Effect of injection timing on alcohol-biodiesel-diesel ternary blends in a CI engine

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The major concerns of using Jojoba oil in CI engines is its high viscosity, low volatility, and high NOx formation. In this work, an analysis of the emission parameters and efficiency of a jojoba biodiesel-fuelled engine is carried out. This research study investigates the impacts of the addition of higher order alcohols with diesel fuel on the performance and emission parameters of CI engine working with diesel-jojoba oil methyl ester blend. 5% and 10% by volume of n-butanol is combined with B20 blend of jojoba oil methyl ester. The experiment is divided in two steps, firstly, the optimum combination of alcohol with biodiesel is evaluated based on the BTE and emission parameters. Secondly, the effect of varying the injection timing from 21º, 23º and 25º BTDC for the alcohol blends of diesel-biodiesel blends are studied. BTE increases by 4.5% for B20+10% butanol and NO emission decreases by 23%. Other emissions are facing a significant drop except HC emissions. Delayed injection timing of 21º BTDC reduces NO emission further by 18.4%. The findings prove that adding n-butanol, oxygenated fuel could enhance the viscosity issue of jojoba oil methyl ester and the mixtures as well resulting in an enhancement in their performance parameters.

Keywords: alcohol, biodiesel, CI engine, emissions

1. Introduction

Energy is an important aspect that is needed to improvise the economy of our country. The effective usage of available energy sources decides the human survival. Fossil fuels being a major source for energy production and consumption, they are limited [1,2]. Transportation and agricultural sectors are energized by IC engines driven with fossil based fuels. The emissions and effective fuel utilization in the CI engine is a big challenge. Researchers are working to minimize the gaseous emissions and improve the combustion characteristics of CI engine [3]. Yesilyurt at al [4] blended heptanol with peanut biodiesel at 20% volume concentration. These improved the fuel properties and in turn the engine combustion characteristics. CO₂ and NOx emissions increased, whereas HC and CO emissions were reduced to minimum values. Atmanli et al [5] compared the effect of blending higher order
alcohols like propanol, butanol and pentanol to waste cooking oil biodiesel. All these alcohols reduced NOx emissions to a reasonable extent. This mode of low temperature combustion is beneficial from fuel consumption point of view. Saravanan et al [6] collectively varied parameters like piston geometry, fumigating alcohol and EGR addition in a CI engine run with jatropha biodiesel. Variation in the above factors has resulted in lesser NOx emissions of 359 ppm and 74.8% smoke opacity. Datta et al [7] tried methanol and ethanol blends to biodiesel and noticed a marginal increase in BTE. The delay period increase prolonged the heat release rate. Effective minimization of NOx emissions was noticed with both the alcohol blends. De Poures et al [8] analyzed the effect of varying the injection timing and EGR in a DI engine run with hexanol fuel. Injection timing of 25 °bTDC and 30% EGR proved to be better for reducing smoke by 35.9% with a slight compromise in NO emission.

In view of the above existing literature, it is understood that alcohols blended at acceptable proportions helped to increase the engine efficiency. Thus varying the injection timing along with alcohol addition may lead to possibilities of reducing emission and enhancing combustion phenomena. This has been focused in the current experimental work and results are analyzed in the following section.

2. Materials and methods

The experiments were conducted on a single cylinder CI engine loaded with dynamometer and a controller. The engine specifications are shown in table 1 and the experimental layout is sketched in Fig.1. The fuels used for experimentation were tested for their physical properties like viscosity, density and calorific value and listed in table 2. Separate fuel tanks for diesel and jojoba biodiesel were used. Air flow rate and fuel flow rate were measured using orifice and burette arrangement. Digital gas analyzer of AVL type was used to measure all the exhaust gas emissions except smoke opacity. AVL smokemeter captured the opacity value in %. Jojoba oil was trans-esterified to obtain jojoba biodiesel and the viscosity was reduced to 3.5. Butanol was added to the engine combustion at two different concentrations of 10% and 20%. Jojoba oil biodiesel is represented as J20 and butanol blends are represented as J20B10 and J20B20.

| Table 1 Engine specifications |
|-----------------------------|
| **Model** | Kirloskar TV1 |
| Bore | 87.5 mm |
| Stroke | 110 mm |
| Compression ratio | 17.5 |
| Speed | 1500 rpm |
| Swept volume | 660cc |
| Rated power | 5.2 kW |

| Table 2 Fuel properties |
|-------------------------|
| **Property** | Diesel | Jojoba biodiesel | Butanol |
| Density | 820 | 845 | 809.7 |
| Viscosity | 4.03 | 4.5 | 2.54 |
| Low heating value MJ/kg | 42.5 | 41.9 | 33.09 |
| Cetane index | 48 | - | 17 |
3. Results and discussion

3.1 Brake thermal efficiency (BTE)

Brake thermal efficiency defines the extent of conversion of fuel energy into useful work. Fig 2 shows the variation of BTE against different load for diesel, J20 and butanol blends of jojoba biodiesel (J20B10 and J20B20). BTE for diesel and J20 are 33.8% and 30.6%. The lower calorific value of jojoba oil biodiesel has resulted in lesser BTE. The energy density of butanol blended biodiesel is higher than J20, hence the BTE improves to 31.35% and 32.4% for J20B10 and J20B20 respectively. Advancing injection timing to 25°CA bTDC, provides sufficient delay period for air fuel mixing, thereby producing good power output. The BTE is raised from 32.4% to 33.1% whereas it is 32.9% for 21° CA bTDC retarded injection timing.
3.2 Brake specific fuel consumption (BSFC)

This parameter determines the efficiency of fuel used to run the engine. Fig 3 shows that BSFC for diesel and J20 are 0.26 kg/kWh and 0.4 kg/kWh. The increased density of J20 causes difficulty in atomization, hence the BSFC of biodiesel is higher than diesel. Blending butanol at 10% and 20% to J20, reduces BSFC to 0.32 kg/kWh and 0.3 kg/kWh. Better utilization of injected fuel to produce power is possible when injection timing is advanced to 25 ºCA bTDC. BSFC for 21 ºCA bTDC and 25 ºCA bTDC injection timing are 0.37 kg/kWh and 0.28 kg/kWh respectively.

3.3 NO emission

Fig 4 shows the NO emission for diesel, J20 and butanol blends of J20 at different injection timings. Diesel and J20 biodiesel produced NO emission of 976 ppm and 1108 ppm. The oxygen molecules in the chemical composition of jojoba biodiesel increase the formation of NOx. Butanol blends contributes to decrease in cylinder temperature due to their high latent heat of vaporization. The cooling effect of alcohol reduces NO emission of J20B10 and J20B20 to 943 ppm and 921 ppm. Advancing the injection timing to 25 ºCA bTDC prolonged the delay period. This resulted in more amount of fuel being accumulated inside the cylinder, thereby leading to increased pressure and temperature. Hence, the NO emission shoot up to 1028 ppm. Retarding injection timing to 21 ºCA bTDC results in NO emission of 807 ppm.
3.4 Smoke emission

Fig. 5 shows the smoke emission for diesel, J20 and butanol blends of J20 at different injection timings. Diesel and J20 biodiesel produced smoke emissions of 71% and 77%. The
additional oxygen availability of biodiesel seems to be beneficial for combustion of fuel. But the increased density of the blend, interrupts the combustion process and leads to formation of unburnt carbon particles. Adding butanol at 10% and 20% further increases smoke emission to 82% and 89% due to cooling effect of butanol. Advancing injection timing to 25 °CA bTDC, reduces smoke emission to 68%, which is attributed to prolonged physical delay. Retarded injection timing of 21 °CA bTDC increases smoke emission to high value of 93%.

3.5 HC emissions

Fig 6 shows the HC emissions for diesel, J20 and butanol blends of J20 at different fuel injection timings. Diesel and J20 biodiesel produced HC emission of 186 ppm and 142 ppm. The inherent oxygen availability has decreased the HC emissions of J20. Blending butanol to J20 biodiesel causes inconvenience in fuel combustion and therefore HC emissions increases to 148 ppm and 152 ppm for J20B10 and J20B20 blend. Advancing injection timing to 25 °CA bTDC helps in improving the atomization and vaporization process, thus reducing HC emissions to 143 ppm. Retarded injection timing of 21 °CA bTDC produces the reverse effect, thus HC emissions increases to 163 ppm.

3.6 CO emission

Fig 7 shows the CO emission for diesel, J20 and butanol blends of J20 at different fuel injection timings. CO emission for diesel, J20, J20B10 and J20B20 are 0.6%, 0.34%, 0.36% and 0.39% respectively. The oxygen molecules which are native of jojoba biodiesel and butanol produces less CO emission by helping to achieve near complete combustion. Retarded injection timing of 21 °CA bTDC allots lesser time for air fuel mixing thereby leading to incomplete combustion with CO emission of 0.46%. Advancing injection timing to 25 °CA bTDC produces CO emission of 0.33%. The results are in close agreement with research works carried out in the recent past [9,10].
4. Conclusions
The impact of blending butanol to jojoba biodiesel at different concentrations and further effect of varying injection timing on performance and emission values of a CI engine were analyzed and the following observations were retrieved from the research work.

1. Blending butanol at 20% to J20 biodiesel, leads to improvement in BTE from 30.6% to 32.4%.
2. HC emissions increased from 142 ppm to 148 ppm and 152 ppm for J20B10 and J20B20 due to cooling effect of butanol. CO emission increased from 0.34% to 0.36% and 0.39% for J20B10 and J20B20 respectively.
3. NO emission decreased from 1108 ppm to 943 ppm and 921 ppm for J20B10 and J20B20 due to latent heat of evaporation of alcohol. Smoke emission increased from 77% to 89% for J20B20 in spite of the additional oxygen content in the blended fuel.
4. Advancing injection timing to 25 °CA bTDC was favorable from the performance and emission point of view except NOx. Retarding injection timing to 21 °CA bTDC produced least NO emission of 807 ppm.

According to the experimental analysis carried out so far, jojoba biodiesel at 20% blended volume with diesel is found to be a suitable fuel in CI engine, with reasonable additions of butanol and variation in injection timing.

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