Fuel 220 (2018) 682–691

Contents lists available at ScienceDirect

Fuel

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

Full Length Article

Analysis of combustion characteristics, engine performances and emissions of long-chain alcohol-diesel fuel blends

Hazrulzurina Suhaimi[a], Abdullah Adam[a,b,*], Anes G. Mrwan[a], Zuhaira Abdullah[a], Mohd. Fahmi Othman[a], Mohd. Kamal Kamaruzzaman[a], Ftwi Yohaness Hagos[b]

[a] Faculty of Mechanical Engineering, University Malaysia Pahang, Pahang, Malaysia
[b] Automotive Engineering Centre, University Malaysia Pahang, Pahang, Malaysia

ARTICLE INFO

Keywords:
Diesel combustion
Long-chain alcohol
Short-chain alcohol
Engine performance
Emission

ABSTRACT

Petroleum-based fuels have been one of the most in demand energy source for various purposes and application. However, rigorous emissions from petroleum-based fuels have forced many governments to introduce stringent regulations and concerns over energy security. Alternative fuel such as short-chain alcohol (methanol and ethanol) had been used as an oxygenated element to increase oxygen content in diesel fuel (DF). However, short-chain alcohol-diesel blends have disadvantages such as low cetane number, low heating value, increase of hydrocarbons (HC) and low miscibility with DF. Recently, researchers have shown interest on long-chain alcohols which have better physicochemical properties than short-chain alcohol. In this experiment, 5%, 10% and 20% of 2-ethyl 1-hexanol (2-EH) was added into DF to produce long-chain alcohol-diesel fuel blends. The fuel blends were prepared by using Hielscher UP400S ultrasonic emulsifier machine at 20% Hz stirring speed. The discussion will focus on combustion characteristics, engine performance and exhaust emissions of single cylinder diesel engine YANMAR TF120M at constant engine speed of 1800 rpm under various loads (0%, 25%, 50%, 75%, and 100%). The results show that HE5 has the preeminent properties among fuel blends in terms of calorific value (45.87 MJ/kg), density (806.1 kg/m^3) and viscosity (3.02 mPa·s). Performance analysis shows BTE had increased by 91.72%, while BSFC had decreased by 45.22% for 5% 2-EH (HE5).

1. Introduction

In this modern world, diesel fuels are important energy source that we use for over 80% in our daily life. Diesel fuels are being used in transportation, railway, aircraft, heavy equipment and others. The excessive demand and usage of diesel fuels has led to various problems. As petroleum-fuels are non-renewable sources, experts have reported that this natural source has severely depleted. Besides that, the processing and the usage of diesel fuel energy gives negative effects such as pollutant emissions to the environment. The four main pollutant emissions are carbon monoxide (CO), hydrocarbon (HC), particulate matter (PM), and nitrogen oxides (NO_x) has affected human respiratory system which led to various health problem such as asthma, asphyxiation and cancer. Moreover, the HC and NO_x emission may cause the formation of ozone layer and green-house effect [1].

The diesel engine is one of the major contributions to excessive emissions that cause pollution and natural disaster. Due to these problems, several countries have expressed concerns over climate issues and energy security thus strictly stating their emission regulations to overcome the issue. This move has urged many researchers to explore and to focus more on producing alternative fuels to replace the dependence on petroleum fuels. Some examples of alternative fuels are synthetic fuels, methane, dimethyl ether, nano-particle, waste cooking oil, higher alcohols and emulsion fuels [2–7]. In the recent decades, alcohol-based fuels have been one of the major interesting diesel alternative fuels. Numerous studies have explained that alcohol such as ethanol, methanol, butanol, pentanol, and hexanol are attractive alternative solutions to meet the energy demand and also to regulate emission [8–11]. Alcohols are being used as fuel blending components to improve unleaded cetane quality, which will increase oxygen content in diesel fuel blends, thus improve blends knock resistance.

Many technical papers and journals have reported that researchers had used alternative fuel by adding short-chain alcohol to diesel fuel (DF) to produce fuel blends [12–14]. The short-chain alcohols namely methanol, ethanol and propanol are well known as an oxygenated liquid that could increase the oxygen content in the fuel thus performing better during combustion and simultaneously reduce smoke emission [15,16]. The most commonly used short-chain alcohol is ethanol. The

* Corresponding author at: Automotive Engineering Centre, University Malaysia Pahang, Pahang, Malaysia.
E-mail address: adam@ump.edu.my (A. Adam).

https://doi.org/10.1016/j.fuel.2018.02.019
Received 24 November 2017; Received in revised form 23 January 2018; Accepted 6 February 2018
0016-2361/

Nomenclature

HRR	Heat release rate
BP	Brake power
BT	Brake torque
BSFC	Brake specific fuel consumption
BTE	Brake thermal efficiency
EGT	Exhaust gas temperature
CAD	Crank angle degree
DI	Direct injection
HP	Horse power
DF	Diesel fuel
2-EH	2-ethyl 1-hexanol
HE5	5% 2-ethyl 1-hexanol + 95% Diesel fuel
HE10	10% 2-ethyl 1-hexanol + 90% Diesel fuel
HE20	20% 2-ethyl 1-hexanol + 80% Diesel fuel
CO	Carbon monoxide
OH	Hydroxyl radical
CO_2	Carbon dioxide
HC	Hydrocarbon
O_2	Oxygen
NO_x	Nitrogen oxide
EGO	Exhaust gas oxygen

addition of short-chain alcohol to diesel fuel changes the physical-chemical properties of the fuel blends. Short-chain alcohol-diesel fuel blends give advantage as it has higher oxygen content than DF. Furthermore, short-chain alcohol-diesel can be used in diesel engine without the need of further engine modifications. However, the disadvantages of adding short chain alcohol to DF are that the physical-chemical properties of the blends are poor compared to DF such as lower cetane number (CN), calorific value (CV) and kinematic viscosity [17]. Moreover, the short chain alcohol-diesel blends have also shown low miscibility and performs phase separations after certain time period. The poor blending stability and low viscosity for high concentrations of short-chain alcohols-diesel blends were observed in 22% ethanol or 45% propanol which were most capable to improve performance and combustion of diesel engine. To overcome the problems, some researchers introduced additives and cetane improvers that can sharply reduce particulates which were added into the blends. Additives were used to stabilize the blends, reducing phase separation and increase its viscosity [18]. Meanwhile, cetane improver can enhance cetane number of the blends that could improve the fuel combustion process [19]. Ciniviz et al. investigated by adding co-solvents, 2 ethylhexyl nitrate (2EN) into ethanol-diesel fuel [20]. This resulted in increased cetane number, increased density and lowered viscosity of 2EN-ethanol-diesel fuels blends. Ciniviz et al. also stated that 2EN addition had an effect on reducing NO_x, CO emission and increased CO_2 emission.

Several attempts have been made to replace short-chain alcohol by application of long-chain alcohol to overcome the disadvantages of short-chain alcohol-diesel blends. A few years back, long-chain alcohol was difficult to produce and expensive. However, in recent developments in the field of producing long-chain alcohol, it has led to a renewed interest in producing new formulated long chain alcohol diesel fuels. Long-chain alcohols such as pentanol and hexanol are receiving increasing attention to be blended with DF and used as alternative diesel engine fuel by numerous researchers [21–23]. The advantages of long-chain alcohol fall in its molecules structures. Due to higher number of carbon chain, long-chain alcohol-diesel could improve the fuel properties such as fuel density, viscosity and flash point leads to better atomization of fuels. For the examples, the disadvantage of the blends are that the blends cetane number and calorific values are still lower than DF [24,25]. Low cetane number and low calorific value usually show prolong ignition delay, delay in combustion that causes high flame temperature and thus expanding NO_x emission. Overall performances of fuel blends have improved compared to when using short-chain alcohols.

As shown in Table 1, the physical-chemical properties of hexanol (long-chain alcohol) are better than ethanol (short-chain alcohol), which is also close to the physical-chemical properties of DF. The percentage of O_2 for hexanol is higher compared to DF. It is also observed that ethanol has lower density than DF by 6.2%. Meanwhile, the density of 2-EH is only 0.12% less than DF. Moreover, the cetane number of 2-EH is also closer to the cetane number of DF than ethanol. With higher cetane number and density, the performance and combustion of the fuels can be improved during engine testing. Even, calorific value of 2-EH is slightly lowered compared to DF but still higher compared to ethanol by 29.0%. Thus, the shorter ignition delayed period will happen and emissions can be improved at the end of experiment. The chemical properties of long-chain alcohol are better than the short-chain alcohol which is closer to physical-chemical properties of DF. Through previous studies, long-chain alcohol seems to be capable of replacing short-chain alcohol for alcohol-diesel blend.

Pentanol is one of the promising alcohols with five carbons in its atomic structure, it has better fuel properties than ethanol, methanol, and even butanol. Due to its low polarity and being hydrophobic, with no phase separation shown when blended with DF, low polar interaction parameter, well miscible with DF and even vegetable oils which make pentanol more promising and reliable. According to Fernandez et al., 1-pentanol can be added up to 25% by volume without engine performance problems [26]. The pentanol-diesel fuels blends exhibit similar heat release rate curves with pure diesel fuel with slight increase at the peak. The brake specific fuel consumption (BSFC) is the same with pure diesel and increase in brake thermal efficiency (BTE). Wei et al. indicated the *n*-pentanol and DF can be blend up to 30% by volume without any additional solvents at room temperature [27]. In his journal, Wei et al. reported that *n*-pentanol enriched oxygen content, as well as improved both the premixed and diffusive combustion stage. However, due to the blends low cetane number, the ignition delay was longer with the addition of *n*-pentanol. The pentanol-diesel fuel blends exhibit similar heat release rate curves with DF with slight increase at the peak. The brake specific fuel consumption (BSFC) increased because of the lower heating value of *n*-pentanol-diesel blends. For gaseous emissions, HC and CO emissions were increased with increased volume of *n*-pentanol in the blends especially at low and medium engine loads due to the low cetane number of the blended fuels. While at high engine load, HC and CO emissions had slightly decreased and NO_x emissions had increased. NO_x formation at higher engine load was associated with higher in-cylinder temperature due to the long ignition delay. Moreover, increase in *n*-pentanol will increase the formation NO_2 emissions caused by the e-OH functional group.

Another potential long-chain alcohol is hexanol which is also known as an organic alcohol with six-carbon chain. There are many types of hexanol, but commonly used hexanol is 2-ethyl 1-hexanol (2-EH).

Table 1
Chemical properties of diesel, hexanol and ethanol.

Fuel properties	DF	Hexanol (2-EH)	Ethanol
Molecular formula	$C_{12}H_{23}$	$C_6H_{14}O$	C_2H_6O
Density at 20 °C (10^3 kg/m^3)	0.829	0.822	0.790
Cetane number	52	23.2	5–8
Viscosity	3.35	5.32	1.20
LHV (kJ kg^{-1})	42,000	39,100	29,700
Latent heat of vaporization	250	486	846