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Research Article

Comparative Study of Biodiesel Produced from Waste Cooking Oil

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Abstract This experimental study evaluated the production of biodiesel from waste cooking oil for use as a green fuel in diesel engines. Furthermore, it identifies the waste cooking oil (WCO) source that will serve as the preferable feedstock for sustainable biodiesel production. Four different samples: WCO from residential apartment, roadside commercial vendor, fast food restaurant and a composite of all these three sources; were used as feedstock in the esterification and transesterification reactions under identical conditions of 60^{o}C and reaction time of 60mins after acid catalyzed methanolysis of the WCO, carried out to reduce free fatty acids. Concentrated sulfuric acid, 98%was used as catalyst followed by an alkali-based methanolysis of the pretreated WCO to produce biodiesel with potassium hydroxide as catalyst. American Society of Testing and Materials (ASTM) fuel test result analysis of the different samples of biodiesel produced met the standard specifications. Hence, biodiesel from waste cooking oil can conveniently be used in diesel engines either as a blend or pure biodiesel. The production yields were 88.50%, 90.30%, 89.40% and 88.60% for samples A, B, C and D respectively. WCO biodiesel from fast food restaurant is more readily available as a feedstock for biodiesel production than the other WCO sources.

Keywords Green fuels, Waste Cooking Oil, Transesterification, Sustainable, Biodiesel

1. Introduction

The growing concern of climatic change resulting from increased greenhouse gas emissions and global warming continues to pose threat to humanity and has become the most discussed topic in this century. Reliance on fossil fuels as mainstream energy source has been fingered as having gradual damaging effect on the ozone layer that protects the world from the impact of the sun. The rise in prices of petroleum fuel and its increasing threat to the environment have generated international interests in developing alternative, non-petroleum renewable fuels that can support the ever-increasing global energy demand [1]. As a solution to these problems, increased research and investments in green fuels are gradually providing an alternative to fossil fuels. The essential minimum requirement for green fuels to be a more sustainable, alternative to fossil fuels and from renewable raw materials with minimal impact on the environment [2].

Biodiesel is a renewable fuel which is an alternative to traditional petroleum-based diesel fuel. Biodiesel is a mono alkyl ester of long chain fatty acids that is produced from vegetable oils or animal fats (ASTM definition). The most common method employed in biodiesel production from oils is by transesterification, which refers to a catalyzed chemical reaction involving vegetable oil and an alcohol to yield fatty acid esters and glycerol. The use of edible vegetable oil and animal fats as feedstock for biodiesel production has recently been of great concern because of its competition with food materials [3]. The cost of raw materials for production accounts for a large percentage of the direct biodiesel production. Thus, one way of reducing the cost is to utilize less expensive raw materials such as animal fats, non-edible oils and waste cooking oil [4]. Waste cooking oils are defined as used oils generated by the food industry, including restaurants and households,that are no longer fit for human consumption [5-7]. The disposal of waste cooking oil can be problematic when not properly managed

and can cause blockages of sewer pipes when the oil solidifies [8]. The physical and chemical properties as well as the continuous availability of the waste cooking oil significantly influence biodiesel fuel properties and its production [9]. Also, Biodiesel is carbon neutral which makes it an environmental friendly fuel.

Currently, most commercial biodiesel productions are performed by alkali-catalyzed transesterification since it can be operated under mild conditions to achieve significant conversion with minimal reaction time and side reactions. Common catalyst used include: NaOH, KOH, K_2CO_3, etc. However, some biodiesel production suffers from the presence of water and free fatty acids (FFAs) in feed stocks. The presence of water favors the formation of FFAs by hydrolysis of triglycerides and esters products (biodiesel). Formation of Free Fatty Acids in the presence of basic homogeneous catalysts gives rise to soap, creating serious problems for product separation and ultimately hindering catalytic activity. As a result, highly refined vegetable oils are required for the process otherwise pre- treatment is required for the feed stocks to reduce the acid and water concentrations to below optimum threshold limits, i.e., FFAs < 1 wt% and water < 0.5 wt% [10]. Canakci et al developed a two- step catalyzed processes for synthesis of bio-diesel by using waste cooking oil. Here, acid catalyst (usually sulphuric acid) was first chosen to reduce the FFA to less than 1%, then the pre-treated feedstock was transesterified under alkaline catalysis. The advantage of this two-step process relies on the fact that it can increase the reaction rate by using alkaline catalyst and avoid soap formation by applying acid catalyst [11].

The aim of this research is to study the production of biodiesel as an alternative to fossil fuels. Uncertainties in quality and quantity of waste cooking oil feed stock are common issues faced in ensuring a sustainable biodiesel production process. Hence, a comparative study is also carried out via transesterification of waste cooking oil obtained from different facilities: residential apartments, roadside commercial vendors and fast food restaurants. A qualitative analysis is carried out, with a view to determining the feedstock that will favor optimal and sustainable biodiesel production.

2. Methodology

2.1 Materials Used

- Sample A: Waste Cooking Oil (WCO) from a residential apartment
- Sample B: Waste Cooking Oil (WCO) from a roadside commercial vendor
- Sample C: Waste Cooking Oil (WCO) from a fast food restaurant
- Sample D: Waste Cooking Oil (WCO), a composite of samples A, B and C in equal proportion.

2.2 Production of Biodiesel

2.2.1 Esterification of the Waste Cooking Oil

- ❖ Reagents
- 99.9% Methanol, 98% Concentrated Sulfuric acid and Distilled water

Procedure

In the first batch, 150 g of WCO sample was weighed. The measured sample was heated to 60 ^oC. 4.01g methanol was measured out for every gram of FFA in the WCO sample. 0.09 g of conc. sulfuric acid was measured out for every gram of FFA in sample and added the alcohol, gently agitate the alcohol-acid mixture until completely mixed. Then alcohol-acid mixture was added to the 150 g of WCO sample. The mixture was agitate at 60^oC for 1 hour and allow mixture to settle-out. After the mixture cools, drain a sample from the bottom fraction and measure new FFA level via acid value measurement. The same procedure was repeated with samples B, C and D.

2.2.2 Transesterification of the treated Oil

- ❖ Reagents
- 99.9% Methanol, Potassium Hydroxide (KOH) pellets and Distilled water

Procedure

In the first batch, 100 g of WCO was heated at 120 ^oC for 5 minutes to remove the moisture. 1g/100g WCO (1 g of KOH) was weighed and dissolved completely in 22.0 g of methanol, using the hot plate and magnetic stirrer

to form potassium methoxide solution. The potassium methoxide solution formed was added into warm oil (at 60 ^{o}C) and then mixed vigorously using the magnetic stirrer. The reacted mixture was poured into a separating funnel. The mixture was left for 24 hours to allow separation by gravitational settling into a clear golden liquid biodiesel on top and light brown glycerol at the bottom. Glycerol layer was drained off from the separating funnel leaving only crude biodiesel. The crude biodiesel was then purified by washing with warm distilled water to remove residual catalysts and excess methanol. The procedure was replicated three times and average yield of biodiesel and glycerol was evaluated. The same procedure was repeated with samples B, C and D.

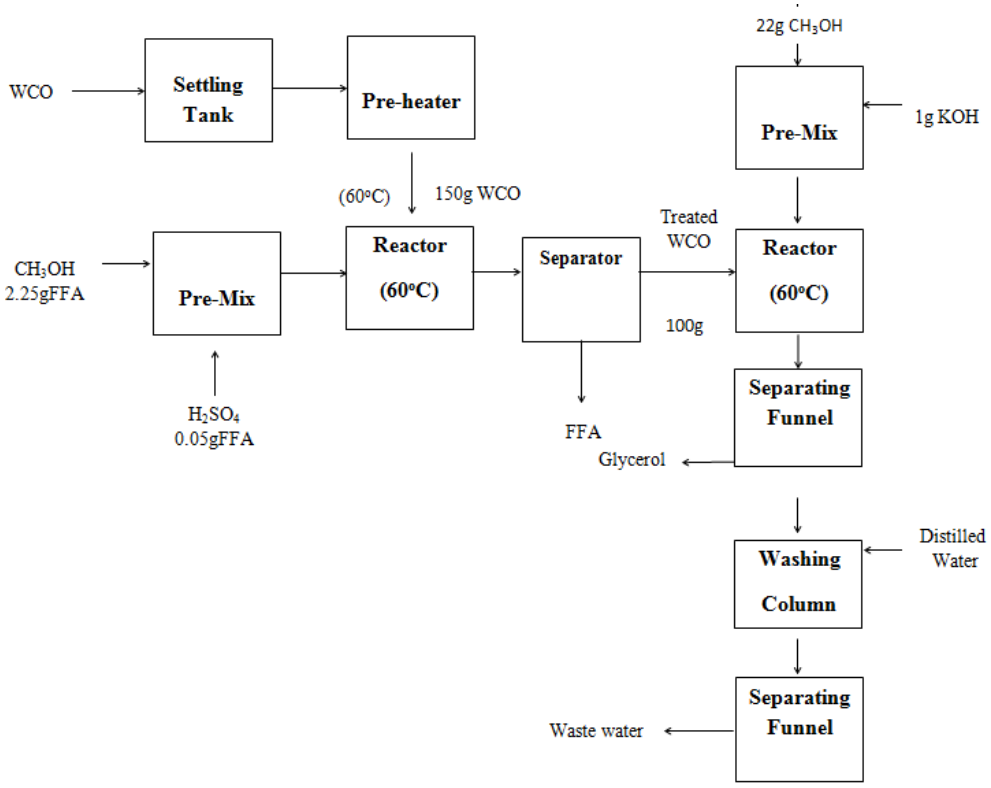

Figure 1: Block diagram for the production of biodiesel from WCO with high FFA

3.0 Results and Discussion

3.1 Waste Cooking Oil Characterization Results

The acid value and free fatty acid value of the waste cooking oil samples were determined experimentally using ASTM D1980 procedure and the values are tabulated below:

Table 1: Acid and Free Fatty Acid Values

Waste cooking oil	Acid value (mg KOH/g)	Free fatty acid value (mg KOH/g)
Sample A	20.91	10.51
Sample B	14.23	7.15
Sample C	11.62	5.84
Sample D	17.65	8.87

Figure 2: Separation of biodiesel (Top layer)

Figure 3: Separation of biodiesel (Top layer) and water (bottom) layer after washing and glycerol (bottom) layer

Figure 4: Pure Biodiesel after washing and drying

Table 2: Results obtained for the four samples of WCO after esterification and transesterification steps

Experimental Materials/Conditions	Average values for the four samples			
	Sample A	**Sample B**	**Sample C**	**Sample D**
Reaction Temperature (^oC)	60	60	60	60
Reaction time (min.)	60	60	60	60
Free Fatty Acid (Mg/KOH)	10.51	7.15	5.84	8.87
WCO quantity (g)	150	150	150	150
Methanol quantity (g) (Esterification step)	42.15	28.67	23.42	35.57
Conc. H_2SO_4 quantity (g)	0.95	0.65	0.53	0.80
Treated Oil quantity (g)	100	100	100	100
Methanol quantity (g) (Transesterification step)	22	22	22	22
KOH quantity (g)	1	1	1	1

WCO biodiesel obtained (g)	88.50	90.30	89.40	88.60
Biodiesel quantity (ml)	99.89	102.18	103.17	100.19
Glycerol obtained (g)	30.80	28.50	29.50	30.90
Losses (g)	2.70	3.20	3.10	2.50
Biodiesel yield (%)	**88.50**	**90.30**	**89.40**	**88.60**

3.2 Biodiesel Quality Results

Table 3: Results obtained from biodiesel quality tests in comparison with ASTM

Quantity	Sample A	Sample B	Sample C	Sample D	ASTM specification	Petro-Diesel
Density @ 15^{o}C (g/mL)	0.8862	0.8837	0.8665	0.8843	0.865-0.885	
Kinematic Viscosity @ 40^{o}C (mm^{2}/s)	4.97	4.63	4.34	4.98	1.9-6.0	1.9-4.1
Flash Point (^{o}C)	170	138	164	158	130min	52min
Pour Point (^{o}C)	-6	-12	-3	-6	Report.	-
Moisture Content	0.05	0.05	0.03	0.05	0.05max	

3.3Discussion

From the table 1, it was observed that the free fatty acid values of the various samples were more than 2%, hence, the justification for pretreatment (esterification) of the waste cooking oil samples for the reduction of the free fatty acids (Zhang et al, 2003).

3.3.1 Biodiesel Yield

Transesterification reaction was carried out for each sample after the pretreatment step at reaction temperature and time of 60^{o}C and 60mins respectively. The results are tabulated in Table 2. The different values of WCO biodiesel yield, glycerol formed and the losses for the four samples are presented in Table 2. The observed yields were 88.50%, 90.30%, 89.40% and 88.60% for samples A, B, C and D respectively. In addition, glycerol (by-product) formed was 30.80g, 28.50g, 29.50g, and 30.90g for samples A, B, C and D respectively.

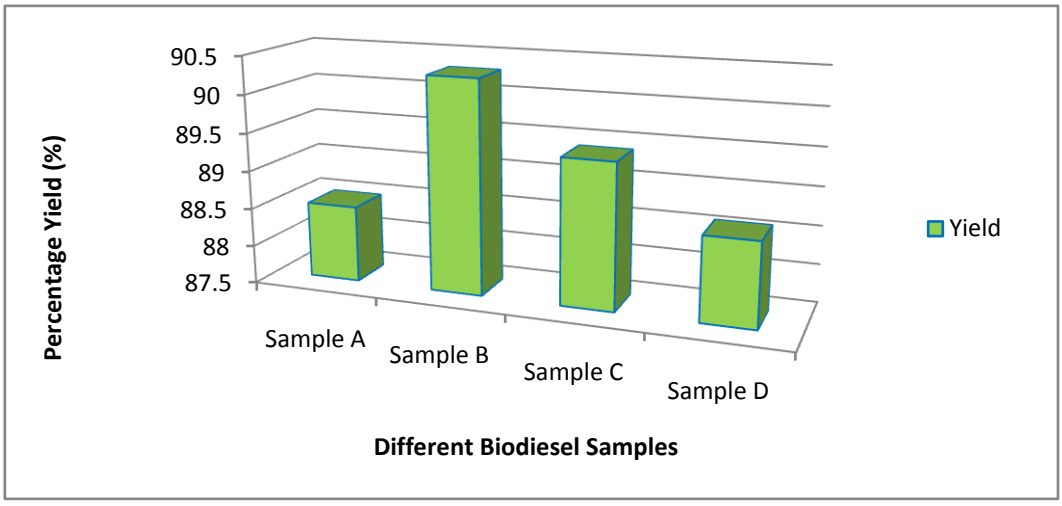

Figure 5: Bar chart showing the percentage yield of WCO biodiesel samples

4.3.2 Fuel Properties

Characterization of the different samples of biodiesel produced was also carried out and the density @15^{o}C, kinematic viscosity @40^{o}C, flash point, pour point and moisture content are contained in Table 3. The results obtained shows that all biodiesel samples met the ASTM specification for biodiesel.

4.3.3. Feedstock Availability

Another consideration is the ready availability of WCO from the different sources to ensure a sustainable production. A research was conducted by distributing questionnaires that were filled by the appropriate personnel at the place of collection of WCO samples. The data collected shows that fast food restaurants provided the most amounts of WCO that can be available for continuous running of a biodiesel production plant using WCO as feedstock. This was based on the amount of WCO generated. The quantity of WCO obtained from roadside commercial vendors and residential homes cannot match the need for the continuous supply of feedstock for optimal running a biodiesel production plant. Also, the biodiesel yield obtained from the fast food restaurant WCO sample will be more stable since operational guidelines would maintain the level of re-use of the cooking oil. This cannot be said of residential and roadside side vendor whose practices are unpredictable.

5. Conclusion

Waste cooking oil obtained from different sources (a residential apartment, roadside commercial vendor and a fast food restaurant) were subjected to identical conditions of 60^{o}C and reaction time of 60mins for esterification with methanol and concentrated sulfuric acid as catalyst. This was done because of high free fatty acids contained in the oils. Transesterification reaction involving the use of 22g of methanol and KOH as catalyst at concentration of 1g per 100g WCO was also carried out. From the technical assessment, all of these WCO sources proved to be feasible for producing a high quality biodiesel product and glycerine as a by-product with production yields of 88.50%, 90.30% and 89.40% respectively. Hence, biodiesel produced from waste cooking oil can conveniently be used as a green fuel for diesel engines. Furthermore, WCO obtained from fast food restaurants are more readily available as a feed stock for biodiesel production than other WCO sources. This will ensure the sustainability of biodiesel for its use in diesel engines either as a blend or B100. Quality assessment of biodiesel produced from fast food restaurant gave a specific gravity @15^{o}C of 0.8665, kinematic viscosity at 40^{o}C of 4.34mm^{2}/s, flash point of 168^{o}C, pour point of -3^{o}C and a moisture content of 0.03. This is well within the quality standard of fuels for diesel engines.

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