Study on Optimization of Process Parameters for Biodiesel Production from Waste Cooking Oil and its Cost of Production

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Abstract—**Waste cooking oil is an important feedstock for biodiesel production. The present paper reports on biodiesel production from waste cooking oil in a pilot scale plant. The process parameters for maximum biodiesel yield have been optimized. The cost of production of biodiesel from waste cooking oil has been estimated. The present paper also reports on experimental results of the performance of a diesel engine fueled with biodiesel produced from waste cooking oil.**

Keywords—*Waste Cooking Oil; Biodiesel, Pilot Scale, Transesterification, Cost Of Production.*

I. INTRODUCTION

The rising concerns for environmental pollution from fossil fuels and their subsequent depletion has driven researchers in search of an alternative fuel that can someday completely replace the fossil fuels. Among the alternative fuels, biodiesel is very promising. It is not only an alternative option but has better emission quality when it is burnt in CI engine and elongates the engine lifetime. For developing countries like India the high cost of energy imports is an inconvenience. Crude oil imports comprise a large proportion of this. The total onshore and offshore crude oil reserves of India were estimated to be 760 million tonne in 2012 [1]. Government of India imported 172.11 million tonne of crude oil and spent 6690.68 billion INR on the imports in the year 2011-2012 [2]. The American Society for Testing and Materials (ASTM) defines biodiesel as monoalkyl esters of long chain fatty acids derived from a renewable lipid feedstock. It is produced through transesterification with base or acid catalysts. Vegetable oils (both edible and non-edible), waste cooking oil (WCO) and animal fat are used as feedstock for biodiesel production. Total edible oils consumption in India, in 2013, was estimated to be 17.55 million tonne of which about 11 million tonne was imported and the rest was indigenous production. Taking an average of 7% WCO production from edible vegetable oils, about 1.23 million tonne WCO is generated per year in India. National Policy on Biofuels, Government of India, has set a target of 20% replacement of diesel by biodiesel by 2017. To achieve this target a huge amount of basic feedstock will be required which is not an easy task. WCO may play an important role in supplying the feedstock for biodiesel production in India. Biodiesel can be produced from WCO when it reacts with methanol in presence of a base catalyst. Shimada et al. reported that potassium hydroxide was considered the best catalyst for transesterification using WCO [3]. Al-Hamamre et al. reported that KOH catalyst is less prone to saponification [4]. WCO requires pre-processing before the transesterification reaction. Steam injection, column chromatography, film vacuum evaporation, and vacuum filtration were reported to be effective [5, 6, 7, 8]. The transesterification reaction produces glycerol as a by-product that can be used after refining. Reaction parameters like reaction temperature, catalyst concentration, molar ratio of alcohol to oil, reaction time and stirring rate affect the quality and the quantity of the biodiesel produced. Biodiesel is non-toxic and biodegradable in nature. Biodiesel can be used as an alternative to diesel in CI engines in blended or pure form. Efficient burning of biodiesel in IC engines can be achieved with better atomization of fuel. Lesser the value of kinematic viscosity facilitates better atomization. In this study biodiesel has been produced from waste cooking oil in a pilot scale plant. The process parameters for biodiesel production from waste cooking oil were optimized on laboratory scale and then have been implemented in a pilot scale plant. In the present investigation, cost of production of biodiesel from WCO has been estimated. Important properties of the biodiesel produced from waste cooking oil have also been estimated. Trials have been carried out to run a diesel generator with the produced biodiesel.

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II. MATERIALS AND METHODS

WCO collected from a canteen was used as a feedstock. Commercial grade methanol of 85% purity was used for pilot scale production of biodiesel. Laboratory grade methanol of 99% purity from Merck was used for bench scale production. Potassium hydroxide of 84% purity was used, as catalyst.

A. Collection of feedstock

Waste cooking oil is a byproduct of restaurants, hotels, many shops that sell fritters, canteens, shops that sell savory snacks, etc. WCO is usually thrown away. If this is collected properly and cleaned then it can be a very useful feedstock for biodiesel production. When such a procedure takes place it handles a local waste management problem. For this study WCO was collected from a canteen. Throughout the present investigation, the single source was used for collection of WCO.

B. Pre-processing of feedstock

Feedstock like WCO requires the removal of impurities before it is used for biodiesel production by transesterification process. The presence of water in the oil sample often leads to hydrolysis, and a high free fatty acid (FFA) content leads to saponification, hence lower biodiesel yield. To eliminate water content, the WCO sample was heated to above 100°C. Suspended solids and other impurities were removed by filtration. For filtration cotton waste was kept in a funnel and then WCO was passed through it. A faster way of filtering away all impurities was vacuum filtration. A sintered glass filter of grade G4 fitted in a Buchner flask was used and the vacuum was created by a suction pump.

III. Experimental Study on Biodiesel Production from WCO on a Bench Scale

Transesterification is a reaction between fats or oils and alcohol in presence of a catalyst. The reaction temperature, reaction time, molar ratio of alcohol to oil, catalyst concentration and stirring rate were varied individually while keeping the other parameters constant. When these parameters were varied the change was observed in the yield of biodiesel and in the kinematic viscosity of biodiesel. Based on the kinematic viscosity the reaction parameters were then optimized. The transesterification reaction was carried out in a 500 ml Erlenmeyer conical flask fitted with a reflux condenser placed on magnetic stirrer and heater. Water was passed through the reflux condenser. A measured amount of potassium hydroxide and methanol were stirred till the catalyst completely dissolved. Then, 100g of WCO was added to the mixture and stirred under reflux for a stipulated amount of time at a desired stirring rate. The reaction temperature is varied from 40°C to 60°C. Secondly, the catalyst concentration was varied from 0.5% to 1.5%. Thirdly, the molar ratio of alcohol to oil was varied from 3:1 to 12:1. Fourthly, the reaction time was varied from 1 hour to 3 hours. Lastly, the stirring rate was varied from 200 rpm to 1000 rpm.

After completion of transesterification the reaction mixture was allowed to stand in a separating funnel for about 12 to 18 hours. As the reaction mixture cooled the separation became more and more prominent. Two layers were formed; the upper layer lighter biodiesel or methyl ester and the lower layer was the heavier glycerol. Biodiesel was collected after separation contained impurities like excess catalyst and traces of alcohol. Washing of biodiesel was carried out by bubble washing technique. The volume of water taken was twice the volume of biodiesel to be washed. The water was heated upto a temperature of about 70°C. After washing the water-oil mixture was made to stand in the separating funnel for 30 to 45 minutes. Water being denser settled at the bottom. Washing was repeated till the pH of water became neutral. The moisture present in the biodiesel was removed by heating as presence of moisture decreases the calorific value of the fuel. It also increases the viscosity of the fuel. Yield of biodiesel from WCO with the change in process parameters on bench scale operation has been given in Table 1. The optimum parameters standardized from bench scale operation are given in Table 2.

IV. Biodiesel Production from WCO on a Pilot Scale

The process of transesterification of WCO was first optimized on a bench scale. Later this has been implemented in a pilot scale biodiesel production unit capable of processing 30 liters of WCO per batch. A schematic diagram of the pilot scale plant is given in Fig. 1.

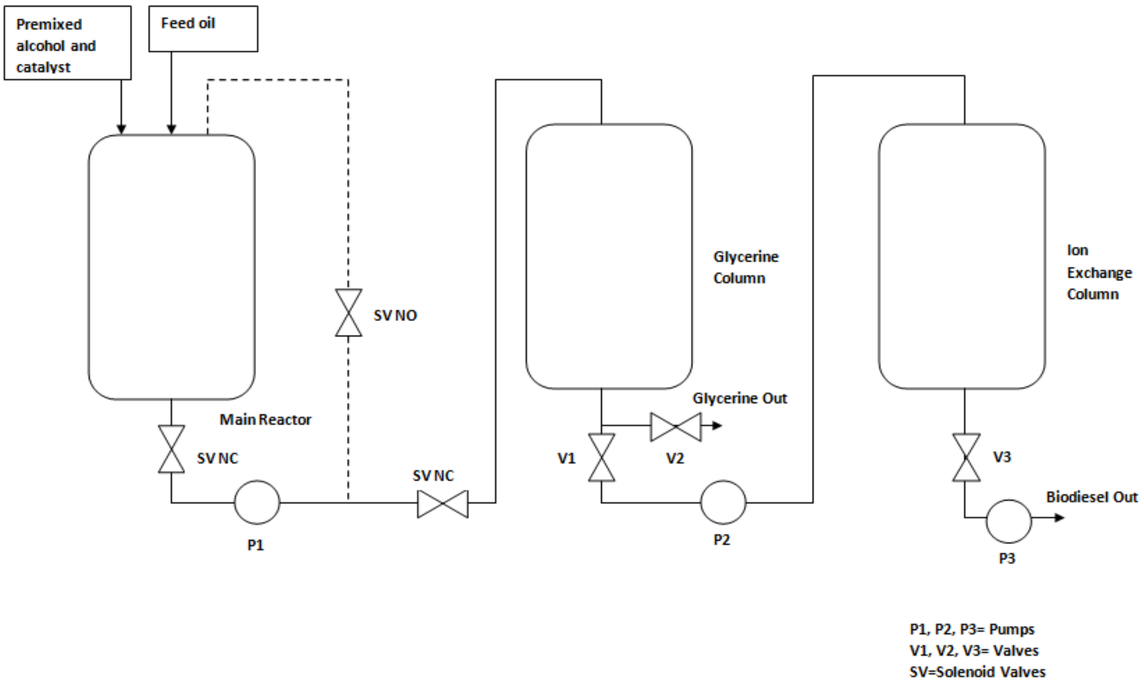

Fig. 1. Pilot scale plant for biodiesel production from WCO

The pilot scale setup consisted of the following main components:

(a) Transesterifier: It is made of stainless steel with its capacity of 45 liters. It is fitted with an electrical heater and connected to pipes and a pump for circulation.

(b) Glycerin separating column: It is made of stainless steel. A solenoid valve operated from the main control panel facilitates in the transfer of liquid from transesterifier.

(c) Ion exchange column: It is made of stainless steel. It contains an ion exchange resin (Purolite PD206) used for dry washing of biodiesel.

Firstly the feedstock was purified completely, devoid of suspended particles and moisture. Then it was added to the transesterifier through a funnel. The feedstock was heated upto the desired set point. The temperature was set on the temperature controller unit and the system was turned on. After the desired temperature (40ºC) was attained then a mixture of commercial grade methanol and KOH was added to the feedstock in the transesterifier. In the laboratory scale, the molar ratio of alcohol to oil was optimized at 8:1 but to minimize the cost of biodiesel production, a molar ratio of alcohol to oil of 6:1 was maintained in the pilot scale operation. The circulation of the reaction mixture was done with the help of a pump, thus resulting in efficient conversion of feedstock to biodiesel. Catalyst (KOH) concentration was 1% (w/w) and the reaction time was two hours. After completion of reaction the mixture was transferred to the glycerin column for settling. As the mixture cooled down the settling happened faster. Glycerol was collected from the bottom through an outlet valve. The unwashed biodiesel was then transferred to the ion exchange column. The biodiesel that was finally collected was pure and had no impurities. The yield of biodiesel produced by the pilot unit has been found to be 90%.

V. Testing of Fuel Properties

The properties of biodiesel produced from WCO in the pilot scale plant have been estimated. Density of biodiesel was measured in a specific gravity bottle. Kinematic viscosity of biodiesel was measured using an Ostwald's viscometer with water as the reference liquid. Flash point and fire point were measured in Pensky-Marten Closed Tester. Calorific value of biodiesel was measured using a Bomb calorimeter. Cetane number of biodiesel has been estimated from these properties [9].

VI. Results and Discussion

The procedure for biodiesel production depends on the reaction temperature, reaction time, molar ratio of alcohol to oil, catalyst concentration and the stirring rate. These parameters also determine the quality of biodiesel produced. The reaction parameters were optimized with respect to the kinematic viscosity of all the biodiesel samples. When the reaction temperature was varied from 40°C to 60°C the yield of biodiesel decreased from 94% to 86% (Table 1). This could be due to loss in methanol as its boiling point is little above 60°C. The yield of biodiesel also decreased at temperatures of 45°C, 50°C and 55°C. The maximum yield was obtained at 40°C. Catalyst (KOH) concentration was varied from 0.5 to 1.5%. For catalyst concentration less than 0.5%, the yield of biodiesel was not significant. When the catalyst concentration was more than 1.5%, a soapy emulsion was formed during washing of biodiesel and the separation became difficult. It was seen that the biodiesel yield was maximum when the catalyst concentration was 1%. As the molar ratio of alcohol to oil was increased the yield of biodiesel also increased. The percentage of conversion of WCO to biodiesel increased as volume of methanol was increased. The yield increased from 82% at 3:1 molar ratio to 94% at 8:1 molar ratio. After this as the molar ratio was increased, the yield decreased to 92%. The reaction time was varied from 1 hour to 3 hours. The longer the reaction took place, the rate of conversion of WCO increased. The yield increased from 88% to 94.5%. The stirring rate was varied from 200 rpm to 1000 rpm. The yield of biodiesel of (94%) was maximum at 1000 rpm. At all other lower stirring rates the yield varied from 90% to 92% (Table 1).

TABLE 1. Yield of biodiesel from waste cooking oil with change in reaction parameters

Parameter changed	Reaction temperature (^{O}C)	Reaction time (hour)	Molar ratio of alcohol to oil	Catalyst concentration (%)	Stirring rate (rpm)	Yield of biodiesel (%)
Temperature (^{O}C)	40	2	8:1	1.0	1000	94
	45	2	8:1	1.0	1000	90
	50	2	8:1	1.0	1000	92
	55	2	8:1	1.0	1000	90
	60	2	8:1	1.0	1000	86
Parameters kept constant: Reaction time, Molar ratio of alcohol to oil, Catalyst concentration, Stirring rate						
Molar ratio of alcohol to oil	40	2	3:1	1.0	1000	82
	40	2	4.5:1	1.0	1000	88
	40	2	6:1	1.0	1000	90
	40	2	8:1	1.0	1000	94
	40	2	9:1	1.0	1000	92
	40	2	12:1	1.0	1000	92
Parameters kept constant: Reaction time, Reaction temperature, Catalyst concentration, Stirring rate						
Reaction Time (hour)	40	1	8:1	1.0	1000	88
	40	1.5	8:1	1.0	1000	90
	40	2	8:1	1.0	1000	94
	40	3	8:1	1.0	1000	94.5
Parameters kept constant: Reaction temperature, Molar ratio of alcohol to oil, Catalyst concentration, Stirring rate						

TABLE 2. Optimum parameters for biodiesel production from waste cooking oil on a bench scale

Optimum reaction parameters and yield of biodiesel	Value
Reaction temperature (^{O}C)	40
Reaction time (hour)	2
Stirring rate (rpm)	1000
Catalyst concentration (%)	1
Molar ratio of Methanol to Oil	8:1
Yield (%)	94

Different properties of the biodiesel produced from WCO in a pilot scale plant have been estimated and listed in Table 3. Density is an important fuel property, because injection systems, pumps, and injectors must deliver an amount of fuel precisely adjusted to provide proper combustion [10, 11, 12]. Density is important mainly during combustion in IC engines because it influences the efficiency of atomization of the fuel. Density of WCO biodiesel was found to be 860 kg m^{-3}. Kinematic viscosity is a measure of a fluid's resistance to flow. Lower kinematic viscosity facilitates efficient atomization and thus better burning of fuel. The kinematic viscosity of biodiesel changes in comparison to changes in reaction parameters. Kinematic viscosity was found to be 4.9 centistokes at 40°C at optimum condition. Fire point is the temperature where the flame will be held by the biodiesel. Flash point is the temperature where the biodiesel gets inflamed and we see a flame then it extinguishes. Flash point and fire point of the WCO biodiesel were estimated to be 155 °C and 182 ^{O}C respectively. Calorific value of biodiesel (higher heating value) produced from WCO has been estimated to be 36.65 MJ/kg. Cetane number of a fuel is defined as the percentage by volume of normal cetane in a mixture of normal cetane and α-methyl naphthalene which has the same ignition characteristics (ignition delay) as the test fuel, when combustion is carried out in a standard engine under specified operating condition. A fuel of higher cetane number gives lower delay period and provides smoother engine operation. Biodiesel has a higher cetane number than petrodiesel because of its higher oxygen content. Cetane number is an important parameter in evaluating the quality of biodiesel fuel. In this study, the cetane number of the biodiesel has been derived from a mathematical model developed by Sivaramakrishnan et al. [9].

$$CN = K_5 + K_4\,\nu + K_3\,HV + K_2\,FP + K_1\,\rho \quad \text{--- (1)}$$

Where K_1, K_2, K_3, K_4, K_5 are constants and ν is kinematic viscosity (mm^2/sec), HV is heating value (MJ/kg), FP is flash point (°C), ρ is density (kg/l). By using the above equation the cetane number (CN) of the biodiesel produced from WCO has been estimated to be 54. The important properties of biodiesel produced from WCO (Table 3) match with the biodiesel fuel specification standard of IS15607 : 2005 (Bureau of Indian Standards) which is the Indian adaptation of ASTM D6571-02 and EN14214.

TABLE 3. Properties of biodiesel produced from waste cooking oil in a pilot scale plant

Property	Biodiesel from WCO
Density (kg/m^3)	860.00
Kinematic viscosity at 40^{0}C (centistokes)	4.90
Calorific Value (MJ/kg)	36.65
Flash Point (^{o}C)	155.00
Fire Point (^{o}C)	182.00
Cetane Number	54.00

VII. Estimation of Cost of Production of Biodiesel from Waste Cooking Oil

The production of biodiesel on a pilot scale utilizes commercial grade methanol rather than laboratory grade which reduces the cost of biodiesel drastically. However, in the present study, the cost of biodiesel production from waste cooking oil has been estimated without considering the fixed cost and labour charges. Cost of raw materials required for the production of biodiesel and the electricity tariff are given below.

Cost of commercial grade methanol = INR 80 per liter

Cost of KOH = INR 672 per kg

Cost of waste cooking oil = INR 30 per kg
(1 kg of WCO occupies a volume of 1.1liter)

Electricity tariff (industrial) = INR 7 per kWh

Yield of biodiesel established through optimization on the pilot scale is 90% for 6:1 molar ratio of alcohol to oil.

TABLE 4. Cost of production of 1 liter WCO biodiesel

Cost Components	**Cost (INR)**
Waste cooking oil	30.00
Methanol	24.80
KOH	6.72
Electricity	1.68
Total cost (INR/liter)	63.20

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VIII. ENGINE STUDY WITH BIODIESEL PRODUCED FROM WCO

A schematic diagram of the CI engine-generator test setup used for performance evaluation of WCO biodiesel is given in Fig. 2.

The WCO biodiesel produced in the pilot unit has been used to fuel a 2.94 kW diesel generator in blended forms with petroleum diesel.

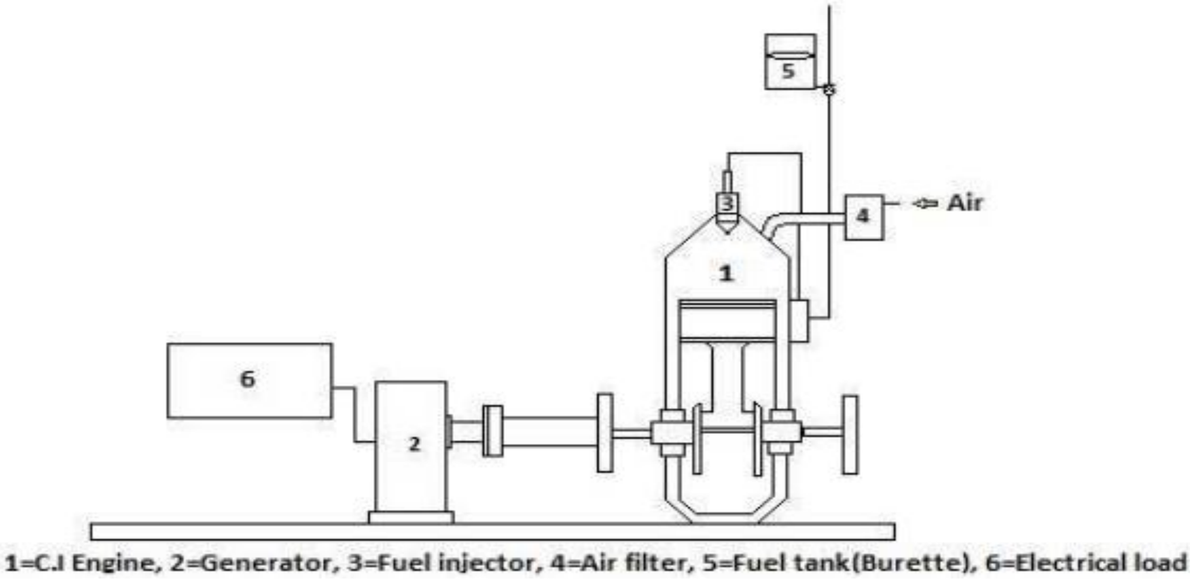

Fig. 2. Schematic diagram of diesel engine-generator setup

The diesel generator was operated with B0 (100% diesel), B5 (95% diesel + 5% biodiesel) and B10 (90% diesel + 10% biodiesel). The engine was operated on B5, B10 and B0 with varying loads of 1 kW, 1.5 kW, 2 kW, 2.5 kW, 2.6 kW and 2.8 kW for extended period of time. The fuel was fed to the engine through a burette. The specific energy consumption and overall efficiency of the system against different loads on the engine using B5, B10 and 100% petroleum diesel (B0) were estimated and have been plotted in Fig. 3 and 4 respectively.

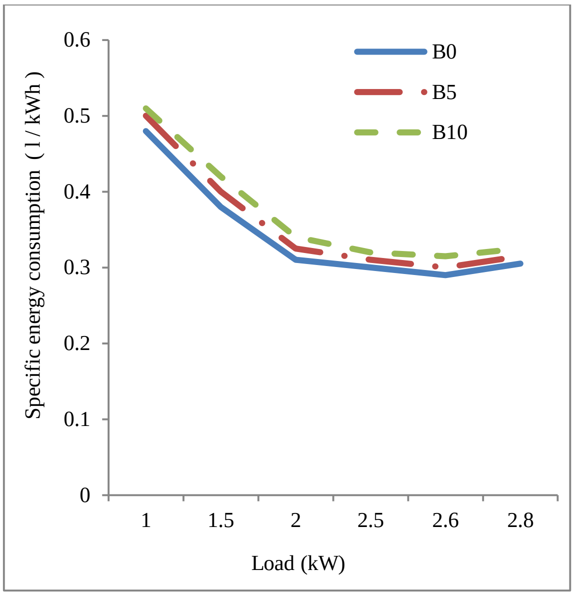

Fig .3. Specific energy consumption vs. electrical load

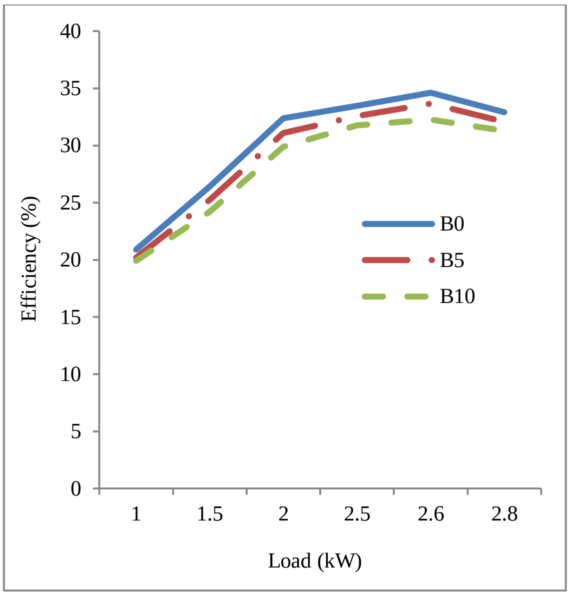

Fig. 4. Efficiency of engine vs. electrical load

From Fig. 3 it is observed that the specific energy consumption decreases with the increase in load, attains minimum at 2.6 kW load, then increases with further increase in load. The load at which minimum specific energy consumption occurred was same for both WCO biodiesel-diesel mixtures (B5 and B10) and 100% petro-diesel (B0). It has been observed that the B5 and B10 blends of WCO biodiesel burnt smoothly in diesel engine and no change in engine vibration and engine sound have been noticed during the experimental trials with WCO biodiesel. Figure 3 also shows that the nature of curves for B5 and B10 are similar to 100% diesel (B0). It can be claimed that the combustion characteristics of the WCO biodiesel-diesel blends are almost identical with the 100% petroleum diesel and also there was no significant change in delay time when the CI engine was run with WCO biodiesel-diesel mixture. It is observed from Fig. 4 that the overall efficiency of the CI engine-generator system was 34.62% when fueled with pure diesel which dropped to 33.67% and 32.27% respectively with B5 and B10 at rated capacity.

IX. CONCLUSIONS

The present study has demonstrated that waste cooking oil is an excellent feedstock for biodiesel production. The process parameters for production of biodiesel from WCO have been optimized. The maximum yield of methyl ester obtained from WCO was 94% on bench scale and 90% on a pilot scale plant. Important properties of biodiesel produced from WCO are comparable to that of petroleum diesel. The cost of WCO biodiesel has been estimated to be INR 63.20 per liter which is 10 to 20% higher than the price of diesel, if fluctuating prices of high speed diesel in recent past in India is considered. However, in estimating the cost of production of WCO biodiesel, in the present study, the fixed cost, labour charge and glycerin selling price have not been included. But it can be argued that cost of biodiesel production from waste cooking oil will further be reduced if commercial scale plant is employed. The engine performance study of WCO biodiesel supports the viability of large scale production of biodiesel from WCO, however a proper collection mechanism of WCO from all possible sources is required.

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