Comparative Performance Evaluation of Biodiesel from Hibiscus Sabdariffa and Hibiscus Surattensis Seeds Oils

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Abstract
This work investigated the viability of using locally available vegetable seed oils to produce biodiesel. Two indigenous seeds-Hibiscus Surattensis (Hausa-rahma) and Hibiscus Sabdariffa (Hausa-yakwua) were used to carry out the research.
Biodiesel from oils derived from these seeds were produced by alkali catalyzed transesterification process. The physicochemical properties of the oils (such as viscosity, flash point, calorific value, relative density, acid value, ash content, carbon content, saponification value, iodine value and hydrogen content) and various blending ratios of biodiesel with diesel obtained from oils of these seeds were investigated and compared with standard diesel fuel. The methyl esters of the samples were comparatively analysed based on their performance characteristics in blends of B30, B40and B50 using a Leyland Compression Ignition Engine coupled to a hydro-dynamometer. Parameters like speed of engine and fuel consumption were measured at different loads for pure diesel and various combinations of biodiesel blends. Torque, brake horse power and specific fuel consumption were calculated. The test results indicate that the biodiesel blends of B40 for H. Sabdariffa has Brake horse power- 12.44kW at a Speed of 2000rpm and Specific Fuel Consumption (SFC) of 0.118 l /kW hr and; B30 for H. Surattensis has Brake horse power- 13.78kW at a Speed of 2000rpm and SFC of 0.332 l/kW hr while Diesel has Brake horse power of 10kW at a Speed of 2000rpm and SFC of 0.204 l/kW hr. Both H. Sabdariffa at B40 blend and H. Surattensis at B30 blend have brake horse power and SFC higher than diesel at the speed of 2000rpm hence H. Sabdariffa blend of B40 and H. Surattensis blend of B30 blend can be recommended for use in diesel engines without making any engine modifications.

Keywords
Biodiesel, Engine, Blend, Hydro-dynamometer, Transesterification, Diesel

I. Introduction
Energy is central to sustainable development and poverty reduction efforts. It affects all aspects of human development – social, economic and environmental. Numerous studies indicated that oil sources in the world will come to an end. As a result, new alternative energy sources will be required to substitute for Fossil diesel [1]. A possible solution to a potential future energy shortage would be to use some of the world's remaining fossil fuel reserves as an investment in renewable energy infrastructure. The use of renewable fuels on a more significant scale than at present would reduce dependence on fossil fuels, thereby reducing the associated environmental impacts.
The major environmental concern, according to an Intergovernmental Panel on Climate Change (IPCC) report, is that "most of the observed increase in globally averaged temperatures since the mid-20th century in due to the increase in anthropogenic greenhouse gas concentration" which is due to burning of fossil fuels [2]. Another concern is the peak oil theory, which predicts a rising cost of oil derived fuels caused by severe shortage of oil during an era of growing energy consumption. The demand for oil will exceed supply and this gap will continue to grow, which could cause a growing energy crisis starting between 2010 and 2020 [3]. Recent survey has indicated that with the present rate of energy consumption, there is combined decline in quantity of crude petroleum which serves as source for diesel oil production. Moreover, the rate of discovery of petroleum deposits is not proportional to the rate of consumption [3]. The above mentioned problems and other facts, necessitate further research or rather awakened new interest for vegetable oil improvement as alternative source. This potential energy source is renewable. "Biodiesel is a non-toxic, biodegradable diesel fuel made from vegetable oils, animal fats, and used or recycled oils and fats" and is used to run unmodified diesel engines – cars, buses, trucks, construction equipment, boats, generators and oil home heating units. Biodiesel is made using the process of transesterification [4]. Also, Biodiesel improves lubricity and reduces premature wearing of diesel engine fuel pumps [5]. In the year 2000, there were about eight million vehicles around the world that ran on alternative fuels, indicating sustainability [6]. Many researchers have concluded that vegetable oils hold promise as alternative fuels for diesel engine [7]. This paper is a comparative performance evaluation of biodiesel from H. Sabdariffa and H. Surattensis. These seeds were locally sourced and biodiesel or methyl ester was produced from the oils extracted from these local seeds. The physicochemical properties of the biodiesel obtained from the oil of these seeds were investigated and compared with standard diesel fuels. The fuels were used to run a diesel engine and the performance of the diesel engine was observed.

II. Materials and Method

A. Hibiscus Sabdariffa L
It has two botanical varieties recognized: var. Sabdariffa, a bushy branched sub shrub with red or green stems and red or pale yellow inflated edible calyces; var. altissima Wester, a tall, vigorous, practically unbranched plant, 10-16ft high [8]. With fibrous, spiny, inedible calyces, grown for fibre. It is called yakuwa in Hausa. H. Sabdariffa is probably a native of West Africa and is now widely cultivated throughout the tropics [8]. The red acid succulent calyces of var. sabdariffa are boiled with sugar to produce sorrel drink (popularly known as zobo drinks). They are also made into jellies, sauces, chutneys and preservatives. The tender leaves and stalks are eaten as salad and as a pot-herb and are used for seasoning curry. The seeds contain oil. Var altissima is grown for fibre in India, Java and the Philippines. They are often found in farmlands and around village homes in Nigeria [8].

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B. Hibiscus Surattensis

H.Surattensis occurs in tropical Africa and tropical Asia. It is found in most countries of tropical Africa, including the Indian Ocean islands, and also in South Africa and Swaziland. It has been introduced in tropical America and is locally naturalized there [8]. It's a prostrate or climbing annual herb; stem prickly with recurved prickles. The leaves alternate, and are simple; stipules are ovate. Its fruit is an ovoid to globose capsule up to ovary superior, many – seeded. H.Surattensis occurs in grassland and at forest edges in lowland and at medium altitudes up to 1700 m, in regions with an average annual rainfall of 1000 – 1600 mm) [8]. It also occurs in marshes, abandoned fields and plantations, on waste ground near habitation, and in coastal habitats such as sand dunes. It is found on a wide variety of oil types. When cultivated, H.Surattensis is propagated by seed. The main management practice is weeding. The leaves can be cooked immediately as a vegetable, or dried, pounded and kept for up to a year and used later in a similar way as fresh leaves [8]. Eaten as salad and as a pot-herb and are used for seasoning curry. The seeds contain oil. They are often found in farmlands and around village homes in Nigeria [8].

H. Sabdariffa and H. Surattensis seeds were sourced for locally within the neighbourhood. The seeds were purchased at the Kawo market in Kaduna North local government of Kaduna State. They were purchased already sun dried. The oil was extracted using the Screw Oil Press machine showed in Plate I. The oil was converted to biodiesel by the Acid – Catalyzed Processes. The methylester was then blended with diesel in the ratio 30:70, 40:60 and 50:50 of biodiesel to diesel. The oil, biodiesel and blends were tested for their physicochemical properties as outlined by Association of Analytical Chemists (AOAC).

III. Results and Discussion

The results of oil extraction, esterification of oil, blending of biodiesel with diesel and comparative analysis with diesel is shown in Tables 1-4. Tables 1-2 showed the physicochemical properties of the Biofuels and diesel. Table 3 showed the various International Standards for biodiesel. Table 4 showed the performance result of 100% base diesel fuel. Plate I showed the machine used in oil extraction.

Table 1: Comparative Analysis of Hibiscus Sabdariffa Oil, Biodiesel, Biodiesel/Diesel Blends and Diesel.

Oil Samples	**Diesel**	***Hibiscus Sabdariffa***				
Properties		**Oil**	**B30**	**B40**	**B50**	**B100**
Relative density (15 °C)	0.85	0.91				
Flash point (°C)	65.5	64	69	71	72	144
Viscosity (mm²/s) (at 37.8° C)	1.6 - 5.5	35.32	4.78	4.9	5.28	5.60
Calorific value (MJ/kg)	64 320	26 790	41 033	40 487	40 047	38 811
Carbon Content (%wt)	4.4	0.46	3.12	2.96	2.72	0.38
Ash content (%wt)	0.01	1.91	0.97	0.97	0.97	0.97
Saponification Value (mg)	-	180.1	180.1	180.1	180.1	180.1
Acid value	-	0.5	0.5	0.5	0.5	0.5
Iodine Number	-	86.18	86.18	86.18	86.18	86.18
Hydrogen Value	-	42.1	42.1	42.1	42.1	42.1

Table 2: Comparative Analysis of Hibiscus Surattensis Oil, Biodiesel, Biodiesel/Diesel Blends and Diesel.

Oil Samples	**Diesel**	***Hibiscus Surattensis***				
Properties		**Oil**	**B30**	**B40**	**B50**	**B100**
Relative density (15 °C)	0.85	0.93				
Flash point (°C)	65.5	70	75	85	87	174
Viscosity (mm²/s) (at 37.8° C)	1.6 - 5.5	30.76	4.35	4.39	4.54	4.88
Calorific value (MJ/kg)	64 320	26 900	42 100	41 551	40 345	39 931
Carbon Content (%wt)	4.4	0.29	3.16	2.85	2.81	0.22
Ash content (%wt)	0.01	2.77	1.76	1.76	1.76	2.77
Saponification Value (mg)	-	188.2	188.2	188.2	188.2	188.2
Acid value	-	1.1	1.1	1.1	1.1	1.1
Iodine Number	-	86.62	86.62	86.62	86.62	86.62
Hydrogen Value	-	38.64	38.64	38.64	38.64	38.64

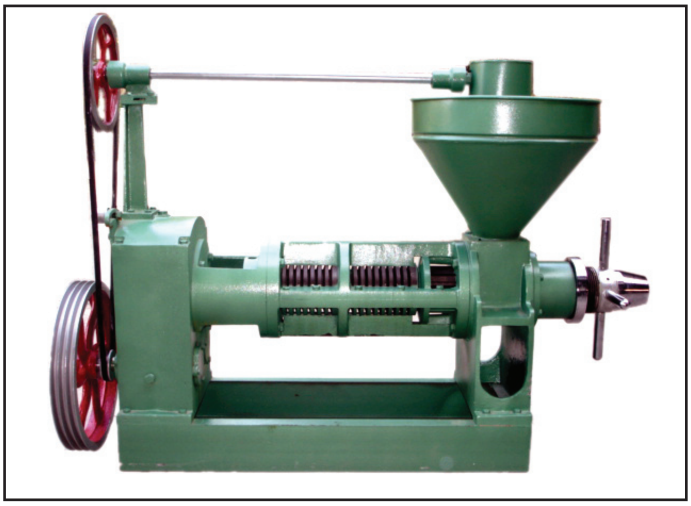

Plate 1: Screw Oil Press Machine
(Courtesy: Ahmadu Mohammad Industrial Limited (AMIL) Kawo, Kaduna).

Table 3: International Standards for Biodiesel

Standard/ Specifications	Test Value	Unit	AUSTRIA	FRANCE	GERMANY	ITALY	SWEDEN	USA	MBTI
			ON C1191	Journal Official	DIN E 51606	UNI 10635	SS 15 54 36	D-6751~02	
Date			1 July 1997	14 Sep 1997	Sep 1997	21 April 1997	27 Nov 1996	10Jan 2002	August 03
Application			FAME**	VOME**	FAME**	VOME**	VOME**	FAME**	FAME**
Density	15ºC	g/cm³	0.85 - 0.89	0.87 - 0.90	0.875 - 0.90	0.86 - 0.90	0.87 - 0.90	-	-
Viscosity	40ºC	mm²/s	3.5 - 5.0	3.5 - 5.0	3.5 - 5.0	3.5 - 5.0	3.5 - 5.0	1.9 - 6.0	4.473
Distillation	I.B.P.	ºC	-	-	-	>300	-	-	339
Distillation	95%	ºC	-	<360	-	<360	-	-	357
Flashpoint		ºC	>100	>100	>110	>100	>100	>130	162
CFPP		ºC	<0/-15	-	<0/-10/-20	<0/-15	<-5	-	-
Pour point	summer	ºC	-	<10	-	-	-	-	-
Total Sulphur		% Mass	<0.02	-	<0.01	<0.01	<0.001	-	0.0004
CCR	100%	% Mass	<0.05	-	<0.05	-	-	0.050	0.04
CCR	10%	% Mass	-	<0.3	-	<0.5	-	-	-
Sulphate ash		% Mass	<0.02	-	<0.03	-	-	<0.02	-
(Oxide) Ash		% Mass	-	-	-	<0.01	<0.01	-	-
Water content		mg/kg	-	<200	<300	<700	<300	<300	0
Impurities total		mg/kg	-	-	<20	-	<20	-	0
Cetane Number		-	>49	>49	>49	-	>48	>47	52.9
Neutral No.		mg KOH/g	<0.8	<0.3	<0.5	<0.5	<0.6	<0.80	0.23
Methanol content		% Mass	<0.20	<0.1	<0.3	<0.2	<0.2	-	-
Ester content		% Mass	-	>96.5	-	>98	>98	-	-
Monoglycides		% Mass	-	<0.8	<0.8	<0.8	<0.8	-	-
Diglyceride		% Mass	-	<0.2	<0.4	<0.2	<0.1	-	-
Triglyceride		% Mass	-	<0.2	<0.4	<0.1	<0.1	-	-
Free glycerol		% Mass	<0.02	<0.02	<0.02	<0.05	<0.02	0.020	0.003
Total glycerol		% Mass	<0.24	<0.25	<0.25	-	-	0.240	0.146
Iodine No.		-	<120	<115	<115	-	<125	-	<120
Phosphor		mg/kg	<20	<10	<10	<10	<10	<10	<10
Alkaline met.	NA/K	mg/kg	-	<5/5	<5	-	<10/10	-	-
**FAME: Fatty Acid Methyl Ester **VOME: Vegetable Oil Methyl Ester									

(Source: Indian BioFuel Awareness Forum by Satish Lele, satish.lele@gmail.com)

Table 4: Performance Results of 100% Base Diesel Fuel

Parameter	Diesel			
Speed (rpm)	1000	1250	1500	2000
Load (N)	29	27	24.5	22.5
Torque (Nm)	10.73	9.99	9.07	8.33
BHP (kW)	6.44	7.5	8.17	10.0
Fuel Consumption (l/hr)	1.240	1.028	1.13	2.037
Specific Consumption (l/kW hr)	0.193	0.137	0.139	0.204
Swept Volume (l³)	2.26	2.26	2.26	2.26
Break Mean Effective Pressure (kN/m²)	341.95	318.6	289.2	265.5
Mechanical Loss (kW)	2.38	2.78	3.02	3.70
Indicated Power (kW)	8.82	10.28	11.19	13.70
Mechanical Efficiency (%)	73	72.95	73	72.99

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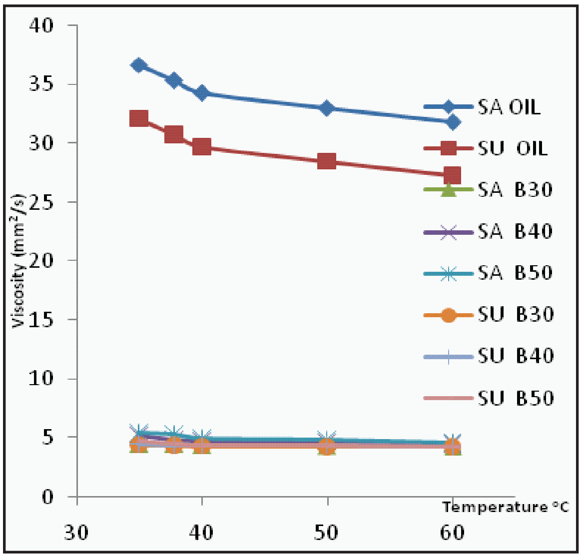

Fig. 1: Viscosity of the Various Biodiesel Blends

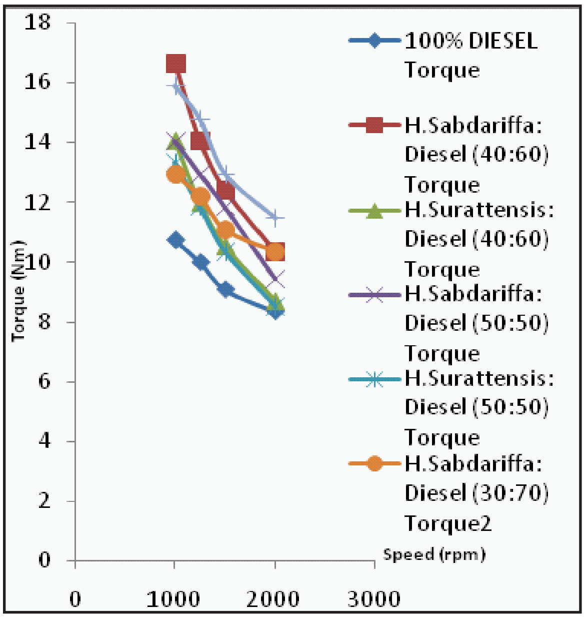

Fig. 2: Grph of Torque Vs Speed

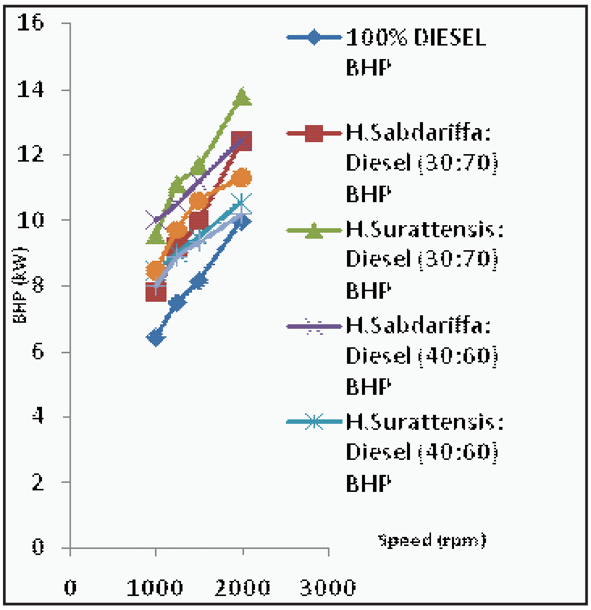

Fig. 3: Graph of BHP Vs Speed

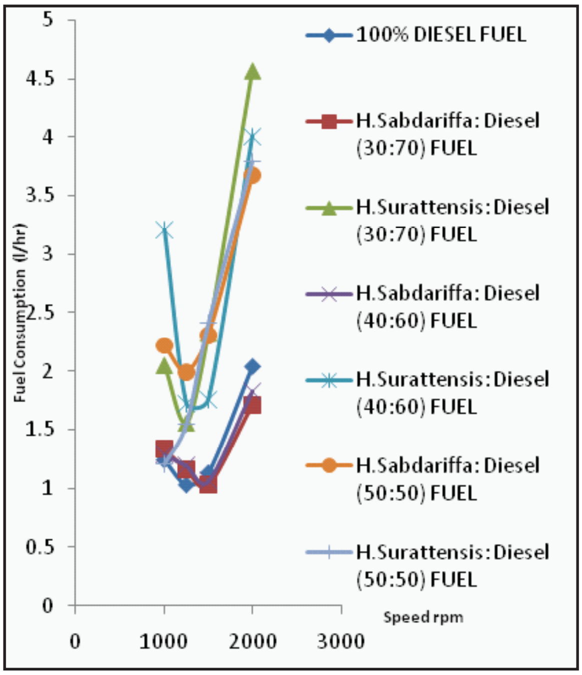

Fig. 4: Fuel Consumption for Different Speeds

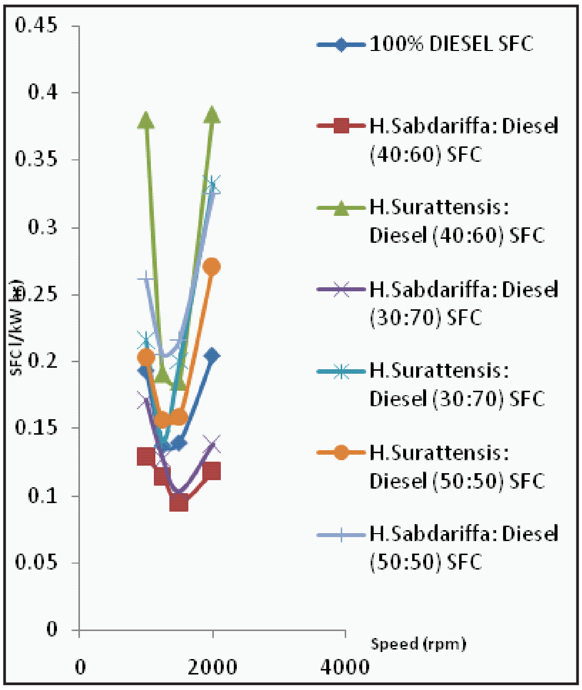

Fig. 5: Graph of Specific Fuel Consumption Vs Speed

IV. Discussion

The graphs for the performance characteristics of the Leyland Compression Ignition Engine are shown above in figures 1-5. Those of interest in this research are the engine torque, brake horse power, fuel consumption and specific fuel consumption.

A. Viscosity

From the graph of viscosity (Figure 1), it can be seen that viscosity decreases with increase in temperature. H. Sabdariffa seed oil is more viscous than Hibiscus Surattensis. Likewise Hibiscus Sabdariffa Biodiesel is more viscous than Hibiscus Surattensis. Viscosity increases from B30 blend to B50 blend. Hibiscus Sabdariffa B50 is the most viscous. This shows that this blend will give the longest ignition delay. Viscosity is a measure of a liquid's resistance to flow. High viscosity means the fuel is thick and does not flow easily. High viscosity fuel will increase gear train, cam and follower wear on the fuel pump assembly because of the higher injection pressure also, fuel atomizes less efficiently and the engine will be more difficult to start.

B. Torque

The relationship between torque and speed is shown in Fig. 2. The torque decreases for all the fuel samples to the minimum at the speed of 2000rpm. Comparing the torque produced by the engine at different loads and engine speeds for the diesel and various blends of fuel, it was observed that the torque increases steadily as load increased. The increase in torque is as a result of the higher calorific value of diesel followed by that of the biodiesel blends of B30 and B40, as well as complete combustion of fuels.

C. Brake Horse Power

The relationship between brake horse power (BHP) and speed is shown in Figure 3. The brake horse power increases with increase in speed for all fuel samples to maximum at 2000rpm. Comparing the brake horse power produced by the engine at different loads and engine speed for various blends of Biodiesel, it was observed that the brake horse power increased steadily. Comparing brake horse power and different speeds for diesel and the different blends of Biodiesel, it was observed that the brake horse power is higher for blends of B30 and B40 than diesel. For B50 the brake horse power is not much more than diesel. Hence it can be concluded that the biodiesel blend of B40 of Hibiscus Sabdariffa and B30 Hibiscus Surattensis can be recommended for use in diesel engines without making any engine modifications [9].

D. Fuel Consumption

The relationship between Fuel Consumption and speed is shown in Fig. 4. The fuel consumption decreases with speed for the various blends of biodiesel to a minimum then increases continuously as the speed increased except for H. Surattensis at B50. Comparing the fuel consumption of the engine at various speeds and loads for the different blends tested, it was observed that fuel consumption is optimum for Hibiscus Sabdariffa blend of B30 at 1.029litre/hr. When fuel consumption is compared between the Biodiesel blends and diesel, it was observed that fuel consumption is optimum with diesel at the speed of 1250rpm while Hibiscus Surattensis has the least fuel consumption of 1.562litre/hr for B30 at speed of 1250rpm. This blend produces more BHP than H. Sabdariffa and diesel.

E. Specific Fuel Consumption

Fig. 5 show the relationship between Specific Fuel Consumption (SFC) and Speed. As Speed increases, specific fuel consumption decreases to the minimum at 1250rpm engine speed and then increases for all blends tested and diesel except for Hibiscus Sabdariffa B30 and B40 whose minimum is at speed of 1500. The specific fuel consumption for Hibiscus Surattensis at B30 is more or less equal to that of diesel at 1250rpm engine speed. The SFC for Hibiscus Surattensis is higher than that of Diesel. This can be due to the lower calorific value of biodiesel than diesel [10].

V. Conclusion

From the results obtained and the discussion made the following conclusions can be drawn from the study:

1. For all the fuel samples tested, torque reached maximum values at 2000rpm while brake horse power reached minimum values at speed of 2000rpm.
2. The dual fuel combination of H. Sabdariffa blend of B30 and B40 and H. Surattensis blend of B30 can be recommended for use in the diesel engines without making any engine modifications. This is in agreement with the results obtained by Stalin, N. and Prabhu, H. J. [4], in their work titled "Performance Test of Ice Engine using Karanja Biodiesel Blending with Diesel."
3. By using this dual fuel combination (B30 and B40), emission of greenhouse gases would be reduced.
4. The possibility of using Hibiscus Surattensis and Hibiscus Sabdariffa methyl esters as alternative fuels in diesel engine has been established.
5. The physicochemical properties of vegetable oils from Hibiscus Surattensis and Hibiscus Sabdariffa seeds where investigated and found to be close to that of diesel.
6. The oils from Hibiscus Surattensis and Hibiscus Sabdariffa seeds were successfully convert to biodiesel by the process of transesterification, and their physicochemical properties compared with those of petroleum- based diesel and the performance of the biodiesels at various blend ratios with diesel were tested using the Leyland Compression Ignition Engine.

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