Assessment of emission and performance characteristics of WCO based biodiesel and n-butanol blends in CI engine

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(Received 04 October, 2015 Accepted 04 November, 2015)

ABSTRACT: Increased concerns of depleting petroleum fuel resources and increasing environmental issues have led to the increased usage of bio-fuels, especially biodiesel. Biodiesel is a renewable, biodegradable and non-toxic alternative to diesel. It can be used without any modification in the diesel engine. The use of waste cooking oil (WCO) as biodiesel feedstock offers a triple-facet solution (economic, environmental and waste management) in developing countries like India as well. In current study, waste cooking oil was trans-esterified to produce biodiesel using molar ratio 6:1. Methanol was used as alcohol substitute. Performance analysis was done by keeping speed constant at 1500 rpm and varying loads on a stationary diesel engine. Also, n-butanol was used as oxygenated additive. The experiments were performed by using various blends of diesel and biodiesel & diesel-biodiesel and n-butanol. 20%, 40% and 60% biodiesel was first blended with diesel and 10% and 20% n-butanol were also blended later on. Performance and emission characteristics were checked and compared with diesel base. Results showed that HC, CO, CO$_2$ and smoke emissions were reduced significantly by 15-25%, 10-25%, 10-30% and 20-28% respectively whereas a slight increase in NOx emissions was observed. However addition of n-butanol decreased the NOx emissions by 1-10%. Performance characteristics BHP, BTE, BSFC, BSEC were also considered and compared. Results indicated that B20 and nB10 blends were optimum and most economic to be used in any diesel engine.

Keywords: Waste Cooking Oil (WCO), n-butanol, trans-esterification, emissions.

I. INTRODUCTION

Alternative resources for petrol and diesel fuels are getting attention as entire world is facing the problem of depletion of petroleum reserves and increased environmental pollutants [1]. With the increasingly emission standards and lesser energy, it has become important to develop new internal combustion engines having low emissions and high fuel efficiency [2]. In this regard, biodiesel can be a dominant diesel substitute. It is produced from renewable sources like plants and vegetable oils and moreover it reduces environmental concerns [3].

Waste cooking oils are degraded vegetable oils which may possess foreign material. These can be proved to be inexhaustible source of energy and power. The difference in properties of used and unused vegetable oil is not much and it can be overcome by simple heating and subsequent filtration. These can be great feedstock for biodiesel production. Also, it is economical and solves the problem of waste cooking oil disposal. Biodiesel production cuts exhaust emissions as well. Biodiesel can be defined as “Biodiesel is a fuel comprised of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats, designated B100, and meeting the requirements of ASTM D 6751”. Biodiesel only contains about 10% oxygen by weight which leads to reduction in emissions due to incomplete combustions [4,5].

Literature studies reveal that vegetable oils are 10-20 times more viscous than the petroleum fuel; therefore directly using vegetable oils as a fuel can cause engine problems like injector fouling and particle agglomeration [6]. So, heating the oil becomes necessary before trans-esterification. Also, oxygenated fuel program was started in 1990 to avoid the problem of cold flow properties of oils especially in winter season.
The program was mainly to reduce carbon mono oxide emissions from vehicles. Previously ethanol was used as oxygenated fuel but now a days several other fuels are also in trend. In trends of oxygenated fuels, n-Butanol has been recently regarded as a more viable transportation biofuel than ethanol. It is less hygroscopic and evaporative than ethanol [7]. More oxygen content in oxygenated fuels is helpful in reducing PM emissions. >30% oxygen content results in no PM emissions from diesel engines [8]. Also, a study by Miyamoto et al (1998) revealed that biodiesel is much biodegradable than low sulfur diesel fuel and blending of biodiesel to diesel fuels makes fuel more biodegradable and more environmentally attractive [9]. Blending oils with oxygenated fuels improves fuel properties [10]. There are several studies on the performance analysis of blending fuels with diesel. In a similar study, S.K. Mahla et al. (2012) examined the properties, performance and emission of B15, B20 and B30 blends of linseed methyl esters and compared it to diesel[11]. He observed B20 to be most optimum in terms of better performance and reduced emissions. B15 and B30 blend were also reasonably efficient having lower smoke, CO and HC emissions. Also, a study by Jindal et al (2014) on Waste Cooking Oils had similar results [12]. Current study indicates that efficiency of biodiesel raised by 13% by adding n-butanol. B20 was the optimum blend and addition of 10% n-butanol proved even more efficient fuel.

II. MATERIALS AND METHODOLOGY

Waste cooking oil was used as feedstock for biodiesel production. It was taken from the Girls hostel mess from Thapar University Patiala. 1% KOH by weight was used and methanol (99.5%) was preferred due to its low cost. Less than 1% fatty acid content led to the use of alkali catalyst. Single stage alkaline transesterification reaction was done using 6:1 molar ratio. Trans-esterification is a reaction of oils and alcohols to form esters. Blending was done by mixing different ratios of diesel, biodiesel and n-butanol. Total 5 blends were made-B20, B40, B60, nB10 and nB20. The emission and performance of these blends was checked.

Engine set-up

A 4-stroke engine of power 3.73 kW, one cylinder was used at constant speed 1500 rpm with following specifications as mentioned in Table 1.

<table>
<thead>
<tr>
<th>Parameters</th>
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</tr>
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<td>Voltage, V</td>
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<tr>
<td>Current, Ampere</td>
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</table>

III. RESULTS AND DISCUSSION

A. Emission Characteristics

The decrease in HC emission occurs with increase in biodiesel blend. B60 showed 55-65% at lower loads and 40-50% at higher loads while B20 showed 15-25% decrease in HC emission at all loads. Butanol blends showed 20-45% decrease at all loads. It was observed that with increase in load the CO emissions increased. This is due to the injection of rich air fuel mixture which led to incomplete combustion of fuel. But with further increase in blend content the emissions were observed to be decreased. This may be due to the higher oxygen content which leads to complete combustion. B40 showed 8-50% decrease and B60 showed 10-25% decrease. The CO emissions were decreased with increase in n-butanol concentration which lowers the delay period and improves the combustion. Butanol addition lowered the emissions by 3-15%.
NOx emissions increased with WCO methyl ester at the pace of 5-25% whereas addition of butanol decreased the NOx emissions by 1-10%. It was observed that with increase in load the CO\textsubscript{2} emissions increases due to better combustion at high loads. The CO\textsubscript{2} emissions with diesel were highest.

As the blend content increased, the CO\textsubscript{2} emissions were decreased. The CO\textsubscript{2} emissions were observed to be decreased significantly with the increase in butanol content due to the good oxygen content and lower ignition delay that led to better combustion.
B20 showed 20-28% decrease in smoke where as B40 and B60 showed 34-50% decrease in smoke as compared to diesel. Butanol blends showed 10-25% decrease in smoke as compared to diesel fuel.

B. Engine Performance Analysis

Brake Horse Power (BHP) increases with load in every case. BHP varies with current as voltage is almost constant. BHP is zero at no load as there is no current flow. B20 showed 8% increase while B60 showed higher increase level (15-20%). n-Butanol also had similar variations as B20.

Brake Fuel specific Consumption (BSFC) varies inversely to load. BSFC decrement was more at higher loads. B20 showed 5% difference at lower loads and of 2% at higher loads. Addition of n-butanol proved to be great advantage. BSFC was 25% at lower loads and 15% at higher loads in n-butanol blends.

Brake Thermal Efficiency (BTE) changes directly with BHP and inversely with calorific value. B20 proved 13.2% more efficient as compared to diesel at lower loads and 7.3% more at higher loads. Other blends were also more efficient compared to diesel and range varied from 2-7%.

Brake Specific Energy Consumption (BSEC) is useful to compare the fuels of different calorific values. The BSEC varies inversely with load for all fuel blends. Higher biodiesel blends and butanol had higher BSEC compared to diesel at all loads. This is mainly due to the slightly lower calorific value. In Figure, B20 and nB10 blends showed a decrease of about 0.1-9% in BSEC at all load as compared to diesel. B40 and B60 showed increase of about 4-15% in BSEC at all loads.
Fig. 6. Brake power variation with load.

Fig. 7. BSFC variation with load.

Fig. 8. BTE variation with load.
CONCLUSIONS

(i) The lower biodiesel blends can be used in diesel engine without any engine modifications. However, need to change fuel filter remains after regular intervals of time.

(ii) B20 proved to be most optimum blend. nB10 was also good at all load conditions. More content of oxygen helped in complete combustion and decreased emissions.

(iii) The properties and performance of bio-diesel-n-butanol-diesel blends resemble with the conventional diesel on CI engines. However, the emissions were lower in biodiesel blends which indicate the regular use of biodiesel as transport fuel. The economic aspects of biodiesel needs to be considered.

REFERENCES


