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The effects of using ethanol as additive on the combustion and emissions of a direct injection diesel engine fuelled with neat lemongrass oil-diesel fuel blend

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ABSTRACT

In this experimental work, ethanol was mixed with neat lemongrass oil (LGO) – diesel fuel blend and the effect of ethanol concentration on combustion, emission, and performance of direct injection diesel engine was investigated. Low concentrations of ethanol (2.5% and 5%) were studied in the blend of neat lemongrass oil-diesel blend. The test results obtained with these blends were compared with those obtained with diesel fuel. The tested blends yielded different performance, emission and combustion characteristics compared to diesel fuel. The ethanol blends resulted in a higher combustion pressure and heat release rate, brake specific fuel consumption and brake thermal efficiency than diesel and LGO25(75% neat diesel + 25% neat lemongrass oil) while they resulted in a higher NO_x emission, CO_2 emission and lower smoke, HC emissions. Further, it is observed that higher combustion duration and ignition delay period for LGO25-ethanol blends than neat diesel and LGO25 fuels.

1. Introduction

One of the main reasons for global warming is the exhaust emissions generated from the automotive vehicles. The reduction of CO_2 emissions makes the most vital contribution to global warming, and bioenergy based fuels can be blended with diesel fuel [1]. Alcohols have been widely used in diesel engines as alternative fuels. Primarily, in 1894, Germany and France were using ethanol in internal combustion engines. Ethanol is a promising alternative fuel which has high octane rating. It can be produced from renewable sources such as corn, starch, and sugar cane. The first experimental investigations on the use of ethanol in diesel engines were carried out in South Africa in the 1970s and continued in Germany and USA during the 1980s [2]. The significant advantage of ethanol is its high latent heat of vaporization which can be used to lower intake charge temperature resulting in a higher charge density and improvements in volumetric efficiency [3]. Further, ethanol has very poor ignition quality and lower cetane number and lower adiabatic flame temperature. It is an eco-friendly fuel as it is produced from the renewable sources like alcoholic fermentation of sugar from corn, sugar cane, sugar beets, barley, sweet sorghum, cassava, molasses and agricultural residues. There are some challenges in the use of alcohol fuels in compression ignition engines due to its low lubricity, the difficulty of vaporization and high auto-ignition temperature. These problems can be overcome through a mixture of alcohols with diesel fuel. However, the solubility of anhydrous ethanol at a lower temperature with diesel is limited [4]. Consequently, they require co-solvents or emulsifiers which, apart from increasing cost, complicate blending and splash heating [5,6]. Blends with 15% (by vol.) ethanol in diesel fuel are considered comparatively safe from the engine durability point of view [4].

On the other hand, liquid biofuels such as biodiesels (methyl or ethyl esters), methanol, butanol, pentanol, and ethers are considered as very promising biofuels for diesel engines. The primary advantages of biofuels are the lower or negligible sulfur and aromatic content, and the higher flash point and lubricity. The disadvantages of biofuels include the higher viscosity, pour point, and the lower cetane number, calorific value, and volatility. Like ethanol, butanol is a biomass-based renewable fuel that can be produced by alcoholic fermentation of the biomass feedstock used for ethanol production. Moreover, it has a straight chain structure with the hydroxyl group at the terminal carbon

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($CH_3CH_2CH_2CH_2OH$). Butanol has a lower hydrophilic tendency, higher heating value and cetane number, lower vapor pressure, higher viscosity and lubricity and perfect miscibility than ethanol [7,8]. DME (dimethyl ether), CH_3OCH_3) has considered as an ignition improving additive in diesel engines which lowers the smoke and NO_x emissions. However, the gaseous fuel DME, requires some engine fuel injection system modifications [9]. Thus, a more appropriate fuel (ether) may be diethyl ether (DEE). DEE an isomer of butanol, can be produced from ethanol. It has some advantages of blending with diesel fuel, including very high cetane number, higher oxygen content, low autoignition temperature and higher miscibility in diesel fuel [8]. DEE ($CH_3CH_2OCH_2CH_3$) can be produced from ethanol, which is produced from biomass [10]. DEE has some favorable features for blending with diesel fuel, including a very high cetane number, low viscosity, higher heat of vaporization, significant energy density, higher oxygen content, low autoignition temperature, extensive flammability limits, and high miscibility in diesel fuel. On the other hand, it has some disadvantages in the form of high volatility and anesthetic effects [8]. DEE is mainly used to improve fuel properties and combustion characteristics in diesel engines.

Ethanol is an alternative fuel due to its biological resource base and oxygenated fuel which reduces particulate emissions in diesel engines [11]. Some researchers have already investigated the combustion, spray, emission, and ignition delay and performance characteristics of diesel with diesel-ethanol and biodiesel-ethanol-diesel blends. Ethanol can be used as fuel in different ways, such as dual injection (separate injection systems for each fuel), ethanol fumigation (addition of alcohols to the intake air charge) [12–14] and ethanol as the main fuel component with modifications on the engine hardware in order to overcome the poor autoignition property of ethanol [15]. Lu et al. [16] used bioethanol in a direct injection diesel engine and found a reduction of NO_x emission but the increase in ignition delay. Guarieiro et al. [17] investigated with soybean oil, castor oil, soybean biodiesel and castor oil biodiesel with the addition of ethanol 7%–15% by volume. They observed improvement in combustion efficiency with complete combustion. Nadir Yilmaz et al. [18] conducted tests with biodiesel from waste cooking oil with ethanol concentrations of 5%–25%. The tested results indicated that emissions are strongly dependent on not only engine operating conditions but also fuel blends concentrations. Cooling effects and oxygen contents of alcohols were two of the most important factors observed from the experimental study. Overall, alcohol blended fuels increased CO emissions and ethanol blended fuels reduced NO emissions. Finally, they concluded that high concentrations of ethanol increased HC emissions. But at 50% load, ethanol decreased HC emissions for all concentrations. The decrease in HC emissions occurred for all concentration at over 70% load.

Murat et al. [1] used blends of methanol, ethanol, biodiesel and vegetable oil with diesel fuel in experiments and reported lower brake power, higher specific fuel consumption, and lower carbon monoxide emissions while operating on ethanol and methanol. Chang Sik Lee et al. [19] tested with biodiesel from soybean oil and bioethanol blended diesel. They observed that increasing biodiesel blending ratio resulted in reduced fuel density and cetane number of bioethanol blended diesel fuel while kinematic viscosity and surface tension increased. Also, they reported an increase in ignition delay and the premixed combustion phasing and decrease in IMEP. Ludivine Pidol et al. [15] studied the properties of ethanol blended fuels and evaluated their behavior in conventional diesel combustion and advanced combustion such as low-temperature combustion (LTC). They found that the addition of ethanol improved blend stability, the cetane number or the flash point and fuel formulation. Further, they reported a combined reduction of smoke levels and NO_x emissions with a significant penalty of fuel consumption and also improved maximum power output.

C.D.Rakopoulos et al. [4] have analyzed the combustion heat release of ethanol or n-butanol-diesel fuel blends in heavy duty, six cylinders, and turbocharged direct injection Mercedes-Benz engine. Their work showed very small displacement in fuel injection pressure diagrams; increase in ignition delay, reduction in maximum cylinder pressure and cylinder temperature during the first phase of combustion. Also, they reported a reduction of smoke opacity and NO_x with increasing percentage of biofuels in the blend. Gvidonas Labeckas et al. [2] found that the addition of ethanol to diesel fuel reduces the NO_x and HC emissions for richer combustible mixtures whereas the influence of a higher ethanol mass content on CO emissions and smoke opacity depends on the air-fuel ratio and engine speed. Can O. Celikten I [20] have conducted tests in a four-cylinder, turbocharged diesel engine with ethanol (10% & 15%)-diesel fuel blends and observed 12.5% and 20% decrease in the engine power. Other researchers conducted tests with ignition improver Hicet 3A (0.16- 2-ethylhexyl nitrate) [21] or cetane improver (0.2% iso-amyl nitrite) [22] in the blends of ethanol-diesel. Ethanol solubility in the diesel fuel depends on the temperature, water content, diesel fuel wax composition in the blend and ambient humidity. The addition of isobutanol [23] would improve miscibility. Further, to improve the blending of ethanol with diesel fuel of 0.5% emulsifier (styrene-butadiene copolymer) and a polyethylene oxide-poly-styrene copolymer) can also be used [12]. Several investigational results [10,24,25] showed that the use of ethanol and rapeseed oil blends increases the NO_x emission in which the combustion temperature plays a vital role. Srinivasa padala.et al. [26] conducted tests in a diesel engine via port injection and advancing injection timings (0, 3, 8 CA aTDC). They have recorded a 10% increase in efficiency with 60% ethanol energy fraction mainly due to the faster burning of the premixed ethanol-air-diesel mixture which increases the heat release rate. They also observed that an increase of HC, CO, and NO_x emissions was noted with increasing ethanol energy fraction.

Wojciech Tutak et al. [27] have used 85% of bioethanol by the port fuel injection technique in a three cylinder direction injection diesel engine. The test results showed a reduction in NO_x and soot emissions while CO and HC emissions increased significantly. Roberto Freitas Britto Jr.et al. [11] investigated dual fuel injection concept with the effect of different compression ratios (14:1, 16:1, and 17:1) and injection pressures (800–1400 bar). They tested the flow structure in the combustion chamber in both quiescent and high swirl modes. The test results showed a CR of 16:1 with an average of higher threshold substitution rate due to a lesser tendency for detonation while the compression ratio of 17:1 exhibited better efficiency on an average. Another finding was that the indicated efficiency with the use of diesel-ethanol was higher with the lower injector flow rate than higher flow injectors. A study was done by using an injection of the steam technique [28] with ethanol-diesel blend without any engine modifications. The steam injection method decreases NO_x emissions and improves the engine performance by using two-zone combustion model for 15% ethanol addition and 20% steam ratios at full load conditions. Dulari Hansdah et al. [29] used biodiesel produced by the fermentation of Madhuca indica flower with flow rates of 0.24, 0.48, 0.96 and 1.22 kg/hr in the suction by using a vaporizer and a microprocessor controlled injector. The bioethanol fumigation exhibited an overall ignition delay of 2–3 °CA, improved brake thermal efficiency, lower NO_x emission and higher CO and HC emissions for all the flow rates at full load. Teemu Sarjovaara et al. [30] focused on the effect of an E85 ethanol/gasoline blend in a heavy duty diesel engine equipped with a common-rail injection system. The test results clearly indicated an increase in CO and THC emissions and a decrease in NO_x