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Development of Clean Burning Fuel for Compression Ignition Engines

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Abstract : Diesel engines are used for automotive application because they have lower specific fuel consumption and superior efficiency compared to S.I engines. However in spite of these advantages NOx and smoke emissions from the diesel engines cause serious environmental problems. Pure vegetable oil poses some problems when subjected to prolong use in diesel engines. The problems are attributed to its high viscosity and low volatility. These problems can be minimized by the process of transesterification. In this study the transesterification reaction of refined coconut oil carried out with methanol using potassium hydroxide as a catalyst to produce methyl ester of biodiesel. The products were evaluated by comparing physical characteristics of biodiesel to conventional diesel oil. These characteristics included specific gravity, density, viscosity, pour point, flash point, fire point, heating value, etc. The biodiesel then tested in a diesel engine to observe their actual performance and emissions.Transesterified coconut oil has exhibited performance very close to that of diesel fuel with reduction in exhaust emissions, the critical reviews conducted on the different aspects of the vegetable oil as substitute fuel for diesel engine including its properties and their effects on performance and emission characteristics.

Key words : Coconut oil, Kinematic viscosity, Calorific value, Compression ratio, Brake thermal efficiency.

Introduction

Biodiesel is an environmentally friendly alternative diesel fuel consisting of the alkyl monoesters of fatty acids. It is obtained from triglycerides through the transesterification process. Triglycerides are the constituents of vegetable oils and fats and are one of the dominant means of energy storage in nature (Agrawal A., 2006). Biodiesel can be derived from edible and non edible vegetable oils, animal fats, and waste restaurant cooking oils. *Transesterification* is a chemical reaction where the triglyceride is reacted with alcohol in the presence of a catalyst. In this reaction, the fatty acid radicals of the triglyceride molecule split away from the glycerin backbone, and the fatty acid radicals make new ester connections with the alcohol molecules, resulting in free glycerin and fatty acid esters. These fatty acid esters are known as biodiesel (Ramesh *et al*., 2003). Use of Biodiesel in diesel engines can reduce the dependence on conventional diesel fuel, and better exhaust emissions.

Materials and Methods

The advantageous features of biodiesel result from the fact that biodiesel has different physical and chemical properties than

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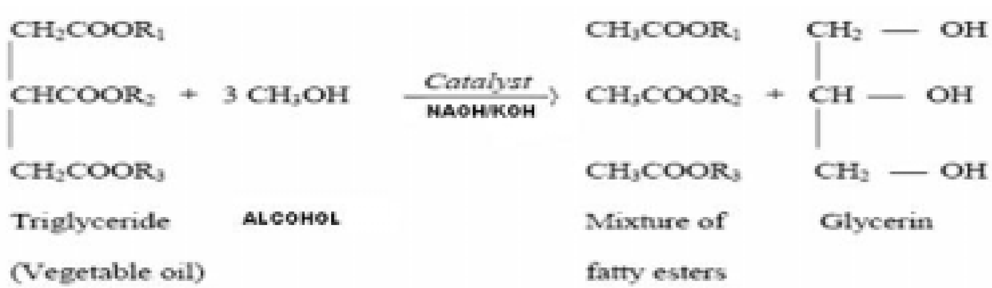

Fig. 1 : Transesterification reaction between triglyceride and alcohol

petroleum-based diesel fuel. 10-11 percent of biodiesel is oxygen by weight and this result in more complete combustion (Forson *et al*., 2004). Also, it has a higher cetane number and lubricity, makes the combustion smoother and the engine less noisy. However, biodiesel has higher values of viscosity, density, speed of sound, and bulk modulus that may cause injection system and combustion anomalies (Paul *et al*., 2005). Vegetable oils and fats are composed of glycerin esters with long chain hydrocarbons as the functional ester groups. These long hydrocarbon chains are represented by R1, R2, and R3 in the fig.2.

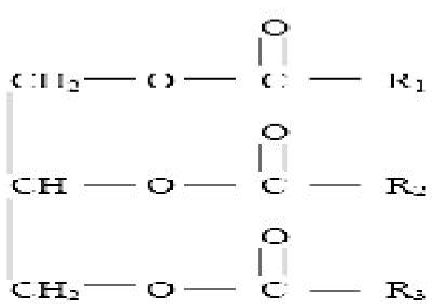

Fig. 2 : The chemical structure of vegetable oil

When separated from the glycerin these long chain hydrocarbons have acid functionality and are known as fatty acids. Up to three fatty acids can be attached to the glycerin molecule, and it is named according to the number of fatty acids that are linked to it. For example, if one fatty acid is attached to the glycerin molecule it is called a monoglyceride, if two fatty acids are attached to a glycerin molecule it is called a diglyceride, and there are three it is called a triglyceride. Vegetable oils and animal fats are composed of triglycerides, as shown in Fig. 1. There are many different kinds of fatty acids that differ in carbon chain length and in the number of carbon-carbon double bonds. The percentage of the different fatty acids in fats or oils varies depending on the source (Sharma, 2005). Table 1. shows the fatty acid composition of some common vegetable oils. Fatty acids compose 90% of the total mass of a triglyceride molecule. Thus, the fatty acids have the greatest impact on the physical properties of oil. For example, when the chain length increases, the viscosity increases, and when the number of double bounds increases, the viscosity decreases (Heywood, 1988). As a result, any alternative fuel derived from oils should be analyzed to determine its fatty acid composition in order to characterize its physical properties. Even though the physical and chemical properties of vegetable oils are close enough to diesel fuel to run diesel engines for short periods without any modifications, using vegetable oils in direct injection diesel engines results in severe engine deposits, dilution of the lubricating oil with unburned fuel, injector choking, piston ring sticking, and high exhaust emissions(Williard W., 2003). Most of these problems are a consequence of the high viscosity of the vegetable oils. Fatty acid

Table 1: Fatty acid composition in vegetable oils (%, by weight)

Fatty Acid	Formula	Coconut Oil (%)	Palm Kernel Oil (%)
Caproic	$C_6H_{12}O_2$	0.2–0.8	0–1
Caprylic	$C_8H_{16}O_2$	6–9	3–5
Capric	$C_{10}H_{20}O_2$	6–10	3–5
Lauric	$C_{12}H_{24}O_2$	46–50	44–51
Myristic	$C_{14}H_{28}O_2$	17–19	15–17
Palmitic	$C_{16}H_{32}O_2$	8–10	7–10
Stearic	$C_{18}H_{36}O_2$	2–3	2–3
Oleic	$C_{18}H_{34}O_2$	5–7	12–19
Linoleic	$C_{18}H_{32}O_2$	1–2.5	1–2

composition in some vegetable oils (%, by weight) shown in table 1.

High viscosity causes poor atomization of the fuel in the combustion chamber and affects the peak injection pressure, the injection duration, the spray cone angle, and the quality of atomization (Pundir, 2007). These changes can lead to poor injection cut-off and nozzle dribble, resulting in injector choking, deposits, and high emissions Also, it is known that when the viscosity of the fuel increases, the cone angle decreases, and the diameter of the fuel droplets and their penetration increase. Thus, the liquid core of the fuel spray can touch the cylinder wall and the piston surface, causing heavy carbon deposits on the walls, piston ring sticking and breaking, and dilution of the lubricating oil (Heywood, 1988). Moreover, high viscosity can cause early injection due to high line pressure, which moves the combustion of the fuel closer to top dead center, increasing the maximum pressure and temperature in the combustion chamber (Pundir, 2007). Transesterification is a way to lower the viscosity of the vegetable oil by breaking up the triglyceride molecule and separating the fatty acid molecules from the glycerin molecule. This makes the properties of the vegetable oils and animal fats closer to diesel fuel, solving the problems due to the high viscosity of vegetable oils. In this process, a triglyceride, which is itself an ester, is reacted with an excess of the stoichiometric amount of alcohol and a catalyst (KOH, or NaOH,) and the triglyceride molecule splits into glycerin and a mixture of fatty esters (Ramesh *et al.*, 2003).

Transesterification process of methyl ester

Equipments, which were used for Transesterification reaction, are magnetic stirrer, thermometer and beaker. Raw materials are refined coconut oil, methanol and potassium hydroxide. Firstly, the refined coconut oil was warmed up to 60-65 °C to change the phase of solid to liquid phase. After that, the liquid phase of refined coconut oil was measured its capacity of 1,000 ml and filled it into the first beaker. Next, it was stirred at 800 rpm and warmed the oil up to 60 °C. In addition, the potassium hydroxide 4 grams was dissolved 200 ml of methanol followed by vigorous stirring. This catalyst/alcohol mixture was added the coconut oil and stirred vigorously at 800 rpm for 1 hour at 60 °C. A successful transesterification reaction produces two liquid phases: the separation ester and crude glycerin could be observed within 5 minutes and completed within 1 hour. Crude glycerin, the heavier liquid, was separated at the bottom and methyl ester is on the top. After completed, water at 80 °C was added to double volume of methyl ester, and then was stirred for 15 minutes. The glycerin was allowed to settle again. The process was repeated until the ester layer becomes clear. The properties of methyl ester were investigated in Table 3.

Fuel-related properties of vegetable oils

Before evaluating performance and emission characteristics of any engine it is essential to examine fuel related properties of vegetable oil because these vary according to fuel fatty acid composition and atmospheric condition. The fuel-related examined properties of vegetable oils are listed in Table 3, The Kinematic viscosity of vegetable oils varies in the range of 25 to 45 cSt at 40^0C.High viscosity of these oils is due to large molecular mass and chemical structure. Vegetable oils have high molecular weights in the range of 550 to 900, which are three or more times higher than diesel fuels. The flash point of vegetable oils is very high (above 200^0C). The volumetric heating values of these oils are in the range of 37 to 40 MJ/kg which are low compared to diesel fuels (about 42.5 MJ/ kg). The presence of chemically bound oxygen in vegetable oils lowers their heating values by about 10%. The cetane numbers are in the range of 32 to 44. The iodine value ranges from 0 to 200 depending upon unsaturation. The cloud and pour points of vegetable oils are higher than that of diesel fuels (Pradeep and Sharma, 2007).

Specific Gravity

The specific gravity of coconut oil was determined by the standard relative density bottle of 50ml coconut oil, separately dry and filled with methyl ester. The weights were measured on an electronic balance. The Density of methyl ester calculated. For the calculation the density of water at desired temperature taken from the standard table. Specific gravity then calculated using the following formula:

$$\text{Specific Gravity} = \frac{\text{Density of coconut oil at desired temperature}}{\text{Density of water at the same temperature}}$$

The same procedure followed for the diesel and blends. The densities of crude coconut oil and coconut oil ester observed to be about 10.6% and 8.4% higher than that of High speed diesel. Thus, density of crude coconut oil reduced by about 9% on its conversion to ester. The densities were observed to increase linearly with the increasing concentration of biodiesel in the blends. The higher densities of crude coconut oil and coconut oil ester, as compared to diesel may be attributed to the higher molecular weights of triglyceride molecules presenting them. Slightly higher densities of blends as compared to diesel make their energy content on volume basis somewhat closer to diesel. Diesel exhibits a specific gravity of 0.83 (ASTM D-287). Biodiesel specific gravity is reported to vary between 0.86 and 0.90 and is typically 0.88 (Sukumar *et al*., 2005) Therefore volumetric metering of biodiesel results in the delivery of a slightly greater mass of fuel. As discussed in the following section, biodiesel is having lower energy content on both a volumetric and a mass basis. Therefore, although a unit injector might deliver a larger mass of fuel, the actual energy delivered is less than for diesel.

Viscosity

Viscosity (ASTM D-445) specification of coconut oil and coconut oil esters determined by Redwood Viscometer apparatus Fig 3. As shown in Table 3. In any case, the viscosity of neat biodiesel is higher than for typical diesel. High viscosity leads to poorer atomization of the fuel spray and less accurate operation of the fuel injectors. Additionally, the Average viscosity of biodiesel and biodiesel blends increases more rapidly as temperature is decreased than that of diesel (Zannikos *et al*., 2003). The viscosity of a fuel is important property, which affects the atomization of the fuel during the injection. A viscometer was used to measure the Kinematic viscosity of diesel fuel, their blends the viscosity calculated using the following formula:

Kinematic viscosity = A * t -- $\frac{B}{t}$

Where A=0.264, B= 190, t= time (sec)

The Kinematic viscosity of Crude coconut oil was found to be near 26.22 cSt, which is 7.3 times more than that of a high speed diesel it reduced to 5.18 cSt after Transesterification. However, the viscosity of blends increased with increasing concentration of biodiesel in the blends.

Fig. 3 : Redwood Viscometer

Flash Point

Flash point of coconut oil and coconut oil esters determined by Pensky Martens apparatus Fig.4, Flash point (ASTM D-93) is a measure of the temperature to which a fuel must be heated such that the mixture of vapor and air above the fuel can be ignited. Flash point of any fuel signifies the temperature at which the fuel self ignites. The flash points of Coconut oil and coconut oil ester were determined to be 260 °C and 161°C respectively and quite high compared to 56°C for the high speed diesel. The flash points of all the blends were also higher than that of diesel. Thus, overall flammability hazard of both coconut oil and coconut oil esters is much less than that of conventional high speed diesel.

Fig. 4 : Pensky Martens apparatus

Gross Calorific Value

The gross calorific values of the methyl ester, diesel and their blends were determined by Bomb Calorimeter method. A weighted quantity of sample was burned in oxygen in Bomb Calorimeter under controlled conditions. Rise in temperature was recorded the gross calorific value was then calculated from the weight of the sample and the rise in temperature. Before using formula water equivalent of Bomb was measured. It was achieved by burning 0.9gm of benzoic Acid with a known mass of water (1.6liters) in the calorimeter and measured the temperature rise.

$$W = \frac{mBA * CVBA - 1.6}{CW * TBA} \quad .... \; 1$$

$$CVf = \frac{(1.6 + W) * Cw * Tf}{mf.} \quad .... \; 2$$

W= Water equivalent of Bomb calorimeter, *mBA*=Mass of benzoic acid kg.

TBA=temperature rise in benzoic acid, *CW*=specific heat of water (4.184kJ/kg-K).

CVBA= Higher calorific value of benzoic acid (26,460kJ/kg), *CV f* =calorific value of fuel, kJ/kg.

Mf=mass of fuel, kg., *Tf*=Temperature rise of test fuel

The gross calorific values of Crude coconut oil and coconut oil ester were found to be 37.260 and 39.312 MJ/kg respectively, Which are 12.4% and 9.2% lower than 42.5 MJ/kg for high speed diesel this could be due to the difference in their chemical composition from that of diesel or the difference in the percentage of carbon and hydrogen content, or the presence of oxygen molecule in the molecular structure of Crude coconut oil and coconut oil ester The calorific values of the blends proportionately decreased with the increase in biodiesel percentage in the blends. It is generally accepted that fuel consumption is proportional to the volumetric energy density of the fuel based upon the lower or net heating value.

Low temperature flow properties

Pour Point

The key flow properties for winter fuel specification are cloud and pour point. Cloud point, ASTM D-2500, is the temperature at which wax formation might begin to plug the fuel filter. It is measured as the temperature of first formation of wax as the fuel is cooled. Pour point (ASTM D-97) is a measure of the fuel gelling point. This temperature is a measure of the temperature at which the fuel is no longer pump able (Usta N., 2005). The pour point is always lower than the cloud point. The cloud point is not generally affected by additives called flow improvers. However, flow improver additives can decrease the size, or inhibit the formation, of the wax crystallites formed upon cooling the fuel and thus lower the temperature at which wax plugging becomes a problem (Terry, 2006). Pour point additives can lower the temperature of fuel gelling significantly. In winter time, diesel fuels are often diluted with kerosene to meet wintertime flow specifications and fuel cloud and pour points are varied by refiners to meet local climatic conditions.(Williams, 2006) The pour points of coconut oil and coconut oil esters were higher than that of high speed diesel. This might be due to the presence of wax, which begins to crystallize with the decrease in temperature. The problems of higher pour point of coconut oil and coconut oil esters could be overcome by blending with high speed diesel.

The properties of biodiesel and diesel fuels are compared in Table 3.The characteristics of biodiesel are close to diesel fuels, and therefore biodiesel becomes a strong candidate to replace the diesel fuels if the need arises. The conversion of triglycerides into methyl esters through the transesterification process reduces the molecular weight to one-third that of the triglyceride, reduces the viscosity by a factor of about eight and increases the volatility marginally. Biodiesel has viscosity close to diesel fuels. These esters contain 10 to 11% oxygen by weight, which may encourage more combustion than hydrocarbon-based diesel fuels in an engine. The cetane number of biodiesel is around 50. Biodiesel has lower volumetric heating values (about 12%) than diesel fuels but has a high cetane number and flash point (Ramesh *et al*., 2003). The esters have cloud point and pour points that are 15 to 258^{0}C higher than those of diesel fuels.

Experimental setup

A smoke analyzer was used for the measurement of smoke in the exhaust .Two fuel tanks are used, which contain diesel and coconut oil, oil supply is ensured by maintaining the proper opening of valve fitted in oil tank, quantity measured by burette enabled the engine fuel consumption measurement method. An air tank fitted with an orifice was connected to the air- induced manometer.

A thermocouple is connected to the exhaust manifold of the engine to measure exhaust gas temperature, and two thermocouples were used to measure the inlet and exhaust coolant temperatures. The engine was allowed to reach steady state and the various readings were noted down. A 12V, 15 W heaters was fixed tube between the injector and fuel injection pump and close to fuel injector. The heater was fixed with an aim of preheating the fuel before the combustion, to reduce the viscosity and physical delay of combustion. The performance test was then carried out under the same operating condition and the procedure followed for testing of coconut oil blends without heater was repeated. The performance and emission tests were started using 100%

Table 2 : Test Engine Specifications

Make	Kirloskar AV-1
Class	Single cylinder, 4-stroke direct injection, water cooled
Power output, kW	3.7(5 Bhp)
SFC, g/kWh	240
Speed, rpm	1500
Fuel	High speed diesel
Bore, mm ϕ	80
Stroke, mm	110
Swept volume, cc	553
Fuel Injection Pressure, bar	170
Injection Timing bTDC	29
Dynamometer	3.5 KVA capacity D.C. generator
Compression Ratio	15

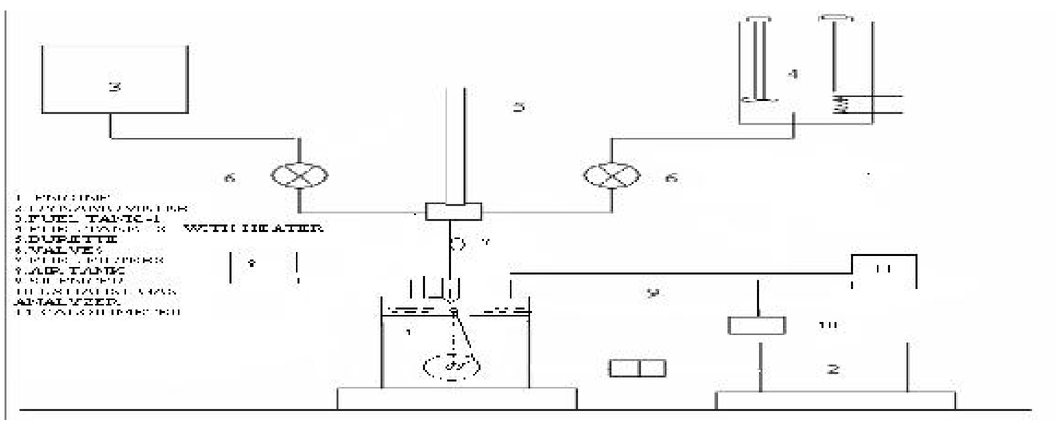

Fig. 5 : Modified Diesel Engine Test set -up

diesel and then fuel was replaced by blended fuels. Experimental set up shown in fig.5.The second method suggested was to use direct coconut oil blends. Experiments were conducted using various blends increased the power output and reduced emission. Moreover vegetable oils were renewable energy that most vegetable oils contained substantial amount of oxygen in their molecular structure and sulphur content was almost negligible. Optimum performance was obtained for 20% coconut oil blend biodiesel. The possible reasons for increased thermal efficiency more complete combustion and additional lubricity of coconut oil. Hence Friction horsepower is reduced. So, the energy saved by decreased friction horsepower additional contribution towards useful energy, cooling losses and exhaust losses. The exhaust gas temperature decreased with increasing coconut oil blends. The exhaust temperature is lower because oxidation of hydrocarbons is occurring during the expansion stroke rather than in the exhaust. Hence, a positive sign glow in this method .the third method suggested was to preheat the fuel before injection into the cylinder. It was mainly aimed at reducing viscosity to get rid of flow related problems. Experiments were conducted using preheated diesel and blended coconut oil.

Test with Coconut Oil Blends

Coconut oil burns more slowly than diesel, which results in a more even pressure applied to the pistons during their movement in the cylinders of the engine. This in turn leads to less engine wear, a quieter engine and better fuel economy. Also, as the coconut oil burns slower and has better lubricating qualities than diesel, the engine gets less hot and there is less wear, which helps to prolong engine life. Coconut oil has a special feature of readily mixing with diesel. It remains crystalline solid at temperatures below 20^0 C, but it is clear liquid when it is blended with ordinary diesel fuel. Further, apart from other vegetable oils, the fraction of coconut oil in blends did not create separation or from any layers on the inside wall of the fuel tank. There is a high production of coconut oil in tropical countries like India, Srilanka and Malaysia and so could be a good partial replacement for conventional diesel fuel. One major drawback is that the price of coconut oil is higher than that of conventional petroleum fuels. But it could be the least cost alternative in terms of the global emissions management because coconut oil based fuels produce reduced exhaust emissions. The engine was warmed up for half an hour. By keeping all the engine parameters constant, the fuel along was modified to various blends. The gas analyzer was first calibrated. The probe of analyzer was properly introduced into the exhaust pipe and also fixed at the center of the exhaust pipe so that maximum temperature of exhaust gas was exposed to the probe. These setting were periodically checked during the period of the experiments. The result of experiments, namely, smoke was noted down. The problems associated with most vegetable oils are the large variation of viscosities than that of the diesel fuel, which lead to flow related problems. However, Transesterification, Micro emulsion, pyrolysis, dilution could overcome such problems, which reduce the viscosities of the vegetable oils. Alternatively this difficulty could also be overcome by preheating. This method was adopted in this work and the performance and emission tests were carried out and compared with that of diesel fuel.

Table 3 : Comparison of Properties of Coconut Oil and Diesel

Properties	Fuel blend									
	100%	100%	Diesel + Percentage coconut oil							
	diesel	Coconut	10	20	30	40	50	60	80	100
Cal value kj/kg	42500	37260	41976	41452	40928	40404	39880	39356	39128	39312
Specific gravity	0.83	0.918	0.838	0.847	0.856	0.865	0.874	0.82	0.891	0.9
Flash point	56	260	101	110	121	125	132	139	152	161
Cetane number	52	37	49	47	46	44	44	-	-	-
Kinematic viscosity, Cst 40^{0}C	3.6	26.22	3.7	3.93	4.7	4.8	5.3	4.89	4.92	5.18

Results and Discussion

In this paper the authors have discussed various essential evaluated properties, specifications prospects of utilizing coconut oil so that environmental degradation could be meet. The objective of this experimental study is to use coconut oil as fuel in diesel engine and to compare its performance with diesel operation. Different performance test conducted on a 5.2 kW, 1500 rpm single cylinder vertical diesel engine. Specifications of the engine shown in table 2. Results show that Fuel properties of diesel, coconut oil and blends are comparable. Short-term engine performance indicates suitability of coconut oil fuel blends up to B40 concentration, beyond this modification in the engine necessary.

In this paper, vegetable oil derived diesel fuels with respect to fuel properties, engine performance, and emissions are reviewed. Using raw oils in diesel engines led to such problems as the sticking of fuel injectors and piston rings due to choking, and the thickening of lubricating oils, resulting in clogging of filters, but these were overcome in a large measure by a chemical process using methanol called transesterification. If we use vegetable oil as fuel in diesel engine in our country, which has a great potential for producing vegetable oils, it will be a big achievement in terms of reducing the sky-rocketing petroleum bills. Coconut oil subjected to transesterification process to reduce its viscosity and resulting coconut methyl ester known as biodiesel used in 5 H.P. Single cylinder diesel engine. Result shows that B-20 blend gave better performance and produced lower smoke emission than diesel.Biodiesel is completely miscible with petroleum diesel fuel, and is generally tested as a blend. The use of biodiesel in neat or blended form has no effect on the energy based engine fuel economy. The lubricity of these fuels is superior to conventional diesel, and this

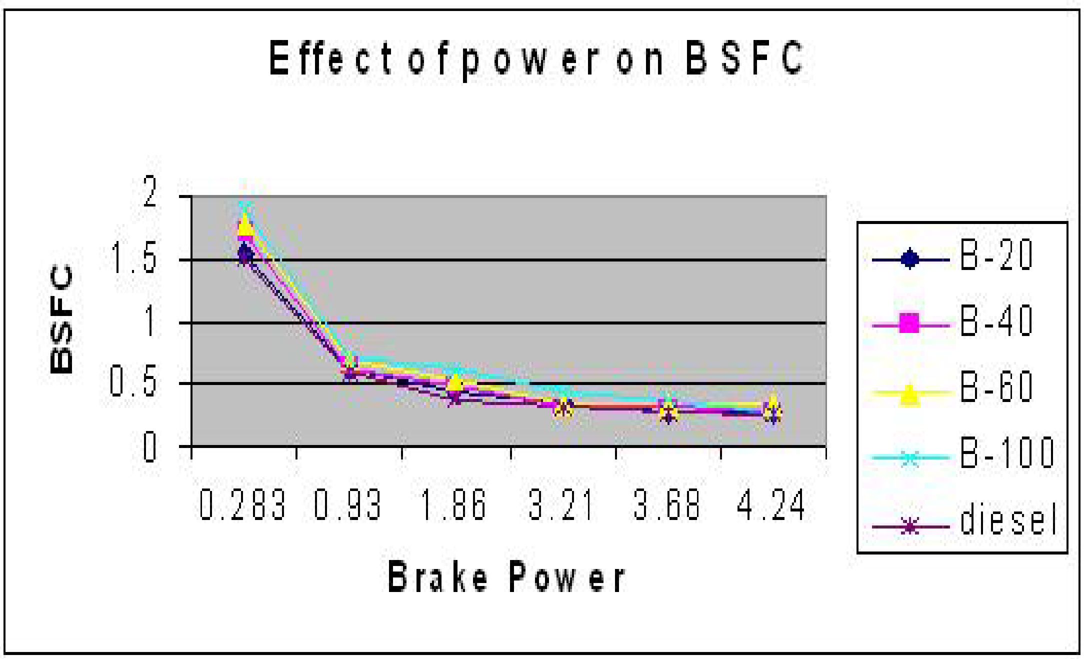

Fig. 6 : Effect of power on BSFC

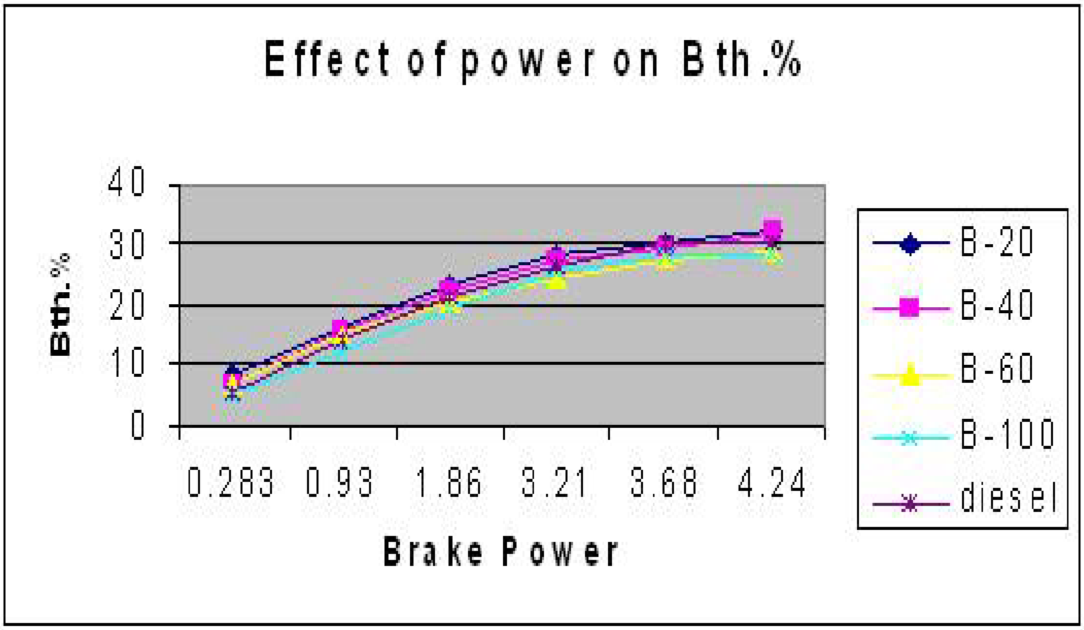

Fig. 7 : Effect of power on Bth. %

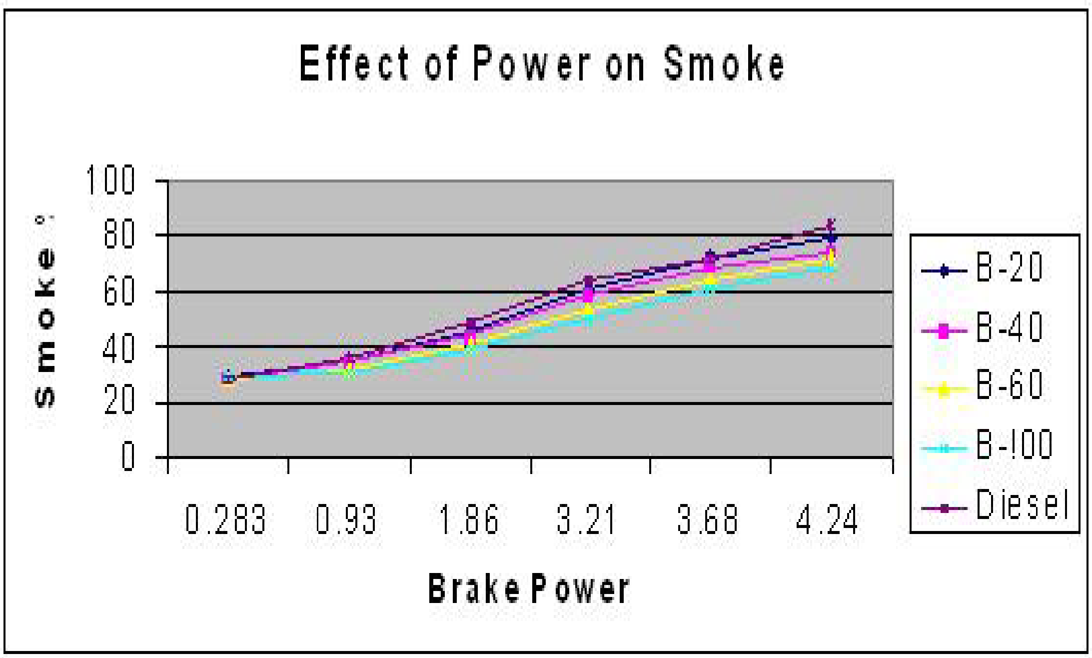

Fig. 8 : Effect of power on Smoke

property is imparted to blends at levels above 20 vol%. emissions can be reduced dramatically through use of biodiesel in engines. Based on experimental data we observe the variation in brake thermal efficiency, specific fuel consumption, smoke, exhaust heat lost in cooling water with respect to brake power.

Fig. 6 shows the variation of brake specific fuel consumption with brake power .the figure shows that the brake specific fuel consumption for B100, B60, B40 are higher than base line diesel fuel. The higher brake specific fuel consumption values in case of vegetable oil esters and its blends can be attributed to the slightly higher density and lower energy content. It is observed that brake specific fuel consumption is lower for B20 blend and comparable with base diesel fuel.

Fig.7 shows the variation of brake thermal efficiency with brake power for coconut oil methyl ester and its blends. For all the blends the brake thermal efficiency increases with increase in load. Among all the blends B20, B40, B60, B100.the B20 has maximum brake thermal efficiency i.e.32.06 % at full load. The efficiency for B20 has increased by 1.70 % when compared to base diesel fuel.

Fig.8 shows the variation of exhaust smoke with variation of brake power for coconut oil methyl ester and its blends here is decrease in the exhaust smoke at all loads for all the blends. The decrease in smoke may be due to more heat being liberated due to better combustion in the combustion chamber. This would have resulted in higher heat in the exhaust.

Conclusions

- Increase in the break thermal efficiency at all loads. Brake thermal efficiency for blend B-20, has increased by 1.70% when compared to diesel operation.
- Brake specific fuel consumption for B100 is higher at all loads.
- Decreases smoke drastically.

Based on the exhaustive engine tests, it can be concluded coconut oil can be adapted as additive fuel for the existing bio diesel engine without major modifications. Preheated (50%) coconut oil blends were found to be better in terms of both emission and performance. Without preheating 20% coconut oil blends gave optimum results, and emissions were higher than those of preheated blends. With respect to the cost analysis, even though the cost of coconut oil is higher than that of diesel, under emission management scenario, this could be a least cost alternative to the existing system.

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