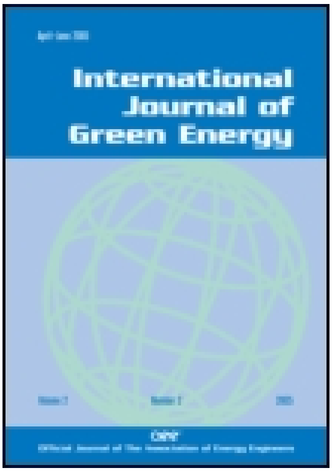

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AN EXTRACTION AND PERFORMANCE ANALYSIS OF RUBBER SEED-METHYL ESTER ON AN IC ENGINE AT VARIOUS COMPRESSION RATIOS

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Energy, Environment, and Economy are the 3E's which drive GDP growth of any country in the world. Energy security is the need of the hour due to high uncertainty prevailing globally, especially for countries like India which depend heavily on oil import to meet their growing energy needs. Use of edible bio-oil for biodiesel production may not be a viable option due to its high demand for cooking purpose. However, nonedible and discarded oils like rubber seed oil can be harnessed to supplement the increasing need for automobile fuels. High free fatty acid (FFA) content of the raw rubber seed oil increases the viscosity which makes it unsuitable for direct use in IC engines. The viscosity was reduced in two stage esterification process by conducting planned sets of experiment. The process parameters were optimized to maximize the oil yield. Fuel properties were ascertained by standard test procedure before conducting performance test in IC Engine. Better performance of the engine, while using biodiesel was found at the CR of 20. The results were compared with standard diesel for performance and emission standards. The emission analyses were done with standard procedure and found to be satisfactory. Biodiesel being an oxygenated fuel yields higher combustion efficiency, in spite of having slightly higher specific gravity than diesel.

Keywords: *Biodiesel; Engine performance; Rubber seed biodiesel; DOE; Emission*

INTRODUCTION

Soaring oil prize and unstable political atmosphere prevailing in the oil-exporting nations force the oil-dependent nations to search for alternate fuel sources. Ever decreasing fossil reserves and environmental pollution are the other major issues that push the world to search for alternative energy sources which are renewable in nature (Atadashi, Aroua, and Abdul Aziz 2010). Currently, spate of research is going on in testing the

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Color versions of one or more of the figures in the article can be found online at http://www.tandfonline.com/ljge usage of various alternative fuels in IC engines (Sahoo et al. 2007; Banapurmath, Tewari, and Hosmath 2008; Xiangmei, Guanyi, and Yonghong 2008; Qi et al. 2010; Vedaraman et al. 2011; Venkata Subbaiah and Raja Gopal 2011; Amarnath and Prabhakaran 2012; Mohanraj and Murugu 2013; Srithar et al. 2013). Vegetable oils are primarily used as source for biodiesel production in India (Babu and Devaradjane 2003; Senthil, Ramesh, and Nagalingam 2003). However, using edible vegetable oil to extract biodiesel may not be a viable alternative for India. But nonedible vegetable oils and biological discards can be effectively utilized to augment some energy in the tremendous need of the growing economy. Moreover, use of vegetable oils both edible and nonedible is definitely beneficial to the environment as they do not contain sulphur, aromatic hydrocarbon, and metals. The use of vegetable oils in IC engines is not a new concept and has been the focus of research for long time (Gerhard 1983).

Although biodiesel has properties on par with conventional diesel fuel, there are several problems that need to be addressed such as its low calorific value, high flash point, high viscosity, low pour point, and poor oxidative stability. Biodiesel obtained from some feed stocks might produce slightly more oxides of nitrogen (1–6%) than the conventional fossil fuels, which are ozone depressors. Higher emission of nitrogen oxides is also reported due to high combustion temperature (Lin et al. 2006). However, these issues can be managed within the allowable limits by blending biofuels with the conventional high-speed diesel fuel. It is found that biodiesel actually improves the thermal efficiency while reducing the emission of unwanted gases during combustion (Ramadhas, Muraleedharan, and Jayaraj 2005a).

Several studies have shown significant reductions in smoke and particulate matter (PM) emissions in IC engines when oxygenates (biodiesel) are blended with conventional diesel fuels. Fuel properties such as hydrogen to carbon ratio, aromatic content, and number of carbon–carbon bonds were used as correlating parameters for smoke formation in hydrocarbon flames. Various types of oxygen-containing compounds including ethers, alcohols, carbonates, acetyl's, and esters have been tested in engines to determine the effect of oxygenates on exhaust emissions (Tsurntani et al. 1995; Miyamoto et al. 1996). All the studies showed a significant reduction in smoke and PM emissions when either pure oxygenates or oxygenate/diesel blends were burned. Biodiesel hydrocarbon chains are generally 16 to 20 carbons in length and contain oxygen at one end, and having approximately 10% of oxygen by weight. The presence of these elements improves combustion efficiency and reduces emission profile (Van Gerpen 2005). However, NOx emissions are slightly increased depending on biodiesel concentration in the fuel (Antolin et al. 2002; Cetinkaya et al. 2005). Researchers are working on to study the feasibility of extracting biodiesel from rubber seed oil and its compatibility for I.C. engine application (Edwin Geo, Nagarajan, and Nagalingam 2009a; Edwin Geo et al. 2009b; Satyanarayana and Muraleedharan 2010). However, to consolidate the works, more optimization works are needed to scale-up the process.

This paper deals with the optimization of biodiesel extraction from the highly viscous rubber seed oil in two stages, namely acid and alkaline esterification process. Rubber seed–methyl ester then produced at the optimized process condition was tested for fuel properties at standard test conditions. The rubber seed biodiesel was tested in a single cylinder diesel engine with data acquisition system at various compression ratios (CR) and their results were compared with conventional diesel fuel for performance.

PROCEDURE FOR BIODIESEL EXTRACTION

Approximately 160 kg of rubber seed is obtained per hectare of rubber plantation annually. They are mottled brown in color weighing 2 to 4 g each and contain roughly 40 to 60 wt.% of oil (Ramadhas, Jayaraj, and Muraleedharan 2005b). The kernels were separated from the seed by breaking the outer shell. The kernels were crushed using the screw press and rubber seed oil is extracted and then filtered. The solid leftover after rubber seed oil extraction, called as rubber seed cake, is rich in protein and is used as cattle and poultry feed. The viscosity of raw rubber seed oil is high and it has an acid value of 35 mg KOH/g, which is equivalent to 17.5% Free Fatty Acid (FFA), which hinders its direct usage in IC engines.

Due to its high FFA, two-stage esterification process is carried out to extract biodiesel from rubber seed oil. The experiments were designed using design of experiment (DOE) technique, which is an efficient multi-variant approach and the results were analyzed using design expert software. The objective in the first stage is to reduce the FFA below 2% by acid esterification and to go for alkaline esterification in the second stage of the process. Temperature, time, and volume percentages of acid and oil/methanol ratio are the major process parameters for the first-stage process and the process parameters were optimized for better reduction in acid value. The extracted oil, having less than 2% FFA where subjected to alkaline esterification process in the second stage to maximize the biodiesel yield. The percentage of biodiesel yield was calculated by quantifying the different fatty acid composition present in the ester by gas chromatography (GC), which is the most accurate method. The biodiesel yield is optimum when methanol/oil ratio is around 0.2% v/v and sodium hydroxide is kept at a minimum level of 0.5% w/v. The result of the alkaline-esterification process is depicted by the 3D graph drawn using design expert software adopted for DOE (Figure 1). The planned experimental process parameters in the second stage and their corresponding yield of biodiesel are shown in Table 1. The detailed process analysis and the optimization results were published elsewhere by the same authors (Melvin Jose et al. 2011).

EVALUATION OF FUEL PROPERTIES

The conversion of triglycerides (raw rubber seed oil) into methyl ester (biodiesel) through two-stage esterification process reduces the acid value from around 35 mg KOH/g to less than 3 mg KOH/g. The acid number of the oil is quantified as mg KOH/g, (which is also a measure of FFA) using the titrated value. One gram of oil after esterification was titrated against standard potassium hydroxide solution using phenolphthalein as an indicator. The viscosity of the oil is measured using BROOKFIELD LV-DV-II+ Pro viscometer, Middleboro, USA, at a constant temperature of 40°C. The viscosity of the raw rubber seed oil was reduced from 37.06 mm^2/s to 3.12 mm^2/s after two-stage esterification process.

The flash point and fire point of biodiesel is determined by using the Pensky Marteins closed cup apparatus. The calorific value of biodiesel is measured with Parr-6772 calorimetric thermometer and found to be very close to that of the diesel. The heating value of the standard diesel is estimated as 44,100 kJ/kg and that of extracted biodiesel as 38,200 kJ/kg. TANAKA ACR-M3 micro carbon residue tester is used in the determination of the amount of carbon residue which forms after evaporation. The cloud point and pour point temperature of biodiesel are high enough for low temperature applications. The closeness of biodiesel properties with diesel made it possible for the diesel engine to perform satisfactorily with the existing engine (Table 2).

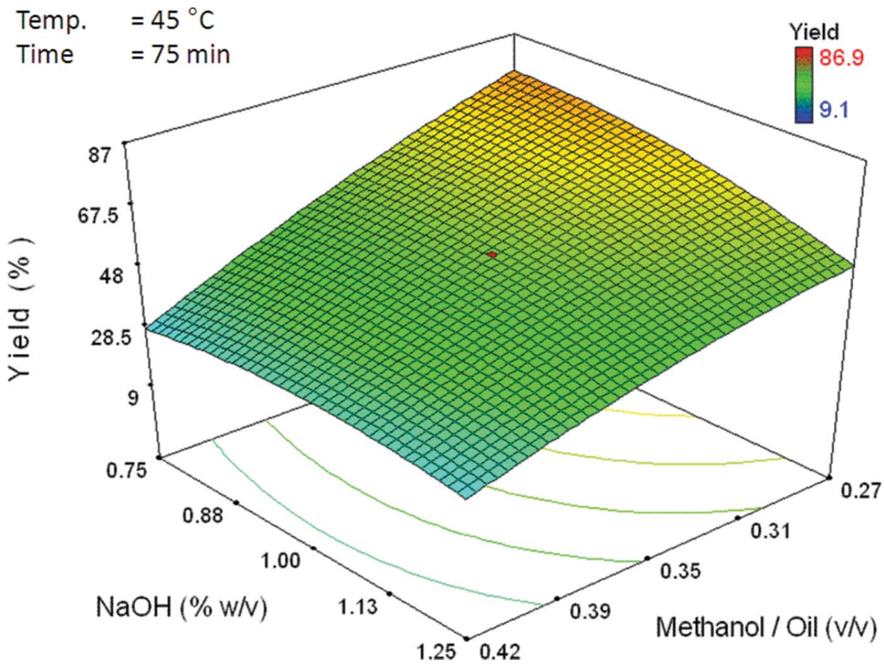

Figure 1 Result of the alkaline-esterification process showing the influence of NaOH and methanol/oil ratio on biodiesel yield.

PERFORMANCE ANALYSIS IN IC ENGINE

Engine Set Up

A single cylinder constant speed variable compression ratio diesel engine with computerized data acquisition was used to evaluate the performance, emission, and combustion characteristics. The major specification of the engine used to carry out the experiments is given in the Table 3 and the same is shown in Figure 2. The fuel and air consumptions were metered by the sensor-transmitter setup and recorded real time in the data acquisition system. Similarly, provisions were made for online recording of exhaust gas and cooling water inlet and outlet temperatures. The engine is loaded in step of 0.5 kW starting from no load to full load condition at the rated speed automatically. The compression ratio of the engine was varied by rotating an arm, which moves the cylinder head up and down thereby changing the clearance volume. One piezo-pressure sensor is mounted on the engine head through a sleeve for recording online cylinder pressure with respect to the crank angle and another one is mounted on the fuel line near injector for the measurement of injection pressure. The signals received from various sensors are interfaced to personal computer through data acquisition system and the software gives the P-θ diagram, P-V plot, and heat release rate (J/deg) with respect to crank angle.

The exhaust gas of the engine was sampled from the exhaust pipe line through a specially designed arrangement for diverting the exhaust to the sampling line of the gas analyzer without increasing the back pressure. The exhaust gas analyzer used for this work was a portable multi gas analyzer, QUINTOX Kane International Ltd. The measurement of smoke intensity/opacity of engine exhaust was measured using smoke meter named Air Emission monitoring system MRU Optrans 1600, 230 V, 50/60 HZ.

Table 1 Experimental Design with Process Parameter and the Corresponding Yield of Biodiesel for the Second-Stage Alkaline Esterification Process

Run	Methanol/Oil	NaOH	Time	Temperature	Percentage of monoesters in biodiesel (by GC analysis)						Yield
	v/v	% w/v	min	°C	Oleic	Linoleic	Linolenic	Palmitic	Stearic	Total	wt. %
1	0.4	1.25	97.5	37.5	3.5	4.9	1.4	0.8	0.7	11.3	80.9
2	0.4	1.00	120.0	45.0	15.1	17.3	3.8	2.9	2.5	41.6	86.1
3	0.3	0.75	97.5	52.5	23.8	25.5	5.6	4.8	3.9	63.6	91.6
4	0.4	0.75	97.5	52.5	6.4	7.8	2	1.2	1	18.4	82.2
5	0.3	1.25	97.5	37.5	12.1	13.5	3.4	2.5	2.2	33.7	84.8
6	0.4	1.00	75.0	45.0	20.5	21.75	4.5	3.6	3.4	53.7	87.8
7	0.4	0.75	52.5	37.5	6.1	7.3	1.9	1.1	1	17.4	82.3
8	0.4	1.00	75.0	45.0	20.8	21.9	4.61	3.71	3.14	54.2	89.4
9	0.3	0.75	52.5	37.5	23.3	24.1	5.2	4.3	3.6	60.5	90.4
10	0.3	1.25	97.5	52.5	20.7	22.1	4.6	3.7	3.1	54.2	88
11	0.4	1.00	75.0	45.0	20.8	22.1	4.7	3.8	3.9	55.3	88.2
12	0.4	0.75	97.5	37.5	4.3	5.5	1.5	1	0.9	13.2	81.5
13	0.4	1.00	75.0	45.0	20.9	21.9	4.6	3.7	3.05	54.2	88.8
14	0.4	1.00	75.0	45.0	20.3	21.65	4.45	3.55	3	52.9	87.6
15	0.4	1.00	75.0	30.0	14.2	16.5	3.7	2.8	2.4	39.6	85.4
16	0.3	1.25	52.5	52.5	14	16.5	3.6	2.8	2.4	39.3	85.1
17	0.4	1.25	52.5	52.5	5.6	6.8	1.8	1.1	1	16.3	81.9
18	0.2	1.00	75.0	45.0	30.7	32.6	9.7	7.5	6.4	86.9	97.1
19	0.3	0.75	97.5	37.5	21.5	22.4	4.8	3.9	3.2	55.8	89
20	0.4	1.00	75.0	60.0	16.6	18.5	4	3.1	2.7	44.9	86.3
21	0.4	1.25	52.5	37.5	15	17.3	3.8	2.9	2.4	41.4	86
22	0.4	1.00	75.0	45.0	20.8	21.8	4.6	3.7	3.05	53.9	87.7
23	0.3	1.25	52.5	37.5	20.1	21.4	4.3	3.4	2.9	52.1	87.5
24	0.4	1.25	97.5	52.5	3.8	5.3	1.5	1	0.8	12.4	81.1
25	0.4	0.50	75.0	45.0	21.7	22.4	4.9	4	3.2	56.2	91.3
26	0.5	1.00	75.0	45.0	3.1	4.1	1	0.6	0.3	9.1	80.2
27	0.4	1.50	75.0	45.0	9.3	11.3	2.6	1.9	1.7	26.8	83.1
28	0.4	0.75	52.5	52.5	6.7	8	2.1	1.2	1	19.0	82.6
29	0.3	0.75	52.5	52.5	26	27.7	6.2	5.1	4.2	69.2	92.5
30	0.4	1.00	30.0	45.0	19.9	21.2	4.3	3.4	2.9	51.7	87.2

Table 2 Properties of Rubber Seed Oil Biodiesel in Comparison with Standard Biodiesel and Diesel

Property	Test procedure	Biodiesel-standard ASTM D6751-02	Rubber seed oil Biodiesel	Diesel
Specific gravity @and 30°C	ASTM D4052	0.87–0.90	0.8796	0.8236
Kinematic viscosity @and 40°C (mm^2/s)	ASTM D445	1.9–6.0	3.92	3.18
Heating value (MJ/kg)	ASTM D240	—	38.20	44.1
Flash point (°C)	ASTM D93	130	128	68
Cloud point (°C)	ASTM D2500	−3 to 12	5	17
Pour point (°C)	ASTM D97	−1.5 to 10	−7	−20
Carbon residue (%)	–	< 0.3	0.14	0.17

Table 3 Major Specification of the Engine used for Performance Analysis

Particulars	Details
Make	KIRLOSKAR
No. of Cylinder	Single
Cooling	Water
Bore & Stroke	87.5 mm × 110 mm
Cycle	Four stroke
Maximum power	5 kW
Speed	1450–1600 RPM
Compression ratio	16–22
Injection timing	23° BTDC
Loading	Auto loading

Performance Analysis of Engine

Initially, the engine was tested with standard diesel oil at various compression ratio’s starting from 16 to 22 and in step of 0.5 kW load to its capacity to analyze its performance. The brake power, brake thermal efficiency, and specific fuel consumptions (SFC) were computed for each load conditions.

Brake thermal efficiency (BTE) is the major factor in characterizing the engine operation apart from engine noise, vibration, pollutant emissions, initial cost, reliability, and durability. Figure 3 shows the brake thermal efficiencies of the engine at various compression ratios in using standard diesel as well as extracted rubber seed-based biodiesel at different operating conditions. The brake thermal efficiency seems to remain same as that of standard diesel in most of the load conditions; however, it is slightly better during full load operations for biodiesel.

Figure 4 indicates that the BTE at full load conditions for different CR’s, which shows that the efficiency increases with increase in CR for diesel as well as biodiesel. Moreover, it can be seen that when using biodiesel as fuel, the efficiency is slightly better at the compression ratio of 20. There were no observed noises or vibration in the engine operation up to CR of 20, indicating smooth combustion. However, at CR of 22, there

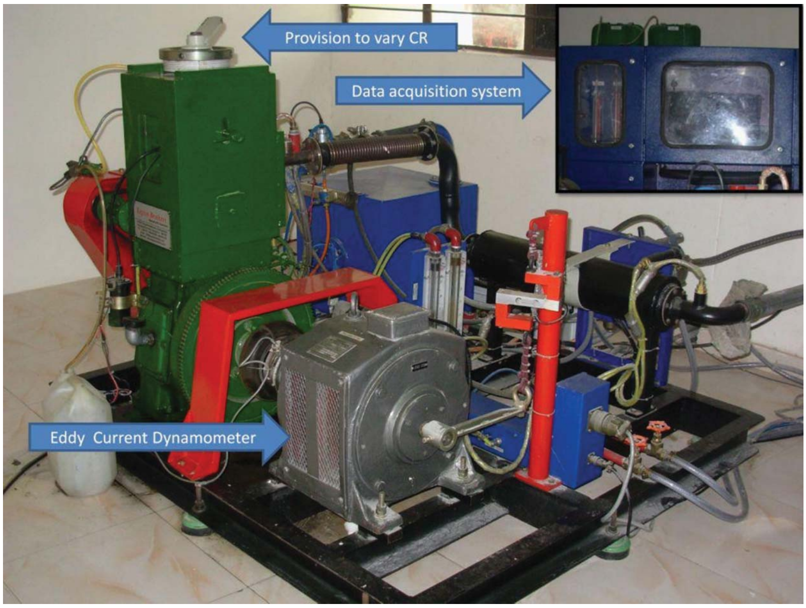

Figure 2 Single cylinder constant speed variable compression ratio diesel engine with computerized data acquisition.

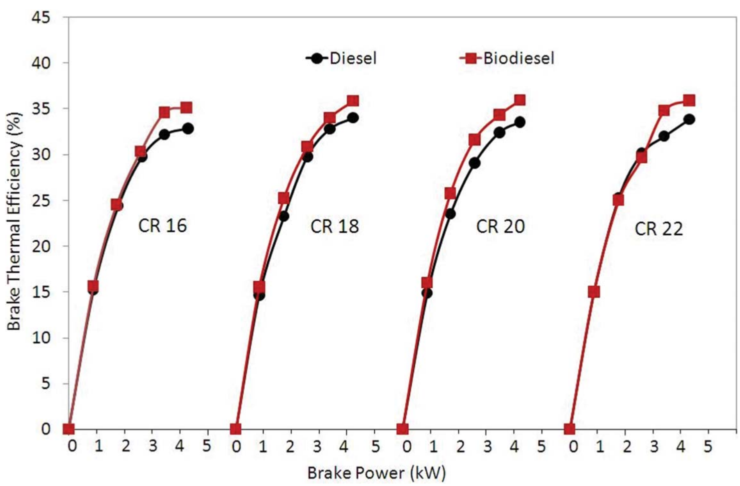

Figure 3 The variation of brake thermal efficiency at different compression ratios of the engine in using standard diesel and biodiesel as fuel.

were some vibrations in the engine, indicating uneven combustion. The heat release rate with respect to crank angle plot observed at CR's 20 and 22 is shown in Figure 5. The heat release is not uniform and shows a drastic raise after the 360° crank angle for CR 22, whereas there is a smooth release of heat at CR 20. The recorded maximum efficiency of the engine in using biodiesel as fuel is 35.96%, which is also at CR 20.

The ideal condition of engine operation in using diesel as fuel is at its rated CR, that is, 18. The thermal performance of biodiesel closely matches with that of standard diesel

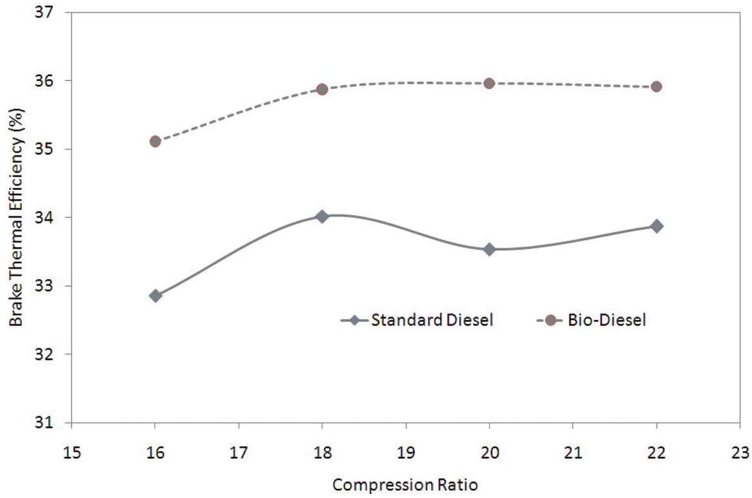

Figure 4 The brake thermal efficiency of the engine at full load condition during various compression ratios while using diesel and biodiesel as fuel.

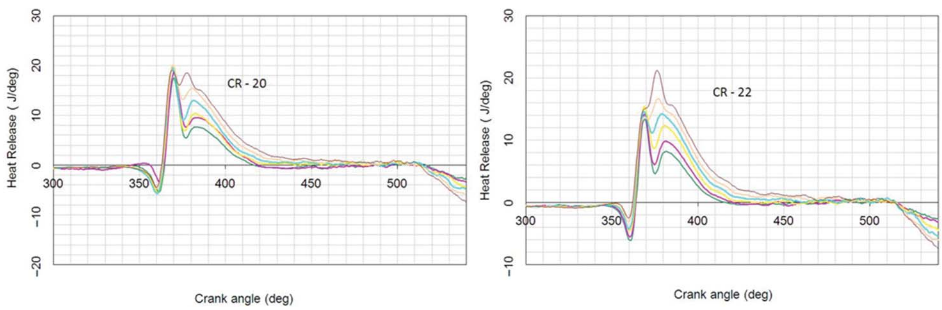

Figure 5 Heat release rate with crank angle of the engine at CR's 20 & 22 when using biodiesel as fuel.

in spite of having low heating value. Even slightly better thermal efficiency for biodiesel is observed, which may be due to the presence of oxygen content in the biodiesel, which facilitates the combustion process (Agarwal 2007; Demirbas, 2009; Atadashi, Aroua, and Abdul Aziz 2010). The oxygen content in the fuel improves and facilitates combustion process, and the better lubricity property of biodiesel yields better performance (Peterson, Wagner, and Auld 1983; Charles and Todd 1998).

Specific Fuel Consumption

SFC is the measure of how efficiently an engine is using the fuel supplied to produce work. The variation of SFC, which is the flow rate per unit power output, with respect to brake power for diesel and biodiesel at various compression ratios is presented in Figure 6. It can be noted that the SFC of biodiesel is slightly higher than that of the standard diesel even though the efficiency is on par with diesel. This is attributed to the fact that the specific gravity of biodiesel is higher than diesel. Similar findings are reported by other researchers also (Jindal et al. 2010; Muralidharan and Vasudevan 2011).

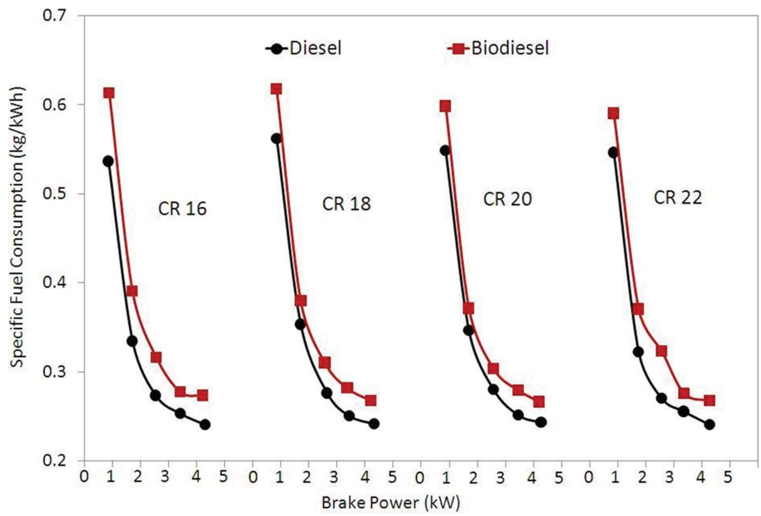

Figure 6 The variation of SFC at different compression ratios of the engine in using standard diesel and biodiesel as fuel.

EMISSION ANALYSIS

The emission parameters such as carbon monoxide (CO), hydrocarbon (HC), and nitrogen oxide (NOx) were analyzed along with exhaust gas temperature. The sensors of the portable gas analyzer were placed inside the exhaust pipe for every engine trail until steady-state conditions were achieved. The details of such analysis are mentioned below.

Exhaust Gas Temperature

The exhaust gas temperature (EGT) is very well in accordance with the combustion temperature of the engine cylinder. Therefore, the analysis of exhaust gas temperature gives some inference on the combustion conditions of the fuel. The variation of exhaust gas temperature at different load conditions of the engine while using diesel and biodiesel as fuel at the compression ratio of 18 is shown in Figure 7.

The exhaust gas temperature of the biodiesel is similar to that of diesel at no load conditions; however, the exhaust gas temperature is slightly low for biodiesel at higher loads. In general, the EGT also decreases with increase in CR and this was observed and indicated in Figure 8. The reason for the decrease in exhaust gas temperature at higher compression ratio is that, the air drawn during the suction stroke will be compressed to higher pressure there by increasing the air temperature. However, the increased air temperature contributes for better atomization of fuel resulting in sudden and complete combustion, which reduces the exhaust temperature. Moreover, the presence of oxygen in the biodiesel supplies excess oxygen which improves the thermal efficiencies and combustion properties. The major cause of NOx formation is the peak combustion temperature.

Emission of NOx

The Figure 9 shows the variation of NOx emission at full load condition while using diesel and biodiesel at different compression ratios. The NOx emission for diesel is comparatively higher at all compression ratios, which is also signified by the higher

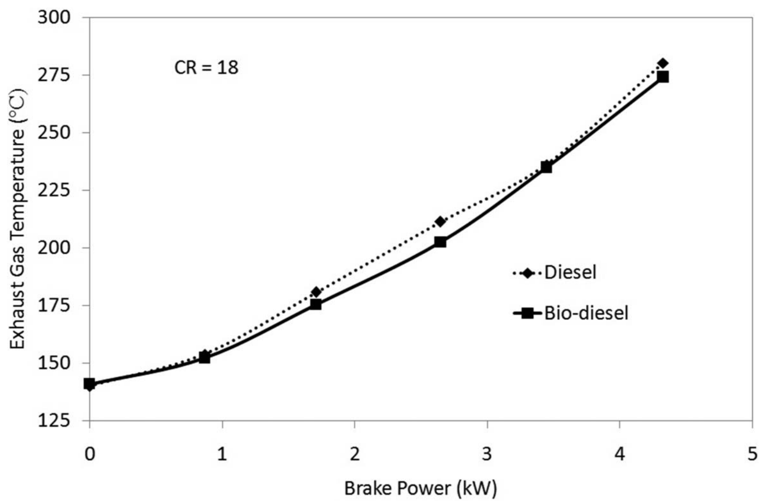

Figure 7 The variation of exhaust gas temperature at different load conditions of the engine at CR of 18.

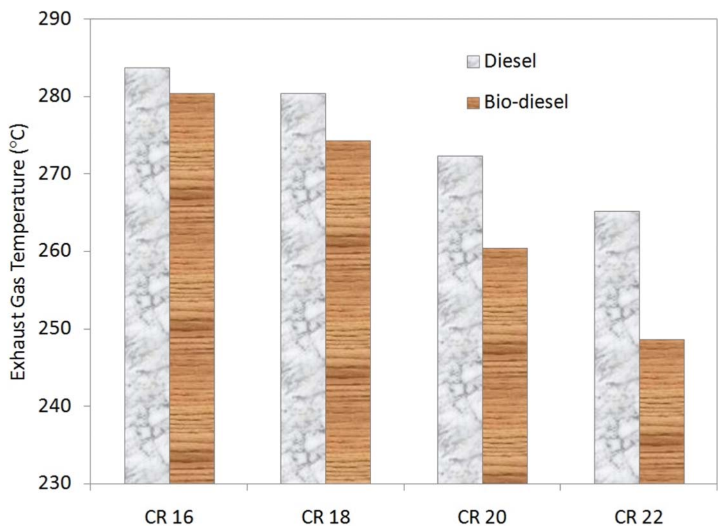

Figure 8 The exhaust gas temperatures at full load condition while using diesel and biodiesel as fuel.

exhaust temperatures for diesel in comparison with biodiesel. On an average, the exhaust temperature reduces by 2% when CR was increased from 16 to 22. The same trend is reflected in the reduction of NOx as the CR increases for both diesel and biodiesel. It can be attributed to better thermal efficiency due to higher compression ratio and better atomization of fuel during the combustion process. This is reflected in the results showing lesser NOx emission for biodiesel.

Emission of CO

Carbon monoxide (CO) is a colorless and odorless gas and is highly toxic to human beings. Figure 10 shows the plot of CO emissions at various CR from 16 to 22 for the given

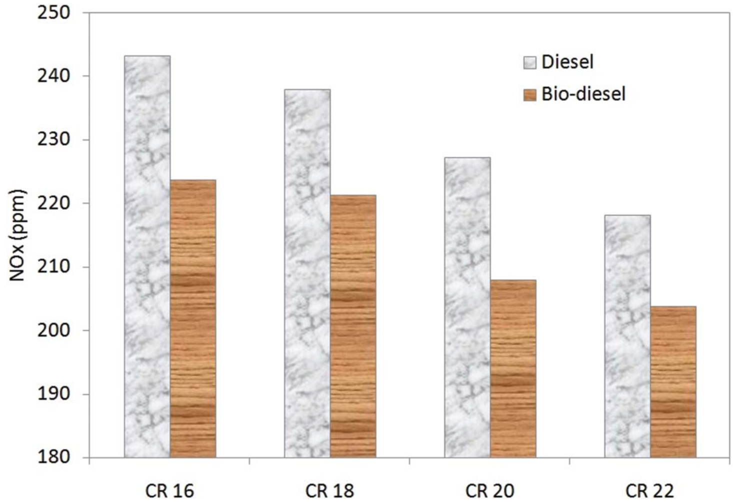

Figure 9 Variation of NOx emission plot at full load condition of the engine while using diesel and biodiesel at different compression ratios.

engine while using diesel and biodiesel as fuel. CO emission is the ideal assessor for the efficient combustion of the product inside the engine within the given stipulated time. CO emission occurs because of incomplete combustion of fuel due to insufficient supply of oxygen, improper pre-mixing of fuel with air, and due to the time constraint in combustion process. The viscosity and specific gravity of rubber seed oil-based biodiesel is slightly higher than that of diesel. But it should be noted that biodiesel is an oxygenated fuel having approximately 11% oxygen content in it by mass (Ramadhas, Muraleedharan, and Jayaraj 2005a). The viscous nature of the oil and marginally low temperature of combustion in the present case resulted in poor atomization of fuel emitting slightly higher percentage of CO in comparison with standard diesel.

Emission of HC

The key component of brown haze of smog is hydrocarbon (HC), which plagues many urban areas causing serious health problems to humans. Figure 11 shows the variation of HC emission at different CR's for standard diesel and biodiesel. The HC emission does not vary much with respect to compression ratio; however, there is a marginal decrease in HC levels in exhaust for biodiesel in comparison with standard diesel, which indicates better combustion of rubber seed oil biodiesel fuel. Lower emission of HC and smoke for biodiesel fuels was also reported by some researcher (Enweremadu and Rutto 2010; Jindal et al., 2010) and at the same time, higher emission of HC for biodiesel is also reported attributing to improper atomization of fuel (Murugan, Ramaswamy, and Nagarajan 2008; Muralidharan and Vasudevan, 2011).

CONCLUSION

Designed two-stage esterification experiments were conducted with acid and alkaline catalyst to reduce the high FFA content of the extracted raw oil. The process parameters were optimized in the first stage for maximum reduction in the acid value and in the

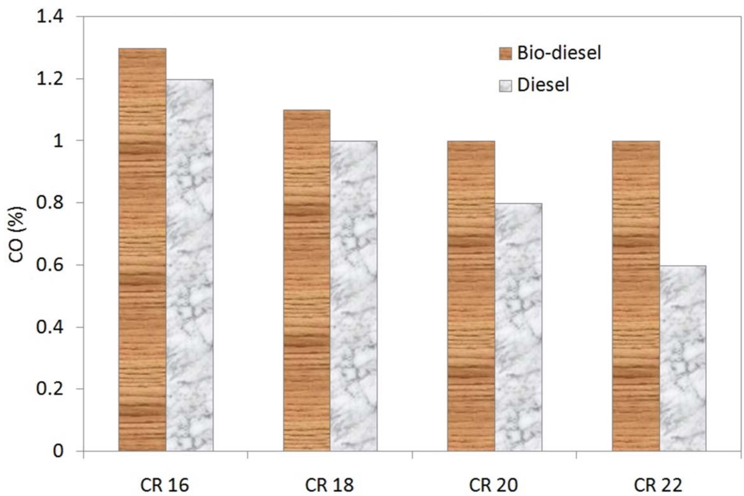

Figure 10 CO emission plot at full load condition of the engine while using diesel and biodiesel at different compression ratios.

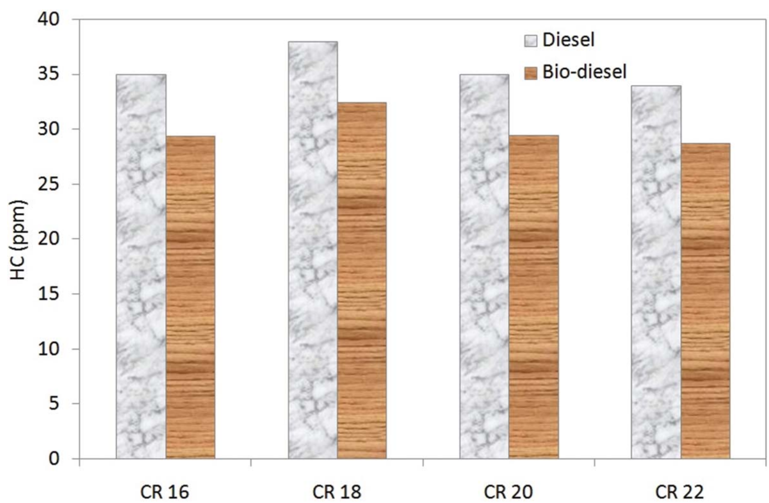

Figure 11 HC emission plot at full load condition of the engine while using diesel and biodiesel at different compression ratios.

second stage for maximizing the oil yield. The estimated fuel properties of rubber seed oil biodiesel were found to be comparable with that of conventional diesel oil. However, the calorific value of biodiesel (38.2 MJ/kg) is slightly lower than diesel. Engine performance were studied for biodiesel and diesel and found that the optimum CR for biodiesel is 20 and that for standard diesel is 18. Uneven combustion and vibrations were observed at higher CR's. The lower EGT for biodiesel reduces the NOx emission and the CO emission decreases with increase in CR due to improved atomization of the fuel. The presence of oxygen in the biofuel contributes for better combustion properties and lower emissions.

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