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Production and Physico-chemical Characterization of Biodiesel from Waste Cooking Oil Available in Bangladesh

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ABSTRACT

High production cost can be considered as the prime challenge for the commercial biodiesel production. However, it can be minimized by manufacturing biodiesel from low-cost and locally available sources and waste materials. Here, biodiesel was produced from waste cooking oil (WCO) through transesterification process using base catalyst. Optimization of the production process showed that the yield was found up to a maximum of 96.87% under the condition of 60 °C reaction temperature, 90 min reaction time and addition of 50 wt.% methanol and 0.8 wt.% NaOH (both are on the basis of wt. of WCO) in the WCO. Physico-chemical parameters e.g., viscosity, density, acid value, pour point, flash point etc. of of the produced Waste Cooking Oil Biodiesel (WCOB) were determined and compared with petroleum diesel and biodiesel standard suggested by ASTM. Engine performance involving the fuel consumption test of the produced WCOB blended with commercial diesel were also carried out. The experimental study indicates that WCO can be used as one of the alternative sources of suitable raw material to produce biodiesel (WCOB) in an economic way.

Keywords: Transesterification, Biodiesel, Waste Cooking Oil, Physico-chemical characterization, Process optimization

1. Introduction

Due to the rapid exhaustion and adverse effect of conventional fuels on the environment, alternative renewable sources of energy have become a crying need for all countries [1], [2]. Biodiesel is one of the competitive alternatives to meet this challenge. Biodiesel has several advantages compared to fossil fuels e.g. renewable sources, less toxicity, biodegradable, etc [3]. Moreover, the emission profile of biodiesel is of superior quality than the fossil fuel. Combustion of biodiesel releases less amount toxic carbon monoxide (CO), particulate matters (PM) and some hydrocarbons [4]. Biodiesel is chemically know as fatty acid methyl ester. Vegetable oil or fat is the ester of glycerin and higher fatty acids, which is recognized as triglyceride. The triglyceride can be converted to biodiesel through the reaction with an alcohol (usually methanol), which is generally known as transesterification. A catalyst, usually NaOH, is required to carry out this process. Glycerin is also obtained as the byproduct of transesterification. The schematic diagram for biodiesel production is represented in **Fig. 1**.

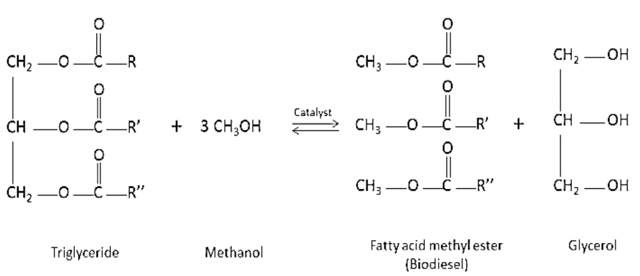

Fig. 1. A simple illustration of transesterification reaction

The major challenge to commercialize biodiesel is the higher cost involved in its production [3]. The price of feed stocks, which are mostly different types of virgin vegetable oil, is fundamentally responsible factors for the higher manufacturing expenses of biodiesel. However, the cost can be minimized with the replacement of virgin oil by locally available low-cost feed stocks for biodiesel production. One of the common feedstocks is Waste cooking oil (WCO), which can play a significant role in this regard as it is less expensive and widely available[5]. Currently, a substantial volume of WCO is generated around the world due to the increase of food consumption by people. It has been reported that the USA generates 4.5-11.3 million liters each year while Japan generates 4×10^5 - 6×10^5 tons each year [6]. Moreover, unused cooking oil is environmentally hazardous [5]. Thus, the management of WCO has become a matter of anxiety worldwide. However, production of WCOB can simultaneously solve the issues of the eco-friendly management of WCO and reduction of biodiesel production cost.

In this work, we are motivated to synthesize biodiesel (Waste Cooking Oil Biodiesel; WCOB) from WCO locally found in Bangladesh. The optimization of the transesterification reaction is carried out based on several parameters e.g., addition (wt.%; based on WCO addition) of methanol and catalyst (NaOH), reaction temperature and reaction time. Different physico-chemical parameters that characterize the quality of biodiesel are also presented with a comparison to conventional diesel and biodiesel standard set by ASTM. Finally, a simple fuel consumption test is conducted for several blending of produced biodiesel and pure diesel.

2. Materials and Methods

Raw material

WCO feed stock was collected from from local cafes, restaurants of Elephant Road area in Dhaka city, Bangladesh. The collected used cooking oil was settled and filtered to remove the residues generated during the burning of food items.

B. Transesterification Reaction

The transesterification reaction was carried out in a batch reactor and the reactor was designed with a 500mL size three-necked round bottom flask. Two of the necks were fitted with a thermometer and a condenser, respectively while the third neck was used to feed the raw material. The three-necked flask was supported with a stand and kept in a water bath for uniform heating. Finally, the water bath with the flask was set on a heater equipped with magnetic stirring facilities.

To produce biodiesel, 100 ml of WCO was taken into three-necked round bottom flask, then 35 - 65% (w/w of oil) methanol and 0.50 - 0.80% (w/w of oil) NaOH were mixed maintaing the reaction temperature of 20- 80 °C and reaction time of 50 - 110 min. The variation in wt.% of methanol, wt. % of catalyst, reaction temperature and reaction time was done to investigate the optimum conditions for biodiesel production. Adding all the required materials (WCO, methanol and NaOH as expected amount) in flask, the reaction mixture was continuously stirred at 400 rpm maintaining the desired time and temperature. Finally, the reaction mixture contained biodiesel, glycerol, unreacted methanol, etc. The produced biodiesel was separated using a separating funnel where the mixture was kept for 12 hours. The upper layer of the mixture contained the biodiesel and the lower layer contained undesired material. The undesired material was separated removing through the exit channel of the separating funnel. Then hot water (60 °C) was used to wash the biodiesel with stirring until neutral pH was obtained and then dried in a rotary evaporator carefully.

The percentage yield of biodiesel after the reaction was calculated by dividing the weight of obtained biodiesel by the weight of WCO, multiplied by 100. Finally, biodiesel was prepared by maintaining the reaction condition at which the highest yield was observed. The optimum condition was found when methanol was 50 wt.% of the WCO, whereas catalyst concentration was 0.80 wt.%. The temperature maintained in the reaction chamber was 60 °C and the reaction was continued for 90 min.

C. Physico-chemical characterization

The physico-chemical parameters including acid value, viscosity, pour point, density, flash point, Sulfide ash content, calorific value (CV) etc. were determined for WCOB. Methods used for the determination of those parameters of waste cooking oil biodiesel are listed in the **TABLE 1**.

Table 1. Methods used for different physico-chemical parameters analysis

Parameters	Methods
Acid value	ASTM-D 974-02
Viscosity at 40^oC	ASTM-D 445-65
Density	IP-160/57
Calorific value	Bomb calorimeter
Flash point	ASTM-D 64-50
Pour point	ASTM-D 97-57
Sulfide ash content	ASTM-D 975-80a

D. Fuel consumption test

The fuel consumption test was carried out simply by measuring engine running time against a fixed volume of fuel (45 mL). The rpm of the engine was fixed at 2600. First, engine running time was calculated for commercial diesel. Then six blending mixtures of diesel and WCOB were prepared. The mixtures were tagged as B-5, B-10, B-15, B-20, B-25 and B-30, which contain 5%, 10%, 15%, 20%, 25% and 30% WCOB respectively. The obtained data was converted into hr/L unit. The fuel consumption test also worked as a reflection of engine performance by all blending mixtures.

3. Results and Discussion

The highest percentage of biodiesel obtained from the WCO was 96.87% at optimum condition. The optimum condition was found by varying following parameters.

Effect of Addition of Methanol

The addition of methanol was an important parameter for the transesterification process i.e., for biodiesel production. Different weight percentages (with compared to the amount of WCO addition) of methanol- 35%, 40%, 45%, 50%, 55%, 60% and 65%, was added for biodiesel production keeping other parameters constant (reaction time: 90 min, temperature: 60 °C and weight percentage of NaOH: 0.8%). The resulting graph is presented in **Fig. 2**. The maximum yield was observed when the amount of methanol addition was 50 wt.% of WCO. However, the yield was found lower when the amount methanol addition was below this concentration due to the lack of sufficient methanol. In contrast, a higher percentage of methanol addition decreses the biodiesel recovery from glycerol [7].

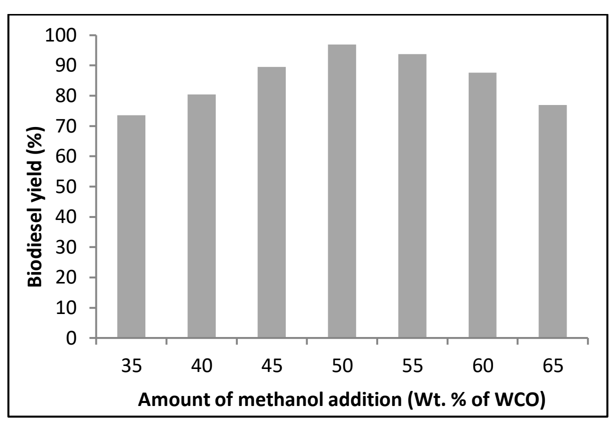

Fig. 2. Variation of yield with the change of methanol addition while other parameters were kept constant (time: 90 min, Temp.: 60 °C and NaOH: 0.8 wt.%)

Effect of Addition of NaOH

In the transesterification process of biodiesel production, sodium hydroxide (NaOH) was used as a catalyst. As a result, the concentration of NaOH had a great impact on biodiesel yield. Seven different doses of catalyst were prepared based on the weight percentage of catalyst to the weight of WCO and showed in **Fig. 3**. They were- 0.50%, 0.60%, 0.70%, 0.80%, 0.90%, 1.0% and 1.1%. Among the tested doses, 0.80 wt.% showed the maximum biodiesel yield. At higher concentration of NaOH, emulsion can be formed. As a result, viscosity increases and finally gel formation occurs[8]. Therefore, biodiesel yield decreases with the increase of the amount catalyst concentration more than 0.80 wt.% of WCO.

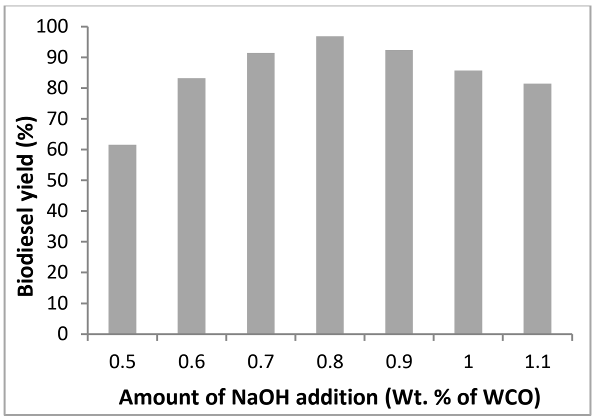

Fig. 3. Variation of biodiesel yield with the change of weight percentage of NaOH while other parameters were kept constant (reaction time: 90 min, Temp.: 60 °Cand methanol: 50 wt.%)

Effect of Reaction Temperature

The effect of temperature on biodiesel yield was studied for every 10°C from 20°C to 80 °Cand presented in **Fig. 4**. The most optimal temperature for WCOB production was found 60°C. The highest yield (96.87%) was found at that temperature. Above 60 °C, the biodiesel yield decreased as higher temperatures caused the evaporation of methanol.

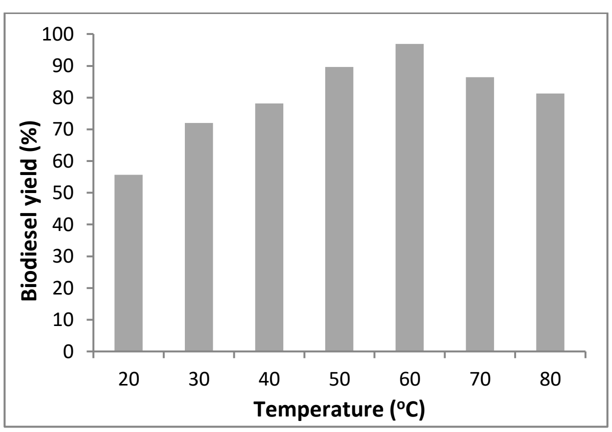

Fig. 4. Variation of biodiesel yield with the change of temperature while other parameters were kept constant (time: 90 min, methanol: 50 wt.% and NaOH: 0.8 wt.%)

Effect of Reaction Time

Reaction time is also an important parameter to optimize a process as lower reaction time gives less product and higher reaction time increases the cost of production. Here, seven reaction times (50 min, 60 min, 70 min, 80 min, 90 min, 100 min and 110 min) was used in order to find out the optimum reaction time. From **Fig. 5**, it is quite evident that the most optimal reaction time for this process was 90 min. However, increasing the reaction time more than 90 min lowered the yield of biodiesel production as it increases the rate of backward reaction.

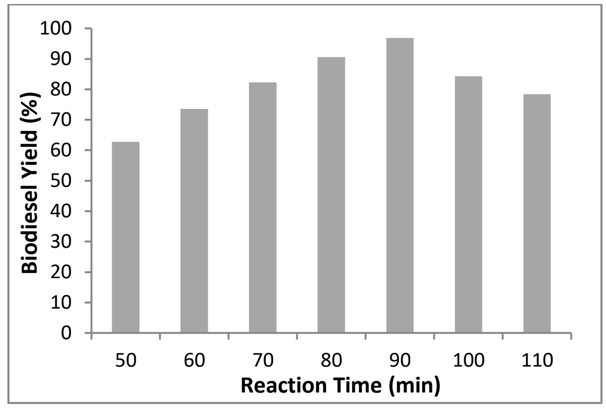

Fig. 5. Variation of WCOB yield with the change of reaction time while other parameters were kept constant (temp.: 60 °C, methanol: 50 wt.% and NaOH: 0.8 wt.%)

Physico-chemical Characteristics of WCOB

To evaluate the quality of Waste Cooking Oil Biodiesel (WCOB), physico-chemical characterization of the produced oil was performed. All the determined parameters are presented in TABLE 2 and the analytical results clearly indicate that the produced WCOB can be used in the internal combustion (IC) engine. Viscosity of the biodiesel is one of the primary parameters for the determination of suitability of produced biodiesel in an IC engine. The higher viscosity results in less atomization of biodiesel which brings about incomplete combustion and deposition of unnecessary material during injection and also promotes polymerization reaction of unsaturated fatty acids [9]. The viscosity of WCOB was found 4.62 cSt which satisfies the value set for biodiesel by ASTM. The density of WCOB was found 0.86 gm/cm^3, which is also in the range of biodiesel standard and slightly lower than petroleum diesel. The lower density of biodiesel reduces fuel consumption and NO_x emission[10].

Pour point, reflects the characteristic of fuel at lower temperatures, is the temperature below which a fuel loses its ability to flow [11]. WCOB biodiesel had a comparatively higher pour point that was in the range set for biodiesel (-15 to 16) but higher than the petroleum diesel (-2). This indicates that WCOB cannot be directly applied in the low-temperature region. Flash point, the minimum temperature to ignite a fuel, is another important parameter of fuel. A higher flash point ensures the safety during ignition [12]. The flash point of WCOB was found

92°C, which is slightly lower than the biodiesel standard, but higher than the commercial diesel.

Acid value, denotes the amount of KOH required for neutralization of 1g of biodiesel, signifies the amount of free fatty acid present in a sample. The presence of higher amount of free fatty acid in biodiesel can break the lubrication system with an increased rate of corrosion [13]. Calorific value (CV) of a fuel is also a key factor to understand the amount of energy released by a specific fuel. Usually, biodiesel shows calorific value of ~ 40 MJ/Kg while the calorific value obtained from conventional diesel (44.5 MJ/Kg)[14]. In this study, the calorific value of WCOB was found 35.16 MJ/Kg. Though this value is lower than that of the standard biodiesel and conventional diesel, it is still higher in comparison to some other common biodiesel produced from different feed stocks e.g., rubber seed oil (32.6 MJ/Kg) [15], palm kernel oil (34.75 MJ/Kg), babassuoil (31.8 MJ/Kg) [16], etc. The lower calorific value of the produced biodiesel was due to presence of higher oxygen content in WCOB composition. However, the presence of higher oxygen content in WCOB greatly contributes in complete combustion of fuel which ultimately results in lower CO emission compared to petroleum diesel [17].

F. FTIR Study of the Produced Biodiesel (WCOB)

Fourier Transform Infrared Spectroscopy (FTIR) was employed in order to investigate the available functional groups present in the WCOB. The obtained FTIR graph of WCOB is illustrated in **Fig. 6** and the detected peaks are listed in **TABLE 3** with corresponding functional groups. Peaks at 1161.15 cm^{-1}, 1234.44 cm^{-1} and 1743 cm^{-1} indicate the presence of esters (*i.e.*, biodiesel) in the WCOB sample.

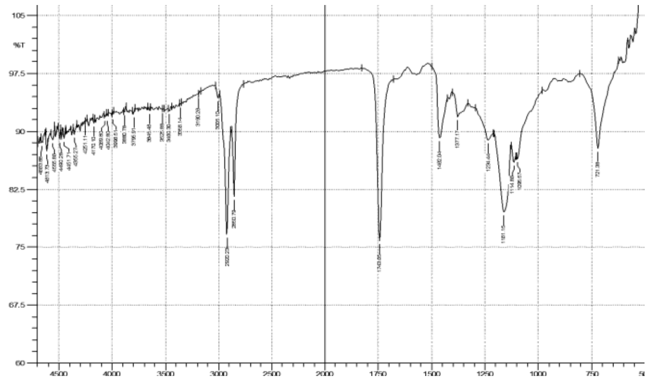

Fig. 6. FTIR Spectra of WCOB

G. Engine Performance Study of WCOB

The fuel consumption test was carried out to understand the perforamance of the produced biodiesel. Biodiesel cannot be used alone in an engine considering the facts of high production cost and lower calorific value of produced biodiesel as well as the requirement of the modification in the existing IC (Internal Combustion) engines. However, WCOB can be blended (at various ratio) with commercial diesel to reduce the depletion time of petroleum. The result of fuel consumption test of the studied blended mixtures of biodiesel and diesel (B-5, B-10, B-15, B-20, B-25, B-30) and locally collected commercial diesel was showed in Fig. 6. From the figure, it is clear that the commercial diesel (Biodiesel unblended) had highest performance *i.e.*, engine running time was the maximum for one litre fuel. The performance of the blended mixture decreased with the increase of biodiesel percentage may be due to the fact that the WCOB has lower calorific value than the conventional diesel.

Table 2. Physico-chemical characteristics of WCOB

Properties	Unit	WCOB	Biodiesel Standard [18]	Commercial Diesel [18]
Viscosity (40 °C)	cSt	4.62	1.9-6	6.06
Density (40 °C)	gm/cc	0.86	0.86 – 0.90	0.85
Pour point	°C	8.9	-15 to 16	-2
Flash point	°C	92	100 to 170	70
Acid value	mg KOH/g	0.36	0.5 (max)	0.34
Calorific value	MJ/Kg	35.16	40.2	44.5
Sulfide ash content	%	3.85	02	3.5

Table 3. Detected peaks with corresponding functional groups present in WCOB

Peak (cm^{-1})	Functional group
721.8	Inorganic Compounds
1234.44, 1161.15	C-C(O)-C stretching vibration of alcohols and esters [19]
1462.04, 1377.17	C-H bending vibration of alkanes[14]
1743.65	C=O stretching vibration of ketones, carboxylic acid, α, β-unsaturated esters [19]
2920.23, 2850.79	C-H stretching (alkanes)[14]

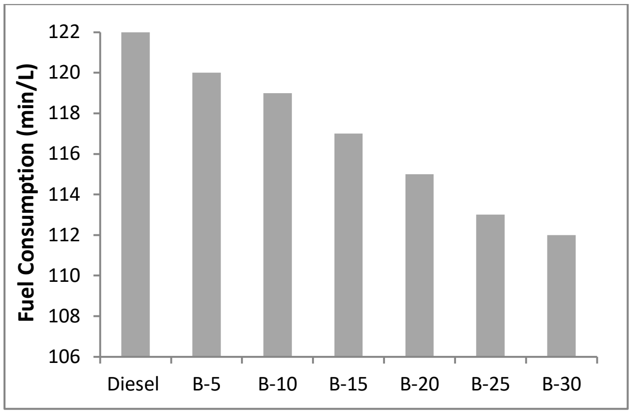

Fig. 7: Fuel consumption behaviour of commercial diesel and WCOB-diesel blended mixtures

4. Conclusion

Biodiesel (WCOB) was successfully produced from environmentally hazardous WCO. The waste cooking oil, which has no significant use, is converted to value added products. Process optimization of transesterification reaction was carried out to identify the most suitable condition for WCOB production. Furthermore, the physico-chemical properties of WCOB were determined which were found comparable with biodiesel standard and commercial diesel. However, the calorific value of the produced WCOB was found slightly lower than that of standard biodiesel. Engine performance study of the WCOB-diesel blended mixtures were also found satisfactory. Considering all these factors, WCO has a great potential to be used as aeco-friendly source for future biodiesel production.

Acknowledgment

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