BIOFUELS FOR DIESEL ENGINES IN THE CZECH REPUBLIC

Doc. Ing. Laurin Josef, CSc., Ing. Josef Blažek, Ph.D.
Faculty of Mechanical Engineering, Department of Vehicles and Engines – Technical university of Liberec, Czech Republic
E-mail: josef.laurin@tul.cz; E-mail: josef.blazek@tul.cz

Abstract: *The paper addresses diesel engine fuel components made of biomass, i.e. bioethanol and biodiesel. It focuses on the biofuels' characteristics, the conditions and potential for their use for diesel engines, and the impact of biofuels on engine exhaust emissions.*

The work briefly summarizes the history of biofuels in the Czech Republic and their anticipated future usage so as to comply with the current expectations of the European Commission respecting the gradual substitution of oil-based engine fuels with alternative ones.

KEYWORDS: *DIESEL ENGINE, ALTERNATIVE FUELS, DIESEL FUEL BLENDS, BIODIESEL, BIOETHANOL, EMISSIONS*

1. Introduction

Pursuant to the European Commission action plan the oil-based fuels should be gradually replaced partly by biofuels, natural gas and hydrogen. In accordance with the Directive of the European Parliament and the Council (2003/30/EC) of 2003 on Support of usage of biofuels and other renewable fuels in transportation, at the end of 2010 biofuels should represent in each member state of the European Union 5.75% of energy supplied for transportation in petrols and oils. Biofuels are considered to be liquid or gaseous fuels made of biomass: bioethanol, biodiesel, biodimethylether, bio-ETBE, bio-MTBE, biohydrogen, pure vegetable oil and synthetic fuels whose components are made of biomass. In the Czech Republic, only bioethanol and biodiesel can be considered as diesel engine fuels in the short-term.
The paper will further address the technical potential of bioethanol and biodiesel for diesel engine operated vehicles in the Czech Republic environment. The paper will not deal with either the relevant legislation or pricing politics.

2. Bioethanol

Bioethanol is generated by ethyl alcohol fermentation of agricultural crops, most frequently corn, potatoes, sugar beet and sugar cane.

In comparison with oil, bioethanol has a low calorofic value, low cetane number and very low lubricating potential. Due to its low calorific value, the biothanol specific consumption exceeds the one of oil, so consequently, in the case of a higher bioethanol content the engine fuel system has to be resized. The higher bioethanol evaporation heat may result in troublesome engine starting under low temperatures.

Even a very low quantity of water in the fuel may trigger considerable problems since water bonds with bioethanol. Bioethanol may cause corrosion of certain components, especially of the engine fuel system, although this unfavourable property can be reduced by corrosion inhibitors. Bioethanol aggressively impacts some plastics and rubbers.

2.1. Bioethanol for diesel engines

The unfavourable bioethanol properties mentioned above (low cetane number, low lubricating power as well as aggressive corrosivity) may be successfully managed by nitrate and ether based additives which are added into bioethanol in accordance with their producers´ recommendation in the amount of 4 to 12%. The bioethanol fueled engine may then differ only slightly from a diesel engine because the bioethanol properties are – except for fuel efficiency – modified by additives to approach the properties of oil.

Table 1: Properties of diesel oil, rapeseed oil, bioethanol and ROME

	Unit	Diesel oil	Rapeseed oil	Bioethanol	Rapeseed oil methyl ester
Density at 15 °C	$kg.m^{-3}$	830	905	794	870
Lower caloric value	$MJ.kg^{-1}$	42.5	37.4	26.8	10.4
Octane number VM		-	-	108	-
Cetane number		51	40	7	58

2.2. Bioethanol operated diesel engines

Bioethanol without cetane number increasing additives may be used for engines which utilize two fuels simultaneously, i.e. diesel and bioethanol. A number of methods are known for bioethanol application in diesel engines: the injection of oil and bioethanol mixture into the combustion space by means of two injection pumps – one pump injects oil, the other bioethanol, or admission of bioethanol and air mixture and injection of oil into a cylinder. The mentioned methods require considerable modifications of the original diesel engine, they are demanding and expensive from a technical point of view and they have not found any wider practical application.
In comparison with oil, bioethanol features a low calorific value and therefore the engine fuel system has to be adapted to increase the injected bioethanol fuel dose dramatically. To achieve a better bioethanol operated engine combustion pattern, the compression ratio of the original diesel engine is increased up to 28:1 [15]. Another alternative is to maintain the compression ratio of the original diesel engine.

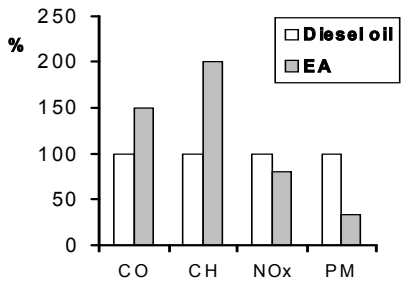

Fig.1 Noxious exhaust emission levels of the LIAZ diesel engine operated with oil and ethyl alcohol with 4% of the AVOCET additive.

The Technical University of Liberec carried out tests of the ZETOR and LIAZ engines on which modifications enabled the injection of higher doses of bioethanol while their original compression ratio remained the same. The injected doses of bioethanol fuel were increased in such a way as to maintain the output parameters of the original diesel engine. The noxious emission measurements for these engines in accordance with tests set forth in the EEC 49 regulation for bioethanol fuel with 4% of the AVOCET additive (produced by ICI) showed that in

comparison with the oil-fuelled engines there is a particle content reduction and NOx content reduction but a considerable increase in carbon monoxide content and unburned hydrocarbons in exhaust gases. The test results shown in Fig.1 [14] are for the six-cylinder supercharged LIAZ bus engine having the displacement of 12 litres, nominal power of 180 kW at the speed of 2000 rev/min equipped with an oxidizing catalyst.

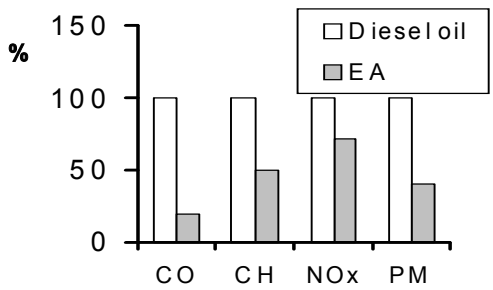

Fig.2: The levels of the SCANIA bus engine noxious exhaust emissions in oil-fuelled engine and modified bioethanol-fuelled engine. The diesel engine compression ratio of 18:1 has been increased for bioethanol up to 28:1.

Bioethanol does not currently have very broad application for diesel engines. As far as Europe is concerned, it is used primarily in Sweden. Bioethanol fuelled city buses are produced by SCANIA and more than 200 city buses are being operated in Stockholm and about 250 in other cities. The buses are equipped with a supercharged engine with exhaust gas recirculation and a catalyst and its compression ratio has been increased up to 28:1. The engine has the displacement of 8.9 litres and the nominal power of 199 kW at the speed of 1900 rev/min.

3. *Vegetable oils*

Pure vegetable oils have unsuitable properties for use as engine fuels, in particular a high viscosity, low cetane number (33…43), low calorific value and low thermal stability. Table 1 illustrates some parameters of refined rapeseed oil. Due to their high viscosity, vegetable oils may only be burned in engines with specific design, e.g. in engines with a specially modified turbulence combustion chamber or in the engine known as Elsbett. The oil has to be preheated at least to the temperature of 70 °C to be used for direct injection engines. Deposits resulting from a prolonged engine operation may occur in the combustion space, on the injector nozzles and also in the fuel system. Vegetable oils cause faster engine oil ageing and therefore intervals for its exchange have to be shortened. Starting of a cold engine is problematic and frequently diesel oil is used for the start. Consequently, vegetable oils have not so far found a wider application as engine fuels.

4. *Biodiesels*

Biodiesels are methyl esters or ethyl esters of fatty acids (FAME) and they are generated by transesterification of triglycerides contained in oils or fats. Raw materials can be vegetable oils, e.g. rapeseed oil, soya oil, palm oil, linseed oil, sunflower oil or animal fats e.g. beef suet, pork lard, poultry fat, cod-liver oil. Used deep frying oils can be used as raw material, too. At present, more than 80% of the European biodiesel production comes from rapeseed oil. Biodiesel produced from rapeseed oil with methanol is rapeseed oil methyl ester (ROME) and biodiesel produced with ethanol is rapeseed oils ethyl ester (ROEE)- Biodiesels have good cetane number, up to 58, suitable lubricating power and a good biodegradability in the case of a ground spill.

Table 2: Properties of fatty acid methyl esters of vegetable oils and diesel oil, [1, 3, 5, 9, 10]

	Unit	Fatty acid methyl ester						Diesel oil
		Rapeseed	Soyabean	Palm	Sunflower	Linseed	Cottonseed	
Density at 15 °C	$kg.m^{-3}$	883	889	874	885	891	885	832
Kinem.viscosity at 40 °C	$mm^2.s^{-1}$	4.3	4.1	4.4	4.1	3.8	4.0	3.0
Lower caloric value	$MJ.kg^{-1}$	37.3	37.3	37.1	37.2	37.1	37.3	42.5
Cetan Number		52-59	51-54	63-69	51-59	51-53	51-55	51
Oxygen content	%	10.9	11	11.3	11.9	10.9	10.8	< 0.6

Biodiesel has a number of unsuitable properties, especially a low thermal-oxidizing stability. The presence of glycerol results in deposits during storage and creation of viscous mixtures which may clog the fuel system, especially fuel filters. Water in biodiesel supports the growth of microorganisms and generation of acid sludges. Hydrolysis of esters occurs in the presence of water and the generated products may polymerize under certain circumstances. Long-term vehicle in operation can lead to the gumming up of the fuel system components requiring the replacement of even the fuel pump. Due to faster engine oil degradation its more frequent exchange becomes necessary. Biodiesel adversely impacts the fuel system sealing materials, rubber hoses and some paints and varnishes. Following the transition from diesel fuel to biodiesel the deposits in the fuel system are dissolved which unfavourably affects the function of fuel filters and injector nozzles.

As far as noxious emissions are concerned, oxygen contained in biodiesels is of great importance because it improves the combustion pattern in the engine, which results in a considerably lower formation of particles in comparison with diesel oil. The lower quantity of particles is also caused by very low sulphur content in biodiesel. Particles with lower sulphur content are less carcinogenic.

A short ignition delay at engine combustion (which is related to the fuel cetane number) is of great significance as well. Due to a shorter ignition delay the quantity of the fuel burned at constant volume will be reduced and the values of max. pressures and temperatures in the engine cylinder are (mainly at the beginning of the combustion process with ROME) lower. The duration of high pressures and temperatures is shorter, which in comparison with Diesel oil, brings NOx emission reduction. The favourable effect of the shorter ignition delay on NOx formation is more likely reduced by the impact of oxygen contained in the fuel and the reduction in NOx generation does not occur. In ROME, the shorter ignition delay brings a lower generation of unburned hydrocarbons.

To verify the basic properties of ROME, especially its impact on the amount of pollutants contained in exhaust gases, the Technical University of Liberec carried out a number of comparison measurements focused on harmful exhaust emissions in accordance with the EEC regulation 49 on a supercharged diesel engine without a catalytic reactor in operation on common diesel oil and ROME from several producers. Fig.3 shows the results of the emission tests for the four-cylinder supercharged engine AVIA D 422.100 having the displacement of 3.9 litres and the nominal power of 98 kW at the speed of 2400 rev/min. With ROME, the emissions of carbon monoxide, hydrocarbons and particles are lower and the emissions of NOx are higher compared with the diesel fuel operation. Similar conclusions for the level of exhaust emissions found in emission tests of various engines operated with diesel oil and biodiesel can also be seen in [2,7,11,13].

The contribution of biodiesels of vegetable origin for the balance of carbon dioxide circulation in nature is frequently emphasized. The generation of carbon dioxide in combustion corresponds with its consumption at photosynthesis. Fuels generated from vegetable produce do not increase the carbon dioxide content in the atmosphere and consequently, they do not add to creation of the greenhouse effect in the atmosphere. The good lubricating power of biodiesel is highlighted as well.

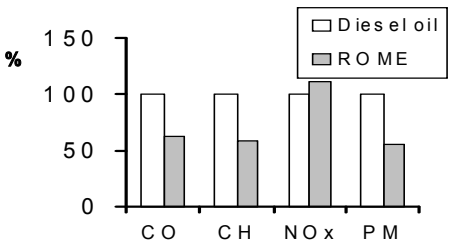

Fig.3: Levels of harmful exhaust emissions of the supercharged engine AVIA D 422.100 operated with diesel oil and ROME [15].

5. *Diesel fuel blends*

Diesel fuel blends (DFB) represent blends of diesel fuel and biodiesel. At lower contents of biodiesel in the diesel fuel blends, when the calorific value of the blend is not significantly reduced, the fuel dose does not need to be increased, whereas higher contents of biodiesel in the blend require a higher dose. Diesel fuel blends with a lower content of biodiesel will demonstrate the unfavourable properties of biodiesels specified above to a lesser degree.

Fig.4 shows the results from the comparison measurements of the mentioned engine (AVIA D 422.100) in accordance with the EEC Regulation 49 being fuelled by diesel oil and diesel fuel blends with 30% of ROME. The diesel fuel blend operated engine features slightly lower emissions of carbon monoxide, hydrocarbons and particles and slightly higher emissions of NOx compared to the diesel oil operated one. Similar results can be found in publication [13].

Graphs 5-8 show the impact of biodiesel in the diesel fuel on noxious exhaust emissions. The graphs present % concentrations change of individual exhaust pollutants for engines fuelled by diesel fuel blends with varying biodisel contents, where the value of 0 % represents concentration of pollutants for a diesel fuel operated engine. It represents the average value of results from many measurements published in [2,7,11,13]. Although various engines (primarily heavy duty truck engines) underwent the tests (mainly FTP) in which biodisels of various origin were used (particularly soya oil methyl ester), the pattern of individual emissions related to biodiesel contents in diesel fuel blends is similar.

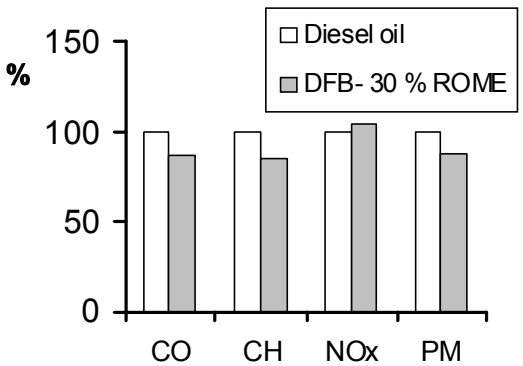

Fig.4: Levels of noxious exhaust emission of the AVIA D 422.100 supercharged engine operated on diesel oil and diesel fuel blend – 30% of ROME [8].

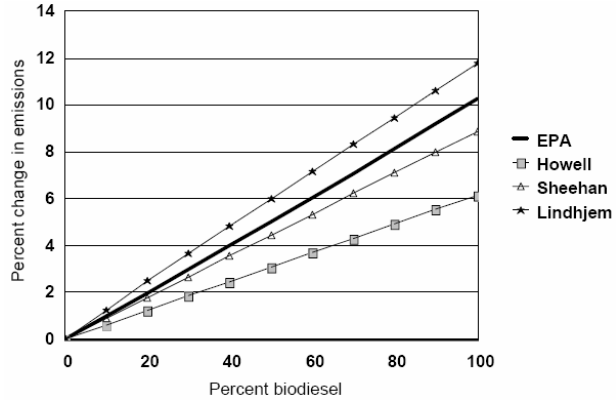

Fig.5: NOx emissions related to the biodisel content in diesel fuel blend [2,7,11,13]

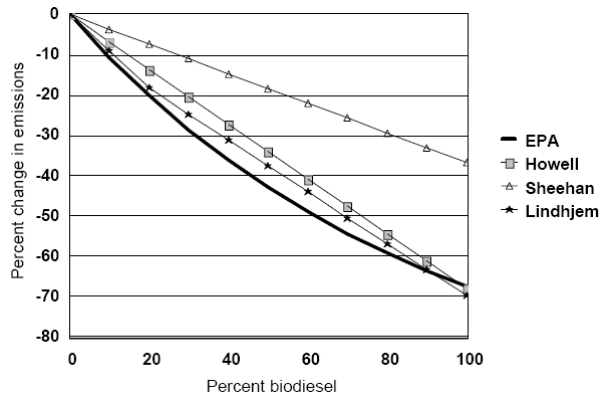

Fig.6: HC emissions related to biodiesel content in diesel fuel blend [2,7,11,13]

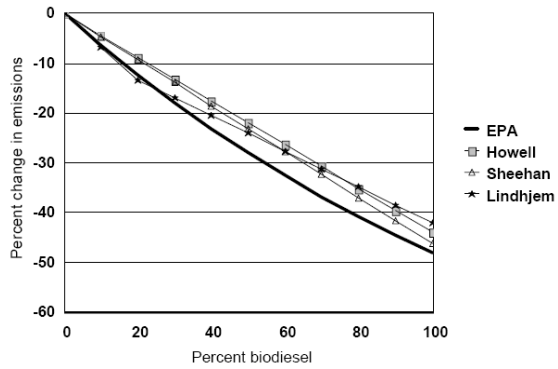

Fig. 7: CO emissions related to biodisel content in diesel fuel blend [2,7,11,13]

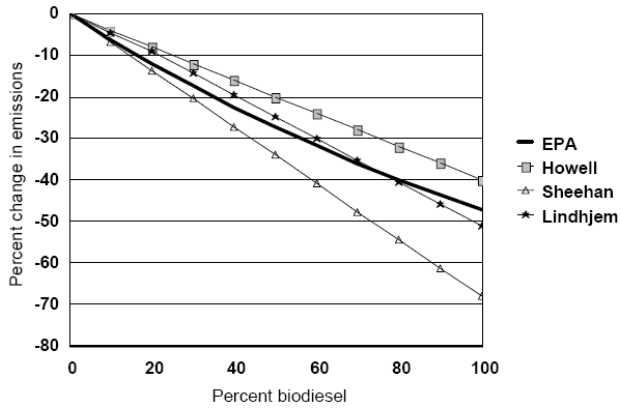

Fig.8: Particle emissions related to biodiesel content in diesel fuel blend [2,7,11,13]

6. History of biofuels for diesel engines in the Czech Republic

In the Czech Republic, ROME was produced pursuant to Czech Standard ČSN 656507 (1994) „Biofuel for diesel engines – Rapeseed Oil Methyl Esters (ROME)“. Due to the issues caused by pure ROME mentioned above, an engine blend consisting, like diesel fuel, primarily of hydrocarbons and only a low amount of ROME started to be produced. Czech standards issued in 1998 set forth requirements for two types of fuel blends. The fuel having min. 30% volume of ROME and the other with max. 5% volume of ROME. The fuel blends where the volume of ROME exceeded 30% were launched with various trade names, e.g. Seta Diesel, Nature Diesel ND 21, Nature Diesel ND 22b, BIOPAL 22, BIOSTER M, Diesel-Economic 96, EKOPAL I, EKOMIX, Diesel SP96 EKO.

Standard ČSN EN 14214 issued in 2004 specified more stringent requirements for quality of fatty acid methyl esters. In accordance with current standards, the diesel fuel blends are produced by blending diesel fuel for moderate climate as specified in ČSN EN 590 and ROME in compliance with ČSN EN 14214. In conformity with ČSN 656508, the supplied diesel fuel blend SMN 30, i.e. engine diesel fuel pursuant to ČSN EN 590, contains over 30% of ROME volume. According to ČSN EN 590, engine diesel fuel may contain max. volume of 5% ROME.

According to the Czech Bureau of Statistics, the production of ROME was 82 thousand tons in 2007, out of which 54 thousand tons were exported. Total rapeseed oil methylester supply to the domestic market was 37 thousand tons, out of which 9 thousand tons were imported.

7. Future of biofuel utilization in the Czech Republic

The Decree of the Czech Ministry of Industry and Trade No. 229/2004 Sb. specifies biofuels for diesel engines as biodiesels – fatty acid methyl esters produced from vegetable or animal fat. Biodiesel (e.g.ROME) can form a part of engine fuel blends. The raw material used in the Czech Republic for the biodiesel production is rape.

ROME is added to diesel fuel since September 2007, in response to the European Commission requirements and to the current Czech Air Quality law 86/2002 Sb. The Ministry of Agriculture estimates that the usage of ROME in the Czech Republic will be 85 thousands tons in 2008 and 194 thousands tons in 2009.

Acknowledgments

Published results were acquired using the subsidization of the Ministry of Education of the Czech Republic for project 1M6840770002 – Josef Božek Research Centre for Engine and Vehicle Technologies II.

References

[1] Holden, B. a spol.: Efect of Ffect of Biodiesel on Diesel Engine Nitrogen Oxide and Other Regulated Emissions Technical Report TR-2275-ENV. NFESC, Port Hueneme, CA. 93043, University of California, Riverside, May 2006.

[2] Howell, S.: Emissions Summary for Biodiesel," MARC-IV Consulting, Inc., memorandum to Sam McCahon, December 8, 2000.

[3] Christopher F., Kwangwook, K.:Operational Evaluation of Emissions and Fuel Use of B20 Versus Diesel Fueled Dump Trucks. Research Project No. 2004-18.North Carolina State University Department of Civil, Construction and Environmental Engineering, 2005.

[4] Korotney, D. a spol.: A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions. Draft Technical Report U.S. Environmental Protection Agency. December , 2002.

[5] Lapuerta, M. a spol.: Diesel emissions from biofuels derived from Spanish potential vegetable oils. Elsevier. Science Direkt. Fuel 84 (2005) str. 773-780.

[6] Laurin, J.: Kvasný líh v motorových palivech v České republice. In: 7 th International Symposium MOTOR FUELS 06. Slovenská společnosť priemyselnej chemie, pobočka SLOVNAFT Bratislava. Vysoké Tatry, 2006.

[7] Lindhjem et al: Impact of Biodiesel Fuels on Air Quality," ENVIRON International Corporation Task 1 Report, June 13, 2000

[8] Moc, L. a spol.: Oxidační stabilita a emisní vlastnosti bionaft. Protokol o autorizovaném měření koncentrací emisí č. P 16/07/02. Technická univerzita v Liberci, Liberec 2002

[9] Rakopoulos , C.,D. a spol.: Comparative performance and emissions study of a direct injection Diesel engine using blends of Diesel fuel with vegetable oils or bio-diesels of various origins. Elsevier. Science Direkt. Energy Conversion and Managament 47 (2006) str. 3272-3286.

[10] Ramadhas, A., S., Muraleedharan, C., Jayaraj, S.: Performance and emission evaluation of a diesel engine fueled with methyl esters of rubber seed oil. Elsevier. Science Direkt. Renewable Energy 30 (2005) str.1789-1800.

[11] Sheehan et al: Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus," National Renewable Energy Laboratory Final Report, May 1998

[12] Šebor, G., Pospíšil, M., Třebický, V.: Možnosti využití biopaliv v dopravě v České republice do roku 2020. (Studie.) Ústav paliv a maziv, a.s., Praha, VŠCHT v Praze. Praha 2005.

[13] U.S. Environmental Protection Agency: A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions (Draft Technical Report) EPA420-P-02-001, 2002.

[14] Výsledky výzkumných prací, týkajících se vlivu alkoholových motorových paliv na provozní parametry zážehových a vznětových motorů. Technická univerzita v Liberci, Liberec 1992 – 2004.

[15] www.scania.com