Use of Esterified Soybean, Sunflower, Mustard, Karanja and Neem Oils in C.I. Engine

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Abstract

In this study, five different transesterified vegetable oils (viz., soybean, sunflower, mustard, karanja, and neem) were tested using an alkaline catalyst. The combustion, performance and emission characteristics of vegetable oil butyl esters and their blends (10:90, 15:85, 20:80, and 25:75) with diesel oil were analysed in a direct compression ignition (C.I.) engine. Studies show that on blending esterified vegetable oils with diesel, there is a remarkable improvement in their physical and chemical properties.

Introduction

Increasing consumption and fast diminishing energy reserves have led to an intensified search for viable and renewable alternative sources of energy. In the present days of fuel crisis and rising fuel prices, it is becoming extremely important to search for alternative sources of fuel. These aspects have drawn the attention of many researchers to conserve and stretch the oil reserves by way of finding new and alternate fuel reserves such as biofuels (Singhal and Rahman, 1994).

The ethyl and methyl esters of vegetable oils and animal fats are collectively known as biodiesel, a renewable alternative fuel that has been shown to be a direct replacement for diesel fuel in Compression Ignition (C.I.) engines. For general audiences, biodiesel is a renewable fuel for diesel engines derived from natural oils, which can meet the specifica-

tions of ASTM D 6751 (Barsic and Hunke, 1981). Biodiesel fuel is mostly generated from soybeans and other crops. In order to avert a potential crisis in increased food costs from the use of crops in the production of biofuels, scientists have been exploring numerous alternative sources. These sources include everything from animal fat to sewage sludge, to bacteria.

A second, more technical, definition of biodiesel is 'a fuel comprised of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats, designated B100, and meeting the requirements of ASTM D 6751' (Barsic and Hunke, 1981). Biodiesel has an energy content that is about 12% less than petroleum-based diesel fuel on a mass basis. It also has a higher molecular weight, viscosity, density, and flash point than diesel fuel. When biodiesel is compared to conventional diesel fuel in engine tests, the power and fuel consumption are nearly in direct proportion to the fuel's energy contents.

The auto ignition properties of vegetable oils are almost the same as those of diesel fuels. Hence, they can be easily used in diesel engines with little or no engine modification (Babu and Devaradjane, 2003). Biodiesel is an oxygenated fuel (10% to 11% oxygen by weight) and thus, it releases less unburned hydrocarbons (HC), carbon monoxide (CO), and particulate matter (PM). Moreover, they are readily biodegradable, a major benefit in case of oil spills. Studies have shown that the usage of vegetable oils is possible but not preferable (Bari, Yu, and Lim, 2002; Schwab, Baghy, and Freedman, 1987). The high viscosity (about 11 to 17 times higher than diesel fuel) of vegetable oils and the low volatility affects the atomization and spray pattern of fuel, leading to incomplete combustion and severe carbon deposits, injector choking and piston ring sticking. Furthermore, acrolein (a highly toxic substance) is formed through thermal decomposition of glycerol (Pryde, 1984; Peterson, Auld, and Korus, 1983; Schwab, Dykstra, Selke, Sorenson, and Pryde, 1988; Filho, Rocha, Brodzki, and Djéga-Mariadassou, 1993).

These experiences have led to the use of modified vegetable oils as fuel. Different methods have been employed to reduce the high viscosity of vegetable oils viz., dilution and microemulsions (e.g. ethanol or methanol) (Pryde, 1984; Peterson, Auld, and Korus, 1983), thermal decomposition (Filho, Rocha, Brodzki, and Djéga-Mariadassou, 1993), catalytic cracking (Ma, and Hanna, 1999) and trans-esterification with ethanol or methanol (Mittelbach, and Tritthard, 1988). Among all these alternatives, trans-esterification seems to be the best choice, as the physical characteristics of fatty acid esters (biodiesel) reach very close to those of diesel fuel and the procedure of its application is also relatively simple. Furthermore, the methyl or ethyl esters of fatty acids can be burnt directly in unmodified diesel engines with very low deposit formation (Kaufman, and Ziejewski, 1984). Several types of vegetable oils, with a diversified composition of fatty acids, have been employed for the preparation of biodiesel. Methyl/Ethyl esters of the oils obtained from sunflower (Silva, Prata, and Teixeira, 2003; Rao, Saravanan, Sampath, and Rajgopal, 2006), rice bran (Kalam, and Masjuki, 2002), palm (Puhan, Vedaraman, Sankaranarayanan, and Ram, 2005), mahua (Bhatt, Murthy, and Dutta, 2004), jatropha (Raheman and Phadatare, 2004), karanja (Freedman, Butterfield, and Pryde, 1986), soybean (Freedman, Pryde, and Mounts, 1984; Lee, Herage, and Young, 2004; Labeckas, and Slavinskas, 2006), rapeseed ([a]Ramadhas, Jayaraj, and Muraleedharan, 2005) and rubber seed (Ramadhas, Jayaraj, and Muraleedharan, 2005$_b$) have been successfully tested as biodiesel fuel on C.I. engines.

Bhatt, et. al. (2004) studied the suitability of mahua oil as alternative fuel for diesel engine and have shown that mahua could be easily substituted up to 20% in diesel without any significant difference in power output, brake specific fuel consumption, and brake thermal efficiency. The performance of engine with mahua oil blends improved with increase in compression ratio from 16:1 to 20:1. Ghosal,, et. al. (2008) also studied the performance of diesel engine by using mahua ethyl ester (biodiesel) and its blends with diesel fuel. Their studies showed that mahua methyl ester (20% mahua methyl ester and 80% diesel) can be used as an alternative diesel fuel with little sacrifice in brake specific fuel consumption. Shashikant, et. al. (2005) developed a technique to produce biodiesel from mahua oil having high free fatty acids (19% FFA). The high FFA level of crude mahua oil was reduced to less than 1% in a 2-step pretreatment process of esterification using acid catalyzed (1% v/v H_2SO_4) reaction with methanol (0.30-0.35 v/v) at 60 ºC. Breuer (1995) studied the effect of fuel properties on heat release through experiments conducted with rapeseed oil and its methyl ester. Sinha and Agarwal (2005) investigated the in-cylinder pressure and heat release patterns of 20% rice bran oil methyl ester-diesel blend.

Kinoshita, et. al, (2006) evaluated the combustion characteristics of biodiesels derived from coconut oil and palm oil. Investigations of Rao et al (2008) on pongamia, jotropha and neem methyl esters as biodiesel on C.I. engine have revealed that their diesel blends showed reasonable efficiencies, lower smoke, CO and HC. Pongamia methyl ester showed better performance compared to jatropha and neem methyl esters. Kuma et al (2009) selected cottonseed oil for biodiesel production. Transesterification results showed that with the variation of catalyst, biodiesel production was realized. A maximum of 76% biodiesel was produced with 20% methanol in the presence of 0.5% sodium methoxide.

Present studies investigated the combustion characteristics and exhaust emissions (such as CO, NOx, and smoke) of diesel-biofuel blends at various percentages in a diesel engine.

Experimental -Transesterification of Vegetable Oils

Five plant oils viz., soybean, sunflower, mustard, karanja and neem oil were selected for the present studies. Oils were esterified viz., esterified soybean (Esoy), esterified sunflower (Esun), esterified mustard (Emus), esterified karanja (Ekar), and esterified neem (Eneem) before blending.

Trans-esterification is the process of using an alcohol in the presence of a catalyst, such as sodium hydroxide (NaOH) or sodium methoxide (NaOMe), to chemically break the molecules of the raw vegetable oil into methyl or ethyl esters of the oil with glycerol as a by-product. This process reduces the high viscosity of oils (Knothe, Dunn, and Bagby, 1997; Bagby, Freedman, and Schwab, 1987). This method also reduces the molecular weight of the original oils to 1/3 of its former value, and the viscosity by a factor of ca. 8 and increases the volatility and cetane number to levels comparable to diesel fuel. Conversion does not greatly affect the gross heat of combustion (Knothe, Dunn, and Bagby, 1997; Dunn, and Bagby, 1995; Anbumani, and Singh, 2009). In the present studies butyl esters of oils were prepared using butyl alcohol and NaOH as the catalyst (Knothe, Dunn, and Bagby, 1997; Bagby, Freedman, and Schwab, 1987). A total of four different blends (10%, 15%, 20%, and 25%) with diesel were made.

Experimental Procedure and Setup

The study was conducted on a 4-stroke, single cylinder, CI engine (Kirloskar Oil Engines Ltd., India) on 20 July 2011 at the RMK Engineering College, Chennai. [1]

An eddy current dynamometer was coupled to the engine to apply

[1] Technical Specifications of the Engine: single acting, totally enclosed, high speed, 4 stroke, vertical, C.I. engine; bore and stroke-78x82 mm, number of cylinders-1, capacity-425cc, maximum power-7.5 BHP, compression ratio-15.5:1, speed-1500 rpm, cooling system capacity- 5 litres, crank case oil capacity-3 litres (Figure1).

the load on the engine for loading the engine. The fuel flow rate was measured by timing the consumption for known quantity of fuel (10 cc) from a burette. Performance data was analyzed in terms of smoke density, brake thermal efficiency and specific fuel consumption of all fuels. Smoke meter was used to measure the smoke density of the exhaust. The main purpose of smoke measurement was to quantify the black smoke emitting from the diesel engine. Visibility was the main criterion in evaluating the intensity of smoke. Bosch meter was used for measuring the diesel engine smoke. It consists of a sampling pump and evaluating unit. The sampling pump was used to draw nearly 300cc of exhaust gas by means of a spring operated pump and released by pneumatic operation of a diaphragm. The gas sample was also drawn through the filtering paper darkening it. The spot made on the filter paper was evaluated by means of a pre-calibrated photocell reflectometer to give precise assessment of the intensity of the spot. The intensity of the spot was measured on a scale of 10 in arbitrary units, called Bosch smoke units for white to black. HORIBA-MEXA-324 FB was used for the measurement of CO and HC emissions. Piezoelectric transducer was used to measure the pressure released in an engine cycle while Cathode ray oscilloscope (CRO) was used to obtain the graph. The potential difference between the outer and inner curved surfaces of the cylinder was a measure of the gas pressure.

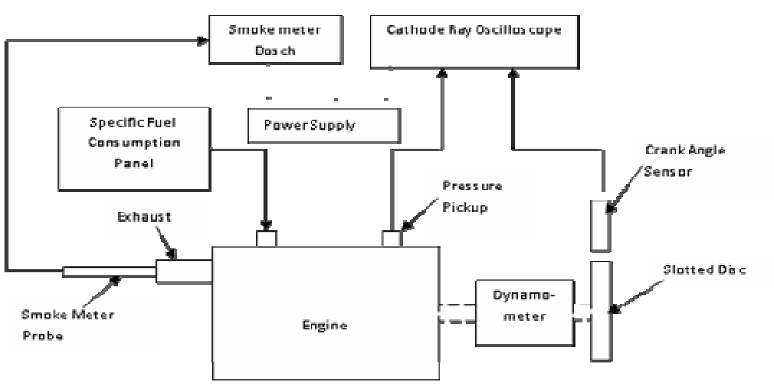


Figure 1. Experimental setup.

Engine Test Procedure

Studies were carried out to investigate the performance and emission characteristics of a stationary single cylinder diesel engine run on five different esterified vegetable oils (soybean, sunflower, mustard, karanja and neem) blended with diesel (10:90, 15:85, 20:80, and 25:75 by volume) and also on diesel fuel alone. The engine was coupled to an eddy current dynamo meter. Before initiating the studies, the engine was started and allowed to warm up for about 15 minutes and was operated first on diesel fuel alone, followed by the five vegetable oil blends. In order to evaluate the performance of oil blends and pure diesel fuel, the following parameters were recorded:

(i) Cetane number (CN), (ii) Flash point, (iii) Smoke intensity, (iv) Total fuel consumption (TFC), (v) Specific energy consumption (SEC), (vi) Specific fuel consumption (SFC), (vii) Brake thermal efficiency (BTE), and (viii) Cylindrical peak pressure (CPP).

The engine was tested under six different loads (0, 4, 8, 12, 16, and 20 kg) conditions at a constant speed of 1500 rpm for each percentage of blending. Thereafter, time taken for 10cc of fuel consumption was noted for each load. The procedure was repeated for various blends used in the study.

Results and Discussion

The main aim of trans-esterification was to lower the viscosity of vegetable oils taking it closer to that of diesel fuel (Connemann and Fischer 1998; ASTM D 6751-2002). Esterification also improved their physical properties (Table 1). The study shows that most of the properties of oil blends after trans-esterification were improved and came very close to those of the pure diesel fuel (Table 1).

(i) Cetane Number: CN of vegetable oils and their blends with diesel fuel was calculated and found almost equal in comparison to diesel fuel after blending (Table 1). This validates the feasibility to run a diesel engine on esterified vegetable oils after blending with diesel fuel (Ramadhas, Jayaraj, and Muraleedharan, 2005_a).

(ii) Flash Point: Since the flash point of vegetable oils in their pure form is comparatively higher than diesel fuel, results show that on esterification, it came very close to the diesel fuel; therefore, the engine can be

safely run on vegetable oil blends.

(iii) Smoke Intensity: Not much variation in smoke intensity were observed among the blends of five oils, however, a marginal decrease in smoke intensity took place in 20% blend, more so in case of soybean oil blend (Figure2).

(iv) Total Fuel Consumption (TFC): The total fuel consumption at different BHP with all percentages of blending was found to be slightly decreased from 0.059 kg/hr to 0.016 kg/hr. Improvement in TFC was perhaps due to better combustion of the fuel because of an increase in calorific value of the vegetable oils after esterification, leading to a reduction in the ignition delay (Figure 3).

(v) Specific Energy Consumption (SEC): A decrease in SEC with increase in load was observed up to a load level of about 16 Kg, and thereafter, a slight increase was observed. The initial decrease in SEC may be attributed to the complete and high combustion of fuel. However, once the load reached full load level, the time taken for complete combustion of fuel decreased, leading to the observation of a slight increase in SEC (Figure 4). Reduction in viscosity and specific gravity after esterification of vegetable oils also seems to play an important role in increasing the performance of engine at full load condition.

(vi) Specific Fuel Consumption (SFC): SFC at different loads with all percentage of blending was found to be slightly decreased from 0.08 kJ/kW-hr to 0.0015 kJ/kW-hr. Improvement in SFC was perhaps due to the better combustion of the fuel, owing to the presence of oxygen in the blend. Esterification also helped to lower the temperature reaction and better combustion. The cetane number of esterified soybean oil was high; hence SFC in its 20% blend was also reduced from 0.051 to 0.006 Kg/KW-hr (Figure 5).

(vii) Brake Thermal Efficiency (BTE): An increase in BTE with increase in load level was observed up to a load level of about 16 kg, and thereafter, a decrease was observed. The initial increase in BTE may be attributed to the complete and high combustion of fuel, but once the load reached full level; the time taken for complete combustion of fuel fell, hence a slight drop in BTE was observed. Oxygen present in the blends perhaps also helped in complete combustion of the fuel at no load and also at partial load conditions. At full load conditions, the change of state

from molecular oxygen to atomic oxygen led to a decrease in BTE. Similar findings were also reported by Bagby et al. (1987), while working on different seed oils for diesel fuel. Specific gravity of the vegetable oils also seems to play an important role in affecting the performance of engine at full load levels (Figure 6).

(viii) Cylindrical Peak Pressure (CPP): It was found that CPP increased at all load levels from 2 to 8 bars with blended fuels as compared to diesel. For the esterified vegetable oils, this increase in pressure may be attributed to the improved combustion of fuel in the presence of oxygen. The presence of oxygen in the fuel particle seems to enhance the low temperature reaction to proceed in the proper direction. A maximum increase of pressure from 3 to 5 bars was observed at full load level of 20% blend (Figure 7 (a), (b), and (c)).

Table 1: Properties of Vegetables Oils Before and After Blending as Compared with Diesel (Murayama, Young-taig, Miyamoto and Chikahisa, 1984)

Before blend						
Properties	Diesel	Soybean	Sunflower	Mustard	Karanja	Neem
Cetane Number (CN)	45-55	49	33.4	37	32	31
Specific Gravity	0.83	0.93	0.963	0.953	0.947	0.968
Viscosity (20°C) mm^2/sec	4.7	28.3	30.6	24.67	45.64	37.42
Calorific value (MJ/kg)	42	35.63	34.83	32.43	36.47	29.97
Carbon %	86	75.2	76.34	74.45	69.32	78.92
Hydrogen %	14	10	11.43	10.63	11.87	13.41
After blend (20% by volume with diesel)						
Cetane Number (CN)	45-55	56	52	54	45	48
Specific Gravity	0.83	0.888	0.92	0.914	0.909	0.934
Viscosity (20°C) mm^2/sec	4.7	9.1	7.2	5.65	8.4	6.3
Calorific value (MJ/kg)	42	36.47	36.98	34.562	38.518	31.142
Carbon %	86	77.32	78.314	76	70.42	83
Hydrogen %	14	12	12.8	11.3	13	15

Figure 2: Variations in Smoke Intensity at 20% by Volume Blends of Five Different Vegetable Oils with Respect to Load.

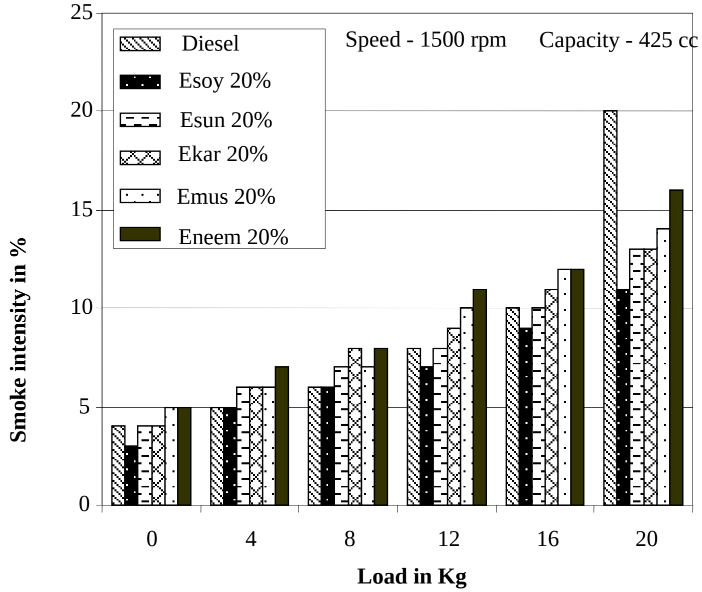


Figure 3: Variations in TFC with Respect to BHP for 20% by Volume Blends of Five Different Vegetable Oils

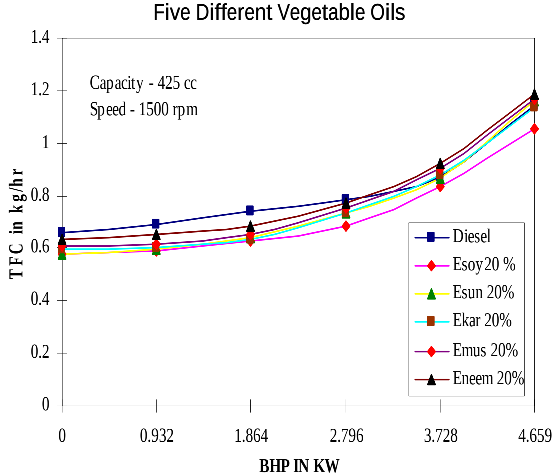


Figure 4: Variations in SEC with Respect to BHP for 20% by Volume Blends of Five Different Vegetable Oils

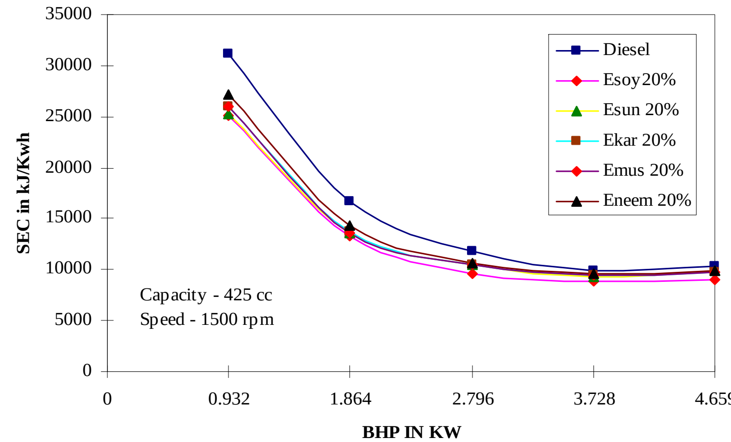


Figure 5: Variations in SFC with Respect to BHP for 20% by Volume Blends of Five Different Vegetable Oils

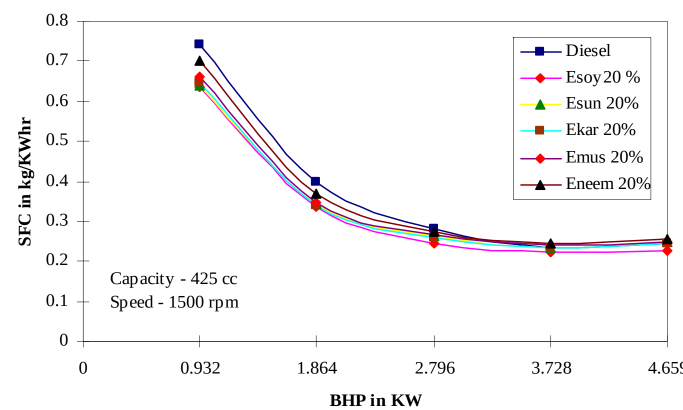


Figure 6: Variations in BTE with Respect to BHP for 20% by Volume Blends of Five Different Vegetable Oils

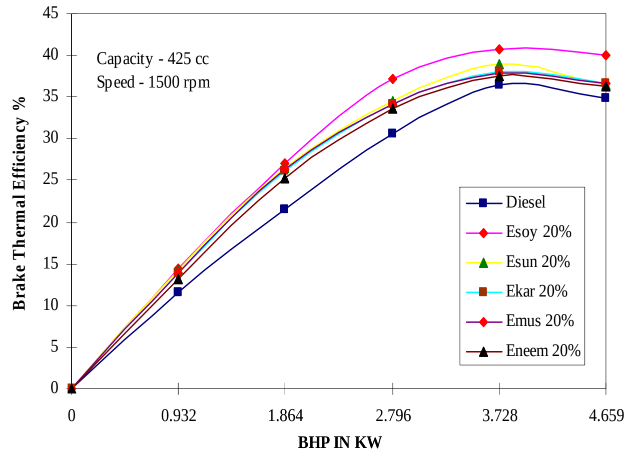


Figure 7(a): Variations in CPP at Initial Load with Respect to Crank Angle for 20% by Volume Blends of Five Different Vegetable Oils

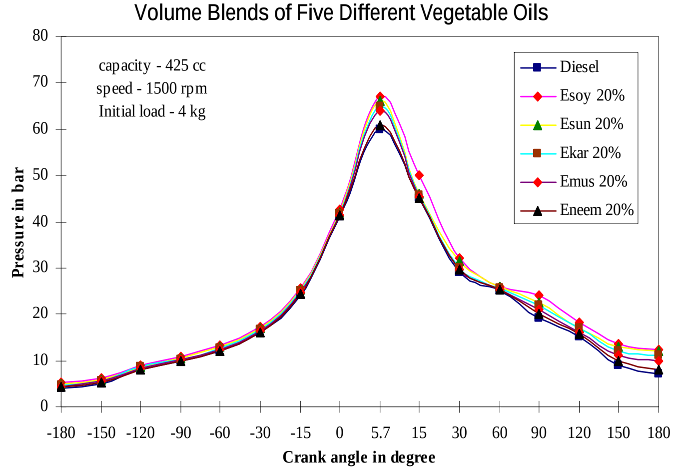


Figure 7(b): Variations in CPP at Partial Load with Respect to Crank Angle 20% by Volume Blends of Five Different Vegetable Oils.

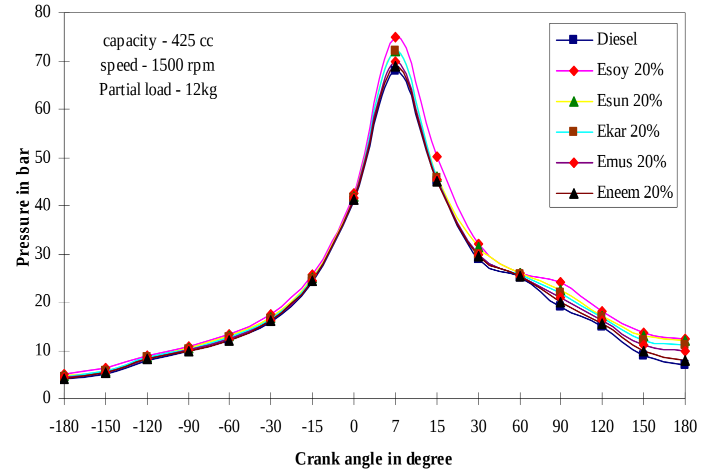
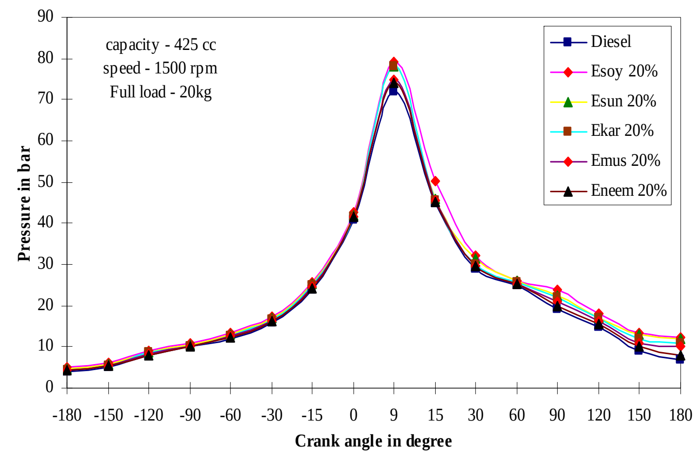


Figure 7(c): Variations in CPP at Full Load with Respect to Crank Angle for 20% by Volume Blends of Five Different Vegetable Oils



Results from other studies on various types of oils have also revealed that trans-esterification leads to alteration in the physical and chemical properties of plant oils making them suitable to be used as biofuel in C.I. engines after blending in suitable ratios with diesel fuel (Bari, Yu, and Lim, 2002). These results are similar to those reported by Bhatt et al. (2004) and Ghosal et al. (2008) on the use of mahua oil and Rao et al. (2008) on the use of methyl esters of pongamia, jatropha and neem oil as biofuel in C.I. engines. Anbumani and Singh (2009) also investigated the use of vegetable oils blended with diesel as biofuel for C.I. engine. Their studies show that among the different vegetable oils blended with diesel, sunflower blend at 15% by volume with diesel fuel exhibited best combustion and performance in terms of total fuel consumption, specific fuel consumption, brake thermal efficiency and cylinder peak pressure.

Appropriate blending ratios and lower smoke emissions are the key factors for good C.I. engine performance. These factors are highly influenced by viscosity, density, and volatility of the fuel. For bio-diesels, these factors are mainly determined by the effectiveness of the trans-esterification process. With properties close to diesel fuel, bio-diesel from soybean, mustard, karanja and neem plant oil can provide a useful substitute for diesel for developing an economically viable and eco-friendly biofuel technology. Irrespective of all the difficulties mentioned in the study, vegetable oils, after suitable processing and blending, seems to be an alternative option for diesel fuel in the near future.

Conclusions

Butyl ester of soybean oil at 20% blend with diesel gave the best performance as compared to sunflower, mustard, karanja and neem oil blend in terms of low smoke intensity, emission of HC and NOx. Cetane number, total fuel consumption, specific energy consumption, specific fuel consumption, brake thermal efficiency, and cylindrical peak pressure were almost equal when engine was run on pure diesel. The trans-esterification process used for making biodiesel was simple and cost effective to solve viscosity problems encountered with pure vegetable oils. Esterified soybean, sunflower, mustard, karanja and neem oil as biodiesel satisfies the important fuel properties as per ASTM D975.

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