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Higher alcohol–biodiesel–diesel blends: An approach for improving the performance, emission, and combustion of a light-duty diesel engine

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ABSTRACT

Pentanol is a long-chain alcohol with five carbons in its molecular structure and is produced from renewable feedstock, which may help to improve the challenging problems of energy security and environmental issues. In this investigation, the performance, emission, and combustion characteristics of a single-cylinder, four-stroke, water-cooled, direct-injection diesel engine were evaluated by using 10%, 15%, and 20% pentanol and *Calophyllum inophyllum* (CI) biodiesel blends in diesel under different speed conditions. The fuel properties of the blended fuels were measured and compared. Combustion attributes, such as cylinder pressure and heat-release rate, were also analyzed. Results indicated that increasing the proportion of pentanol in biodiesel blends improved the fuel properties compared with 20% blend of CI biodiesel (CI 20). The modified blends of pentanol showed reduced brake-specific fuel consumption with higher brake thermal efficiency and brake power than CI 20. Although the modified test blends showed a slightly higher nitric oxide emission, the carbon monoxide emission and unburned hydrocarbon emission for 15% and 20% blends of pentanol showed even better reduction than CI 20. Smoke emission was also reduced significantly. The carbon dioxide emission of the test blends were reduced at the maximum speed condition compared to CI 20. In terms of combustion, the modified test fuels exhibited a significant improvement, thus indicating better performance and emission. This study concluded that the 15% and 20% blends of biodiesel, diesel, and pentanol can optimize engine performance and emission without any engine modification.

1. Introduction

Rigorous emission regulations and concerns over energy security have recently increased research interest on alternative renewable fuels [1]. The present energy demand of the world mainly depends on petroleum-based fuels. Approximately 26–27% of the energy consumption is fulfilled by petroleum-derived fossil fuels in the transportation sector; this type of fuel should be replaced by biofuels within 2050 [2]. The utilization of biofuels is projected to increase from 1.3 million barrels of oil equivalent per day in 2012 to 4.6 million barrels of oil equivalent per day in 2040, and their share will be approximately 8% of road-transport fuel demand [3]. Biofuels, such as biodiesel and alcohol-based ethanol, methanol, butanol, and pentanol from renewable sources, are attractive alternative solutions to meet the energy demand and to regulate emissions [4]. Owing to its renewability, biodegradability, and superior fuel properties to diesel, biodiesel is currently considered a future alternative for diesel fuel [5,6]. Interests are growing on how to improve fuel properties and to overcome the problems. Although the utilization of alcohols enriched with oxygen content improves both the premixed and diffusive burning stages, their low Calorific Value (CV), low Cetane Numbers (CNs), miscibility and stability issues, weak auto ignition quality, and improper lubricating behavior limit their use as a pure diesel engine fuel [7].

1.1. Objectives of the study

This experimental investigation analyzed the feasibility of pen tanol–biodiesel–diesel blends as a substitute for petro diesel for single-cylinder diesel engines. The influences of adding pentanol on the basic fuel properties of *Calophyllum inophyllum* (CI)

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Nomenclature

ATDC	After Top Dead Center
BTDC	Before Top Dead Center
BP	Brake Power
BSFC	Brake Specific Fuel Consumption
BTE	Brake Thermal Efficiency
CA	Crank Angle
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CI biodiesel	Calophyllum-Inophyllum biodiesel
CI	Compression ignition
CI 100	Neat Calophyllum-Inophyllum biodiesel
CI 20	Calophyllum-Inophyllum (20%)
C10P10	Calophyllum-Inophyllum (10%) + Pentanol (10%)
C15P15	Calophyllum-Inophyllum (15%) + Pentanol (15%)
C20P20	Calophyllum-Inophyllum (20%) + Pentanol (20%)
CV	Calorific Value
CN	Cetane Number
DC	Diffusion Combustion
FAC	Fatty Acid Composition
GC	Gas Chromatograph
HCCI	Homogeneous Charge Compression Ignition
HRR	Heat Release Rate
ID	Ignition Delay
IMEP	Indicated mean effective pressure
ISFC	Indicated Specific Fuel Consumption
LHV	lower heating value
NO	Nitric Oxide
NO_2	nitrogen dioxide
NO_X	oxides of nitrogen
OC	organic carbon
PM	particulate matter
PC	Premixed Combustion
SOI	Start of Injection
SOC	Start of Combustion
ULSD	ultra low sulfur diesel

biodiesel were examined and compared with the standards specified by ASTM D6751 and EN 14214. The effects of high alcohol as biodiesel blend additives on the engine performance, emission, and combustion characteristics of diesel engine were also analyzed and compared with those of 20% blend of CI biodiesel (CI 20) and diesel.

1.2. Literature survey

The implementation of alcohol as additives to biodiesel blends is an optimistic process to improve the utilization of both biodiesel and alcohol [8]. However, a previous study indicated that low-carbon alcohols, such as ethanol and methanol, as diesel fuel additives or diesel–biodiesel blend additives in diesel engines are mainly limited by their low CV, low cetane index, poor blending solubility and miscibility, and long ignition delay [9]. By contrast, high alcohols can restrain the problems of low alcohols. Alcohols with a high-carbon structure, such as butanol (four carbons) and pentanol (five carbons), have high CV, high CN, better miscibility, and can be used as fuel additives to improve the low-temperature fluidity of biodiesel [1,9,10]. The aforementioned alcohols are generally made from coal-derived syngas, which are a renewable source [7]. The concept of a biorefinery for high-alcohol manufacturing combines the ethanol structure via aging with the exchange of an ordinary alcohol medium into high-carbon alcohols [11]. The large-scale manufacturing of n-pentanol is examined. For example, the biosynthesis of pentanol from glucose or glycerol is accomplished by utilizing the metabolic design of novel biocatalysts [12–14].

Many investigations have been performed by using n-butanol as high alcohols in biodiesel blends and have reported that introducing n-butanol to the blends increases nitrogen oxide (NO and NO_2) formations and drastically decreases the formation of Carbon Monoxide (CO) and hydrocarbon (HC) emissions [15]. The particulate mass and element carbon concentrations, total number of particles, total particle-phase polycyclic aromatic HC emission, carcinogenic potential, and cytotoxicity of particle extracts decrease by adding butanol compared with adding 20% blends of biodiesel. The proportion of organic carbon in the particles increases with increasing butanol in the ternary fuel [16]. Ten percent of butanol is more beneficial to lessen the soot emission than 5% of blended fuels [17]. Imtenan et al. [18] studied the emission behavior of a diesel engine by using 5–10% of n-butanol in diesel–jatropha blends and reported that the HC emission increased with n-butanol addition in the blends, whereas both the 5% and 10% of n-butanol-blended fuels showed reduced CO and smoke emission [19,20]. Rakopoulos [21] used 20% of n-butanol with cottonseed biodiesel blends and found that the NO_X, CO, and smoke emission of the blends decreased. Yilmaz et al. [22] concluded that, although butanol addition decrease NO_X, but as the butanol proportion in the blends increased, NO_X emission also increased. They also reported that, HC emission was higher for all the loads, but 20% butanol addition showed reduced HC emission. Imtenan et al. [23] reported that the use of 5% of n-butanol in palm biodiesel–diesel blends increased the Brake Power (BP) to 6% in contrast to using P20. Mixing n-butanol also decreases the brake-specific fuel consumption (BSFC), whereas the Brake Thermal Efficiency (BTE) increased in contrast to P20 [24]. Altun et al. [25] reported that the addition of n-butanol in cottonseed biodiesel blends reduced the emissions of NO_X, HC, and CO with high BSFC [22,26]. Zhang and Balasubramanian [16] investigated the performance and particulate emission of a diesel engine fueled by ultra-low sulfur diesel and palm biodiesel blends with the addition of butanol (5%, 10%, and 15% by volume) in a single-cylinder engine. The results showed a small change in BSFC with an improvement in the BTE at medium and high engine loads by using up to 10% butanol. Imdadul et al. [2] reviewed the effects of additives on the combustion in a CI diesel engine running on diesel–biodiesel blends. They reported that the increased proportion of n-butanol in biodiesel blends decreased the cylinder gas pressure (CGP) and peak pressure (PP), the heat-release rate (HRR) decreased at Premixed Combustion (PC), and increased in Diffusion Combustion (DC), and Ignition Delay (ID) increased with delayed Start of Combustion (SOC) [18,27]. The high latent heat of evaporation and low dynamic injection timing led to delayed SOC. More perfect fuel atomization and vaporization were found.

Pentanol is a long-chain alcohol with five carbons in its structure and has great potential as a blending component with diesel fuel owing to its high energy density, high CN, better blend stability, and less hygroscopic nature than other widely studied low alcohols, such as ethanol, methanol, and butanol [8]. The addition of pentanol in diesel–biodiesel blends diminishes the soot emissions. At low and medium loads, the emissions of NO_X are accordingly reduced. A diesel engine fueled with oxygenated fuel blends can reduce CO and unburned total HC emissions at a low engine