Production of Bio-mix Biodiesel Fuel and its Impact on Diesel Engine Applications

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ABSTRACT

In India, food industries are growing fast day by day. The wastage coming out from these industries like meat waste and used cooking oils are nearly 3 million tons per year. Due to the lag of waste management, these wastes have been dumped in landfills which increase environmental pollution and health problem for human as well as animals. To solve this problem, attention has been made to develop a renewable alternative fuel through bio-mix approach. For biodiesel production, chicken fat, waste cooking oil, and jatropha oils were used. This feedstock was mixed together to form a raw bio-mix oil. This raw bio-mix oil was converted to bio-mix methyl esters through a transesterification reaction. The reaction parameters like methanol/oil ratio, catalyst and reaction time were investigated. Two samples of bio-mix biodiesel BMB-I and BMB-II were prepared with nanocatalyst and base catalyst (KOH) respectively. Furthermore, fuel properties have been investigated and were found within the standard values. Engine study shows that both the bio-mix biodiesels (BMB-I, BMB-II) have higher brake specific fuel consumption (BSFC) and lower brake thermal efficiency (BTE) as compared to diesel fuel. Exhaust emissions like NOx, CO, CO_2, HC, and smoke were found to be lower for BMB-I as compared to BMB-II and diesel fuel respectively. Thus the Nano-catalyst was used in this study was found to be cost-effective and low toxic for biodiesel production compared to the use of base catalyst.

Keywords: Biodiesel, Bio-mix, Transesterification, Nano-catalyst, Cost-effective and Emissions

1 INTRODUCTION

The Waste Cooking Oil (WCO) generated from household and food industrial sources is an expanding issue all over the world. This oil remnant ensuing in problems for waste water treatment plants or is integrated into the food chain through animal feeding, thus becoming as a major cause of human health problems [1]. Many end user like the preparation of soaps or of energy by anaerobic digestion, thermal cracking, and more recently the production of biodiesel, a fuel that can be used as a mineral diesel substitute for engines are available for this oil waste [2].

Poultry waste and used cooking oil are the two most commonly wastes of our daily life. These two wastes can be used for biodiesel production [1,2]. Biodiesel is an alternative fuel from the renewable source to replace fossil fuels which are more responsible for air pollution and climate change [3]. Biodiesels are the mono-alkyl ester of long chain fatty acids produced from renewable bio-lipids and animal fats via the trans-esterification process. It is a clean burning eco-friendly fuel [4]. Some parameters of biodiesel quality are related to its fatty acid (FA) composition which is varying according to the carbon chain length and degree of saturation level in the esters [5,6]. Since the chemical process also influence the FA composition of the oils, the fatty acid methyl ester (FAME) profile of the biodiesel is slightly different from the oil or fat of its origin [5,6]. The biodiesel molecular structure varies, depending on the feedstock used for the biodiesel production. Abdelrahaman B et.al [7] studied the biodiesel production behavior from the mixed castor seed oil and waste fish oil. The prepared sample was CF50:50 (50% castor oil and 50% Fish Oil). It was reported that, mixing saturated oil into highly unsaturated oil, increased Saturated Fatty Acid (SFA) percentage. Sample CF50:50 consisted of higher SFA than castor biodiesel. The main objective of this study was to utilize food wastes for energy production. Based on the literature study, it is important to note that there is no single oil seed with the finest FA composition that simultaneously favours all the quality parameters of biodiesel. This indicates that there is a need to focus on fuel composition design towards optimising the required FAME composition to improve the biodiesel fuel properties. The objective of this present study is can be listed as (a) development of Nano-catalyst from egg shell powder, (b) Biodiesel production from the different blends of chicken fat and waste cooking oil, (c) To increase the level of saturated fatty acids (SFA), (4) Characterization of fuel samples, (d) Analysing the suitable bio-mix model according to ASTM and Indian standards (BIS), (e) Impact of the prepared fuel on diesel engine applications.

2 Materials and methods

2.1 Catalyst Preparation

The nano-catalyst $CaCu(OCH_3)_2$ was prepared by heating calcium oxide in dehydrated methanol under 55°C for 10 hours. The reaction is given below:

$$(CaCu)O + 2CH_3OH \xrightarrow{55°C} CaCu(OCH_3)_2 + H_2O \quad (1)$$

Table 1, FAME profile obtained from GC-MS test

Biodiesel	WCOB	BMB	CFB	JB
C14:0	0.12	1.5	4	0.14
C16:0	10	16.3	25	13.79
C16:1	0.01	2	0.8	0.79
C18:0	3	14.5	28	4.52
C18:1	2.1	5.6	40	40.32
C18:2	10.2	15.5	10	30.42
C18:3	70	37	7	0.52
C20:0	0	0	0	0.1
C22:0	0	0	0	1.35

BMB- Bio-mix biodiesel, BMB-20% waste cooking oil, 20% jatropha oil, and 60% chicken fat oil

Table 2, Biodiesel fuel properties

Properties	WCOB	BMB-I	BMB-II	CFB	JB
Viscosity at 40°C (mm^2/s)	5	4.2	4.5	4	4.72
Density (kg/m^3)	889	880	883	877	879
CN	51	58	57	62	55
CV (MJ/kg)	39.8	39.4	39.52	40.2	38.45
Flash point (°C)	165	170	170	170	160
I.V (gI^2/100 g)	175	75	75	60	108
OS (h)	3	7	6.7	9	5.5

CN-Cetane number, CV- calorific value, IV- Iodine value, OS- Oxidation stability, WCOB waste cooking oil biodiesel, CFB- Chicken fat biodiesel, JB- Jatropha biodiesel

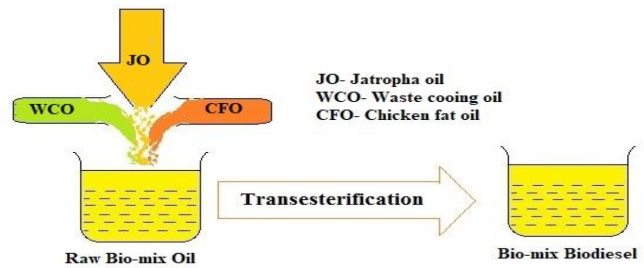

Fig. 1 Bio-mix Biodiesel Production Process

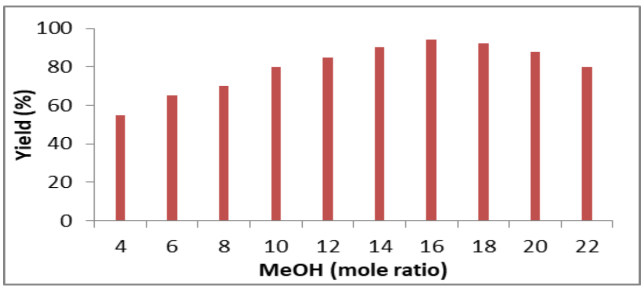

Fig. 2a Effect of methanol ratio on yield percentage

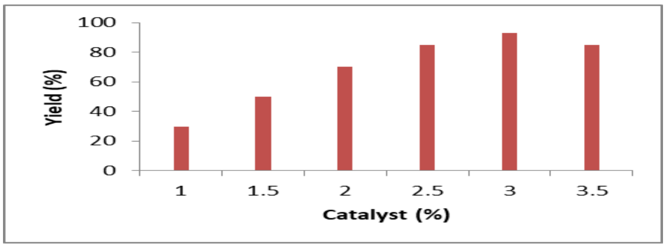

Fig. 2b Effect of catalyst on yield percentage

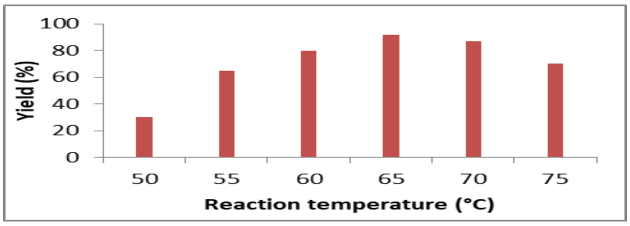

Fig. 2c Effect of reaction temperature

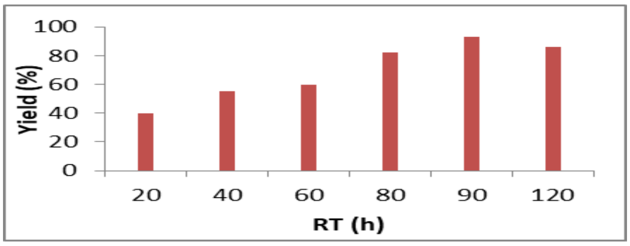

Fig. 2d Effect of reaction time (RT) on yield percentage

2.2 Preparation of bio-mix biodiesel fuel

Bio-mix biodiesel fuel (BMB) was formed from the mixture of raw oils such as chicken fat oil (CFO), jatropha oil (JO), and waste cooking oil (WCOB) as shown in Fig. 1. In this regard, first, raw bio-mix (RBM) oil was formed by the blending of raw oils. Sample raw bio-mix oil (RBMO) was prepared from the mixture of 20% waste cooking oil, 20% jatropha oil, and 60% chicken fat oil. In the Nano-catalyst process, 16:1 methanol to oil molar ratio was used with 3% (wt/wt) $CaCu(OCH_3)_2$ added to the preheated oil at 65°C and stirred for 90 min with a constant stirrer speed of 900 rpm. After the completion of the reaction, the mixture was transferred to the separating flask and allowed to settle overnight for separation of glycerol. Nano-catalyst was settled at the bottom with glycerol. Biodiesel was separated carefully and post-treatment process (washing) was completed. Similarly, individual biodiesel samples also prepared with KOH/methanol followed by the previous process [4].

2.3 Catalyst analysis for yield percentage

It is necessary to analyse the effect of catalyst on yield percentage like methanol molar ratio, reaction temperature, reaction time and catalyst percentage. It is observed that 16:1 methanol molar ratio gives higher yield and beyond that it start reducing as shown in Fig. 2a. The required catalyst % was measured by weight basis (wt/wt%) and it is observed that 3% catalyst (3% of oil weight) gives higher yield as shown in Fig. 2b. The reaction temperature is always plays an important role in heterogeneous catalyst. From Fig. 2c it is observed that 65^{o}C temperature was suitable to get higher yield beyond that methanol starts vaporise and can lower the yield percentage. Reaction time is also important for heterogeneous catalyst to obtain higher yield. It is found that 90 min time was sufficient to obtain required yield percentage as shown in Fig. 2d.

3 Experimental Setup

A single cylinder, four-stroke, water cooled, direction injection compression ignition (DICI) Kirloskar TV1 engine was used in this study. The engine was coupled with an eddy current dynamometer. The specifications of the engine are shown in Table 2. HORIBA (MEXA 584L) gas analyzer was used to measure exhaust emissions. AVL 437c smoke meter was used to measure the smoke opacity. All the biodiesel samples were tested under three load conditions (0%, 50% and 100%) at a constant speed of 1500 rpm and a compression ratio of 17.5:1, injection pressure 205 bar and injection angle 23^{o}bTDC.

4 Results and discussion

4.1 Fuel Properties:

It is necessary to know physical and chemical properties of fuel prior to the test in an IC engine. The measured fuel properties of biodiesels are given in Table 2. Fatty acid methyl ester profile of biodiesel was obtained from GC-MS analysis.

The density of bio-mix biodiesel fuel was found lower than individual biodiesels due to the lower number of C=C double bond as given in Table 1. Lower the density of fuel better will be its spray structure and combustion [4-7]. Density was measured from the hydrometer (BIS IS1448). The density of BMB-I was reduced by 1.01% compared to WCOB and increased by 0.34% and 0.11% than CFB and JB.

Viscosity was measured from the redwood viscometer (BIS IS1448). Higher viscosity creates resistance to the fluid flow which deforms by either tensile stress or shear stress. Higher viscosity leads to poor atomization, vaporization and spray penetration results in poor combustion and emissions [4,5,6,7]. The viscosity of BMB-I and BMB-II are measured 4.2 mm^2/s and 4.5 mm^2/s as shown in Table 2. It is observed that the viscosity of BMB-I is reduced by 10%, and 5% than WCOB and JB respectively.

The calorific value (CV) of the fuel refers to the heat of combustion of the fuel. Higher unsaturation percentage or number of C=C double bonds increased the heating value of biodiesel [4,5,6,7]. Lower CV value means engine requires more fuel to maintain the constant speed at a particular load, hence increases the fuel consumption [4,5,6,7]. The CV of all the samples was measured by Bomb calorimeter (BIS IS1448-6). BMB consists of higher SFA% and lower C=C double bonds which reduced the heating value of RBM. The CV of BMB-I and BMB-II were measured to be 39.4MJ/kg and 39.52 MJ/kg as given in Table2. The CV of BMB-I was found to be 1%, 2%, and 2.5% lower than WCOB, CFB, and JB.

Cetane number (CN) is referred to ignition quality of the fuel, higher CN means better combustion particularly during cold starting conditions [4,5,6,7]. A Lower CN fuel refers to longer ignition delay (ID) time which increases the in-cylinder temperature hence increased the NOx emission [6,7]. CN of biodiesel is higher than diesel fuel due to the presence higher saturated fatty acids (SFA) level and longer carbon chain length. Increases the SFA and carbon chain length, increased the CN of biodiesel [4,5,6,7]. CN of all the fuel samples was measured by IQT (ASTM D6890). CN of BMB was found higher than individual biodiesel due to higher SFA% and lower number of C=C double bonds. CN of BMB-I and BMB-II were 58 and 57 respectively as given in Table2. CN of BNB-I increased by 13%, and 5% than WCOB and JB but 6.89% lower than CFB respectively.

Iodine value (IV) of biodiesel refers to the degree of unsaturation and the upper limit fixed by European standards EN14214 is <120 whereas no limit is fixed by the US and Indian Standards. The main reason for restricting this value is due to the tendency of high iodine value to polymerization during combustion [5,6,7]. Iodine value (IV) is reduced with increases the SFA%, higher the SFA lower the IV. IV of all the fuel samples was measured by titration method (BIS IS4276). The measured IV of BMB-I and BMB-II were 120gI^2/100g as shown in Table2. IV of RBF-I was observed to be 57.14%, 30.55% lower than WCOB, JB but 20% lower as compared to CFB.

Oxidation stability (OS) is an important fuel property with respect to storage stability and performance of biodiesel fuel. Unstable fuel leads to increased viscosity and acid value, the formation of gum or sediment [6,7]. OS is strongly influenced by unsaturation level of FAME, generally higher the unsaturation, lower the OS [6,7]. OS of BMB was observed 7h and 6.7h as given in Table 2. It is because of higher SFA%. OS of BMB increased by 47.14% and 21.42% than WCOB and JB but 22.22% higher than CFB.

4.2 Engine Emission Analysis

From Fig. 3, it is observed that samples CFB and BMB-I shows the lowest NOx emission at all the engine load conditions (0%, 50%, and 100%) as compared to JB and WCOB biodiesel due to higher SFA, cetane number and low viscosity. On the other hands, WCOB and JB show high NOx emission at all engine load conditions due to a higher degree of unsaturation (DU) [8,9]. Higher CN advanced the start of combustion which reduced the ignition delay (ID) period. A shorter ID allows less fuel to burn in pre-mixed combustion phase and prolongs the diffusion combustion phase which reduced the in-cylinder temperature. Results in lower thermal NOx formation [8,9,10].

Smoke emission is a visible indicator of incomplete combustion due to rich mixture formation at full load condition [8,9,10]. Smoke opacity for bio-mix biodiesel and single fuel biodiesel are shown in Fig. 3. Smoke opacity for CFB and BMB-I was found lower than the WCOB and JB at 0% load and full load (100%) respectively. Smoke increases with increases in load due to the mass of fuel per stroke increased with increase in load.

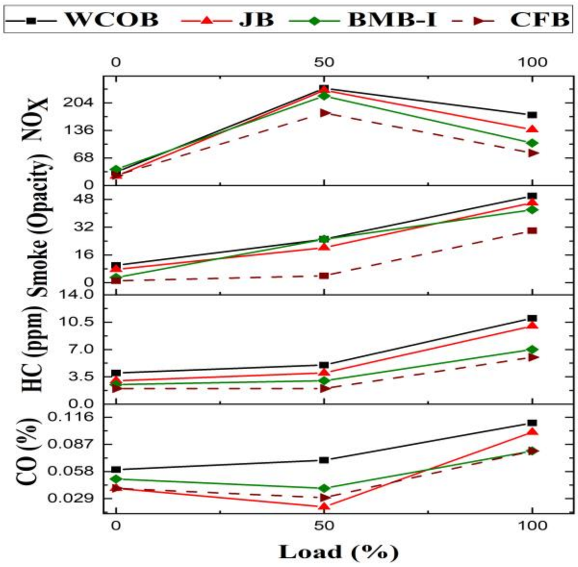

Fig. 3 Emission analysis

Regarding, the formation of CO emission in IC engine refers to incomplete combustion due to lower oxidation temperature and residence time required for oxidation of CO to CO_2 [8,9,10]. CO for bio-mix biodiesel and single fuel biodiesel are shown in Fig. 3. CO was found higher for WCOB at all the engine loads due to higher viscosity and density, increased fuel mass per stroke and less residence time for oxidation. Meanwhile, fuel properties like density and viscosity also influences the CO formation. Sample CFB, BMB-I and JB shows the lower CO emissions at all the engine load conditions as compared to WCOB.

HC emissions also increased with increase in the engine load due to increased fuel mass per stroke [8.9.10]. HC emission was found lower for CFB and BMB-I but it is higher for WCOB and JB at all engine load conditions as shown in Fig. 3.

5 Conclusions

The production of bio-mix biodiesel fuel and its emission behavior on a single cylinder diesel engine were investigated in this study. Fuel Properties of the bio-mix biodiesels were improved through the blending proposition. Saturated fatty acids (SFA), cetane number, and calorific values were increased whereas, viscosity and iodine value was decreased. All the emissions NOx, Smoke, CO, and HC were found to be lower for CFB and BMB-I as compared to WCOB and JB. The overall conclusion of this study is, blending of waste cooking oil and chicken fat with fresh non-edible oil is the new and novel approach to utilize our wastage effectively. Bio-mix biodiesel samples give overall better performance as compared to single biodiesel. This study suggested that bio-mix model could be the alternative replacement of diesel fuel.

6 REFERENCES

[1.] Amir Awaluddin, Saryono, Adhy Prayitno, and Tearful Amri, "Transesterification of Waste Chicken Fats for Synthesizing Biodiesel by CaO as Heterogeneous Base Catalyst" International Conference on Energy and Sustainable Development: Issues and Strategies, (2010), Pp.1-5.

[2.] S.A. Kochewada, Y.P. Gadekarb, L.R. Meenac and Sanjeev Kumard. Meat Production in India-A Review, International Journal of Animal and Veterinary Sciences | Year-2017 | Volume 04 | Pages 24-29.

[3.] Ravi Teja Mandapaka, Prasanna Kumar Kukkamalla. Food Safety Evaluation and Food Waste Management – An Indian Perspective, RRJFPDT | Volume 3 | Issue 2 | April-June, 2015

[4.] A.E.Atabani, A.S. Silitonga, H.C.Ong, T.M.I. Mahila, H.H. Masjuki, Irfan Anjum Badruddin, H. Fayaz, 2013, Non-edible vegetable oil: A critical evaluation of oil extraction, Fatty acid composition, biodiesel production, characteristics, engine performance and emissions production. Renewable and Sustainable Energy Reviews 18, 211-245.

[5.] A. S Ramadhas, S. Jayraj, C. Muraleedharan, Biodiesel production from high FFA rubber seed oil, Fuel 84 (2005) 335-340.

[6.] Md. Amin Ruhul, Md. JoynulAbedin, S.M. AshrafurRahman, Bin Haji Hassan Masjuki, Abdullah Alabdulkarem, Md. AbulKalam, Islam Shancita, 2016, Impact of fatty acid composition and physicochemical properties of jatropha and Alexandrian laurel biodiesel blends: An analysis of performance and emission characteristics. Journal of Cleaner Production 133 (2016) 1181-1189.

[7.] Abdelrahaman B. Fadhil, Emaad T.B. Al-Tikrity, Mohammed A, Albasree. Biodiesel production from mixed non-edible oils castor seed oiland waste fish oil. Fuel 2010(2017) 721-728.

[8.] Chetankumar Patel, Krishn Chandra, Joonsik Hwang, Rashmi A, Agarwal, Neeraj Gupta, Choongsik Bae, Tarun Gupta, Avinash Kumar Agarwal. Comparative compression ignition engine performance, combustion and emission characteristics and trace metals in particulates from waste cooking oil, jatropha and karanja oil derived biodiesels. Fuel 236 (2019) 1366-1376.

[9.] P. Tamilselvam and G. Nagrajan. Combustion and emission characteristics of a diesel engine fuelled with biodiesel having varying palmitic acid, stearic acid and oleic acid in their fuel composition. Int. J. Oil, Gas and Coal Technology, vol. 8, No. 3, 2014.

[10.] R Sathiyamoorthi, G. Sankaranarayanan, S.B. Adhith Kumaar, T. Chiranjeevi, D. Dilip Kumar. Experimental Investigation on performance, combustion and emission characteristics of a single cylinder diesel engine fuelled by biodiesel derived from Cymbopogon Martinii. Renewable Energy 132(2019) 394-415.