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An assessment on the effects of 1-pentanol and 1-butanol as additives with Calophyllum Inophyllum biodiesel

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ABSTRACT

The aim of the present study is to investigate the effect of higher alcohols with Calophyllum Inophyllum biodiesel on the diesel engine characteristics under various engine loads. Two higher alcohols have been identified for the present investigation namely 1-pentanol and 1-butanol and the six fuel samples have been prepared with Calophyllum Inophyllum biodiesel at 40%, 50% and 60% concentrations by volume. All the experiments are carried out in a single cylinder, four stroke and constant speed diesel engine and the experimental results are compared with conventional diesel and pure biodiesel fuels. The study revealed that the diesel engine operation with higher alcohol-biodiesel blends has shown lower brake thermal efficiency and higher brake specific fuel consumption. The reduction rate is higher with a higher concentration of alcohol in the fuel blends. On the other hand, the cooling effect of higher alcohol in the blend reduces the NOx emission due to their higher latent heat of vaporization. Moreover, the CO, HC and smoke emissions are decreased for all higher alcohol-biodiesel blends. The combustion characteristics are followed similar pattern for all tested fuels and peak pressure is comparatively lower for higher concentration of alcohol in the fuel blend. Finally, it is revealed that 1-pentanol and 1-butanol can be successfully used as partial substitute to diesel or biodiesel fuel.

1. Introduction

Diesel engines have become the most common power source in both rural and urban territories, largely owing to their good conversion efficiency, high brake power, high torque, low fuel utilization and low maintenance cost [1]. The rapid depletion of fossil fuel reserves around the globe and the environmental hazards posed by diesel engines have driven researchers to focus on more affordable, safe and cleaner sources of energy that can effectively substitute diesel without compromising on the performance of the diesel engine [2]. A variety of alternative fuels are available for diesel engines, out of which, biofuels have received more attention in the recent years. The usage of these biofuels can address the energy crisis and significantly ease the detrimental effects of fossil fuel combustion on the environment and reduce the dependency on non-renewable sources of energy [3,4]. In recent times many research activities have been carried out for the partial or complete replacement of the diesel fuel with biodiesel under various operating conditions in diesel engines [5]. Among many available feedstocks for biodiesel production, non-edible vegetable oils are gaining greater attention around the world due to their eco-friendly nature, survival potency under any adverse climate conditions and more importantly its economic prices [6].

Calophyllum Inophyllum vegetable oil is one of the easily and widely available feedstock, which can be derived from the seed of an ornamental tree and that is spread in the countries like India, Japan, China and Africa. Transesterification is the best and feasible technique for the biodiesel production from raw vegetable oil using various catalysts in order to reduce the high free fatty acid (FFA) content. The resultant product of Calophyllum Inophyllum oil is commonly known as Calophyllum Inophyllum methyl ester and it's properties easily meets the United States (ASTM D 6751) and European Union (EN14214) biodiesel standards [7]. As per the International Energy Agency report, the production cost of biodiesel is around US$0.5 per litre, which is 1.5–3 times higher than conventional fossil fuels in many of the

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; CB100, 100% Biodiesel (Calophyllum Inophyllum); 1P40-CB60, 40% 1-pentanol + 60% Biodiesel; 1P50-CB50, 50% 1-pentanol + 50% Biodiesel; 1P60-CB40, 60% 1-pentanol + 40% Biodiesel; 1B40-CB60, 40% 1-butanol + 60% Biodiesel; 1B50-CB50, 50% 1-butanol + 50% Biodiesel; 1B60-CB40, 60% 1-butanol + 40% Biodiesel; HC, Hydrocarbons; NOx, Oxides of nitrogen; ppm, Parts per million

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developed countries. Therefore, more systemic efforts and developments should be take place so that the biodiesel availability will be economically viable and feasible around the globe [8]. Atabani et al. [9] have critically reviewed the main advantages and drawbacks of Calophyllum Inophyllum oil compared to other feedstock and they pointed out that Calophyllum Inophyllum has higher yield content, more heating value and better lubricity property. The study was also revealed that Calophyllum Inophyllum methyl ester can be used as fuel either in neat or solution mode in diesel engines due to the effective reductions of exhaust emissions except for NOx emissions. Moreover, the effective use of any biodiesel for diesel engine applications is limited by their cold flow property and high viscosity. Some important properties of biodiesel such as cloud point and pour point, cold filter plugging point would cause the biodiesel solidification, which resulted in blockage of fuel in filters, fuel starvation and operability issues. Moreover, the high viscosity of biodiesel leads to poor atomization and deposit formations [10]. The above mentioned problems along with simultaneous reductions of NOx and soot emissions for biodiesel fuels are achieved by many techniques like low-temperature combustion (LTC), exhaust gas recirculation and retardation of injection timing etc. More importantly, the addition of fuel having low cetane number and higher volatility with biodiesel is the viable alternative technique to achieve this low-temperature combustion without any major modifications [11]. In this regard, alcohols are considered as a viable candidate due to their faster evaporation and inherent oxygen content. Furthermore, alcohol does not provide any kind of penalties in a diesel engine, because of their higher latent heat of vaporization and low energy content [12].

Among all the available alcohols, higher alcohols (high carbon content) are getting much more attention in recent times compared to lower alcohols like methanol and ethanol because of their higher cetane number, heating value, the lower oxygen-carrying capacity and their easily blending ability with diesel or biodiesel [13]. Furthermore, higher alcohols have better combustion characteristics, lower evaporative emissions and they do not deposit any carbon in the engine, resulting in a better life of the engine components. It is to be noted that the concentration of carbon increase in the alcohol leads to increase the cetane number, calorific value and reduce the oxygen content. This higher cetane number of higher alcohols decreases the ignition delay period and reduce the heat loss through the combustion chamber [14]. Fewer research works have been carried out in recent times with various types of higher alcohols in diesel engine under different proportions. The present study aims at utilizing the 1-butanol and 1-pentanol as a partial substitute to biodiesel in the existing compression ignition (CI) engine. Interestingly, 1-butanol is a four straight carbon chain structure higher alcohol and it offers many benefits as automotive fuel additive such as higher calorific value, cetane number, flash point, better lubricating properties and lower volatility, less corrosive nature as compared to other lower alcohols [15]. Moreover, the low polarity and hygroscopic nature produce better solvency and stability while adding with diesel or biodiesel fuels. In addition, the low hygroscopic nature of 1-butanol provides less corrosiveness in the fuel delivery system than that of other higher alcohols [16,17]. All these positive factors lead to focus on butanol and its isomers as automotive fuel in the recent years. Further, 1-pentanol has longer carbon chains, which consumes lower energy during production process when compared to other higher alcohols. It also offers many significant benefits like low hygroscopic nature and better blend stability and higher calorific value [18,19]. It was also revealed that the blending of 1-pentanol with diesel or biodiesel has resulted in improved fuel atomization spray characteristics [20]. Recently, Campos et al. [13] pointed out that these kinds of higher alcohols can be produced through a fermentation process from many renewable sources in an effective manner.

2. Background of the research work

Very few studies have been reported in recent times around the globe with 1-butanol and 1-pentanol as a substitute for diesel under various concentrations. Tuccar et al. [21] evaluated the effect of the addition of butanol to microalgae biodiesel and diesel as a ternary fuel blend by varying the concentration of diesel and butanol. These blends were also found to have properties that allowed them to use in conventional CI engines without major modifications. They concluded that there was a slight decrease in the power and torque output of the engine when butanol is added to the ternary blends due to reduced energy content. However, the emissions such as CO, NOx emission and smoke opacity values are reduced with the addition of butanol. Yilmaz et al. [22] examined the effect of butanol addition with biodiesel as a binary blend in the ratio of 5%, 10% and 20% on volume basis. It has been reported that the addition of butanol with biodiesel has produced higher BSFC compared to pure diesel and biodiesel due to the reduction in heating value of the blend. The addition of butanol with biodiesel also reduces the NOx emissions and the reduction rate is increased with a higher fraction of butanol in the blend.

Altun et al. [23] carried out an experimental campaign for 10% and 20% (by volume) butanol addition with 20% biodiesel (20% biodiesel and 80% diesel in volume) as fuel and the results have been compared with conventional diesel and biodiesel. It was noted that the BSFC and BTE were found to be slightly higher for the addition of butanol with 20% biodiesel-diesel blend. In addition, significant reductions have been observed in CO, HC emissions except for NOx emission. Yoshimoto et al. [24] studied the impact of the 1-butanol addition of 40% by volume with palm oil biodiesel. The drawback of the high pour point of the palm biodiesel has been overcome by the addition of 1-butanol. The addition of 1-butanol to the palm oil alters the thermal efficiency and smoke emissions little bit as compared to the base fuel. However, the HC and CO emissions are higher for the 1-butanol blends at lower engine loading condition. In another study, Nabi et al. [25] have investigated the effect of n-butanol with diesel fuel on six cylinders turbocharged common rail diesel engine characteristics under 13-mode European stationary cycle. It was pointed out that the NOx emission was significantly higher along with 70% reductions of PM emission during butanol addition with palm biodiesel.

In a similar way, few researchers have examined the influence of 1-pentanol with diesel or biodiesel as a substitute for diesel engine applications. Li et al. [26] evaluated the effect of neat pentanol as regular fuel in a single cylinder diesel engine and the results showed that there was a reduction in fuel consumption with improved brake thermal efficiency compared to neat diesel fuel. This is due to the superior knock resistance behavior with stable combustion during premixed combustion phase. The fuel spray behavior of n-pentanol was evaluated by Dhanasekaran et al. [27].The presence of excess oxygen content in n-pentanol has shown better combustion efficiency and thereby lower smoke and carbon monoxide emissions. In a study, n-pentanol was used as an additive for ternary blend preparation and has shown improved performance [28]. Ileri [29] studied the additional impact of cetane improver with the ternary blend of diesel (70%), biodiesel (20%) and 1-pentanol (10%) by volume. The addition of cetane improver provides a positive effect on the fuel properties and improves the brake thermal efficiency significantly. The NOx emissions are decreased due to the reduction of ignition delay period for cetane enhancer addition. Yilmaz et al. [30] studied the impact of 1-pentanol as a fuel additive with waste cooking oil methyl ester on a volume basis and the results are compared with diesel blends. The concentration of 1-pentanol is varied by 10% and 20% with biodiesel and the properties of the blends are in test standard limits. Higher oxygen content in the 1-pentanol leads to increase the brake thermal efficiency of the biodiesel blends and the results are reversed for the addition with diesel due to the reduction in calorific value. Yilmaz and Atmanli [31] extended the similar work with waste cooking oil, biodiesel, 1-pentanol, and diesel as a ternary