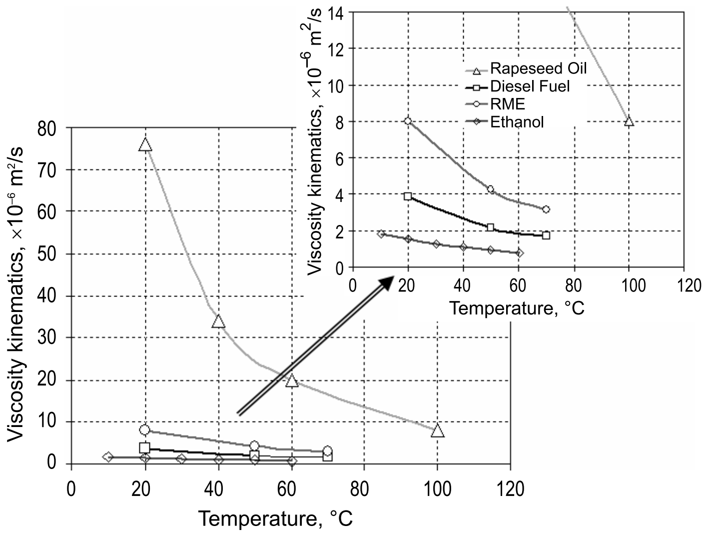

Fig. 1. Dependence of different fuels viscosity upon temperatures

$$TCV_{t_1-t_2} = \frac{\left(\upsilon_{t_1} - \upsilon_{t_2}\right)}{\upsilon_{\left(t_1+t_2\right)\cdot 0,5}}, \quad (2)$$

where: υ_{t1}, υ_{t2} and $\upsilon_{(t1+t2)0.5}$ – are the values of the viscosity of fuels or luboils (here fuel) at temperatures t_1, t_2 and $(t_1 + t_2)/2$, i.e. lower, upper limits and the mean values of temperature intervals according to the temperature interval 20–70 °C . Values TCV_{20-70} are for *D* – 0.94 and for *RME* and *RO* 1.02 and 2.05 respectively. *TCV* of ethanol is the least – 0.83.

One of the main disadvantages of using alcohol is low self-ignition that is worsened by the considerably higher vaporization temperature of alcohol. This makes difficulties with using alcohols. More than 4-times for methanol and 3-times for ethanol, an increase in the heat of vaporization from 250 KJ/kg up to 1104 KJ/kg and 841 KJ/kg correspondingly lead to a considerable in the (150–200 °C) decrease of temperature of the air charge in the cylinder during the compression stroke. Pure alcohol fuels (100%) are not used owing to a decrease in diesel engine reliability indices and starting properties. The above mentioned alcohol fuels can be used after the considerable modernization of diesel engine.

The cetane number characterizing the ability of fuel to self-ignition in the diesel engine cycle constitutes only 3 units for methanol and 8 units for ethanol. The cetane number of diesel fuel is in the range of 45–55 units and RME reaches 62 units. In addition, the temperature of methanol ignition at 215–235 °C and ethanol at 140–160 °C is higher comparing with D.

As a result of complex influence of these factors, the conversion of diesel engine operation onto alcohol leads to the extension of a period of ignition delay φ_i, and at a further stage, to the expansion of heat release rate intensity at the first stage of combustion. The process of combustion and consequently heat release rate in the cylinder approaches to one-stage action (Naeser and Bennett 1980; Матиевский и Кулманаков 2000). The parameters of the dynamics of the diesel engine operating process are increased and the maximum pressure of combustion pressure P_{max} and the maximum velocity of pressure increase $(dp/d\varphi)_{max}$. Therefore, mechanical loads on cylinder-piston assembly parts are increased which negatively influences the safety and service life of diesel engine. According to the data provided (Матиевский и Кулманаков 2000), the operation of high-speed transport diesel engine 1CH13/14 (bore *D* = 130 mm, stroke *S* = 140 mm, engine speed *n* = 1800 r.p.m.) on a mixture of biofuels with mineral biofuels having concentration up to 20–60% entailed 2–2.5 times increase of φ_i from 11–14 CA deg. (Crank Angle deg.) to 20–35° CA deg.; 1.5–2.0 times increase $(dp/d\varphi)_{max}$ and 15–20% increase of P_{max} from operation level on diesel fuel.

When running on alcohol fuels, the starting characteristics of diesel engine especially in 'cold' state and under conditions of cold climate become quite critical. Mainly, due to the reason of a decrease in diesel engine safety indices and worsening its starting characteristics, pure 100% alcohol fuels without significant constructional improvement in diesel engine are not used. As per review data (Хачиян 1984), the main methods of using alcohol fuels by diesel engines are as follows:

- carburetion or alcohol fuel injection into the intake system combined with an injection of prime fuel in the cylinder by means of ordinary fuel injection equipment;
- alcohol injection in the cylinder by means of another fuel system while an alcohol-air mixture is ignited by priming fuel portion. An alternative is as follows: when two fuel systems are present, one injector is used where fuel mixing occurs before its injection.
- separation of charge when inner mixing is used and ignition is serviceable;
- use of emulsions and alcohol-diesel fuel solutions.

Nowadays, the above mentioned methods have not been principally changed except from a wide application of the electronic systems of fuel injection process control and optimization.

The physical-chemical properties of alcohols ***characterizing the difficulties of applying them as diesel fuels*** are as follows: high pressure of saturated vapor, low lubricating properties, aggression to non-ferrous metals and high flushing.

Due to high saturated vapor pressure comparatively with mineral diesel fuel, the processes of vaporization are intensified into the fuel feeding system, viz. a tendency of steam locks existing into low pressure fuel piping. To avoid the destabilization of injection in respect of phase and quantity, it is necessary to increase the pressure of fuel in low pressure fuel piping. This to be done by an increase in feeding fuel pump capacity.

The low viscosity and lubricating property of alcohols and its interaction with fuel additives (i.e. mud as sediments emerge) can cause the wear, scuffing and blocking of fuel equipment precision pairs. To avoid this situation, a little quantity of oil, e.g. castor oil must be added, i.e. from 1–2% up to 5% as per different data (Хачиян 1984; Матиевский и Кулманаков 2000). Besides, because of fuel leakage in the fuel equipment precision pairs, the regulation phases of fuel feed are changed. A higher conductivity of alcohols is a reason of electrochemical (galvanic) corrosion caused to the fuel oil system parts made of non-ferrous metals (Хачиян 1984). Therefore, the definite parts of the fuel system to be maintained in order to run on alcohol fuels and metal pairs in one and the same part of a system can cause galvanic corrosion, and for this reason need to be excluded, e.g. steel – aluminum, copper alloys etc. The parts made of polymers also need to be changed.

The high flushing properties of alcohols can also be a reason of fuel filter choking with resinous sediment from fuel tanks and can cause the disruption of the operation of fuel supply system precision pairs (high pressure fuel pump, fuel injector) directly after replacing diesel fuel with alcohol-containing fuel. Thereafter, a schedule for the maintenance of diesel engines should be supplemented with a system of fuel flushing while replacing the type of the fuel used.

3. Problems of Using Multi-Component Alcohol Containing Fuels

The use of the multi-component mixtures of alcohol and ordinary diesel fuel is the most efficient method to compensate poor characteristics of the engine containing alcohols, i.e. combustibility, low calorific value, high heat of vaporization, ignition temperature etc. However, alcohols are of very low solubility concerning diesel fuel. This makes difficult to apply binary mixtures *D–E* (*D–M*) in practice. Under standard atmospheric conditions, methanol (*M*) does not dissolve in diesel fuel. The solubility of ethanol (*E*) in diesel fuel (*D*) is about 8% (Хачиян 1984; Makarevičienė *et al.* 2005). Besides, ethanol solubility worsens considerably when a part of water in solution increases. As per experimental researching data (Makarevičienė *et al.* 2005) when 99.8% of absolute ethanol is replaced with 98.5% of ethanol, its solubility in *D* decreases from 8% to 5.4 %, but 96 % of denatured alcohol and diesel fuel (*D*) do not dissolve reciprocally.

The use of the third component – reciprocal solvent for both *D* and alcohol is one of several methods to overcome difficulties concerning its mixing. This reciprocal solvent must possess the properties of both *D* and alcohol, i.e. a molecule must be the polar one and have an aliphatic component to combine with hydrocarbons.

The total thermodynamic characteristics of a triple solution as well as the reciprocal solubility of components are defined by calculations based on *UNIFAG* or *UNIQUAC* theory (Вагнер 2000) or determined by an experiment. The end results are graphs in the form of nomographs (see Fig. 2) where the concentration area is divided by binary into a heterogeneous phase (under binary curve) and a homogeneous phase (above binary curve). The components of *D–M* couple do dissolve reciprocally. The solubility of *D–RME* couple is unlimited. The solubility of *M* in *RME* is limited by 17.3% (Makarevičienė *et al.* 2005).

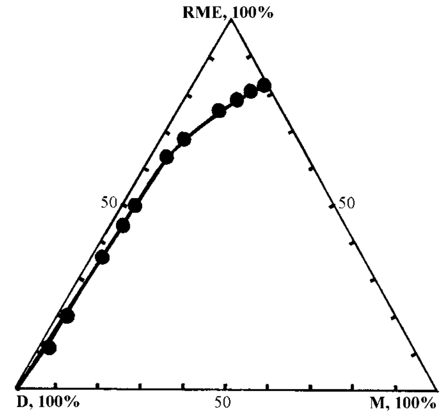

Fig. 2. The solubility nomograph of *D–M–RME* blend components

Solvents for alcohols in diesel fuel are hydrocarbons including heterocyclic, aromatic, amine, polyhydric alcohols, acetate, ethers and esters. While running on three-component biofuels with different solvents mixtures, diesel engine operating indices have minor differences (Вагнер 2000).

A high price that increases the price of fuel mixtures becomes a principal factor taking into consideration the expansion of the renewable fuel kinds and the portion of those. The use of rape seed and methyl ethers as a solvent for alcohol, i.e. ethanol not only increases the main part of renewable fuels in different fuel mixtures but due to physical-chemical properties, (see Table) engine performance is improved.

The main mutually compensated physical-chemical properties of *RME* and *E* are viscosity, density, ability of self-ignition, cetane number, ignition temperature etc.

A comparison of the non-compensated characteristic of biocomponents H_{um} and mineral diesel fuel clearly points to a lower calorific level of the biocomponents.

This stipulates the necessity of increasing fuel feed cyclic portions. However, this circumstance is not crucial while *D–RME–E* diesel fuel mixtures are used where a portion of *RME* based on stipulation solubility is more than *E*. This is based on the condition of solubility. The value of H_{um} of *RME* is approximately 12.5% less than H_{um} of *D*, but considering that the density of *RME* is higher than the density of *D*, this value is actually 6.5% lower.

An extra positive factor is a better diesel efficiency index (η_i).

The seasonal use of *D–RME–E* fuels in summer time can promote the solution of the solubility of *E* in *D*.

4. Conclusions

1. Used as fuels, alcohol mixtures are technologically efficient and prosperous alternatives to *RME* biofuels standardized by the EU, whereas mineral diesel fuel gradually replaced with biofuels for diesel engine fleet is still operating in Lithuania.
2. The use of fuel mixtures consisting of three components, viz. *D–RME–E*, where *RME* is used to thin ethanol out and to dilute it with mineral diesel fuel, is prosperous for Lithuanian transport. Nowadays, the out-of-date diesel engine types designed and built in 70's and 80's are dominating in Lithuania and are still in use, and therefore the force feed of fuel mixtures provided by the main fuel system is the most efficient.
3. Due to a fundamental difference between the physical-chemical properties of ethanol and *RME*, viz. density, viscosity, self-ignition, evaporativity etc., fuel mixtures consisting of three components *D–RME–E* have got the engine performances similar to those of mineral diesel fuel. The main aspects of exploring the development and process design of multi-component alcohol fuels is the improvement of the following engine performances:
   - improvement of reciprocal solubility *E–D* taking into consideration the quality of alcohol are practically used and operating the temperature of machinery;
   - selection of biocomponents *E–RME* ratio in mixture that allows to realize the acceptable characteristics of ignition, kinetics of combustion and heat release into the cylinder of diesel engine.
4. Alcohol fuels have got a number of unfavorable operating characteristics embracing aggressiveness to polymers, the ability to cause electrochemical/galvanic corrosion to the heterogeneous couples of metals and high flushing properties. Thus, a very important component of researches is finding an adequate solution to the problems solved in an appropriate way:
   - to ensure the resistance of the precise parts of the fuel system to run-out;
   - to increase the stability of fuel injection characteristics, especially for partial loads;
   - to complete the fuel system with parts made of biocomponents resistant to forceful operation;
   - to revise a maintenance schedule of the fuel system concerning the types of fuel replacement.

In conclusion, on the basis of the above mentioned facts and considerations, a long period of bench and field tests must be conducted for diesel engines running on different types of alcohol fuels.

References

Adelman, H. G.; Pefley, R. K. 1980. Utilization of pure alcohol fuels in a diesel engine by spark ignition, in *Proceedings of the IV International Symposium on Alcohol Fuels Technology*, Vol 2, 5–8 October 1980, Guarujá, São Paulo, Brazil, 453–456.

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

Agarwal, A. K. 2007. Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines, *Progress in Energy and Combustion Science* 33(3): 233–271.

Carpetis, C. 1982. Comparison of the expenses required for the on board fuel storage systems of hydrogen powered vehicles, *International Journal of Hydrogen Energy* 7(1): 61–77.

Directive 2003/30/EC of the European Parliament and the Council of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport. Available from Internet: <http://ec.europa.eu/energy/res/legislation/doc/biofuels/en_final.pdf>.

Hansen, A. C.; Hornbacker, R. H.; Zhang, Q.; Lyne P. W. L. 2001. On farm evaluation of diesel fuel oxygenated with ethanol, *American Society of Agricultural Engineers (ASAE)*, paper No 01-6173.

He, B.-Q.; Shuai, S.-J.; Wang J.-X.; He, H. 2003. The effect of ethanol blended diesel fuels on emissions from a diesel engine, *Atmospheric Environment* 37(35): 4965–4971.

Janulis, P. 2006. *Aplinkos taršos mažinimas gerinant biodyzelino gyvavimo ciklo rodiklius:* Habilitacijos procedūrai teikiama mokslo darbų apžvalga [Decrease of Environmental Pollution due to Improvement of Biodiesel Fuel Essential Cycle Indices. Scientific Work Review Dedicated to Habilitation Procedure]. Kaunas, 33 p.

Janulis, P.; Zakarevičienė, V. 2004. *Biodegalų ir bioalyvų naudojimas Lietuvoje* [Use of Biofuels and Bio-oils in Lithuania]. Vilnius. 71 p.

Lebedevas, S.; Vaicekauskas, A.; Lebedeva, G.; Makarevičienė, V.; Janulis, P. 2007a. Change in operational characteristics of diesel engines running on RME biodiesel fuel, *Energy & Fuels* 21(5): 3010–3016.

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

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

Lebedevas, S.; Vaicekauskas, A.; Lebedeva, G.; Makarevičienė, V.; Janulis, P.; Kazancev, K. 2006b. Use of waste fats of animal and vegetable origin for the production of biodiesel fuel: quality, motor properties, and emissions of harmful components, *Energy & Fuels* 20(5): 2274–2280.

Li, D.-G.; Zhen, H.; Xingcai, L.; Wu-Gao, Z.; Jian-Guang, Y. 2005. Physico-chemical properties of ethanol-diesel blend fuel and its effect on performance and emissions of diesel engines, *Renewable Energy* 30(6): 967–976.

Lingaitis, L. P.; Pukalskas, S. 2008a. Ecological aspects of using biological diesel oil in railway transport, *Transport* 23(2): 138–143.

Lingaitis, L. P.; Pukalskas, S. 2008b. The economic effect of using biological diesel oil on railway transport, *Transport* 23(4): 287–290.

LST EN 14214:2009. Automobiliniai degalai. Riebalų rūgščių metilesteriai (RRME), skirti dyzeliniams varikliams. Reikalavimai ir tyrimo metodai [Automotive fuels – Fatty acid methyl esters (FAME) for diesel engines – Requirements and test methods].

Makarevičienė, V.; Sendžikienė, E.; Janulis, P. 2005. Solubility in multi-component biodiesel fuel systems, *Bioresource Technology* 96(5): 611–616.

Naeser, D.; Bennett, K. F. 1980. The operation of dual fuel compression ignition engines utilizing diesel and methanol, in *Proceedings of the IV International Symposium on Alcohol Fuels Technology*, Vol 2, 5–8 October 1980, Guarujá, São Paulo, Brazil.

COM(2003) 739 final. 2003/0300 (COD). Proposal for a Directive of The European Parliament and of the Council on Energy End-Use Efficiency and Energy Services. Commission of the European Communities. Available from Internet: <http://www.ofgem.gov.uk/Europe/Backgrd/Legal/Documents1/Energy%20Service%20Directive%20(Draft).pdf>.

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.

Smailys, V.; Lebedevas, S. 2008. Atsinaujinančios energijos sektoriaus plėtros perspektyvos Lietuvoje [Prospects of renewable energy sector expanding in Lithuania], *Technologijos mokslo darbai vakarų Lietuvoje* [*Technological Research Activities in West Lithuania*] 6: 171–177.

Вагнер, В. А. 2000. Применение альтернативных топлив в ДВС [Wagner, V. A. Utilization of the alternative fuels in Internal Combustion Engine], в кн. *Вестник Алтайского государственного университета им. И. И. Ползунова* [Proceedings of the Altai State Technical University] 2: 77–86. Available from Internet: <http://elib.altstu.ru/elib/books/Files/Vestn_2000_02/10/10.htm>.

Варгафтик, Н. Б. 1963. *Справочник по теплофизическим свойствам газов и жидкостей* [Vagraphtick, N. B. Reference book on heat-physical characteristics of gases and liquids]. Москва: Наука. 708 с.

Льотко, В.; Луканин, В. Н.; Хачиян, А. С 2000. *Применение альтернативных топлив в двигателях внутреннего сгорания* [Liotko, V.; Lukanin, V. N.; Khachiyan, A. S. Utilization of the alternative fuels in internal combustion engines]. Москва: МАДИ (ТУ), 311 с.

Матиевский, Д. Д.; Кулманаков, С. П. 2000. Применение смесевых спиртовых топлив в дизелях автотракторного типа [Matiyevskiy, D. D.; Kulmanakov, S. P. Utilization of mixed alcohol fuels in diesel engines of auto-tractor type], в кн. *Вестник Алтайского государственного университета им. И. И. Ползунова* [Proceedings of the Altai State Technical University] 2. Available from Internet: <http://elib.altstu.ru/elib/books/Files/Vestn_2000_02/11/11.htm>.

Плотников, С. А.; Гущин, С. Н.; Лебедев, С. Р. 2004. Влияние состава спиртосодержащего топлива на показатели процесса топливоотдачи [Plotnikov, S. A.; Gushchin, C. N.; Lebedev, S. R. Influence of alcohol-containing fuel on the indices of fuel supply process], *Двигателестроение* [Engine Engineering] 3: 43–45.

Плотников, С. А.; Гущин, С. Н.; Лебедев, С. Р. 2003. Исследование показателей работы дизеля 2Ч10,5/12,0 на спиртосодержащих топливах с присадками целенаправленного действия [Plotnikov, S. A.; Gushchin, C. N.; Lebedev, S. R. Research of the indices of 2CH10.5/12.0 diesel engine running on alcohol-containing fuels with special additions], *Двигателестроение* [Engine Engineering] 1: 36–39.

Хачиян, А. С. 1984. Применение спиртов в дизелях [Khachiyan, A. S. Utilization of alcohol in diesel engines], *Двигателестроение* [Engine Engineering] 8: 30–34.