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Biodiesel from Household/Restaurant Waste Cooking Oil (WCO)

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Abstract

The use of waste cooking oil (WCO) from extended household and restaurants was considered as a suitable feedstock for biodiesel production in this paper. The paper also focuses to showcase the qualities of biodiesel produced from WCO compared to that of other virgin oil. The oil that was supposed to be disposed, at times indiscriminately was de-odoured and purified using appropriate solvents. The purified oil was characterized and used for biodiesel production. The physical and fuel properties such as density, viscosity, cloud point, pour point, cetane number etc were determined according to ASTM standards. The properties obtained were not only comparable with that of others but also within standard limits.

Keywords: WCO; Biodiesel; Cloud point; Pour point; Cetane number; ASTM

Abbreviations: WCO: Waste Cooking Oil; ASTM: American Society for Testing and Materials; API: American Petroleum Institute

Introduction

Biodiesel, a renewable fuel made by trans-esterification of vegetable oil with alcohol, is becoming more readily available for blending with conventional diesel fuel for use in transportation applications. Fossil fuels such as petroleum, coal and natural gas, which have been used to meet the energy needs of mankind are associated with negative environmental impacts such as global warming [1,2]. Similarly, the fossil fuels accumulated over series of geological activities are irreversibly consumed at a rate more than million times faster than they were formed [3]. This has left us in a precarious position especially for petroleum products. The hike in price of petroleum and its products, both in national and international scenes is frequent for two reasons; the mounting demands and fast depletion of reserves [3] the duo of which call for alternative source of energy. Similarly in developing countries, the price paid for petrol, diesel and petroleum products now dominates over all other expenditures and forms a major part of country's import bill. Biofuel/Biodiesel made from natural oils and fats is being considered as a promising substitute for petrol diesel. Although biodiesel cannot entirely replace fossil fuel, the following reasons however further justify its development.

- It provides a market for excess production of vegetable oils.
- It decreases the dependence on imported petroleum.
- It does not contribute to global warming due to its closed carbon cycle.
- The exhaust emissions of carbon monoxide, unburned hydrocarbons and particulate emissions from biodiesel are lower than fossil fuel [4].

Though much has been done in the area of biodiesel production especially with the use of various feed stock; soya bean oil, corn oil, peanut oil, olive oil, cotton seed oil, safflower, rape seed oil/canola, line seed oil, sunflower, coconut oil, palm kernel oil, jathropa seed oil etc as further evidenced in the report of [5,6] but still, few research has been carried out on the use of WCO for biodiesel production.

The conversion of vegetable oil carried out by [7] under optimized conditions in presence of co-solvent (n-hexane) obtained with solid base catalyst Na/NaOH/ γ - Al_2O_3 is comparable to that obtained with conventional homogeneous NaOH catalyst. Heterogeneous solid oxide catalysts of the type $(\text{Al}_2\text{O}_3)_4$ (SnO) and $(\text{Al}_2\text{O}_3)_4$ (ZnO), have been examined by [8] for the transesterification of vegetable oil using different chain length alcohols. The highest yield of 84% was observed with methanol. Also, [9] found that calcined Mg-Al hydrotalcite at 400°C was most effective catalyst for the transesterification of jatropha oil, obtaining conversion of jatropha oil of 96%. Sathivel ultimately feels that biodiesel production from waste salmon oil holds promise because the biofuel represents a use of a currently under-utilized resource—and salmon oil biodiesel burns more cleanly and efficiently than pure salmon oil [10]. Recently, report in the literature showed that satisfactory result was obtained when the mixture of canola oil and used cooking oil was used as feedstock for biodiesel production [11]. Biodiesel production with biocatalyst produced biodiesel with a very high degree of purity [12]. Different lipases, such as *Candida Antarctica* [13], *Pseudomonas cepacia* [14] and *Thermomyces lanuginosus* have been employed as biocatalysts in the production of biodiesel from vegetable oil.

Huge quantities of waste cooking oils are generated in the developed countries as contained in Table [15]. Management of such oils poses a significant challenge because of their disposal problems and possible contamination of the water and land resources. Even though some of this waste cooking oil is used for soap production, a major part of it is discharged into the environment. The Energy Information Administration in the United States estimated that some 100 million gallons of waste cooking oil is produced per day in USA, where the

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average per capita waste cooking oil was reported to be 9 pounds [16]. Waste oil has the potential to become a new source of high-oleic oil and its full potential should be exploited beyond being a suitable way to reuse waste materials [17]. The total waste cooking oil produced in Canada could be approximately 135,000 tons/year. In the EU countries, the total waste cooking oil production was approximately 700,000-1,000,000 tons/yr [18]. UK produces over 200,000 tons of waste cooking oil per year [19]. As large amounts of waste cooking oils are illegally dumped into rivers and landfills, causing environmental pollution [20], the use of waste cooking oil to produce biodiesel as petro-diesel substitute offers significant advantages because of the reduction in environmental pollution. This work therefore focuses on the appreciation and workability qualitatively and quantitatively of transition from the use of virgin oil to spent cooking oil in biodiesel production under catalyzed conditions and the determination of the fuel properties of the waste oil produced biodiesel. In addition, further analysis was also carried out in this work on the waste oil [15].

Methods and Materials

The vegetable oil after been used to fry large size fish several times for a considerable number of days in an extended household in Lagos metropolis of Nigeria (Latitude 6.5833 and Longitude 3.75) was collected in a 2 litre bottle. The oil was de-odoured and purified.

Purification of spent oil

Accurately prepared 0.73% NaCl was poured in the spent oil contained in a separating funnel and shaken rigorously for about 15 minutes. After allowed to settle by gravity, the bottom sediments were removed. A mixture of Chloroform, Methanol and 0.58% NaCl in the ratio 5:48:47 was added to the partially purified oil in the separating funnel. Shaking took place for another 15 minutes followed by gravitational settling and later removal of the second sediments. The purified oil was poured in a beaker of wider surface area and placed in a water bath for any residue solvent to escape. The oil was kept for further analytical tests and the eventual trans-esterification reaction.

pH: The pH of the spent oil was determined using table pH meter.

Density: The density of the oil was determined using a density bottle at 25°C and this is the ratio of the mass of the oil to its volume.

Solvent Miscibility: Solvent miscibility of the oil was determined by physical observation of the uniform blending of oil samples in acid (HCL), alkali (NaOH), sodium hydrogen carbonate solution, ether and water at room temperature.

Congeeing temperature: The congealing temperature of the oil was determined crudely by putting 20ml of the dried oil sample in a 100ml beaker and inserting a simple laboratory thermometer into the oil and putting it in a freezer. The oil sample was closely monitored as the temperature reduces. The temperature at which the initial fluid oil sample starts getting jelly was noted, and the temperature at which gelation took place within the oil was also noted and an average of the two gave approximate congealing temperature.

Further process details

Titration process: The essence of the titration process is to get the number of gram of NaOH that will be used per liter of oil in the transesterification process. This will give a rough guide on the amount of catalyst that will give an optimum yield. 1gram of NaOH was dissolved

in 1 liter of distilled water (0.1%NaOH) solution. Phenolphthalein solution was used to get the end point. In a smaller beaker, 1ml of WCO oil is dissolved in 10ml of pure isopropyl alcohol. The beaker was warmed gently by standing it in some hot water, stirred until all the oil dissolves in the alcohol and the mixture turns clear. 2 drops of phenolphthalein solution was added. Using a burette, 0.1% NaOH solution was added drop by drop to the oil alcohol phenolphthalein solution, stirring all the time, until the solution stays pink for 10 seconds. The number of ml of 0.1% NaOH solution used added to 5.0 will give the number of NaOH to be used per liter of oil [21].

Heating of oil: 43g of the oil in a beaker was pre- heated to about 60°C using heating mantle with temperature range of 0-100°C to further reduce the reaction time.

Mixing of methanol and catalyst: Less than 1g of NaOH (Lye) as roughly described by the titration process was added to methanol (about 60% in excess) prior to methanolysis of the heated oil. Continuous agitation for 90 minutes using shaker was done to ensure complete dissolution of the lye catalyst.

Transesterification (biodiesel reaction): The methanol in excess was added to the pre- heated oil in a 250ml beaker serving as a batch reactor. The mixture was agitated in a shaker at 200rpm for 90 minutes and then left overnight for phase separation to take place due to gravity. A yield of about 30% was obtained; though it can be greatly improved

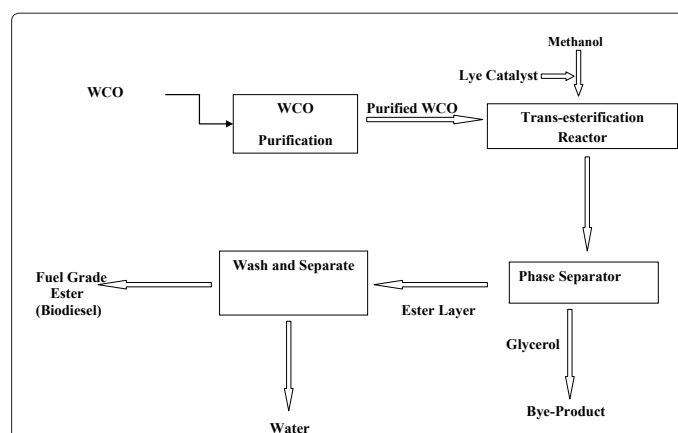


Figure 1: Biodiesel Manufacturing Flow Sheet From Waste Cooking Oil (WCO).

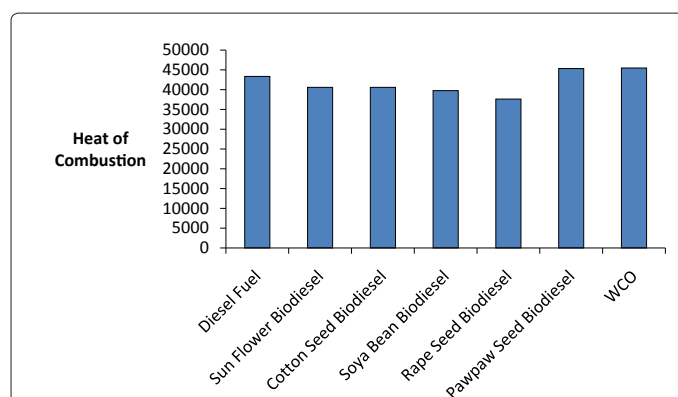


Figure 2: Comparison of Heat of Combustion of WCO biodiesel with other biodiesel fuel.

by tampering with the process thermo-kinetics conditions. This aspect is on-going and shall be separately published. The flow chart indicating the detailed experimental algorithm is stated in Figure 1 while Figure 2 & Figure 3 indicate the WCO undergoing purification and the produced biodiesel respectively.

Washing of fuel: This was done using a small quantity of water. (a misting of water over the fuel, draining water off the bottom).The purpose is to wash out the remnants of the catalyst and other impurities. The washing process was repeated for several times until the washed water became clear. The clean biodiesel was dried in an incubator for 48h. The final product was analyzed to determine its fuel properties.

Fuel properties of oil

Specific gravity, density & API (America Petroleum Institute) gravity: Density is the mass of unit volume of a material at a specific

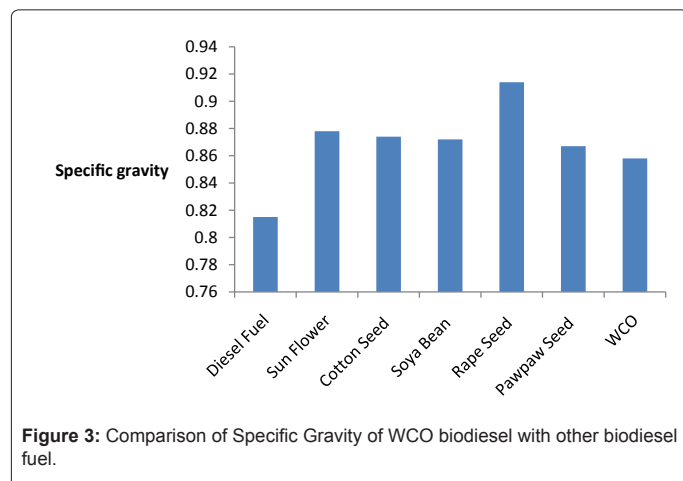


Figure 3: Comparison of Specific Gravity of WCO biodiesel with other biodiesel fuel.

Restaurant	Years in Business	Volume of Waste Oil Disposed Per Month In Gallons	Amount Paid For Disposal Per Month in Dollars
Miraku	1	117lbs	Free
Sandy's Place	1year 2 months	80	Free
Las Magarita	5	100	120
Moraghot	2.5	160lbs	Free
Boston Market	8	100	150
JP Gators	20	50lbs	Free
Napolatano	12	300lbs	<10
Calypso Bar & Grill	1.5	72-80	Free
El Toro	14	600lbs	40
Mildred's Cafe	8.5	30	Free
Chik-Fil-A	24	1052lbs	Free
Kotobuki	14	600lbs	Free
Ballyhoo Bar & Grill	3	3400lbs	511-550 per year.
Porter's	4	20	80
Clara's	1	420	150
Hot Wok	10 months	100	230
Mr.Han's Restaurant & Night Club	17	140	60
Miya Sushi	8	12	100
Timber Creek Steakhouse	12	560	130

Table 1: Selected Restaurants in the City of Gainesville (U.S.A) to Determine Supply Lines for Waste Cooking Oil.

Test	Result
P ^H	3.91
Specific Gravity	0.895
Congeaing Temperature	11°C
Solvent Miscibility	Miscible with ether

Table 2: Results of the Waste oil characterization.

temperature. A more useful unit used by the petroleum industry is specific gravity, which is the ratio of the weight of a given volume of a material to the weight of the same volume of water measured at the same temperature. Specific gravity is used to calculate the mass of oils. The API (American Petroleum Institute) gravity is another way to express the relative masses of oils. The API gravity could be calculated mathematically using the equation:

$$^{\circ}API = \frac{141.5}{Sp.Gr60 / ^{\circ}60F} - 131.5.$$

A low API gravity indicates heavier oil, while a higher API gravity means a lighter

crude or product. Specific gravities of crude oils roughly range from 0.82 for lighter crudes to over 1.0 for heavier oil.

Flash point: This is the minimum temperature at which the vapour from oil sample will give a momentary flash on application of a standard flame under specific test conditions. This is used to predict the possible fire hazard during transportation, storage and handling.

Pour point, Cloud point: The pour point of a crude oil or product is the lowest temperature at which oil is observed to flow under the conditions of the test. Handling and transporting oils and heavy fuels is difficult at temperatures below their pour points. Often, chemical additives known as pour point depressants are used to improve the flow properties of the fuel. The temperature at which wax crystals begin to form on the surface of the biodiesel is the cloud point.

Aniline point, Diesel Index: Aniline Point is the minimum temperature at which equal volumes of anhydrous aniline and oil mix together. A low aniline point indicates low diesel index. Diesel index is a measure of ignition quality of a fuel. Aniline point can also predict the amount of carbon present in the oil as given by the equation

$$\%C = 1039.4n_D^{20} - 470.4d_{20} - 0.567AP(^{\circ}C) - 1104.42.$$

Where n_D^{20} = Refractive index at 20°C and d_{20} = Density at 20°C.

Cetane Number: This is a corollary of the Index Number.

Heat of Combustion: The amount of heat evolved when 1 mole of the biodiesel is burnt.

Viscosity: This is the resistance to flow of oil. Ease of starting depends on viscosity.

Results and Discussions

Conclusion and recommendation

Table 1 shows selected restaurants in some part of the world and the volume of WCO generated. This will determine the supply lines for waste cooking oil. The purified WCO was used for biodiesel production. Specific gravity, cetane number, diesel index, viscosity, pour point, cloud point and other fuel properties determined exhibited similar properties with those of virgin oil. The specific gravity and

Fuel Property	¹ (Petroleum diesel)	² (PKO Biodiesel)	³ Rapeseed Biodiesel	⁴ Canola Biodiesel	⁵ Jathropa Biodiesel	⁶ Pawpaw Biodiesel	⁷ WCO Biodiesel
Specific Gravity	0.853	0.883	0.876	0.878	0.880	0.867	0.858
Flash Point °C	74	167	124	177	170	135	150
Pour Point °C	-16	2	-2	-1		4.000	7
Cloud Point °C	-12	6	-10	-6		7.000	10
Aniline Point °C						5.000	4
API Gravity						31.710	33.42
Heat of Combustion Cal/g						10821.45	10854.06
Viscosity @ 40°C mm ² /s	2.847	4.839	6.170	4.892	5.65cSt	1.650	1.89
Cetane Index					50	11.140	10.96
Diesel Index						1.585	1.337
pH						7.400	7.43

¹⁻⁴ Alamu et al, 2008; ⁵ Reddy et al. 2005 & [22]; ^{6,7} (Owolabi et al. 2011)

Table 3: Characterization of the WCO based biodiesel.

Fuel Type	Heat of Combustion kj/kg	Specific Gravity
Diesel Fuel	43350	0.815
Sun Flower Biodiesel	40579	0.878
Cotton Seed Biodiesel	40580	0.874
Soya Bean Biodiesel	39760	0.872
Rape Seed Biodiesel	37620	0.914
Pawpaw Seed Biodiesel	45342	0.867
WCO	45479	0.858

(Doysan, 1999; Paksoy, 1999; Recep Altim et al., 2000, Owolabi et al, 2011 (This Study)

Table 4: Heat of a Combustion and Specific gravity of other vegetable biodiesel fuel compared to WCO biodiesel fuel.

viscosity at 40°C of the WCO biodiesel was 0.858 and 1.89 respectively which are the closest to the petro-diesel of all the biodiesel from other feed stocks reported in literature. The 7.43 PH also indicate neither acidic nor basic fuel. The temperature at which the WCO biodiesel will give a momentary flash was 150°C which was close to that of biodiesel from PKO. The pour point, cloud point, aniline point and API were found to be 7°C, 10°C, 4°C and 33.42. The API gravity value of WCO biodiesel is greater than that of pawpaw seed oil biodiesel indicating that WCO is lighter. The pour and cloud point were not too far away from that of PKO while the low value of aniline point is an indication of likely low carbon % of the WCO biodiesel. The difference in heat of combustion of the WCO biodiesel compared to that of others especially pawpaw seed oil and petrol-diesel was not significant. The low value of cetane number will lead to higher ignition delay and higher rates of pressure rises. This tends to increase the combustion noise, decreases engine efficiency and power input. However, the WCO biodiesel can be improved to have the desired high cetane number with the use of certain additives.

Therefore used cooking oil can be recommended as the supplementary oil feedstock for biodiesel production. Production of biodiesel from waste cooking oils for diesel substitute is particularly important because of the decreasing trend of economical oil reserves, environmental problems caused due to fossil fuel use and the high price of petroleum products in the international market.

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