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Comparison of properties of a compression ignition engine operating on diesel–biodiesel blend with methanol additive

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HIGHLIGHTS

- Analysed properties of Audi 1Z engine fueled by biodiesel, methanol and diesel fuel.
- The energy, ecology properties and characteristics of $dQ/d\varphi_{max}$ and $dp/d\varphi_{max}$ were analysed.
- Break specific fuel consumption increased for B30 and B30 + 10M, break thermal efficiency increased respectively.
- Both blends showed reduced soot concentration, increased CO_2 and ambiguous distribution of incomplete combustion product emission values.
- Using these blends, the maximum values of $dQ/d\varphi_{max}$ and $dp/d\varphi_{max}$ are higher than the values of diesel fuel.

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ABSTRACT

This article shows the research results and the analysis of the engine properties of diesel fuel, rape seed methyl ester and methanol (M). In the test two blends, 30 V/V% biodiesel (FAME, B30) and 30 V/V% FAME with 10 V/V% methanol (M, B30 + M10) were investigated compared to the reference diesel fuel (D). These properties were researched using an Audi 1.9 TDI 1Z compression ignition (diesel) engine loaded in wide range *BMEP* = 0.236–1.203 MPa (M_B = 36–179 N m) and 4 speed regimes in range n = 2000–3500 min^{-1}. The change of energy and ecology properties during engine work on different fuels was analysed as well $dQ/d\varphi_{max}$ and $dp/d\varphi_{max}$ for the assessment of thermal and mechanical load of engine parts. While *BSCF* increased up to 3.5% for B30 and varied in range of 2–13% for B30 + 10M the *BTE* increased 1–2% and 2–2.5% respectively. The part of ecology indicators improved by adding M to B30: high engine loads characterized by 2–13% reduced CO and whole engine load range – 13–45% reduced concentration of soot. However emission rates of NO_X, HC and CO_2 were close to or higher than reference diesel fuel (D). Research of thermal and mechanical load criteria (values of $dQ/d\varphi_{max}$ and $dp/d\varphi_{max}$) showed that the additive of M to B30 blend has no such a strong effect as expected.

1. Introduction

Fatty acid methyl esters (FAMEs) are well known as fuels for compression ignition or diesel engines. Because of their biological origin, chemical composition and so on, FAMEs are used to reduce the consumption of fossil diesel fuel, environmental pollution and to improve the efficiency of energy use in transport sector [1–3]. Biofuel use in transport sector is related with long term storage that could result the change of properties due to biofuel oxidation. To avoid an oxidation effect the synthetic antioxidants (butylhydroxytoluene, butylhydroxyanisole, tret hydroxycoumarin, propyl gallate, etc.) are used. However, despite the use of antioxidants, the oxidation reaction takes place in long stored biodiesel [4], which affects the change of the fuel's physical and chemical properties. During oxidation reaction viscosity increases, this factor deteriorates fuel injection and atomisation, and at the same time worsens the quality of the combustion process [5]. Just like viscosity, increased density can result higher fuel consumption (by weight), while the sediment can lead to nozzle coking and damage [5,6]. This is especially relevant for today's high-pressure fuel systems, which are highly sensitive to fuel quality [7]. One of the ways to eliminate the negative impact of devious values of density and viscosity is the addition of alcohol. Methanol is one of the cheapest technical alcohols and cheaper than ethanol or butanol [5,8]. Methanol (M) is an alcohol that contains 30% more oxygen (O_2) than fossil diesel fuel [9]. A higher amount of O_2 in a combustion

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process reduces emission rates of incomplete combustion products. According to various scientific research results [9–11], the emission of incomplete combustion products (carbon monoxide and hydrocarbons), engine cold start, as well as cold exploitation and engine efficiency could be improved using M as an additive for fossil diesel fuel (D) and biodiesel blends. However, the use of M in a diesel engine can cause negative consequences. Increased fuel consumption and rates of nitrogen oxides emission encountered in Yasin et al. [9] and Yilmaz [11] research works. Also the blending M with diesel fuel is limited by separation. For the latter reason the use of acidic base fuels such as FAME or vegetable oil is appropriate in the mechanical mixed blend of diesel fuel and M.

The engine properties of D, FAME and M blends (D-FAME-M) are being widely researched [12–14]. The rates of nitrogen oxides (NO_X), carbon monoxide (CO), hydrocarbons (HC) emission, fuel consumption, efficiency and smokiness are researched by Li et al. [15], Cheung et al. [16] and others. However, the several scientific works showed controversial results. Results of Cheung et al. [16] show that the use of biodiesel (B) and M (15%) blend improved (compared to D) the pollutions rates (even NO_X concentration) as well as engine brake thermal efficiency (*BTE*). Scientists Shahir et al. [1] and the Arbab et al. [2] have achieved opposite results, in the case of M use (5–20%) in fuel blend across tested load range the NO_X emission rates of engine exhaust gases (EG) increased compared to operation on D.

Scientific literature is full of analysis of ecological and energy parameter characteristics while diesel engine running on fuel blends containing M. Only few of scientific sources provide results of pressure and heat release rates in a wide engine load and speed ranges. M is characterized by low cetane number (*CN*), which is less than 5 units [10,17–20] and prolongs the ignition delay of air–fuel mixture [21,22], at the same time increase the peak values of in-cylinder pressure rise ($dp/d\varphi_{max}$) and heat release ($dQ/d\varphi_{max}$) characteristics. Increased peak values of characteristic $dp/d\varphi_{max}$ are directly related to the increased mechanical load of engine part as well as $dQ/d\varphi_{max}$ with thermal load. Increased loads firstly affect the parts of piston-connecting rod group and the change of these loads can reduce engine exploitation duration.

2. Research methods

2.1. Fuels

The blend of methanol (10% vol.) and diesel fuel showed separation, which hinders the formation of usable fuel blends. However, the use of FAME as a solvent [9,10,21] gave a homogeneous and stabile blend. So diesel fuel (D2, EN 590) FAME, in this case rape seed methyl ester (RME, EN 14214) and methanol (CH_3OH) were used for engine tests. The main data of fuel properties of the used FAME (RME) are presented in Table 1. The detailed information about RME properties was taken from another comparative research [3] of biofuels. Rape seed methyl ester was supplied by the largest Lithuania's biodiesel company JSC "Mestilla" (Klaipėda).

Technical alcohol M (CH_3OH) was purchased from JSC "4 BIK" (Lithuania) and its properties' specification was given by supplier. The main properties of M are shown in Table 2.

2.2. Engine and test regimes

Engine tests were carried out in Jendrassik György laboratory of Department of Energy Engineering (BME). Four cylinder passenger vehicle's Audi diesel engine 1.9 TDI 1Z with eddy current brake dynamometer Borghi & Saveri FE-350S was used for these tests. Engine had an open combustion chamber (direct injection), a turbo compressor, an exhaust gas recirculation (EGR) system and an electronic control unit (ECU). In order to achieve more accurate heat release results the EGR system was disabled during tests. The main technical data of engine 1.9 TDI 1Z is shown in Table 3.

During the tests in the selected four engine speed regimes the each fuel test included a maximum Brake Mean Effective Pressure (*BMEP)* determination (100% of load), then the 75%, 50% and 25% of *BMEP* were set by the throttle (accelerator pedal) position sensor, varied in a range of ~45–100% and a stand load range was ~36–179 N m (power range: 9.0–52.5 kW). Table 4 shows detailed information on experimental load points (LP), engine speed (*n*) and the measured *BMEP*.

A wide range of engine speed and load were chosen for detailed research of different fuel effects on diesel engine work and exhaust parameters. Regimes of high engine load are very valuable for CO, soot and HC research, because reaching a high load of the engine the characters of these rates' changes are different compared with regimes of low and average engine load [23,24].

Table 1
The main characteristics of used experimental rape seed methyl ester [3].

Parameter	Unit	RME	EN 14214
Ester content	%	98.7	Min 96.5
Density at 15 °C	kg/m^3	882.0	Min 860, max 900
Viscosity at 40 °C	mm^2/s	4.88	Min 3.50, max 5.00
Oxidation stability, 110 °C	h	6.32	Min 6.0
Acid value	mg KOH/g	0.40	Max 0.5
Iodine value	g J_2/100 g	116.3	Max 120
Flash point	°C	185	Min 120
Sulfur content	mg/kg	7.5	Max 10
Water content	mg/kg	240	Max 500
Total impurities	mg/kg	8.9	Max 24
Methanol content	% (mass)	0.08	Max 0.20
Lower calorific value	MJ/kg	37.26	–
Linolenic acid methyl ester content	% (mass)	9.5	Max 12.0
Monoglyceride content	% (mass)	0.625	Max 0.8
Diglyceride content	% (mass)	0.110	Max 0.2
Triglyceride content	% (mass)	0.090	Max 0.2

Table 2
The main characteristics of experimental methanol [4 BIK].

Parameter	Norm	Result
Methanol content (mass) (%)	>99.95	99.988
Density at 15 °C (g/cm^3)	0.791–0.792	0.792
Boiling temperature (°C)	64.0–65.5	64.3–65.0
Water content (mass) (%)	<0.05	0.011
Free acid content (%)	<0.0015	<0.0008
Aldehydes and ketones content (%)	<0.003	0.0012
Mass fraction of iron compounds (%)	<0.00001	0.000003
Chloride content (%)	<0.0001	0.00002
Sulfur content (%)	<0.0001	0.00001
Insoluble matter (%)	<0.001	0.0003
Electrical conductivity (S m/m)	<0.00003	0.000011
Ethanol content (mass) (%)	<0.01	0.0002

Table 3
Technical data of diesel engine 1.9 TDI 1Z.

Parameter	Dimension	Value
Engine displacement	dm^3	1.896
Number of cylinders	–	4
Compression ratio	–	19.5
Brake power	kW	66 (4000 min^{-1})
Torque	N m	180 (2000–2500 min^{-1})
Max brake mean effective pressure	MPa	1.19 (180 N m)
Bore	mm	79.5
Stroke	mm	95.5