Fuel 235 (2019) 984–994

Contents lists available at ScienceDirect

Fuel

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

Full Length Article

Study on isobutanol and Calophyllum inophyllum biodiesel as a partial replacement in CI engine applications

B. Ashok[a], K. Nanthagopal[a,*], B. Saravanan[b], Kalam Azad[c], Deepam Patel[a], B. Sudarshan[a], R. Aaditya Ramasamy[a]

[a] School of Mechanical Engineering, VIT University, Vellore 632014, India
[b] Indian Institute of Technology (IIT), Hyderabad, India
[c] School of Engineering Technology, Central Queensland University, Australia

ARTICLE INFO

Keywords:
Calophyllum inophyllum
Biodiesel
Methyl ester
Higher alcohol
Isobutanol
Ternary blend

ABSTRACT

Calophyllum inophyllum biodiesel is seems to be a potential alternative fuel for diesel engine applications due to its non-edible form, easily cultivable nature and abundant availability everywhere in the world. Isobutanol is the next generation biofuel which can be used as partial substitute to petroleum diesel or biodiesel due to its better solvency character. In the present study, a comparative assessment on diesel engine characteristics is carried out using isobutanol as an additive with diesel and biodiesel in the form of binary and ternary blends. Five blends are prepared by 20% of isobutanol with diesel and biodiesel as D80IB20 and B80IB20 along with three ternary blends of diesel-biodiesel-isobutanol using 10%, 15% and 20% concentrations of isobutanol. Experimental study in a diesel engine revealed that the brake thermal efficiency is improved by 3.19% for 10% isobutanol addition in diesel-biodiesel blends with significant improvement in brake specific fuel consumption when compared to biodiesel. All binary and ternary blends of isobutanol reduce CO emission by 13–59% than that of diesel fuel with substantial penalty in HC emission. Meanwhile, when compared to biodiesel, the oxides of nitrogen emission is decreased by 8.16% for isobutanol addition with diesel and biodiesel in terms of binary and ternary blends but higher than that of conventional diesel fuel. Furthermore, momentous improvement is observed in heat release rate during isobutanol addition for B80IB20, D70B10IB20, D70B15IB15 and D70B20IB10 fuel blends when compared to pure biodiesel. Finally, it is noted that isobutanol would be a feasible additive for the partial replacement of diesel and biodiesel in the blends for diesel engine applications.

1. Introduction

Diesel engines are considered to be a vital power source in the areas of transportation, power generation, agriculture and construction engineering sectors due to its superior performance characteristics [1]. Diesel engines have the capability to provide higher torque, better fuel conversion efficiency, higher durability and higher power output characteristics as compare to gasoline engines. These features make diesel engines a better choice over gasoline engines in wide a range of applications. However, diesel fuel dependency on fossil fuel resources, uncertainty in oil price, global warming, toxic pollutants and stringent emission regulations are the motivating factors to search for an alternative fuel source to diesel engine applications [2,3]. Alternate fuels have gained popularity and attention due to their availability, sustainable in nature, lower emissions, etc. Among the various alternative fuel sources, biodiesels derived from different feedstock and higher alcohols with more carbon atoms in their atomic structure are attracting more attention nowadays due to the possible direct application in diesel engines [4]. Biodiesels and alcohols are considered as forefront alternate fuel source in the nations having the potential of biomass sources [5].

Bioenergy obtained from different natural sources like plants and trees are termed as biodiesels and such fuels are increasingly used as alternative fuels in the CI (Compression Ignition) engine. Biodiesels are

Abbreviations: CI, compression ignition; CIME, Calophyllum inophyllum methyl ester; CO, carbon monoxide; BTE, brake thermal efficiency; BSFC, brake specific fuel consumption; BSEC, brake specific energy consumption; B100, biodiesel (100% Calophyllum inophyllum methyl ester); B80IB20, 80% biodiesel and 20% isobutanol; D100, diesel; D80IB20, 80% diesel + 20% isobutanol; D70B10IB20, 70% diesel + 10% biodiesel + 20% isobutanol; D70B15IB15, 70% diesel + 15% biodiesel + 15% isobutanol; D70B20IB10, 70% diesel + 20% biodiesel + 10% isobutanol; HC, hydrocarbons; NO_x, oxides of nitrogen; ppm, parts per million

* Corresponding author.
E-mail address: nanthagopalk@yahoo.com (K. Nanthagopal).

https://doi.org/10.1016/j.fuel.2018.08.087
Received 14 February 2018; Received in revised form 26 April 2018; Accepted 21 August 2018

renewable, non-toxic, and essentially free of sulfur, aromatics and biodegradable with environmental friendly nature leads to wider acceptance over diesel fuel. Biodiesel derived from various vegetable sources such as pongamia, jatropha, palm, Calophyllum inophyllum, etc and the properties of such fuels are similar to diesel fuel [6,7]. Biodiesel can be used directly in the CI engine without any major modifications but the problem of torque and power output loss due to its lower calorific value has to be a major limiting factor. Problems that arise due to high viscosity and high NO_x emissions limit the utilization of biodiesel as the sole fuel in CI engine. In order to obtain the desirable features of diesel, it can be blended with higher alcohols [8]. Biodiesel obtained from non-edible crop such as Calophyllum inophyllum seed is a potential fuel source due to its wide range availability from countries like India, Srilanka, Australia and Southern East Asia. Calophyllum inophyllum is a second generation biodiesel that consists of high free fatty acids (FFA) which can be removed through the transesterification process to produce Calophyllum inophyllum methyl ester (CIME) [9,10]. In order to improve the biodiesel properties and obtain better performance and emission characteristics from CI engine, higher alcohols with longer carbon chains such as butanol, pentanol can be effectively blended with biodiesel [5]. Such type of biodiesel blending with the higher alcohol has attracted significant attention in the recent times to partially replace the diesel fuel.

Higher alcohols, termed as second-generation biofuels, have the lower latent heat of vaporization, higher calorific value, viscosity, flame speed, cetane number, etc as compared to that of ethanol and methanol. The higher carbon content and better solvent capability enable the higher alcohols to easily blend with diesel and biodiesel [5]. Among the various higher alcohols, isobutanol and its isomers have lower production cost and lower corrosive properties. Further, the benefit of using the isobutanol is that the existing ethanol fuel production plants that produce ethanol from sugarcane, cellulose, and corn can be retrofitted to yield the isobutanol with the suitable modification of the catalyst [11]. Some o research on the application of isobutanol as a fuel blend with diesel and biodiesels has been carried out across the globe. Karabektas and Hosoz [12] studied the performance and emission parameters of CI engine fuelled with isobutanol and diesel fuel blend in the ratio of 5%, 10%, 15% and 20%. Due to the lower energy density of isobutanol, the brake thermal efficiency is reduced while an increase in brake specific fuel consumption is observed. Brake power of 10% and 20% isobutanol blend shows an average decrement of 1.47% and 6.04% respectively. However, the CO and NO_x emissions of all the isobutanol blends are reduced as compared to base diesel fuel. Zunqing et al., [13] investigated the effect of various butanol isomers such as isobutanol, n-butanol, *tert*-butanol and *sec*-butanol as a blend with diesel fuel in the ratio of 20% and 40% in volume basis. The study has been further extended to analyze the effects of low-temperature combustion on the blends of butanol. The exhaust gas recirculation (EGR) has been varied from 0% to 65% for achieving low-temperature combustion of the butanol blends. The butanol blends exhibit a longer ignition delay period as compared to diesel fuel; this leads to higher premixed heat release rate during combustion. Among the isomers, isobutanol shows higher ignition delay period and soot emissions are lesser as compared to other butanol isomers. Rajesh and Saravanan, [14] studied the effect of low-temperature combustion by varying the injection timing, EGR for isobutanol and n-pentanol blends with diesel fuel to control the smoke and NO_x emissions in a single cylinder diesel engine. The retardation of injection timing with 30% EGR for 40% isobutanol and 60% diesel blend shows the NO_x reduction of 41.7% and smoke at the rate of 90.8% as compared to the pure diesel fuel. The lower cetane number of isobutanol leads to longer ignition delay period as compared to the n-pentanol blends. Rajesh et al., [15] also investigated the emission and combustion phenomena with intermediate blend ratio of 38% isobutanol and 62% diesel to reduce the smoke and NO_x emissions simultaneously. The charge dilution increases the premix duration which results in lower peak pressure and temperature which in turn leads to reduced NO_x emissions from isobutanol blends. Yilmaz et al. [16] have studied the effect of 5%–20% of butanol with biodiesel on diesel engine characteristics under various engine loads. The investigation pointed out that the there was a reductions in exhaust gas temperature and NO_x emission for the addition of butanol with biodiesel at all fractions while the results were reversed in CO and HC emissions. Tuccar et al. [17] have carried out the evaluation on diesel engine using butanol as partial replacement for diesel, micro algae biodiesel at various proportions. The tested results revealed that the exhaust emissions were reduced with marginal reductions in engine torque and power output during butanol addition with microalgae biodiesel. Kumar et al. [18] analyzed the effects of combustion and emissions for the higher alcohol such as n-pentanol, n-hexanol, n-octanol and isobutanol with the 30% (by volume) of diesel fuel. Isobutanol blends show a higher heat release rate (HRR) and peak pressure accompanied with faster combustion duration as compared to the all tested higher alcohols. The experimental result of the isobutanol shows lesser emissions of oxides of nitrogen (NO_x), smoke and carbon monoxide (CO) among the tested fuels. The impact of higher alcohols with biodiesel was investigated by Yilmaz et al. [19]. Higher fuel consumption and exhaust gas temperatures were noted for 10% higher alcohol addition with biodiesel. Meanwhile, 10% pentanol addition with biodiesel reduces the HC emission by 45.41% when compared to pure biodiesel.

Another investigation on various ternary blends of 1-pentanol, diesel and waste cooking oil methyl ester for diesel engine applications was carried out by Yilmaz and Atmanli [20]. They reported that the higher latent heat of evaporation of pentanol leads to provide more cooling effect inside the combustion chamber which in turn resulted in lower combustion efficiency. Similar investigation was done by Yilmaz and Atmanli [21] on 1-pentanol with diesel at fractions 5%, 10%, 20%, 25% and 35% with conventional diesel fuel. All the experiments are conducted at various engine torques. Notably, the increase in fractions of 1-pentanol with diesel lowers the cetane number and net calorific value. Finally, it is concluded that the 5% 1-pentanol addition with diesel seems to a viable alternative fuel due to its excellent impact on CO and NO_x emission at the expenses in HC emissions.

Very few research activities have been carried out with isobutanol as an additive with biodiesels for fuelling CI engines. Yang et al. [22] studied the impact of isobutanol as an additive with the blend of waste cooking oil biodiesel and diesel fuel. The quantity of isobutanol is fixed as 10% (by volume) and the biodiesel volume is varied up to 40% with diesel fuel. The experimental results suggested that the isobutanol content in biodiesel leads to decrease in NO_x, PM and CO emissions in the order of 32.5%, 38.5% and 3.45% as compared to pure diesel fuel. Further, the brake specific fuel consumption is increased for isobutanol-biodiesel blend and this is due to the lower heating value. Sastry et al. [23] investigated the effect of isobutanol and ethanol fuel as an additive with biodiesel for the different injection pressures. Biodiesel derived from fish oil is blended with diesel at the concentration of 5% and 10% by volume. Similar mixtures are prepared for the ethanol fuel and both the results are compared with base diesel fuel. The CO and smoke emissions were found to decrease with the addition of isobutanol and the downward trend continues for higher injection pressures. However, the NO_x emission is found to decrease marginally for the isobutanol additives and the results were reversed with higher injection pressures. Mathan et al. [24] analyzed the impact of isobutanol addition to the cottonseed biodiesel in a single cylinder diesel engine. Isobutanol is added in the ratio of 5% and 10% by volume with the B10 (90% diesel and 10% biodiesel) and B20 biodiesel blends. Isobutanol addition increased the brake thermal efficiency with the reduction of fuel consumption and this is due to the higher energy content of the fuel blend. Moreover, the NO_x emissions are found to be lower for a higher concentration of isobutanol in the blend as compared to pure biodiesel. In recent time, fewer quaternary blends are prepared by the researchers using propanol and pentanol with diesel, biodiesel and vegetable oils for the emission and performance evaluation in diesel engine. The