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Effect of next generation higher alcohols and *Calophyllum inophyllum* methyl ester blends in diesel engine

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ABSTRACT

Biodiesel can serve as potential alternate fuels in compression ignition engine as it leads to an effective reduction in consumption of fossil fuels. Moreover, it has been observed that biodiesel has the potential to reduce the exhaust emissions as well as their usage is sustainable in nature. However, the lower calorific value of biodiesel coupled with higher oxygen content leads to a poor performance and higher oxides of nitrogen emissions when compared to diesel fuel. Hence, in the current study, the effect of introducing higher alcohols as a blend with *Calophyllum inophyllum* biodiesel in order to improve the performance and reduce the oxides of nitrogen emissions. Two different higher alcohols namely n-pentanol and n-octanol are blended with biodiesel in the proportion of 10%, 20% and 30% by volume in order to evaluate the performance, emission and combustion characteristics. The blending of higher alcohols with biodiesel reduces the auto ignition quality and density of the blends. Meanwhile, the increase in the concentration of n-pentanol with biodiesel reduces the calorific value and kinematic viscosity, whereas for n-octanol the results are reversed. The fuel samples are tested in a single cylinder, constant speed engine at different loads and the results are compared with diesel and pure biodiesel. The experimental study revealed that brake thermal efficiency is 8.9% and 3.6% is higher for B70O30 (70% of biodiesel and 30% of n-octanol) and B90P10 (90% of biodiesel and 10% of n-pentanol) compare to pure *Calophyllum inophyllum* biodiesel. It is observed that the blending of higher alcohols with biodiesel decreases the hydrocarbon emissions 8–22% and increase the carbon monoxide emission by 16–50%. Oxides of nitrogen emission are reduced significantly by 4.1% and 6.8% for B90P10 and B90O10 respectively at full engine load condition. On the other hand, the smoke emission increases from 21 to 35% for higher alcohols addition with biodiesel. Furthermore, the combustion characteristics better for higher alcohol blends due to their higher calorific value. In general, the blending of higher alcohol with biodiesel can overcome many shortcomings of pure *Calophyllum inophyllum* biodiesel for diesel engine applications.

1. Introduction

Fossil fuel depletion and stringent emission norms are the alarming factors that lead to a search for an alternate renewable energy source in the diesel engine applications. Diesel engines are considered to be a vital power source in the field of automotive, commercial, agriculture and construction sectors due to its high torque capability, durability and high-efficiency characteristics. However, the exhaust emissions from diesel engine such as NOx, smoke are higher than its counterpart and this could affect the human health and the environment in a serious manner (Rahman et al., 2014). Similarly, the usage of diesel engine power source keeps on increasing which leads to increase the atmospheric pollution and weakens the fossil fuel resources. To overcome the limitation of fossil fuel reserves, uncertainty in the oil price, global warming issues, toxic pollutants and problem in finding the oil suppliers are the factors that motivate various nations to derive an alternate energy source in the power sectors. Such kind of alternate energy source must be affordable, renewable in nature, availability and provides almost clean operation in diesel engines. In recent years, alternative fuels have shown a potential energy source due to its sustainable methods of production from various biological sources and the properties of the fuels is suitable for diesel engine

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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	100% Biodiesel (*Calophyllum inophyllum*)
D100	100% Diesel (Conventional diesel)
B90P10	90% Biodiesel + 10% n-pentanol
B80P20	80% Biodiesel + 20% n-pentanol
B70P30	70% Biodiesel + 30% n-pentanol
B90O10	90% Biodiesel + 10% n-octanol
B80O20	80% Biodiesel + 20% n-octanol
B70O30	70% Biodiesel + 30% n-octanol
HRR	Heat release rate
HC	Hydrocarbons
NOx	Oxides of nitrogen
ppm	Parts per million

applications. Biodiesel and alcohols are considered as a forefront alternate fuel source in the nations having the potential of biomass sources (Agarwal, 2007; Demirbas, 2008; Salvi et al., 2013; Li et al., 2015).

Among many available alternative energy sources, biodiesels are considered as viable and feasible alternative in recent times. These sources are renewable, biodegradable and eco-friendly in nature which could produce any kind of edible and non-edible vegetable oil or animal fats. In addition, the non-edible biodiesels are also reduced the edible oil dependency and low cost due it's widely available form (Atabani and da Silva César, 2014). *Calophyllum inophyllum* is one of the non-edible vegetable oil, which is gaining more attention in recent times due to their availability in countries like India, Australia and East Asia in the past few years. Many techniques have been used for the direct utilization of *Calophyllum inophyllum* vegetable oil in diesel engines such as dilution, pyrolysis, and micro-emulsion by the researchers and scientists around the globe. Even then, these techniques are more effective for the partial replacement of diesel for short-term application due to its higher viscosity and poor auto-ignition quality. Further, the free fatty acid (FFA) content of *Calophyllum inophyllum* vegetable oil can cause many operational issues in a diesel engine. Transesterification is the most commercial and feasible technique for the effective reduction of *Calophyllum inophyllum* vegetable oil viscosity and this method being used everywhere in the world. The resultant product obtained from transesterification of *Calophyllum inophyllum* vegetable oil is commonly known is *Calophyllum inophyllum* methyl ester (CIME) (Nanthagopal et al., 2017). Many literature studies of *Calophyllum inophyllum* biodiesel applications in diesel engine revealed that the diesel engine operation with biodiesel produced low power output and torque due to its lower calorific value. In addition, the biodiesel usage in diesel engine has limited by higher NOx emissions, cold flow issues, and high viscous nature. All these issues play a dominant role in direct application of *Calophyllum inophyllum* biodiesel in a diesel engine as sole fuel. The drawbacks of the biodiesel usage have to be eliminated by improving its fuel property through the proper blending of biodiesel with diesel, alcohols, etc. Blending of *Calophyllum inophyllum* methyl ester with diesel, alcohols and other biodiesel shows a significant enhancement in the fuel properties (Imdadul et al., 2016; Atmanli, 2016a). In recent years, the research works has been focused on the higher alcohols such as butanol, pentanol, hexanol, octanol, etc to be blended with the biodiesels to obtain the better performance and emission characteristics. Several research reports indicated that higher alcohol could be produced through non fermentative production process. However, Atsumi et al. (2008) suggested that higher carbon alcohols can be synthesized using *Escherichia coli* which are renewable in nature. In addition, higher alcohols could be intermediate product during fermentation of lower alcohols. This literature survey revealed the possibility of producing higher alcohol from various sources in near future.

Atmanli (2016b) has shown that the higher alcohols having longer carbon chain in its structure are beneficial over lower alcohols due to its characteristic features such as higher cetane number, calorific value, density, flame speed, lower latent heat evaporation, viscosity and superior blend stability because of its hydrophobic nature. In present research work, two renewable higher alcohols such as n-pentanol and n-octanol are blended with biodiesel. n-pentanol has five straight carbon chain in its arrangements and it is obtained through fermentation and biosynthesis of various sources of biomass such as cornstalks, rice-straw, sugarcane and wood pulp (Dhanasekaran et al., 2017; Kumar and Saravanan, 2016). The properties of n-pentanol such as higher cetane number, energy density, lesser hygroscopic and better blend stability when compared to the butanol isomers make it suitable for diesel engines (Ma et al., 2017). In recent years, n-pentanol has been considered as an alternate fuel to CI engine and it was providing a notable performance when blended with diesel fuel as shown by various research groups (Saravanan, 2015; Kumar et al., 2016a,b; Campos-Fernandez et al., 2013; Zhang et al., 2016a,b). However, there were few works investigated on the performance and emission characteristics of n-pentanol blended with various biodiesel.

Zhu et al. (2016) analyzed the performance, combustion and emission aspects of CI engine fuelled with n-pentanol and waste cooking oil biodiesel blend at the ratio of 10%, 20% and 30% in volume basis. The experimental result shows that the BTE is higher with reduced BSFC was resulted for all the alcohol blends as compared to the pure diesel and biodiesel due to the faster combustion rate. Also, the particulate matter of the n-pentanol shows lesser count due to the higher oxygen concentration and the ignition delay period in the fuel blend. Dhanasekaran et al. (2017) tested the CI engine fuelled with ternary blends consists of diesel, waste cooking oil (WCO) and n-pentanol at different ratios in volume basis. Three blends are prepared such as D50-WCO45-P5, D50-WCO40-P10 and D50-WCO30-P20 and the test was further extended by the presence of EGR at different rates. The prepared ternary blends exhibit a stable solution without phase separation for almost two months with improved viscosity and density. BTE for the 20% blend of n-pentanol without EGR is comparable to the diesel fuel due to the presence of higher oxygen content results in improved combustion efficiency. However, the increase in the n-pentanol content leads to promote NOx formation and this condition is addressed by the presence of EGR. Babu and Anand (2017) utilized the ternary blend of diesel, waste sunflower biodiesel and n-pentanol with variation of alcohol at 5% and 10% by volume. The obtained results in a constant speed diesel engine were compared with base diesel, pure biodiesel and n-hexanol blends with the same ratio. The fuel properties are enhanced by the addition of both the higher alcohols. Addition of n-pentanol with the biodiesel improves the BTE and BSFC values as compared to pure biodiesel. The result concludes that both higher alcohols have better performance, emissions and combustion aspects which are well ahead of the pure biodiesel. Atmanli (2016b) evaluated the performance and emission characteristics of the CI engine fuelled with blends of waste oil biodiesel (40%), diesel (40%) and 1-pentanol (20%). The results are compared with the similar blend