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Effects of minor addition of aliphatic (1-pentanol) and aromatic (benzyl alcohol) alcohols in Simarouba Glauca-diesel blend fuelled CI engine

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ABSTRACT

The objective of the present study is to explore the effects of the minor addition of 1-pentanol and benzyl alcohol, classified respectively as aliphatic and aromatic type alcohols based on the classified hydroxyl group position in their molecular structure. Simarouba glauca and diesel blends (B20 and B40) were prepared and tested to study the CI engine performance, emission and combustion characteristics under different load conditions. To each of the four combination fuel samples prepared for B20 and B40, 1-pentanol and benzyl alcohol additives were added at 5% and 10% concentrations by volume. Experimental tests for all of the different fuels were performed in a single cylinder, four-stroke and constant speed CI engine and the engine characteristics were compared with diesel and biofuel blends. The experimental study reveals that the poor performance of B20 and B40 is enhanced with 1-pentanol (P) and benzyl alcohol (Bn) addition. The improvement in performance is considerable with an increase in the concentrations of alcohol in B20 and B40 blends. Higher HC, CO and smoke emissions associated with B20 and B40 blend fuels are reduced with alcohol addition. NOx emissions are also reduced with the addition of alcohol blends and 1-pentanol shows more promising results in terms of low NOx emissions compared to benzyl alcohol. Alcohol addition with B20 and B40 extended the ignition delay period due to low cetane number. However, combustion phasing is reduced as a result of improved combustion. The outcome of this research work is that poor combustion characteristics of the biofuel-diesel blend can be improved with the minor addition of aliphatic and aromatic alcohol. Except for comparatively higher NOx emissions, benzyl alcohol showed promising results in terms of performance parameters like efficiency, emission and combustion improvement.

1. Introduction

Diesel engine is a popular prime mover in transportation and agricultural sectors due to its high torque capacity, better fuel economy and low maintenance cost, compared to gasoline engine [1]. The rapid depletion of petroleum reserves, fluctuating price of crude oil, environmental concerns and target-based emission reduction to reach stringent EURO emission norms desired by various countries, all these factors demand an alternative, affordable and easily available source of fuel to replace diesel in a CI engine [2]. Among the various alternative fuels proposed for a diesel engine, biomass derived fuels (straight vegetable oil) have gained much attention particularly because they can be utilized directly without modifying the existing engine structure [3]. These fuels can address the energy crisis and also reduce the harmful effects to the environment. Additionally, they reduce the dependency on petroleum-based fuel. However, a single type of fuel cannot fully match the performance of a diesel engine and hence a number of new varieties of blended fuels were explored and their feasibility in the diesel engine was studied in a few review articles [4,5]. Straight vegetable oil possesses high viscosity and poor volatility which affect the fuel atomization process and subsequent fuel-air mixing. Therefore, direct use of vegetable oil in a CI engine leads to poor combustion along with long-term problems like piston ring sticking and injector clogging [6].

This study uses Simarouba glauca (paradise oil) seed oil as the straight vegetable oil. The plant grows widely across South America, Central America and India. Its seed contain 55–65% oil content. The oil has many industrial uses and it can also be turned into fat or margarine [7]. About 200 trees can be grown in one hectare of land which gives 6000 kg of seeds that provides around a ton of oil. It was introduced to

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Nomenclature

B20	Simarouba oil (20%) + Diesel (80%)
B40	Simarouba oil (40%) + Diesel (60%)
P	1-pentanol
Bn	Benzyl alcohol
TDC	Top dead centre
BP	Brake power
BTE	Brake thermal efficiency
BSEC	Brake specific energy consumption
CA	Crank angle
EGT	Exhaust gas temperature
NOx	Oxides of nitrogen
CO_2	Carbon dioxide
CO	Carbon monoxide
HC	Hydrocarbon

India in 1961, from El Salvador. It can adapt to diverse soil and climate conditions and it is also drought tolerant [8]. Its major fatty acid composition is 52–54% oleic acid, 27–33% stearic acid and 11–12% palmitic acid [9]. A few studies exist on the use of transesterified paradise oil as a fuel for diesel engines. Devan et al. [10] tested the biodiesel blends with diesel in a single cylinder CI engine. They pointed out that while the brake thermal efficiency of biodiesel and its blends with diesel is lower compared to diesel. They also observed that biodiesel reduced HC, CO and smoke emissions significantly with a penalty of higher NOx emission. To improve the performance of paradise oil, Devan et al. [11] blended eucalyptus oil in various proportions and tested it in a CI engine. They observed that low viscosity and better volatility of eucalyptus oil improved the performance of paradise oil biodiesel in the CI engine. This also reduced HC, CO and smoke emissions further. On the contrary, NOx emissions increased further due to improved combustion. Bedar et al. [12] tested Simarouba glauca biodiesel blends with diesel, with exhaust gas recirculation (EGR) to reduce NOx emissions. They observed that EGR did not affect the performance much and this combination aided in reduced particulate and NOx emissions.

1.1. Research justification

Numerous methods were proposed by Martin et al. [13] to improve the performance of a diesel engine using straight vegetable oil. Among them, blending with diesel and oxygenate, namely alcohol addition to form a ternary blend is selected and explored in this study. Among the various alcohols, higher order alcohols (based on carbon content) are gaining much attention due to their higher cetane number and calorific value compared to lower order alcohols like methanol and ethanol for CI engines. Another major classification of alcohol is based on the position of the OH (hydroxyl) group in their molecular structure, namely aliphatic and aromatic. In aliphatic alcohol, OH group is bonded to saturated carbon atom and generally, its structure is a straight chain. Aromatic alcohol, on the other hand, has the OH group bonded to aromatic benzene ring (aromatic carbon atom).

Aliphatic alcohol, namely 1-pentanol is taken for this study; 1-pentanol has five carbon atoms and is classified as a higher order alcohol. 1-Pentanol requires less energy input for production compared to other higher alcohols [14]. The improved blend stability with higher calorific value and cetane number of 1-pentanol extends its application as fuel [15]. While the current method of production is from fossil fuel, researchers are working on the production of 1-pentanol from fermentation process to achieve yet another renewable fuel [16]. Investigation/Analysis of 1-pentanol as fuel with diesel, biodiesel and its blends in CI engine has been undertaken by various researchers [17–23].

Yilmaz and Atmanli [17] blended 1-pentanol with diesel at various blend ratios to determine the engine characteristics at different load conditions. 1-Pentanol was added 5, 10, 20, 25 and 35% by volume with diesel and all the blends were tested in the CI engine. They noted that low calorific value and cetane number of 1-pentanol reduced the brake thermal efficiency with higher fuel consumption. However, due to the high latent heat of vaporization, NOx emissions were reduced. They also observed that CO emissions were reduced with slightly higher HC emissions. It is noteworthy that the effect on performance and emission improved/reduced with an increase in 1-pentanol blends. Sivalakshmi and Balusamy [18] blended various alcohols including 1-pentanol with neem oil (straight vegetable oil) in a single cylinder CI engine at different load conditions. The alcohol proportions were 5%, 10%, 15% and 20% by volume for all the alcohol blends with neem oil. The blend ratio was limited to 20% to avoid knocking. They observed that brake thermal efficiency improved with increase in blend ratio of alcohols. With respect to emissions, NOx and smoke emissions were found to have reduced with neem oil and n-pentanol combination with marginal improvement in HC and CO emissions. Li et al. [19] compared the effect of n-pentanol addition with diesel and diesel-biodiesel combination on performance, emission and combustion characteristics in a single cylinder CI engine at different load conditions. They observed that addition of n-pentanol showed shorter combustion duration and higher heat release rate during the main combustion phase. Also, higher thermal efficiency with improved fuel economy was observed with n-pentanol addition in the blend. They observed that while HC and CO emissions were reduced at higher engine loads it was bound to be higher at lower engine loads. They noted that NOx emissions increased at higher loads and was lower compared to base fuels at lower load conditions. The authors stated that, with reference to NOx emissions, positive effects like high latent heat of vaporization and negative effects like low cetane number and presence of oxygen in n-pentanol counteracted each other and may be reason for variable NOx emissions at low and high load conditions.

In another research work, Atmanli [20] blended diesel and 1-pentanol with hazelnut oil and tested it in a CI engine at different load conditions. The blend ratio of 1-pentanol was limited to 10% by volume; they observed reduced cetane number for the blend. To improve the cetane number, 2-ethylhexyl nitrate (EHN) was added at 500, 1000 and 2000 ppm concentration with the blends which improved the cetane number by 4.65%, 12.69% and 21.09% respectively. The results showed that the blend of diesel-hazelnut oil-1-pentanol with EHN resulted in a significant reduction in fuel consumption and NOx emissions. Higher alcohol addition also improved the brake thermal efficiency, as reported in a few studies [21–23]. With reference to NOx emissions, few studies showed higher NOx emissions [19–21] while other studies showed reduced NOx emissions [17,18,22,23] with n-pentanol addition compared to base fuels. These studies showed that n-pentanol blend concentration and cetane number of the blend play a major role in NOx formation and hence the results are not consistent in all the studies. This is also evident from an earlier review article based on use of higher alcohol fuels [24].

Aromatic alcohol, namely benzyl alcohol is taken for the purpose of this study. Benzyl alcohol has seven carbon atoms and is hence classified as a higher order alcohol. Benzyl alcohol can be produced naturally from Lignin by hydrolysis method and is found in a variety of essential oils including jasmine and hyacinth [16]. It has higher calorific value and cetane number compared to 1-pentanol. The effect of benzyl alcohol in diesel engines has been studied by a few researchers [25,26].

Zhou et al. [25] investigated NOx-soot tradeoff and fuel efficiency of various aromatic oxygenates, namely anisole, benzyl alcohol and 2-phenyl ethanol blended with diesel in a heavy-duty engine. The blended oxygen concentration for all the three diesel blends was 2.59% by wt.