Experimental study on alcohol fumigation in a CI engine energized with waste cooking oil

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Abstract

Consumption of fossil fuels rose drastically over the global level. Replacement for fossil fuels is necessary, since every year the automobile production is increasing the consumption of fossil fuels like petrol and diesel in rapid phase. Although strict vehicle emission control norms like Euro5, BS6 etc are implemented in different countries, the emission of harmful gas like Hydrocarbons (HC), Carbon monoxide (CO), NOx, VOCs etc have not been reduced to greater extent. So for the replacement of fossil fuels, a suitable alternative fuel which is a combination of waste cooking oil with hexanol added to it by fumigation technique is selected which would reduce the toxic emissions released by automobiles. The aim of this paper is to study the effect of adding hexanol at different concentration by fumigation method on the performance and emission characteristics of a CI engine. NOx emission reduces by 21% and smoke opacity by 28%. BTE is negatively affected by the fumigation mode 2 and reduces to 27.2%. From the emission point of view, the fumigation method proves to be beneficial while running a CI engine with waste cooking oil.

Keywords: alcohol, biodiesel, CI engine, emissions

1. Introduction

In reference to the current situation of increasing global population and the corresponding higher energy demands in the transportation sector, humans face many health problems because of fossil fuel emissions. Hence, it is very important to minimize this fossil fuel usage in automobiles [1]. Renewable fuels replace these fossil fuels, especially alcohol blended with biodiesel are good alternatives for CI engines [2]. Santhosh et al [3] analyzed the effect of blending hexanol at equal quantity with diesel. The standard injection timing was advanced and retarded to understand its effect on gaseous emissions. HC and CO emissions were lesser for advanced fuel injection timing whereas NOx emissions was higher.
Gaurav et al [5] blended kerosene and ethanol with waste cooking oil biodiesel at different proportions and proved their feasibility for operation in CI engines. Aphaslan et al [6] prepared two different blends with butanol and pentanol to diesel. Due to inferior heating value and cetane number, the blends consumed more fuel to produce unit BP. The brake thermal efficiency decreased for both the blends, but comparatively diesel- butanol blend produced a better efficiency. Gad et al [7] chose gasoline as additive to waste cooking oil biodiesel to improve the combustion pattern of diesel engine. Viscosity for the gasoline blends reduced by 5% to 21%. BSFC was reduced by 10% and the gas emissions are reasonably minimized. Victor et al [8] evaluated the effect of varying EGR and injection timing in hexanol blends of diesel in a CI engine. Smoke opacity was reduced by 36% at 25°CA bTDC and 30% EGR.

Thus, it is understandable that waste cooking oil biodiesel has been investigated by researchers in the past to improve the BTE of the engine. Though, alcohols were blended to the biodiesel in different proportions, higher order alcohols were rarely studied. Also, the fumigation mode of alcohol addition is very limited. Therefore, in this work in a way of addressing this gap, hexanol was fumigated at two different percentages mentioned as mode 1 and 2. The performance and emission parameters of the CI engine are measured and compared with that of blended fuel and base fuel, diesel.

2. Materials and methods

The experiments were conducted on a single cylinder CI engine loaded with dynamometer and a controller. Separate fuel tanks for diesel and biodiesel- hexanol blend 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 %. Waste cooking oil was transesterified to obtain WCO biodiesel and the viscosity was reduced to 4.76. Hexanol was added to the engine combustion both by blending and fumigation mode. In blending mode, 20% of biodiesel and 10% of hexanol was added to diesel. Whereas, in fumigation mode 1 and 2, 50% and 75% of hexanol was directly fumigated at the intake manifold. The fuels used for experimentation were tested for their physical properties like viscosity, density and calorific value and listed in table 1. The engine specifications are shown in table 2 and the experimental layout is sketched in Fig.1.

| Table 1. Fuel properties |
|--------------------------|
| **Property**             | **Diesel** | **Waste cooking oil biodiesel** | **Hexanol** |
| Density at 15° C          | 820        | 866                              | 821.8       |
| Viscosity                 | 4.03       | 4.76                             | 3.32        |
| Low heating value MJ/kg   | 42.5       | 39.2                             | 39.01       |
| Cetane Index              | 48         | 52                               | 23          |
Table 2. Engine Specifications

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

3. Results and discussion

3.1 Brake thermal efficiency (BTE)

This parameter is a measure of the engine performance. BTE determines the probability of approaching near complete combustion. Fig. 2 shows that the BTE for diesel and biodiesel blend are 33.8% and 31.7% respectively. The higher viscous nature of biodiesel alcohol blend creates difficulty in atomization process, thereby reducing the BTE by 1.2% compared to diesel. In the fumigation mode, the high cooling environment is created by the alcohol, which in turn leads to incomplete combustion process. Therefore, BTE decreases to 29.3% and 27.2% for mode 1 and 2 respectively.
3.2 Brake Specific Fuel Consumption (BSFC)
BSFC is highly determined by the calorific value of fuel used. The calorific value of biodiesel being 39.2 MJ/kg requires more amount of fuel to be burnt to produce unit BP output. Fig. 3 shows the BSFC of diesel and biodiesel blend are 0.26 kg/kWh and 0.3 kg/kWh respectively. Fumigation mode 1 and 2 further increases the BSFC to 0.38 kg/kWh and 0.42 kg/kWh respectively.

3.3 NO emission
The adiabatic flame temperature and oxygen composition of the fuel and the resident time decides the rate of formation of NO emission. Fig.4 shows that the NO emission of diesel and blended hexanol-biodiesel fuel are 976 ppm and 882 ppm. Adding hexanol in fumigation mode, attributes to reduced flame temperature by their high latent heat of evaporation, thereby producing a cooling effect. Fumigation mode 1 and 2 reduces NO by 2.9% and 15.8% compared to blended fuel mode.
3.4 Smoke emission
The different operating load conditions, nature of lubricant oil and oxygen participation in the fuel combustion process determines the amount of smoke formation. The carbon particles in the biodiesel blend do not burn completely in reduced adiabatic flame temperature, thus leading to an opacity value of 82% compared to diesel fuel smoke opacity of 71% as shown in Fig. 5. The fumigation mode 1 and 2 in turn increases the opacity to 85.4% and 89.3% respectively due to the latent heat of evaporation of higher order alcohol.

3.5 CO emission
Unfavourable air fuel ratio and increased complete combustion leads to CO formation. Fig.6 shows that CO emission for diesel and biodiesel_hexanol blend are 0.9% and 0.7% at full load condition. The BTE of fumigation type 1(75% hexanol) and type 2(50% hexanol) being better than blended mode, results in low fuel air ratio, hence CO emission being lesser than
the other base fuel and blended fuels. Fumigating hexanol to the engine at different concentrations has reduced the CO emission by 31% and 44.4% respectively.

![Fig. 6 CO emission vs load](image)

![Fig. 7 HC vs load](image)

### 3.6 HC emissions

Improved combustion pattern of the engine results in lesser HC emissions. Fig.7 shows the reduction in HC emission for blended mode and fumigation mode compared to that of diesel. Due to increased flame temperature, the quenching layers were lesser, thereby reducing HC emissions.
emissions to 142 ppm and 126 ppm for fumigation mode 1 and 2 respectively. The decrease in HC emissions for bended mode is 8.6% compared to diesel, however the value remains higher compared to fumigation mode.

4. Conclusions

The study aims in analyzing the effect of adding alcohol by fumigation method to waste cooking oil biodiesel. It was found that the BTE was negatively affected by fumigation mode 2. A decent reduction in NO emission was noticed and the fumigation mode 1 and 2 produces NO emission of 856 ppm and 742 ppm respectively. HC and CO emission were also lesser compared to the blended mode of alcohol- biodiesel. HC and CO emission reduced to 126 ppm and 0.5% for fumigation mode 2. The decreased adiabatic flame temperature could not favor the carbon particle oxidation and hence increased smoke opacity to 85.4% and 89.3% for mode 1and 2 respectively. It can be summarized that considering the engine performance, the blended mode was suitable, whereas, in view of emission parameters, the fumigation mode is suitable.

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