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Influences of ignition improver additive on ternary (diesel-biodiesel-higher alcohol) blends thermal stability and diesel engine performance

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ABSTRACT

Pentanol is a long chain alcohol produced from renewable sources and considered as a promising biofuel as a blending component with diesel or biodiesel blends. However, the lower cetane number of alcohols is a limitation, and it is important to increase the overall cetane number of biodiesel fuel blends for efficient combustion and lower emission. In this consideration, ignition improver additive 2-ethylhexyl nitrate (EHN) were used at a proportion of 1000 and 2000 ppm to diesel-biodiesel-pentanol blends. Experiments were conducted in a single cylinder; water-cooled DI diesel engine operated at full throttle and varying speed condition. The thermal stability of the modified ternary fuel blends was evaluated through thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC) analysis, and the physic-chemical properties of the fuel as well as engine characteristics were studied and compared. The addition of EHN to ternary fuel blends enhanced the cetane number significantly without any significant adverse effect on the other properties. TGA and DSC analysis reported about the improvement of thermal characteristics of the modified blends. It was found that, implementing ignition improver make the diesel-biodiesel-alcohol blends more thermally stable. Also, the brake specific fuel consumption (BSFC), nitric oxides (NO) and smoke emission reduced remarkably with the addition of EHN. Introducing EHN to diesel-biodiesel-alcohol blends increased the cetane number, shorten the ignition delay by increasing the diffusion rate and improve combustion. Hence, the NO and BSFC reduced while, carbon monoxide (CO) and hydrocarbon (HC) emissions increased slightly.

1. Introduction

The essentiality of renewable alternative fuel in transportation, industry, power and agriculture is dependably in expanding pattern because of the consumption of petroleum reserves throughout the world. Numerous countries have taken action while avoiding by several other countries remarkably contributing to the climate change that must be under better control [1]. Environmental Protection Agency (EPA) directive in the USA and Euro VI standards in Europe have set the new emission regulations which will be acknowledged by 2017 and NO, CO and PM exhausts ought to be lessened by 25%, 24% and 10% individually by 2030 [2,3]. As a renewable source, biodiesel offers an excellent solution for the above-stated problems because of its comparable properties to the conventional diesel. However, at present, many research works have been performed on this territory concentrate on enhancing efficiencies and reducing emission levels of biodiesel blends. In the advanced study, the addition of additives to the biodiesel blends has been considered as a positive way. Alcohols are preferable as a blending component or additive to diesel-biodiesel blends as they are renewable in nature [3–5]. Much research work has been done using short chain ethanol and methanol alcohol as alternative fuels in diesel engine [6,7]. However, due to having few disadvantages like weak lubrication property, low cetane numbers, and calorific values, phase separation issues intercepted them to be utilized directly in diesel engines [8]. However, recently long chain or higher alcohols like n-butanol, pentanol are receiving increasing attention to be used as a diesel engine fuel by numerous researchers [4,9,10].

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Nomenclature

BP	brake power
BSFC	brake specific fuel consumption
BTE	brake thermal efficiency
CO	carbon monoxide
CO_2	carbon dioxide
DTBP	di-tertiary butyl peroxide
DSC	differential scanning calorimetry
DTG	derivative thermogravimetric
EHN	ethyl hexyl nitrate
FAC	fatty acid composition
GC	gas chromatograph
LHV	lower heating value
NO	nitric oxide
PM	particulate matter
PB20P5	palm biodiesel (20%) + diesel (75%) + pentanol (5%)
PB20P5E1	palm biodiesel (20%) + diesel (75%) + pentanol (5%) + 1000 ppm EHN
PB20P5E2	palm biodiesel (20%) + diesel (75%) + pentanol (5%) + 2000 ppm EHN
PB10P10	palm biodiesel (10%) + diesel (80%) + pentanol (10%)
PB10P10E1	palm biodiesel (10%) + diesel (80%) + pentanol (10%) + 1000 ppm EHN
PB10P10E2	palm biodiesel (10%) + diesel (80%) + pentanol (10%) + 2000 ppm EHN
TGA	thermogravimetric analysis
TG	thermogravimetric

Among the long chain alcohols, pentanol is one of the promising one with five carbon in its atomic structure having better fuel properties than ethanol, methanol, and even butanol. Due to its low polarity and being hydrophobic, no phase separation happened, low polar interaction parameter (δpnP: 2.2), well miscible with diesel and vegetable oils which make pentanol more reliable [3,4]. Pentanol is also an excellent renewable alternative produced from renewable sources. It has long been known to the food industry as one of many flavor compounds produced during fermentation. Pentanol being a longer-chain alcohol requires lesser energy for its production compared to other alcohols [11]. The *n*-pentanol or 1-pentanol can be produced from acidic fermentation of lignocellulose that produces valeric acid, and then by hydrogenation. The isopentanols are obtained substantially from fuel oils that are a co-product of alcoholic fermentation. It can be produced from biological pathways like natural microbial fermentation using engineered microorganisms [12] and biosynthesis from glucose using *Escherichia coli* [13]. However, its production cost is high, and research has been going on to reduce the cost as well as its commercial utilizations all over the world [12].

Long chain alcohols, when mixed with the diesel or biodiesel blends improved the fuel properties like density, viscosity, flash point, boiling point leads to better atomization of fuel, but the cetane number and the calorific values are getting lower [4,14]. Imdadul et al. [4] concluded that, the density and viscosity of pentanol treated biodiesel blends were improved along with the higher calorific value and cetane number than that of lower carbon alcohol. However, they are not sufficient to reduce the NO and CO_2 emission due to increasing the proportion of oxygen. Also, lower cetane number, calorific value with delayed combustion caused high flame temperature and expanded NO emission [15]. It was reported that CO, HC, and smoke of the tested blends have attained a remarkable decrement than that of diesel-biodiesel blends. Campos-Fernández et al. [11] reported that pentanol-blended fuel shows the improved brake thermal efficiency (BTE), comparable power and torque and better BSFC compared to the diesel fuel [16]. Wei et al. [17] observed that mixing 30% *n*-pentanol with diesel fuel increases the HC and CO emissions at low load condition. However, HC and CO emissions decreased as the load increased [18] and slightly higher NO_X was observed with the significant increase in NO_2. Because of having shorter hydrocarbon chain length of alcohols, they endure lower cetane number and requires some ignition-influencing agent while utilizing them as a part of a diesel engine. Production of NO_X mainly happened at premixed combustion phase and it related to the in-cylinder temperature. Because, in-cylinder temperature increases the premixed combustion due to high combustion rate [19,20]. The increment in the cetane number reduces the ignition delay and premixed combustion resulted in improve the combustion and decrease the NO_X [21–23]. Both lower and higher carbon alcohols have lower cetane number than diesel and biodiesel fuel. Therefore, ignition improvers may be the solution for assisting the combustion of higher alcohol treated ternary blends to found the better stability of the engine, efficient burning of fuel and low exhaust, which has never been done previously by any other researcher [24–26]. However few studies like Atmanli et al. [3] added a different proportion of EHN alcohol (n-butanol and pentanol) treated biodiesel blends and reported that the addition of EHN showed 13.12% and 12.26% higher cetane number respectively without any significant negative impact on fuel property. Also, the BSFC and NO_X emission from the engine decreased. Li et al. [21] used 3000 ppm concentration of EHN with diesel-biodiesel blends contained 10% methanol and observed that it improves the cetane number and reduce the NO_X emissions while increased the HC and CO emissions. Suppes et al. [27] used 1000 ppm of EHN in B20 biodiesel blends and reported that the EHN reduced the ignition delay by enhancing the cetane number that leads to decrease NO_X about 4.5%. They reported that the improvement of engine characteristics using EHN in the blends attributed to the higher cetane number, calorific value, lower density and viscosity of the modified fuel blends.

Moreover, thermal properties of biodiesel and their blends are also is an important issue. Numerous studies have reported about biodiesel thermal properties through thermogravimetric and differential scanning calorimetry. Jain et al. [28] conducted research to measure the thermal degradation of various antioxidant treated biodiesel blends to find the best blends that improved using higher alcohols. Vega-Lizama et al. [29] measured the amount of thermal degradation of soy biodiesel using the residual mass obtained from the decomposition curve and reported that TGA is an optimistic way to measure the oxidation degree of biodiesel without knowing the biodiesel oxidation process. However, higher alcohol treated biodiesel-diesel blends are considered as good thermal and cold flow properties. Hence, the thermal properties of higher alcohol-biodiesel blends and the EHN treated blends need to be evaluated.

Using higher alcohols in CI engines has picked up lots of consideration recently. It was reported that the fuel properties of higher alcohols treated blends need some improvement by treating them with ignition improver to enhance the cetane number [4,30–32]. There is a few/no extensive work has been done using EHN with longer chain alcohols-diesel-biodiesel ternary blend fuels to improve the blends thermal properties and other engine characteristics. In the present investigation, 5% and 10% pentanol has been used with 20% and 10% of palm biodiesel-diesel blend. Afterward, the ignition improver additives 2-ethylhexyl nitrate (EHN) at a