Fuel 212 (2018) 34–40

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Full Length Article

Combustion, performance and emission characteristics of various alcohol blends in a single cylinder diesel engine

A. Osman Emiroğlu[a], Mehmet Şen[b,*]

[a] Abant Izzet Baysal University, Department of Mechanical Engineering, 14100 Bolu, Turkey
[b] Abant Izzet Baysal University, Department of Automotive Technology, 14100 Bolu, Turkey

ARTICLE INFO

Keywords:
Alcohols
Diesel engine
Combustion
Performance
Emissions

ABSTRACT

In this study, the influence of the various alcohol additions in diesel fuel on combustion, performance, and exhaust emission characteristics of a single-cylinder diesel engine was investigated at different loads. The alcohol blends obtained by mixing 10% of butanol, ethanol, and methanol with diesel fuel (called B10, E10 and M10 respectively) and petroleum-based diesel fuel (D100) were used in the experiments.

The results showed that the ignition delay of the alcohol blends is longer than D100 due to the low cetane number of the alcohol fuels. Their peak cylinder pressures are higher compared to the diesel fuel for all engine loads. In addition, the maximum heat release rates of the alcohol blends are higher than diesel fuel due to the longer ignition delay and excessive oxygen content of alcohols. D100 has the lowest brake specific fuel consumption and the highest brake thermal efficiency compared to alcohol blends for all engine loads because of the higher heating value. B10, E10, and M10 follow D100 respectively in accordance with the heating values of the fuels. Also, alcohol addition causes a slight increase in nitrogen oxides (NO_x) emissions while causing a reduction in smoke and carbon monoxide (CO) emissions.

1. Introduction

The rise in energy requirement, the decrease of oil reserves, the increase in oil prices, and air pollution problems related to the use of fossil fuels has increased the interest in alternative and clean fuels. Diesel engines are commonly used in many different industries because of their high efficiency [1]. Using bio-based fuel in diesel engines is an effective technique for decreasing emissions [2]. Alcohol fuels can contribute to reducing diesel exhaust emissions and the oil dependency [3]. Alcohols are suitable diesel additives because of their liquid nature and high oxygen content [4].

Among the alcohols, low carbon alcohols (containing three or fewer carbon atoms), such as methanol and ethanol, as a diesel fuel blend have received great interest due to their advanced production technologies and high oxygen content [5,6], which can effectively improve combustion characteristics and reduce the exhaust emissions [7]. However, the low cetane number, the high latent vaporization heat, and stability and miscibility problems greatly limit the use of low carbon alcohols as alternative fuels for diesel engines [8]. High carbon alcohols containing four or more carbons may provide additional advantages as diesel fuel additives compared to low carbon alcohols. They have higher cetane number and heating value than low carbon alcohols. They can also be blended with diesel fuel even at large mixing ratios because of their better miscibility. In addition, the less hygroscopic nature of high carbon alcohols facilitates storage and transport [8]. The effects of various low and high carbon alcohol-diesel blends on the combustion behavior, engine performance, and exhaust emissions of the compression ignition engines will be discussed below.

Ethanol (C_2H_5OH) is the most commonly used alcohol due to being renewable and having high oxygen content as diesel fuel additive. The high oxygen content of ethanol improves combustion and reduces emissions [9]. However, ethanol requires more precautions in preparing ethanol-diesel blends because its flash point is much lower compared to diesel fuels [3]. Since the evaporation temperature of ethanol is about 2–3 times lower than the diesel fuel, mixing of diesel fuel with ethanol can advance the start of fuel evaporation, which accelerates the preparation of a mixture of air and fuel. A number of experimental studies have been carried out on ethanol used in diesel engines. Rakopoulos et al. [10] studied the use of ethanol-diesel blends (E5, E10, E15) in direct injection diesel engine at 2000 rpm under four different loads. CO and smoke emissions notably decreased, while NO_x slightly decreased with the use of blends. On the other hand, brake thermal efficiency (BTE) and brake specific fuel consumption (BSFC) increased slightly as the ethanol increased in the blends. Labeckas et al.

* Corresponding author.
E-mail address: sen_m@ibu.edu.tr (M. Şen).

http://dx.doi.org/10.1016/j.fuel.2017.10.016
Received 13 February 2017; Received in revised form 15 June 2017; Accepted 5 October 2017
0016-2361/

[11] have reported that the ethanol addition reduces smoke, CO, and sulfur dioxide (SO_2) emissions because of the higher oxygen mass content and the lower carbon-hydrogen ratio (C/H) of ethanol. Ajav et al. [12] investigated the effects of ethanol additives to diesel fuel (E5, E10, E15, and E20) in a diesel engine at a constant speed and reported that the use of ethanol blends increased BSFC while NO_x and CO were reduced significantly without any important reduction in power.

In the literature, there are studies in which methanol (CH_3OH) is used as an alternative fuel additive for diesel engines, although not as much as ethanol [13–15]. Methanol can be produced at low cost from petroleum-based fuels or coal but has limited miscibility in diesel fuel [9]. However, ethanol is more advantageous than methanol since it is renewable (bio-ethanol) and more highly miscible with diesel fuel [9]. Sayin [16] conducted an experimental research to compare the use of methanol blends (M5, M10), ethanol blends (E5, E10) and diesel fuel in a direct injection diesel engine under constant torque at different engine speeds. The use of alcohol decreased CO, HC and smoke emissions while increased NO_x. BSFC of methanol blends increased more than that of ethanol blends. BTE decreased with the addition of the alcohols and the lowest value of BTE was reached with M10. As reported in the literature, a larger range of flammability, lower viscosity, significant oxygen content, and higher latent heat of vaporization of methanol can be seen as an advantage as regards faster combustion, lower NO_x, and smoke emissions [17,18].

The fuel properties of the four carbon alcohol butanol (C_4H_9OH) are more similar to petroleum-based fuels. Butanol has some advantages over other alcohols as an alternative fuel for diesel engines because of its higher cetane number, higher miscibility, and lower vapor pressure. In addition, butanol has higher energy content and less corrosivity. For this reason, butanol is considered to be a more suitable ingredient for use as a diesel fuel additive [4]. Butanol is also a renewable biomass-based fuel such as ethanol. Butanol production from biomass is predominantly the tendency to produce the straight chain molecule normal butanol. Because of its lower volatility, higher heating value, and higher viscosity and like properties, butanol is considered as very promising alcohol fuel for diesel engines compared to ethanol and methanol. For this reason, studies on butanol have recently become popular. The studies on the diesel engines fueled with butanol-diesel blends indicated that lower exhaust emissions can be achieved without significant changes in engine performance [19,20]. Kumar et al. [4] reported that the addition of butanol to diesel fuel reduces smoke density and CO emissions and increases NO_x emissions, but reduces NO_x emissions when the amount of butanol in the fuel blend increases. Rakopoulos et al. [21] investigated the effects of butanol-diesel blends on the emission and performance of direct-injection diesel engines at different loads. They reported that butanol-diesel fuel blends significantly reduced smoke emissions, resulting in a slight reduction in NO_x and CO emissions. Dogan [22] explored the performance and exhaust emissions of the fuel blends prepared by mixing 5% and 10% of butanol with diesel fuel on the four-stroke, single cylinder, direct injection diesel engine under constant engine speed at different loads. It has been found that as the content of butanol increases in the fuel blend, exhaust gas temperature, NO_x, smoke opacity and CO emissions decrease while BSFC and BTE increase slightly.

As mentioned above, many studies have been conducted on diesel engines to investigate the exhaust emissions and engine performance of various alcohol-diesel blends. However, studies on the combustion behavior of alcohol fuels are rather limited compared to performance and emission studies in the literature. For a comprehensive fuel analysis, it is necessary to simultaneously analyze and compare the effects of various lower and higher alcohol blends on the combustion behavior, engine performance, and exhaust emissions of diesel engines.

The main objective of this experimental study is to simultaneously and systematically examine the effect of lower and higher alcohol blends on combustion, performance, and exhaust emission characteristics. For this purpose, the experiments related to combustion behavior, engine performance, and exhaust emission characteristics of a direct-injection single-cylinder diesel engine were performed at 1500 rpm at different engine loads using various alcohol blends obtained by mixing 10% butanol, ethanol, and methanol with diesel fuel. These alcohol blends were then compared with each other and with petroleum-based diesel fuel. The results show that alcohol addition to diesel fuel generally reduces the exhaust emissions without seriously affecting diesel engine performance and the higher alcohol butanol has the potential to overcome problems encountered in the use of ethanol and methanol.

Table 1
Specification of test fuels.

Properties	Diesel	B10	E10	M10
Density (kg/m^3)	831.5	829.3	827	827.4
Flash point (°C)	70	23	21	20
Kinematics viscosity (mm^2/s)	2.4	2.6	2.2	2.1
Lower heating value (MJ/kg)	43.2	41.7	41.2	40.4
Cetan Number	58.8	55.6	53.4	52.1
Carbon (wt%)	86.6	84.4	83.2	81.7
Oxygen (wt%)	0	2.2	3.5	5
Hydrogen (wt%)	13.4	13.4	13.3	13.3

2. Materials and methods

In this study ethanol, methanol, and butanol blends and petroleum-based diesel fuel were used in order to understand the effect of different alcohol additions on combustion behavior, engine performance, and exhaust emissions. Diesel fuel called D100 was used to obtain reference data. Then butanol, ethanol, and methanol were mixed with the diesel fuel in 10 wt% proportion and called B10, E10, and M10 respectively. Table 1 shows the basic properties of these fuels. In spite of the high oxygen content of the alcohols, the alcohol proportion in the test blends was chosen 10 wt%, which is the optimum mixture ratio, in order to minimize the poor combustion characteristics due to low cetane number and heating value of the alcohols. The problem of phase separation has been encountered in the use of methanol-diesel fuel blends. However, pure ethanol and butanol can be easily blended with diesel fuel at room temperature [23,24]. Nevertheless, a magnetic stirrer was used in the fuel tank as a precaution to prevent any phase separation during all tests. Thus, no phase separation was observed during the experiments.

The tests were carried out without any modification on the engine and under variable engine loads of 2.5 Nm, 5 Nm, 7.5 Nm, and 10 Nm at the engine speed of 1500 rpm which is the lowest speed the engine can run stable at full load. Prepared blends were tested under the same condition for comparison with petroleum-based diesel fuel. Fig. 1 indicates a schematic diagram of the engine test rig. The engine tests were performed on an air-cooled, naturally-aspirated, direct injection, and single-cylinder diesel engine.

Table 2 gives the main characteristics of this engine. Kemsan brand DC dynamometer (15 kW at 3000 rpm) was used to load the engine. The engine torque was obtained using a Kistler brand 4550A model torque meter. A Kistler 2614B model encoder was coupled to the crank shaft in order to collect crank angle, top dead center and speed of the engine. A3 Kistler 6052C brand piezoelectric pressure sensor and 5064 charge amplifier were used for measuring the cylinder pressure. Fuel line pressure was measured using a Kistler 4065B piezoresistive sensor coupled to a 4665 amplifier which connected to the fuel line with 6533A clamp adaptor. The cylinder pressure and fuel line pressure were recorded at a resolution of 0.1 degrees crank angle. All the signals were recorded using a Kistler KiBox data collection system.

The heat release rate (HRR) and maximum heat release rate (HRR_{max}), maximum cylinder pressure (CP_{max}) and its location (ACP_{max}) and angles of start and end of combustion were calculated by