Waste Cooking Oil Biodiesel: Its Testing, Performance and Emission in an Unaltered Diesel Engine

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Abstract. Rapid climate changes with global warming are the primary dispute of the recent era cause of diesel engine emission. Among the probable fuels, biodiesel is the most promising one as the alternative of petroleum diesel. Biodiesel can be formed from residue of cooking oil by transesterification. The reaction rate can be increased with alkali Catalyst at a 55°C temperature. The actions of waste cooking oil biodiesel (WCOB) compared with petroleum diesel were performed to observe the nature of an unaltered stationary diesel engine. In this study the specific fuels are: B10 biodiesel-diesel blend contained 10% WCOB and petroleum diesel (B0). The performance of an unaltered diesel engine fuelled with WCOB blend is examined in this study. In order to find out the performance results constant engine speed (1500 rpm) is being maintained during the experiments under 0%, 25%, 50% and 100% load conditions. It has been observed that when the engine setup was fuelled with WCOB blend B10, the performance depleted at mid to top load conditions but no drastic reduction in emission.

1. Introduction

The growing modernisation and industrialisation in the world led to the rise in demand and consumption of petroleum based fuel more and more. This causes air pollution and consequently accumulation of green house gases into the atmosphere. Two kinds of internal combustion engine e.g. petrol engine and diesel engine contribute for growing the air quality in the urban area. There are 22% of green house gas emits from the transportation sector for increasing demand of vehicles. IEA renowned as the international Energy Agency forecasts that the emission of carbon dioxide from transportation sector will increase by 92% between 1990 to 2020. It is also reported that average global temperature is hiked by 20 centigrade during this period [1]. Again the petroleum based fuels have limited reserve potent in specific sector of the globe. Many research experts says that the supply of petroleum based commodity can be drained within 40 to 60 years and also their increasing price make alternative fuel more and more attractive. The form of renewable energy is hydropower, wind power, solar energy, and biomass and bio fuels. The contribution of all these resources is important because of the economic and environmental reasons, and biodiesel could be one of the solutions. In an article, it indicates that India can produce about 30-40% and rest 70% petroleum is imported, which will cost around Rs.10,00000 million per year. On the other hand 5% biodiesel blend can save Rs.40,000 million per year [2]. Typically in the production of biodiesel edible vegetable oils are used [3, 4]. In modern era waste cooking oil (WCO) was targeted for its low cost and disposal problems. The primary obstacle for neat WCO is viscosity when applied directly in unaltered engines [5, 7], also blockage in the delivery valve of fuel line, poor atomization and incomplete combustion are the
associated drawbacks [8]. To overcome this problem transesterification process is used with catalyst to yield biodiesel from neat WCO. The neat WCO reacts with methanol and converts into fatty acid methyl esters having more influence and realized as ‘Green’ to the environment compared to fossil fuels. Not merely, fuel recuperated from waste oil could balance the energy demand but also it could provide a better waste management solution. Addition to that WCO transformation into biodiesel is renewable and eco-friendly, where throwing it away without taking any measurement is a serious hazard to the environment [9]. WCO can be reprocessed into profitable commodity as glycerol, soap, biodiesel etc. A huge amount of WCO can be possessed from various food chain industry, restaurants and hotels. In India a single unit of renowned food chain centre can produce 15 liters of WCO per day [10]. In this study WCO was collected from local guest house kitchen at Jadavpur University and converted into biodiesel (WCOB) by transesterification process. The produced biodiesel yielding was optimized by varying catalyst concentration, reaction temperature and molar ratio of the reactant. The fuel properties were also tested (Table 3) for the requirement as engine fuel. Outcome of fuel blend B10 WCOB at the zero load conditions and higher load conditions has been analyzed with reference to the performance and emission.

2. Problem description and solution procedure

In this study biodiesel was produced by ‘Lab scale batch reactor’ method, the WCO was collected from local guest house kitchen at Jadavpur University. With the reagents as waste cooking oil, methanol, base catalyst (KOH) and distilled water, biodiesel was prepared by following the procedure of treatment of raw materials, alcohol-catalyst mixing, chemical reaction, separation of the reaction products, purification of the reaction products and removal of moisture. Depending on the optimal results by varying catalyst concentration, reaction temperature and molar ratio the yield percentage were observed at catalyst concentration (0.5-1.5 %), reaction temperature (50-65°C) and molar ratio (1:8 to 1:15). Single cylinder VCR (variable compression ratio), 4- stroke DI (direct injection) diesel engine is used to find out combustion fluctuation and nature of performance with Diesel and B10 WCOB biodiesel blends. An eddy current dynamometer is used (Technomech, 10 BHP) for loading the test engine through a controller (230V, AX155, Apex). Combustion pressure, mass burn fraction is detected by a pressure sensor (Piezotronics, S111A22, up to 5000psi). A data retrieval system (NI USB-6210, 16-bit, 250kS/s.) collects spontaneous temperature, mass burn fraction, pressure, air flow, fuel flow & volume information from the engine cylinder. All the engine cylinder information is monitored using a real time software interface. During experiments test engine is being operated at 1500 rpm & 18:1 compression ratio but at particular loads (0 %, 25%, 50%, 75% & 100%). A gas analyzer is used to measure the emission of test fuel (Manatec make Eco Gas 100).

![Figure 1.(a)](image1.png) Schematic of experimental setup and (b) Photographic view of the experimental setup.
Table 1: Experimental setup specifications

| Diesel Engine specifications | Make and model | Make Kirloskar, Model TV1, 1cylinder, 4 stroke. |
|-----------------------------|---------------|-----------------------------------------------|
| Bore X Stroke               | 87.5 mm X 110 mm |
| Compression ratio           | 18            |
| Max power,                  | 3.6 kW        |
| Operating speed             | 1500 rpm      |
| Injection type & timing     | Direct Injection at 23˚CA BTDC |

| Gas Analyzer specifications | Make and model | Make Manatec, Model Eco Gas 100. |
|-----------------------------|---------------|---------------------------------|
| Technology & Operating temperature | Non dispersive Infrared (NDIR) technology, + 5˚C to + 45˚C |

| Measurement Parameters | CO (Carbon Monoxide) | Range: 0 - 15%, Resolution: 0.01% |
|------------------------|----------------------|----------------------------------|
|                        | HC (Hydro Carbon)    | Range: 0 - 20000 PPM, Resolution: 1 PPM |
|                        | NOx (Oxides of Nitrogen) | Range: 0 - 5000 PPM, Resolution: 1 PPM |

3. Results and Discussions

Optimum reaction parameters for biodiesel production from waste cooking oil on a batch scale reaction method have been shown in Table 2. Yielding of biodiesel is specified as the ratio of actual pure biodiesel produced from the amount of oil used interaction. The yield percentage is dependent on many factors such as methanol against oil molar ratio, reaction temperature, amount of catalyst and speed used in experiment. The optimal yielding was obtained at 1% Concentration, 55˚C Reaction Temperature and 1:8 Molar ratio of the reactant. The performance characteristics of B10 WCOB & B0 (Diesel) fuels blends have been tested in a single-cylinder (661.45cc), four-stroke, direct-injection, compression-ignition engine (3.50 kW @ 1500) experimental setup coupled with a dynamometer (TMEC10). All the performance and emission results were collected at 18 compression ratio. Relevant engine performance criterion like Brake power, BTE (brake thermal efficiency) and BSFC (brake specific fuel consumption) have been examined at various load percentage at 1500 rpm.

![Figure 2](a) Graphical illustration of Brake Thermal Efficiency at different loading, B10 WCOB biodiesel blend & B0 Diesel, (b) Graphical illustration of brake specific fuel consumption at different loading, B10 WCOB biodiesel blend & B0 Diesel at compression ratio:18.
The deviation in BTE for the test fuels are illustrated in figure 2.(a). High BTE for petroleum diesel at mid to high engine loads conditions has been observed as 15.46 % for B0 and 13.14% for B10, also 23.05% for B0 and 19.39% for B10 respectively. It is natural as the petroleum diesel has better spray atomization characteristics which lead to enhanced combustion compared to B10 blend. Though at low engine load conditions BTE for B10 blend has similar trends compared to petroleum diesel, this may be the reason of additional lubricity and presence of oxygen in biodiesel.

Table 2: Yield of biodiesel from WCO with change in reaction parameters

| Catalyst Concentration (%) | Reaction Temperature (°C) | Reaction Time (hr) | Molar Ratio | Speed (rpm) | Yield (%) |
|----------------------------|----------------------------|--------------------|-------------|-------------|-----------|
| 1                          | 50                         | 1                  | 1:6         | 1000        | 87.5      |
|                            | 55                         | 1                  | 1:6         | 1000        | 89.4      |
|                            | 60                         | 1                  | 1:6         | 1000        | 92        |
|                            | 65                         | 1                  | 1:6         | 1000        | 82        |
|                            | 55                         | 1.5                | 1:8         | 1000        | 93.2      |
|                            | 55                         | 1.5                | 1:10        | 1000        | 90        |
|                            | 55                         | 1.5                | 1:12        | 1000        | 88.5      |
|                            | 55                         | 1.5                | 1:15        | 1000        | 88        |

In figure 2.(b), it was noticed that as the engine load raised BSFC for test fuels fall off. Marginal differences were observed in BSFC for all the test fuels at mid to high engine loads conditions as 0.65 kg/kWh for B10 and 0.5 kg/kWh for B0, also, 0.44 kg/kWh for B10 and 0.38 kg/kWh for B0 respectively. This may be the reason of combined effort of greater density, low calorific value and viscosity of WCOB.

In figure 3.(a), it is noticed that as the engine load was raised, the carbon monoxide (CO) emission was decreased then lastly increased. At low engine load condition the cylinder temperature is low which leads to inadequate combustion and comparatively high CO emission. During the gradual increase in engine load conditions, the cylinder temperature also increases which provides better combustion and leads to lower CO emission as the oxidation rate of CO is enhanced at relatively higher temperature. At peak engine load condition the amount of fuel entering the cylinder is very high, thus leads to drastic increase in CO emission for all the test fuels. It is observed that at peak engine load condition CO emission for biodiesel is marginally high; this may be the reason of poor atomization, irregular air-fuel mixing.

Table 3: properties of produced waste cooking oil biodiesel at optimal yielding conditions

| Property                  | Unit          | Experimentally determined value |
|---------------------------|---------------|--------------------------------|
| Density at 200°C          | gm/cc         | 0.964                          |
| Acid Value                | mg KOH/gm     | 0.898                          |
| Free Fatty Acid           | Wt %          | 0.451                          |
| Saponification Value      | mg KOH/gm     | 185.13                         |
| Molecular weight          | gm/mol        | 913.52                         |
| Heating value             | MJ/Kg         | 38                             |

In figure 3.(b), it was noticed that as the engine load was raised Hydrocarbon (HC) emission was increased with load as the fuel quantity was increased. Though HC emission was marginally low compared to petroleum diesel; this may be the reason of oxygen presence in fuel.

Oxides of nitrogen (NOx) emission depend on combustion temperature and duration, along with oxygen presence. The deviations in NOx emission at various engine load conditions are presented in figure 4 for the test fuels. Initially NOx emission was high for B10 blend due to high combustion duration and pressure which leads to high combustion temperature. However, at peak load condition
NOx emission for B10 blend was marginally low compared to B0 petroleum diesel, this may be the reason of low calorific value of WCOB which leads to low combustion temperature.

**Figure 3.** (a) Carbon monoxide emission at different loading, B10 WCOB biodiesel blend & B0 Diesel (b) Unburnt hydrocarbon emission at different loading, B10 WCOB biodiesel blend & B0 Diesel

**Figure 4.** Graphical illustration of oxides of nitrogen emission at different loading, B10 WCOB biodiesel blend & B0 Diesel

4. Conclusions
In this study, it has been identified that waste cooking oil could be a sustainable source of waste cooking oil biodiesel. Optimization has been done to increase the production and maintain the quality of biodiesel. The performance study indicates WCOB biodiesel blend B10 can be used to reinstate petroleum diesel at low engine load conditions. Although there are concerns regarding poor performance criterion at mid to high engine loads. The viscosity variation, poor atomization and low heating value of fuel in WCOB blends affects the performance quality for B10 blends compared to Diesel (B0). The main conclusions are summarized as follows:

- Optimum yielding of biodiesel is about 93.2% for WCOB when the average heating value is about 38 MJ/Kg.
- Results reveal that quality of performance the sink around 15% in mid to high engine loads conditions compared to petroleum diesel fuel in terms of BTE (brake thermal efficiency).
Marginal differences were observed in BSFC for B10 blend compared to petroleum diesel B0 at mid to high engine loads conditions. It is observed that at peak engine load condition CO emission for B10 biodiesel blend is marginally high about 14% compared to diesel. HC emission was marginally low about 6% compared to petroleum diesel. At peak load condition NOx emission for B10 blend was marginally low about 2% compared to B0 petroleum diesel. Though no drastic reduction in emission was observed for B10 WCOB biodiesel blend.

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Nomenclature

| WCOB | Waste cooking oil biodiesel | WCO | Waste cooking oil |
|---|---|---|---|
| B0 | Petroleum Diesel | KOH | Potassium hydroxide |
| B10 | Blend contained 10% WCOB | VCR | Variable compression ratio |
| rpm | Revolutions per minute | NOx | Oxides of nitrogen |
| BTE | Brake thermal efficiency | BSFC | Brake specific fuel consumption |
| HC | Unburnt Hydrocarbon | CO | Carbon monoxide |