Journal of Engineering and Applied Science *Volume 4, September 2012*

www.cenresinpub.org

LOOFAH (*LUFFA CYLINDRICA,* L.*)* BIODIESEL AS FUEL FOR DIESEL ENGINE

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ABSTRACT
This study focussed on biofuel properties of biodiesel from loofah oil. Loofah oil was transesterified in a two-step transesterification process to produce ethyl-esters and glycerol. Biofuel properties of ethyl-esters were determined using ASTM Standards and compared with that of Automotive Gas Oil (AGO). Ethyl-ester yield of 80.0% was obtained from loofah oil. Same specific gravity of 0.88 was obtained for raw loofah oil and its ethyl ester was 1.023 times that of AGO. Higher viscosity at 40ºC (25mm^2/s and 43.4mm^2/s) was obtained for loofah ethyl ester and raw loofah oil respectively compared to 2.95 mm^2/s obtained for AGO. Lower heating value (28.75 MJ/l) was obtained for loofah ethyl-ester compared to 30.2 MJ/l and 44.68 MJ/l obtained for raw loofah oil and AGO respectively. Lower amounts of sulphur, 9.13% for loofah ethyl ester and 10.41% for raw loofah oil than the reference AGO which was 61.8% were recorded. Higher pour (3ºC for both biofuels), cloud (7ºC and 8ºC) and flash (86ºC and 79ºC) points were obtained for loofah ethyl ester and the raw oil, respectively, compared to -16ºC, -12ºC and 74ºC respectively obtained for AGO. Loofah oil contained 76.46% of unsaturated fatty acids. Loofah ethyl ester had better fuel quality than raw loofah oil and fuel properties which are close to ASTM standards for diesel engine fuels.
Keywords: *Loofah oil, Ethyl esters, Biodiesel, Fuel.*

INTRODUCTION
In the last century, there was serious concern that the fast depletion of crude oil resources and instability in the price of petroleum products would plunge the world into an energy crisis. Today, despite the economic advantage of fossil fuel, there is the persistent fear that its continued use might affect the global climate such as causing global warming, frequent heavy rains, rain hurricanes and flood threatening lives and properties by emitting carbon dioxide (CO_2) and other harzardous emissions due to burning of carbon- containing fuels. This anxiety has generated an intense international interest in developing alternative non-petroleum fuels for engines. The general trend now is to reduce global warming and increase the use of environmental friendly fuels [1]. Nigeria as a nation shares in this anxiety. It has been reported that the country's fossil-led economy is under severe pressure, because in decades to come, crude oil production will gradually decline and come to an end [2]. Presently, Nigeria imports about 80% of her petroleum requirement and has been hit hard by rapidly increasing cost and uncertainty. These reasons had caused the country to envision an energy transition from crude oil to renewable energy in the medium (2008-2015) and long terms (2016-2025) [2]. The Nigerian Energy Commission has developed a comprehensive energy policy for the country, which was approved in April, 2003 [3]. The policy acknowledges the significant biomass energy resources in Nigeria which can be harnessed for power generation. The by-products can be used as fertilizers, thus reducing dependence on chemical fertilizers.

The policy seeks to integrate biomass energy resources with other energy resources through the adoption of an efficient conversion technology, and thus develop a biomass technology for the country and maximize the use of agricultural residues, animal and human wastes for energy generation. It is envisaged that this will help reduce health problems associated with biomass incineration at open waste-dumping sites scattered across the country. Vegetable oils such as canola, rapeseed, soybean and jatropha oils have attracted attention as potential renewable resources for the production of alternatives for petroleum based diesel fuel also known as automotive gas oil. Various biofuels derived from vegetable oils have been proposed as alternative fuels for diesel engines, including pure vegetable oils, combinations of vegetable oil with automotive gas oil and alcohol esters of vegetable oil [4]. Silvio *et al.* [5] reported that high viscosities of pure vegetable oils have limited their application because it reduces fuel atomization and increase fuel spray penetration, which would be responsible for high energy deposits and thickening of lubricating oil. Alcohol esters of vegetable oils known more generically as biodiesel appears to be the most promising alternative to petroleum based diesel fuel [6]. Krawczyk [6] identified biodiesel as a possible replacement to fossil's fuels as the world's primary energy source.The most noted attribute of biodiesel is the similar operating performance to conventional diesel fuel and the lack of major changes required in facilities and maintenance procedures [7,8]. Also, it is renewable and has positive environmental benefits because it burns up to 75% cleaner than conventional diesel fuel made from fossils fuels [9,10,11]. The major drawbacks of using biodiesel over fossil fuel include the fact that biodiesel fuels have higher viscosity, higher pour point, lower heating value and lower volatility than petroleum diesel fuel and that there is unfavourable cold weather flow properties of the biodiesel fuel leading to operational problem of the engine in cold climate and temperate regions [7,8,10,12].

Most of the current challenges facing the use of biodiesel globally is its production cost, as the cost of biodiesel is still higher than its petro-diesel counterpart [13]. However, the use of waste seeds such as loofah seeds as biodiesel production feedstock offers the advantage of reducing the production cost. Loofah (*Luffa cylindrica* L.) is a plant commonly found in the tropics. It is a herbaceous plant and it thrives commonly with twinning tendrils. The plant has conspicuous leaves, which are attached alternatively to the hairy hollow stem. It produces berry like fruit whose colour at tender stage is green and yellow at maturity. The fruit could be borne in a bulky or single stalk as the case may be. The fruit has fibrous mesocarp, which is used locally as sponge. The spongy part contains several black seeds and it is propagated by seeds and it grows well at the onset of rain [14]. The seeds of loofah have been found to contain 31.6% oil content, and compared favourably with the oil content of such seeds as cotton (18.28%) and soya bean (11-25%). Loofah oil has been identified for antibiotic and fungicidal applications [15]. However, no work was reported in literature on the fuel properties of loofah biodiesel using ethanol as the alcohol for transesterification. The use of loofah oil for the production of biodiesel is a good effort towards the possibility of harnessing and converting the waste seeds from loofah plants which is largely regarded as weeds. This research focused on loofah oil obtained from waste fruit/seeds in the bush as an effective option to reduce the cost of biodiesel as well as extend its supply. The result of this work would encourage the use of biodiesel as a fuel for diesel engines in Nigeria, thus reducing the problem of global warming, cancer risks and other human health problems associated with the use of fossil- fuel in the country.

MATERIALS AND METHODS

Sample Preparation

Dry and mature loofah fruits were collected from small bushes around Ogbomoso, Oyo State, Nigeria. The exterior brownish part was peeled, revealing the interior spongy fruit which was dissected into four parts using a knife, for easy removal of the seeds. The oilseeds were ground to tiny coarse particle sizes and roasted in the oven preset to a temperature of 100^0C for about 30 minutes. After roasting, the samples were wrapped in cheese cloth and introduced into the pressing cylinder of a laboratory press. The oil expressed was collected into a funnel beneath the cylinder and then drained into a container for storage. The selection of the alcohol for transesterification reaction was based on cost, availability, renewability and toxicity. Hence, ethanol (95% absolute) was chosen for this work because it is derived from locally available agricultural products, renewable and biologically less objectionable in the environment. The use of ethanol as the alcohol for transesterification also means that the two main materials for the production of biodiesel were agriculturally produced, renewable and environmentally friendly. Based on cost and performance, potassium hydroxide (85% absolute) was used as the catalyst in the reaction.

The Production of Loofah Biodiesel

Three operations were performed in the production of loofah biodiesel as described by Saifuddin and Chua [13].

a) *Transesterification:* The process of transesterification to produce ethyl esters was a two-step process. The advantage of the two-step process is the ease with which each phase of the transesterification process can be monitored.
b) *Phase separation:* When the transesterification reaction was complete, the reaction products were separated into two layers by allowing the product mixture to settle overnight; the ester product formed the upper layer and by-product glycerol formed the lower layer. The residual catalyst and unreacted excess alcohol were distributed between the two phases.
c) *Washing:* After separation of the phases, the catalyst and alcohol were washed from the ester with water.

The kinetics of the Transesterification Experiment

Potassium hydroxide was added to ethanol to form potassium ethoxide. The ethanol-KOH mixture (potassium ethoxide) was poured into the plant oil (loofah oil), and the transesterification reaction occurred as shown in Fig. 1. Therefore 963.51g of plant oil reacts with 138.21 g of ethanol to produce 1009.02 g ethyl ester. The transesterification reaction is reversible and thus an excess alcohol is usually used to force the equilibrium to the product side. Therefore, ethanol was added at 65% stoichiometric excess, or a molar ratio of 5.0:1(ethanol to oil). The input amount of potassium hydroxide used as catalyst for transesterification to occur was calculated from the following formula as explained by Saifuddin and Chua [13].

∴ For 1litre of loofah oil, the volume of ethanol needed for transesterification = 165% of 0.147 litre

= 0.2426 litre

Therefore, the input amount of ethanol used to transesterify loofah oil was calculated from the following formula:

$$EtOH = 0.2426 \times LO \qquad \text{...(eqn 1)}$$

Where,
EtOH = amount of ethanol required in litres
LO = the desired amount of loofah oil processed in litres

$$KOH = 0.013 \times LO \qquad \text{...(eqn 2)}$$

Where
LO = as defined above.
KOH = amount of potassium hydroxide required in kilogram.
Therefore, potassium hydroxide was added at 1.5% of the weight of oil.

Determination of the Yield of Esters

The yield of the ethyl esters, Y produced was calculated thus;

$$Y = \frac{V_e}{V_r} \times 100\% \qquad \text{...(eqn 3)}$$

Where
Y = Yield of the ethyl esters, %.
V_e = Volume ethyl esters produced in litres.
V_r = Volume raw oil used in litres

Determination of the Fuel Properties of the Loofah Oil and its Ethyl Esters

The fuel properties of raw loofah oil, its ethyl esters and Automotive Gas Oil (AGO) used as reference such as kinematic viscosity, specific gravity, flash point, cloud point, pour point, free fatty acid composition and heating value were determined according to ASTM standard methods [16]. The cetane number of groundnut biodiesel was calculated as outlined by Oniya [17]. The saponification value, iodine value, pH value, ash content, sulphur content and carbon content of the oil samples were determined according to the method prescribed in the AOCS official and tentative methods. The detailed procedures of all these analytical tests had been discussed elsewhere [17].

RESULTS AND DISCUSSION

Oil yield of 8.8% was obtained from loofah seeds (Table 1) and ethyl-ester yield of 80.0% was obtained from loofah oil (Table 2). Alamu *et al*. [18] worked on alkali-catalysed transesterification of palm kernel oil, and the process yielded 95.80% palm kernel oil ethyl ester on weight basis. Also, Obibuzor *et al.* [19] reported a yield of 88 – 97% alkyl ester from the transesterification of *raphia hookeri* mesocarp oil, the transesterification of jatropha oil with methanol yielded 84% methyl ester [20], whereas the transesterification of soybean oil with methanol using whole cell biocatalysts yielded 72% methyl ester [21].

The Fatty Acid Profile of Loofah Oil

The fatty acid profile of loofah oil is presented in Table 3. It was observed that loofah oil contains 13.77% palmitic acid, 27.16% oleic acid and 48.80% linoleic acid, while the remaining acids shared the rest in small percentages. The result showed that loofah oil consisted of 76.46% unsaturated fatty acid with mainly 27.16% oleic acid and 48.80% linoleic acid. The composition of loofah oil was similar to soybean oil (22.8% oleic acid, 53.7% linoleic acid and others), rubberseed oil(27.8% oleic acid, 37.7% linoleic acid and others) and cottonseed oil (19.2% oleic acid, 55.2% linoleic acid and others) which had more linoleic acid than oleic acid and were found suitable as sources of biodiesel fuels [8, 17].

Loofah Biofuel Characterization

The results of fuel properties of raw loofah oil, its ethyl esters and AGO used as reference are presented in Table 4. The viscosities of raw loofah oil and its ethyl ester were 43.4mm^2/s and 25mm^2/s respectively. Therefore, loofah ethyl ester showed 42.39% reduction in viscosity thus enhancing its fluidity in diesel engine. Kinematic viscosities of loofah ethyl ester with AGO at various temperatures are as presented in Table 5. The viscosity of the biodiesel fuels decreased with increase in temperature as recorded for reference AGO which was similar to the results obtained by Alamu [18] for biodiesel produced from palm kernel oil and the result obtained by Ajav and Akingbehin [22] for biodiesel produced from ethanol. At 15ºC, specific gravity values of both raw loofah and its ethyl ester were obtained as 0.88 while that of AGO was 0.86. The low value of the specific gravity of the loofah oil and its ethyl ester indicated good ignition property [23]. This signifies that loofah and its ethyl ester have good combustion characteristics. The specific gravity values obtained for both loofah oil and its ethyl ester fell within the limit specified by various international standards EN14214 (Europe), ONC1191 (Austria), CSN656507 (Czech Rebublic), Journal Officiel (France), DINV51606 (Germany), UN110635 (Italy) and SS155436 (Sweden) standards which range from 0.86-0.9, 0.85-0.89, 0.87-0.89, 0.87-0.9, 0.875-0.9, 0.86-0.9 and 0.87-0.9 respectively for biodiesel fuels.

The heating value of loofah oil ethyl ester was 28.75 MJ/l, which was lower than 30.2 MJ/L obtained for raw loofah oil. This shows that transesterification reduces the heating value and therefore the energy content of the vegetable oil. The reduction in the energy content was due to the fact that the carbon content of loofah oil reduced considerably after transesterification from 37.5% to 10.2%. However, the heating values of loofah oil and its ethylester were lower than that of AGO obtained as 44.68 MJ/l. Also, the heating values of the samples were quite high and close to the values obtained for soybean oil (34.7MJ/l), jatropha oil (34.7MJ/l) and tigernut oil (34.6MJ/l) which have been found as useful biofuels for diesel engines [24]. Therefore, loofah oil and its ethyl ester have potentials to power a diesel engine. The biofuels contained lower amounts of sulphur (9.16% for loofah oil ethyl ester and 10.41% for raw loofah oil) than the reference AGO which was 61.8%. Therefore, SO_x emissions are expected to be considerably reduced in diesel engines using the biofuels. Higher pour points (3ºC for both biofuels), cloud points (7ºC and 8ºC) and flash points (86ºC and 79ºC) were obtained for loofah ethyl ester and the raw oil respectively compared to -16ºC, -12ºC and 74ºC respectively obtained for AGO. Also, the high flash point of the biofuel ensures safe storage and safe transportation free from fire hazards. The higher cloud and pour points of the biofuel than the reference diesel fuel may involve some complications for their use in diesel engine during cold weather. Ash content values (0.02 and 0.01 respectively) were obtained for loofah oil and its ethyl esters. The ash contents of loofah oil and its ethyl esters were lower compared to AGO obtained as 0.12. Since the ash content is a measure of the amount of metals contained in the fuel, therefore this result indicated that the use of loofah biofuels would reduce injector tip plugging, combustion deposits and injector system wear compared to AGO which had higher ash content. The use of the biodiesel fuels would not constitute a corrosion problem in the injection system and pressure chamber of a diesel engine. The results are consistent with the values of ash contents obtained for jatropha oil, rapeseed methyl ester, sunflower methyl ester and jatropha methyl ester obtained as 0.03, 0.007, 0.004 and 0.013 respectively [25, 26, 27]. The pH value of raw loofah oil and its ethyl ester were found to be 3.2 and 3.1 respectively, which implied that raw loofah oil was not as acidic compared to its ethyl ester. Also, the pH values of all the biofuels were higher than that of AGO obtained as 2.8. It is noteworthy that the acidic nature of the biofuels was due to the presence of free fatty acid while that of AGO was due to the sulphur content.

The iodine value of loofah oil obtained as 0.31 wijis was higher than that of its ethyl ester which was obtained as 0.08 wijis. This result indicates that the process of transesterification reduced the iodine value which is a measure of the stability of the biofuels during storage. Therefore, the ethyl ester was more stable than the raw oil. This was because the lower the iodine value, the more stable the fuel. The cetane number of loofah oil ester was determined as 51.3 The cetane number of pure linoleic acid was reported as 36.8, while that of oleic acid was reported as 57.2 [28]. The cetane number of loofah biodiesel was within the range of the cetane number of dominating fatty acid constituents. This agrees with the findings of Bamgboye and Hansen [28] who reported that the cetane numbers of esters of soybean, rapeseed, sunflower, cottonseed, peanut, palm oil, lard, tallow and canola oils were within the range of the cetane number of the dominating fatty acid constituents. The cetane number of loofah biodiesel was also close to the values reported by Bamgboye and Hansen [27] and Moreno *et al.* [26] for esters of soybean oil (45 - 60), rapeseed oil (44 – 59), sunflower oil (50 – 61.2), cottonseed oil (45 – 55), peanut oil (54), palm oil (58 – 70), lard (63.6), tallow (58 – 64.8) and canola oil (53.9 – 55). The cetane number of loofah biodiesel obtained as 51.3 agreed with the biodiesel standard of 49 minimum specified by the Technical Standard of the European Union.

CONCLUSIONS

From the results of transesterification of loofah oil, biofuel characterisation of raw loofah oil and its ethyl ester carried out, the following conclusions were drawn; Oil yield of 8.8% was obtained from loofah seeds and ethyl-ester yield of 80.0% was obtained from loofah oil. Higher viscosity at 40^oC (43.4 mm^2/s) was obtained for raw loofah oil compared to 25 mm^2/s and 2.95 mm^2/s obtained for loofah ethyl-ester and AGO respectively. Lower heating value (28.75 MJ/l) was obtained for loofah ethyl-ester compared to 30.2 MJ/l and 44.68 MJ/l obtained for raw loofah oil and AGO respectively. At 15ºC, same specific gravity of 0.88 was obtained for raw loofah oil and its ethyl ester which was 1.023 times that of AGO. The biofuels contained lower amounts of sulphur (9.13% for loofah ethyl ester and 10.41% for raw loofah oil) than the reference AGO which was 61.8%. Higher pour (3ºC for both biofuels), cloud (7ºC and 8ºC) and flash (86ºC and 79ºC) were obtained for loofah ethyl ester and the raw oil respectively compared to -16ºC, -12ºC and 74ºC respectively obtained for AGO. The gas chromatography (GC) analysis showed that loofah oil contains 76.46% unsaturated fatty acids. Transesterification enhanced fluidity of loofah oil ethyl ester in diesel engine and reduced the heating value and therefore the energy content of the vegetable oil. Also, SO_x emissions are expected to be considerably reduced in a diesel engine using loofah biodiesel. The high flash point of loofah biodiesel ensures safe storage and safe transportation free from fire hazards. The higher cloud and pour points of loofah biodiesel than the reference diesel fuel may involve some complications for its use in diesel engine during cold weather. Loofah oil and its ethyl ester have good combustion characteristics and potentially able to power a diesel engine. The use of the biodiesel fuel would not constitute a corrosion problem in the injection system and pressure chamber of a diesel engine. Loofah oil ethyl ester was found to have better fuel quality than raw groundnut oil and it can successfully fuel a diesel engine. The results are consistent with those of other researchers and agree with international standards.

ACKNOWLEDGEMENTS

The management of Food Engineering Laboratory, Ladoke Akintola University of Technology, Ogbomoso, Nigeria is acknowledged for granting permission to utilize facilities for extraction of loofah oil and biofuel characterization. The assistance rendered by LUBCON Nigeria Ltd., Ilorin, Nigeria in making available materials for fuel characterization is also acknowledged.

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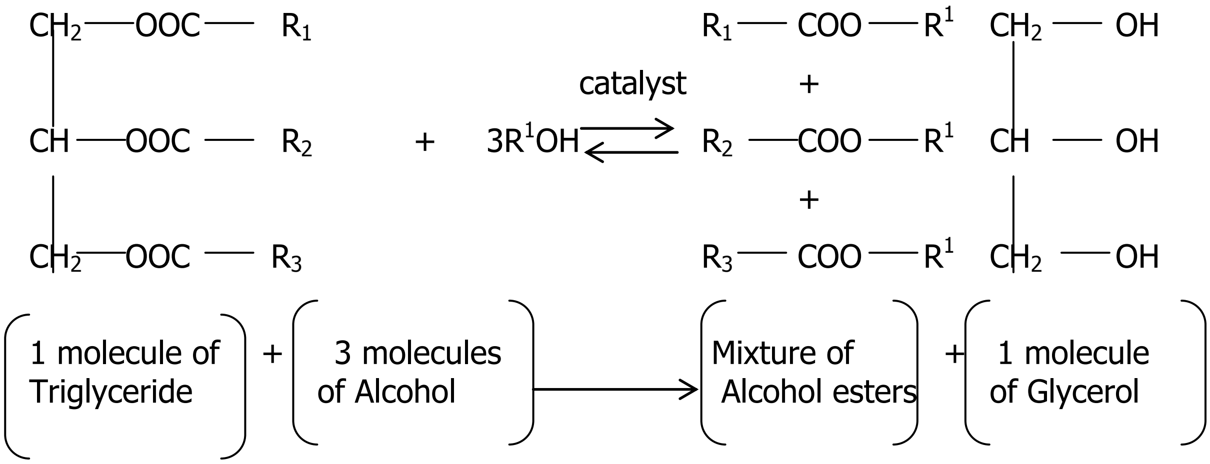

Fig. 1: Transesterification of Triglycerides (or plant oils) with alcohol [4]

Tables

Table1: Loofah Oil Extraction

Experiment No	Mass of grounded loofah sample, M_l (g)	Mass of loofah oil, M_{lo} (g)	Percentage oil yield, $\frac{M_{lo}}{M_l} \times 100\%$ (%)
1	150.5	13.3	8.8
2	1488.8	132.5	8.9
3	752.5	65.5	8.7
		Average	**8.8**

Table 2: Transesterification of Loofah Oil

Experiment No	Volume of oil(ml)	Volume of oil ethyl ester (ml)	Yield of esters (%)
1	200	160	80.0
2	100	80	80.0
		Average	**80.0**

Table 3: The Fatty Acid Profile of Loofah Oil

Component	Formula	Percentage composition	Name	Type
C 16:0	$C_{16}H_{32}O_2$	13.77	Palmitic acid	Saturated.
C 18:0	$C_{18}H_{36}O_2$	8.64	Stearic acid	Saturated.
C 18:1	$C_{18}H_{34}O_2$	27.16	Oleic acid	Unsaturated.
C 18:1	$C_{18}H_{34}O_2$	0.50	Oleic acid	Unsaturated.
C 18:2	$C_{18}H_{32}O_2$	48.80	Linoleic acid	Unsaturated.
C 20:0	$C_{20}H_{40}O_2$	0.55	Arachidic acid	Saturated.

Table 4: Fuel Properties of AGO, Loofah Ethyl Ester and Raw Loofah Oil

FUEL PROPERTIES	**AGO**	**LOOFAH OIL ETHYL ESTER**	**RAW LOOFAH OIL.**
Viscosity at 40ºC (mm^2/s)	2.95	25	43.4
Lower Heating Value(MJ/L)	44.68	28.75	30.2
pH	2.8	3.1	3.2
Specific Gravity at 15ºC	0.86	0.88	0.88
Cloud Point(ºC)	-12	7	8

Pour Point(ºC)	`-16	3	3
Ash Content (%)	0.12	0.01	0.02
Flash Point(ºC)	74	86	79
Sulphur Content (%)	61.8	9.16	10.41
Carbon Content (%)	13.4	10.2	37.5
Iodine Value (wijis)	0.21	0.08	0.31
Peroxide Value (meq/KOH)	0.14	0.08	0.08
Free Fatty Acid(g/100g)	8	5.6	3.48

Table 5: Kinematic Viscosity of Loofah Oil Ethyl Ester and AGO at various Temperatures in mm^2/s

Blends	27ºC	40ºC	60ºC	100ºC
AGO	3.6	2.95	2.25	1.5
Loofah oil ethyl esters	31	25	18	12