BMD BIO-FUEL FOR DIESEL ENGINES

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Abstract

The paper regards the use of bio-blends consisting of vegetable oil and higher alcohol (biobutanol) as a new component of diesel fuels. The use of rapeseed oil as one of the components eliminates the need energy-intensive conversion rapeseed oil to FAME. The use of higher alcohol, such as a butanol obtained directly from biomass is in accordance with requirements of the EU on the promotion of renewable energy resources. Experiments on chassis dynamometer with fuels containing 20% by volume bio-blend (BM) and 80% of diesel fuels (D) were performed. Main parameters of engine (power output, torque, specific fuel consumption) and the main exhaust gas components (THC, CO, NOx and PM) showed very promising results.

The properties of different alcohols and engine fuels, properties of investigated fuels, examples of investigations results on the car test chassis bed by NEDC test load and by fuelling the engine with investigated bmd20 and standard diesel fuel, relatives change of pollutants emission and fuel consumption by fuelling the car engine with BMD20 and Diesel fuel, the differences in emission and fuel consumption during fuelling the car engine with BMD20 and Diesel fuel recorded during the test bed investigation of the car, relatives change of pollutants emission and fuel consumption during engine fuelling with BMD20 and Diesel fuel are presented in the paper.

Keywords: *road transport, biobutanol, rapeseed oil, bio-fuel, combustion engines, air pollution, environmental protection*

1. Introduction

People are strongly dependent on crude oil for their transport needs. In order to diminish this dependence, we need to introduce clean, CO2-efficient, secure and affordable transportation fuels. The current production of liquid bio-fuels in the EU25 is less than 1% of the market. Recent assessments have concluded that the 2010 target: 18 Mt (Mega Tones) of biofuel consumption in the transport sector is unlikely to be achieved.

There are three basic possibilities to accomplish this target:

– the use of alcohols (first of all ethanol) and their mixtures with petrol,
– the use of fatty acids esters (methyl or ethyl esters) of vegetable oils and their mixtures with diesel fuel,
– the use of synthetic hydrocarbons produced from synthesis gas coming from biomass and their mixtures with "classical" hydrocarbons.

Nowadays we have an overproduction of ethanol in EU. At the same time we have an overproduction of petrol, and on the other side on the market is observed increasing sales of diesel oil. However, in the nearest future, despite the increase of engine efficiency, the situation will not changes because of our growing fuel needs.

This paper presents a novel way of using alcohols as fuels for a diesel engine. It was shown the use of heavy alcohols as a solvent for straight vegetable oil (this mixture is called the biomix or BM). Such a mixture, after obtaining the density similar to the density of diesel fuel, is mixed with diesel fuel (D) giving biomixdiesel (BMD). In this paper for BMD preparation was used the n-butanol as an alcohol, rapeseed oil and conventional diesel fuel. Long term, bio-butanol is a direct 'Drop-In' replacement for gasoline and has significant potential as an alternative fuel blend with ethanol (in E-85 as a replacement for gasoline).

The old and new technology of butanol production is known as an ABE process and the second generation process using lignocellulosic waste material, respectively. Butanol, like ethanol, can blend with gasoline very well. Furthermore, butanol could be a future option for blending with diesel. Butanol contains more oxygen content compared with the biodiesel, leading to further reduction of soot. NOx emissions can also be reduced due to its higher heat of evaporation, which results in a lower combustion temperature [6]. The butanol has more advantages than the widely used ethanol and FAME. However, the main disadvantage of butanol is low production. Also there is higher production yield for ethanol fermentation process (up to 30 times) comparing with ABE process. As was mentioned above, we can distinguish conventional ABE fermentation process based on sugars material (cane or beet) or starch (wheat, corn, or rice) which is easily broken down into sugars. Novel technology TMO process is based on a selected group of thermophilic micro-organisms (Thermophiles). The optimal feedstock for bioconversions could be waste biomass (e.g. straw, wood chips and paper pulp effluent) and crops specially grown for their high biomass production rate (kenaf, miscanthus and short rotation woody crops). Such sources of raw materials can be described as "cellulosic biomass" because of their high cellulose and hemicellulose content.

Main alcohols used as a fuels component are: methanol, ethanol and n-butanol. These alcohols have different properties. Some of them are presented in Tab.1. They are compared with conventional engine fuels.

Tab.1. The properties of different alcohols and engine fuels

Fuel	Energy density	Heat of vaporization	Kinematic viscosity at 20°C
Diesel	38.6 MJ/l	0,47 MJ/kg	>3 cSt
Gasoline	32.0 MJ/l	0.36 MJ/kg	0.4–0.8 cSt
Butanol	29.2 MJ/l	0.43 MJ/kg	3.64 cSt
Ethanol	19.6 MJ/l	0.92 MJ/kg	1.52 cSt
Methanol	16.0 MJ/l	1.20 MJ/kg	0.64 cSt

It is interesting that the butanol has similar energy density as petrol. Butanol is very good solvent of heavy hydrocarbons (such diesel fuels). Mixture of these components is homogeneous (it doesn't separate after several months). In contrast, ethanol is slightly soluble in diesel fuel. It is important that the water is nearly insoluble in butanol (in contrast to ethanol which dissolves water in any proportion). We used for preparation BMD, 1-butanol, also known as n-butanol, which has a straight-chain structure with the –OH at the terminal carbon. Another isomer is 2-butanol, also known as sec-butanol, is also a straight-chain alcohol but with the OH group at an internal carbon. Iso-butanol is a branched isomer with the OH group at the terminal carbon and tert-butanol refers to the branched isomer with the OH group at an internal carbon.

2. Experimental and Results

Prepared under laboratory conditions mixtures of n-butanol with diesel fuel were investigated on the chassis dynamometer. Obtained results encouraged the further investigations with other mixtures – one of them is presented in previous paper [5].

There were prepared BMD mixtures. In the first step the rape oil (straight vegetable oil) was mixed with butanol as such proportions to obtain a mixture having a density similar to the density of diesel fuel. This mixture is denoted as a BM (Bio Mix). In the second step this fuel (BM) was mixed with conventional diesel fuel (EN 590) to obtain biomixdiesel (denoted as a BMD). These fluids were mixed in the following proportions:

- biomix (BM) 20 % v/v,
- diesel fuel (D) 80 % v/v,

giving fuel called as biomixdiesel (BMD20). In contrast to the mixture of ethanol with rape methyl ester and conventional diesel fuel, this mixture is very homogeneous.

The comparison of new fuel with requirements of the standard diesel fuel is presented in Tab.2.

Tab.2. Properties of investigated fuels

No.	Property	Test method	Limits PN-EN 590	
			BMD20	
1	Cetane number	PN-EN ISO 5165	44.4	min 51.0
2	Cetane index	PN-EN ISO 4264	46.8	min 46.0
3	Density at 15°C, kg/m^3	PN-EN ISO 12185	837.9	820.0 – 845.0
4	Polycyclic aromatic hydrocarbons, %(m/m)	PN-EN 12916	1.9	max 11
5	Sulphur content, mg/kg	PN-EN ISO 20846	5.7	max 10.0
6	Flash point, ^{o}C	PN-EN ISO 2719	< 40.0	above 55
7	Carbon residue (on 10% distillation residue), %(m/m)	PN-EN ISO 10370	0.48	max 0.30
8	Ash content, %(m/m)	PN-EN ISO 6245	< 0.001	max 0.01
9	Water content, mg/kg	PN-EN ISO 12937	110	max 200
10	Total contamination, mg/kg	PN-EN 12662	<6.0	max 24
11	Copper strip corrosion (3 h at 50^{0}C)	PN-EN ISO 2160	class 1	class 1
12	Lubricity, corrected wear scar diameter (wsd 1,4) at 60°C , μm	PN-EN ISO 12156-1	281	max 460
13	Viscosity at 40°C, mm^2/s	PN-EN ISO 3104	2.710	2.00 – 4.50
14	Distillation %(V/V) recovered at 250^{o}C, %(V/V) recovered at 350^{o}C, 95%(V/V) recovered at , ^{o}C Finish boiling point, ^{o}C	PN-EN ISO 3405	 47.3 -- -- 349.9	 < 65 min 85 max 360 --
15	Fatty acid methyl ester content, FAME , %(V/V)	PN-EN 14078	< 1.6	max 7.0
16	Oxidation stability, g/m3	PN-ISO 12205	66	max 25

Comparing the results of bio-fuels B20 with quality requirements for diesel fuel it worth to note that most of the parameters meet these requirements; however, several parameters deviate from the normative requirements. Cetane number is lower than the required standard that is at least 51 units. This is due to the participation of 20% biocomponents. Rapeseed oil has a cetane number of the order of 40-50 units [4] and a small addition to the diesel fuel should not drastically reduce the Cetane number. However alcohol is usually characterized by a very high octane number, which is beneficial in case of composing gasoline, added to the diesel fuel can degrade the diesel engine start-up parameters. The process of starting engine and his operation is also influenced by fractional composition of fuel, particularly temperature distillation of 50% by volume of fuel, T50. The lower the temperature T50 is the easier start, but at too low temperature ignition characteristics fuel property is worsen - Cetane number decreases. The investigations of fuel properties under operating conditions were carried out with a modern diesel engine on the chassis bed dynamometer in the NEDC test. Main output parameters of car engine (power output, torque, specific fuel consumption) and the main exhaust gas component (in this case THC, CO, CO_2, NO_x, THC+ NO_x, PM) and fuel consumption is evaluated and explain here in g/km. In Tab. 3. there are presented examples of obtained results.

Tab. 3. Examples of investigations results on the car test chassis bed by NEDC test load and by fuelling the engine with investigated BMD20 and standard Diesel fuel

Emission	Fuel	Pollutants g/km						Fuel consumption, g/km
		THC	CO	CO2	NOX	THC+NOX	PM	
UDC	BMD20	0.1000	1.3900	163.6367	0.1933	0.2967	0.0042	6.2467
UDC	Diesel	0.0833	1.3400	162.1367	0.2000	0.2867	0.0053	6.1933
EUDC	BMD20	0.0100	0.0367	118.7567	0.2133	0.2267	0.0064	4.4667
EUDC	Diesel	0.0100	0.0467	114.5500	0.1600	0.1700	0.0078	4.3167
NEDC	BMD20	0.0467	0.5367	135.2933	0.2067	0.2533	0.0056	5.1233
NEDC	Diesel	0.0367	0.5233	132.1100	0.1767	0.2167	0.0069	5.0100

The fuelling of the car engine with different fuel leads to a diversity of output parameters of the engine. But the differences are not so significant. Differences between the results obtained for the tested BMD20 fuel and diesel fuel are presented below. To better show the results of investigations of pollutant emission, they are presented here as relative to the results obtained by fuelling the engine with the conventional diesel fuel. The results expressed in g/km are shown in Tab. 4.

Tab.4. Relatives change of pollutants emission and fuel consumption by fuelling the car engine with BMD20 and Diesel fuel

Test	Pollutants						Fuel consumption
	THC	CO	CO2	NO_x	THC+NO_x	PM	
	g/km						
UDC	0.0167	0.0500	1.5000	-0.0067	0.0100	-0.0011	0.0533
EUDC	0.0000	-0.0100	4.2067	0.0533	0.0567	-0.0014	0.1500
NEDC	0.0100	0.0133	3.1833	0.0300	0.0367	-0.0013	0.1133

The results are presented in graphical form on the Fig. 1.

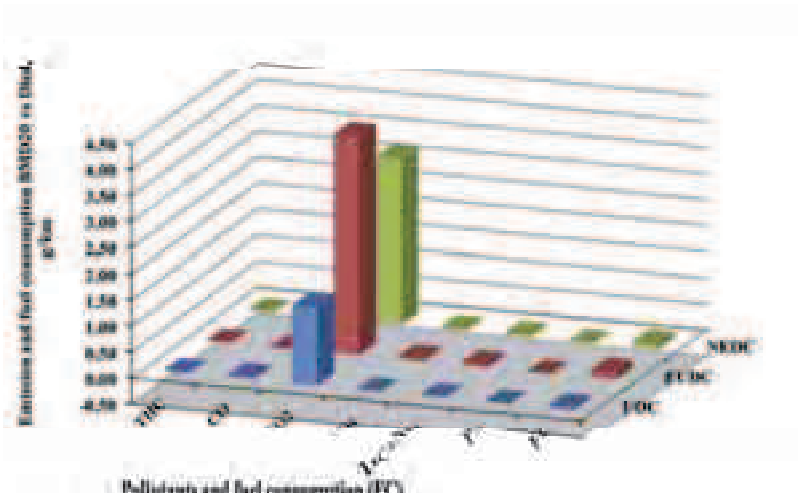

Fig. 1. The differences in emission and fuel consumption during fuelling the car engine with BMD20 and Diesel fuel recorded during the test bed investigation of the car

Research results are interesting. In all phases of the test, during fuelling the engine with BMD20, increasing the carbon dioxide (CO_2) is observed. Emissions of other toxic components and fuel consumption are not differing from those when the engine is fuelled by conventional fuel.

Small differences in the results are becoming clear when relative changes are expressed in %. The results of this analysis are presented in Tab. 5. and illustrated on Fig. 2.

Tab. 5. Relatives change of pollutants emission and fuel consumption during engine fuelling with BMD20 and Diesel fuel

Test	Pollutants						Fuel consumption
	THC	CO	CO_2	NO_x	THC+NO_x	PM	
	%						
UDC	20.00	3.73	0.93	-3.33	3.49	-20.75	0.86
EUDC	0.00	-21.43	3.67	33.33	33.33	-18.38	3.47
NEDC	27.27	2.55	2.41	16.98	16.92	-18.93	2.26

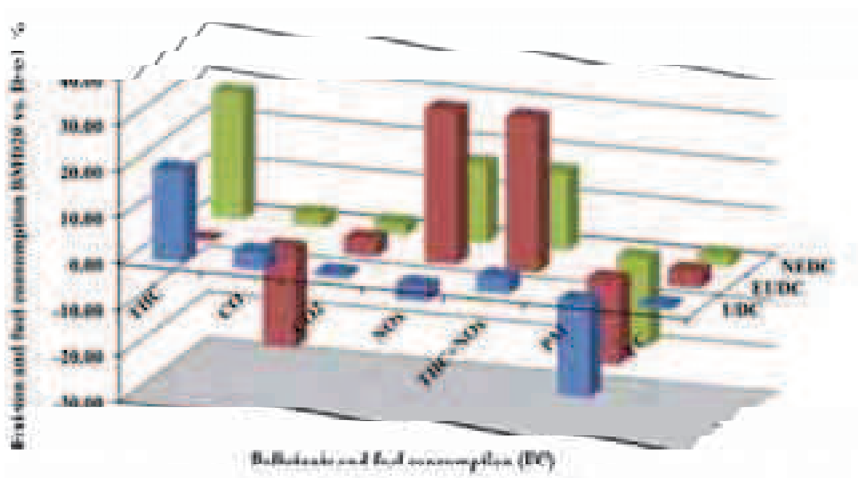

Fig. 2. Relative change of emissions and fuel consumption of the car engine fuelled with BMD20 and diesel oil

During fuelling the car engine with the BMD20, the fuel consumption is not significantly different (less that 3.5%) from observed for Diesel oil. The differences in the emission of pollutants are depended on the test phase (UDC or EUDC). For example the emission of THC in the EUDC phase is the same as that recorded for diesel oil, but the quantity THC grows in UDC phase. Thus in full test (NEDC) the relative emission of THC grows. Other trend is observed for carbon monoxide (CO) emissions. In the UDC phase emission of CO slightly increases, in the EUDC phase significantly decreases (more then 21%) so, therefore in the NEDC test the emission of CO slightly grows.

The emissions of NOx grows, first of all, in the EUDC phase. This is understandable if we take in into consideration the engine load – the higher combustion temperatures (peaks) in this phase favour the formation of nitrogen oxides. In the same phase, the emission of THC neither increases nor decreases, so in the entire test, the summary quantity of $THC+NO_x$ increases (the emission of THC increases in the UDC phase).

It is important that, the PM emission decreases in all phases of test. The decrease is significant, about 21% in the UDC phase and more than 18% in the EUDC phase.

The above results were obtained without any change of engine control parameters (the engine control parameters were the same as during supplying the engine with conventional diesel fuel). It appears that after optimization of engine control parameters the results will be much better.

3. Conclusions

There have been given the first investigations results of application of heavy alcohols as a component of diesel fuel. There have been presented results for mixture of butanol (as heavy alcohol), rape oil (as vegetable oil) and conventional diesel fuel. This mixture was called the biomixdiesel (BMD). The tests showed very promising results.

It is important is that for practically the same fuel consumption, the emissions of main toxic compounds decreased. Particularly important is the decrease of emissions for particle matter (PM). Increase of emissions of NOx is avoiding today's in modern engines equipped with the SCR catalyst, so the emissions of nitric oxides can be minimized.

The production of butanol is known. There is observed trend in transformation of ethanol plants into butanol one. There has also been presented another way to use alcohols (and vegetable oils – without transesterification process) as diesel engine fuel.

It can be concluded, that the expanding production o butanol and European production of vegetable oils will contribute to fulfil expected requirements of European Union connected with biofuels.

The future works will focus on better adjusting of the engine to new fuel (especially engine control parameters), as well as blending a new fuels for specific exploitation needs.

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