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Performance Analysis of Diesel Engine with Palm Stearin (PS) Biodiesel

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Abstract - The world's requirement on fossil fuel reserves is expanding quickly and at the current pace of utilization, it is assessed that the world will before long be confronting an extreme vitality emergency because of the fatigue of fossil fuel assets. This research work is pointed toward exploring the possibility of utilizing Palm Stearin Methyl Ester as a fuel substitute for CI engines. GCMS was used to determine the fatty acid composition of Palm Stearin Methyl Ester. Combustion, emission, and engine performance were measured and compared across a range of bio-diesel blends. The Kirloskar TV1 VCR Engine with a typical 17.5:1 Compression Ratio was used for the test. Using bio-diesel blends reduces frictional loss, leading to greater mechanical efficiency. We found that using Palm Stearin bio-diesel reduced emissions of both hydrocarbons and carbon monoxide. This means that Palm Stearin bio-diesel may be considered a viable alternative fuel to petro-diesel.

Keywords - Transesterification, Esterification, Biodiesel, PSME, CI-Compression Ignition, Emissions, GCMS.

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INTRODUCTION

Rising oil costs and growing awareness of the harm caused by using fossil fuels have prompted research into viable renewable energy alternatives. The renewable alternative fuel is relatively pollution-free since it is sourced from naturally occurring substances. Due to their potential utility in transportation and agriculture, CI engines have been the subject of several studies investigating alternative fuels and methods for reducing emissions [1]. Researchers have shown that biodiesel is the most economically viable and environmentally benign alternative fuel [2]. Biodiesel may be made from the oil of non-food crops such as Karanja, Neem, Pongamia, etc. The low calorific value, high density, and high viscosity of these oils prevent their direct use as a fuel in engines. Transesterification is required to get rid of the glycerol. Performances, emissions, and environmental factors for biodiesel are extensively researched for both edible and non-edible vegetable oils. Diesel engines are unmodified for use with Palm Stearin biodiesel blends, which reduces hazardous emissions. Experimental tests show that the thermal and mechanical efficiency of the engine utilizing biodiesel were greater than those for regular diesel [3], making it the most viable option. Methyl ester isolated from fish oil is studied for its potential to enhance combustion through the addition of oxygen to the fuel mixture [4]. The neem oil transesterification process is described, and neem oil/diesel mixtures are shown to have greater BTE than diesel alone [5]. Turpentine oil is mixed with Jatropha biodiesel because it has a higher volatility and lower viscosity than Jatropha oil methyl ester. Emissions from the aforementioned mixture are determined to be very low [6]. Oil refinery diesel is mixed with oxygenated fuel and canola safflower biodiesel for the test [7]. The production of biodiesel from vegetable/animal fat is problematic because of the low availability and the necessity for a transesterification procedure [8]. Biodiesel derived from lemon grass oil has been shown in experiments [9] to have worse heating value, cetane number, and viscosity compared to other biodiesels. Biodiesels, which are derived from plant oils rather than petroleum, reduce operating costs in an internal combustion engine (IC).

Using biodiesel instead of regular diesel has the potential to cut CO2 emissions by 78% over the course of its entire life cycle [11]. Biodiesel fuels have the potential to reduce carbon dioxide emissions since the biodiesel-producing species (plants) absorb CO2 during photosynthesis. When biodiesel is mixed with regular diesel, engine performance improves and HC and CO emissions drop [12]. Exhaust emissions for HC and CO were found to be in a wider range with Rapeseed biodiesel fuel compared to regular diesel; a 50% reduction in CO emissions was observed for rapeseed fuel [13]. Many studies have shown that non-food sources are superior than food ones as feedstocks for biodiesel synthesis [14]. Palm stearin oil (PSO) is the byproduct of palm oil production. Palm stearin methyl ester's primary raw material is easily sourced in South and Southeast Asia and India. Using palm stearin biodiesel also avoids the ethical dilemma of competing food and fuel needs. As a developing country, India has a dilemma if it attempts to generate fuels from edible sources: the country must choose between feeding its people and keeping them warm. The biodiesel made from palm stearin in this experiment is made from a non-food oil. When compared to palm biodiesel, Palm Stearin Methyl Ester (PSME) has a lower viscosity. In this article, we use a variety of PSME/diesel fuel mixes to investigate how they affect the test engine's emission, performance, and combustion properties.

MATERIALS AND METHODS

Transesterification of Palm Stearin Oil

Biodiesel has recently received a lot of attention due to its many environmental benefits and the fact that it is produced from a renewable resource. Because of its lower viscosity, biodiesel produced by the transesterification of natural oils and fats is preferable to other techniques of biodiesel production. Transesterification and glycerol recovery are two approaches that may reduce production costs. Since the continuous transesterification process requires fewer steps and has a higher throughput, it has a lower production cost. According to [15], a transesterification procedure may be used to convert palm stearin into biodiesel. The following flowchart depicts the steps required to produce Palm Stearin biodiesel (methyl ester).

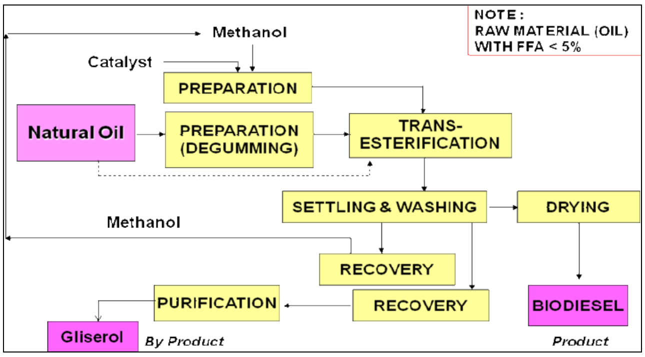

Figure 1: Transesterification of Biodiesel from Palm Stearin Oil

Palm stearin oil contains around 8.5% fatty acids; thus, a transesterification technique is required to transform palm stearin into palm stearin methyl ester (biodiesel). Methanol and NaOH were used at a molar ratio of 1:6 to perform the transesterification. A container was used to bring the methoxide solution and the palm stearin oil to a boil at 65 degrees Celsius. After the chemical reaction was complete, the byproducts were allowed to settle in layers. Methyl ester (biodiesel) was separated from glycerin, which was found in the bottom layer. Distilling the top layer allowed for the recovery of the surplus methanol, which was then used to wash the methyl esters in hot water, which drove out any lingering residues of glycerin. The finished product was then exposed to hot air for an hour in order to remove excess moisture. The final transesterification efficiency was 93.70 percent, yielding 76 milliliters of Palm Stearin biodiesel.

Biodiesel Characterization

Analytical GC-MS is used to determine the contents of a fuel sample, including the Fatty Acid Methyl Ester profile (FAME) of Palm Stearin methyl ester. Calibration curves of FAME present in palm stearin methyl ester are obtained by analysis of standard reference samples. GC-MS, equipped with a scanning device for higher energy collisions and dissociation, is used to evaluate FAMEs, allowing for structural analysis. The Agilent 6890 gas chromatograph has electronic pressure control and works in tandem with the Agilent 7673 auto liquid sampler. Compounds are identified by establishing a link to MS-Data Processing Software. Spectra are measured from 1 to 1000 m/z with a resolution of 6000 and an extreme standardized mass of 1500 daltons. To facilitate silica gel column chromatography, the lipid fraction is resuspended in n-hexane. Aliphatic hydrocarbons throughout the fatty acid column include the carotenoids at their ends. The lipid components of the hydrocarbon fraction are analyzed by GC-MS before being passed on. A split-less injector automatically introduces the 1 ml measurement into the system at 300 °C.

Preparation of fuel blend

Engines were tested using Palm Stearin Methyl Ester (PSME) blends with diesel fuel at volumes ranging from 10% to 50%. Diesel and PSME are mixed together molecularly using a special emulsifier. The following mixtures are used as fuel:

1. B10 –90% Diesel + 10% PSME
2. B20 –80% Diesel + 20% PSME
3. B30 -70% Diesel + 30% PSME
4. B40 –60% Diesel + 40% PSME
5. B50 –50% Diesel + 50% PSME
6. Normal Diesel

Fuel properties

Table 1 displays the physicochemical differences between raw Palm Stearin oil, regular Diesel, and Palm Stearin biodiesel.

Table 1: Physio Chemical Properties Of Fuels

Parameter	Diesel	Palm Stearin Oil	Palm Stearin Methyl Ester	Method
Density@15^{0}C (g/cc)	0.832	0.912	0.882	I.S:1448(PART-16)
Kinematic Viscosity@40^{0}C (cSt)	3.7	-	5.67	I.S:1448(PART-25)
Flash Point (^{0}C)	60	290	65	I.S:1448(PART-21)
Fire Point (^{0}C)	65	300	75	I.S:1448(PART-21)
Cloud Point (^{0}C)	-12	38	22	I.S:1448(PART-10)
Pour Point (^{0}C)	-16	32	9	I.S:1448(PART-10)
Iodine value by Wiji's method	--	48.68	47.06	I.S:548(PART-1)-1964
Calculated Cetane Index	42 - 49	38.24	47.53	ASTM D 976-91
Gross Calorific Value (kcal/kg)	10,707.45	8933	9244	I.S:1448(PART-6)
Sulphur Content (%)	0.05	0.15	0.13	I.S:1448(PART-33)
Conradson Carbon residue (%)	--	0.32	0.35	I.S:1448(PART-122)
Boiling Point (^{0}C)	180 -360	196	102	I.S:1448(PART-18)

EXPERIMENTAL SET-UP

The experiments are conducted using a dynamometer (Eddy current type) and a single-cylinder, four-stroke, multi-fuel (research) engine (with the ability to alter the compression ratio, injection pressure, and EGR flow rates). Combustion pressure, crank angle, temperatures, air and fuel flow, load, and temperature measurements are all integral parts of the system. Signals may be sent using a data collecting device that sends information rapidly to a computer. A fuel measuring device, pressure measuring manometer, transmitters, air box, piezo powering unit, and process indicator are all part of the experimental setup housed in a separate panel box. Instruments like calorimeters and Rotameters are utilized for quantitative analysis. Diesel injection measurement can be taken on a computer, although that feature is completely discretionary. The experimental apparatus used in this investigation is shown in Fig. 2, and its settings are summarized in Table 2. Where,

T1 --> Inlet temperature of engine coolant

T2 --> Outlet temperature of engine coolant

T4 --> Outlet temperature of calorimeter coolant

T5 --> Outlet temperature of engine exhaust gases

T6 --> Outlet temperature of exhaust gases from calorimeter

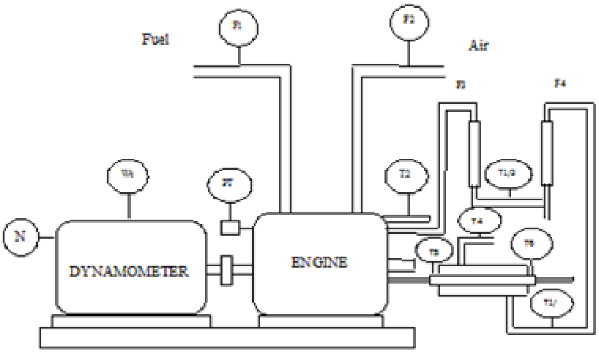

Figure 2: Test Engine Setup

Table 2: Engine Specifications

Make & Model	**Kirloskar, TV1, Four Stroke, VCR, Multi fuel engine**
Compression Ratio	12:1 to 18:1
No. of cylinder	Single
Fuel	Petrol/ Diesel
Rated Speed	1500 rpm
Rated Output	3.5kW
Starting	Crank
Method of Cooling	Water-cooled
Dynamometer	Eddy Current
Stroke Length	110 mm
Cylinder diameter	87.5mm

RESULTS

Gas Chromatography – Mass Spectrometry Analysis

GC-MS is utilized to classify the quantification of Fatty Acid Methyl Esters of Palm stearin biodiesel which is being explained in this study. Hydrocarbon combining is distinguished as < C15, C15-C20, C20 - C30 and > C30 regarding the retaining time of standard HC such as Arachidic acid methyl ester, Palmitic acid, margaric acid, Bovinic acid, myristic acid, Polymic acid Palmitoleic acid, Methyl palmitoleate acid, Oleic acid. The examination proves that the GC-MS is utilized to classify the quantification of Fatty Acid Methyl Esters of Palm stearin biodiesel which is being explained in this study. Hydrocarbon combinin is distinguished as < C15, C15-C20, C20 - C30 and > C30 regarding the retaining time of standard HC such as Arachidic acid methyl ester, Palmitic acid, margaric acid, Bovinic acid, myristic acid, Polymic acid, Palmitoleic acid, Methyl palmitoleate acid, Oleic acid. The examination proves that the occurrence of 9 main fatty acids amid C15:0 and C21:0.

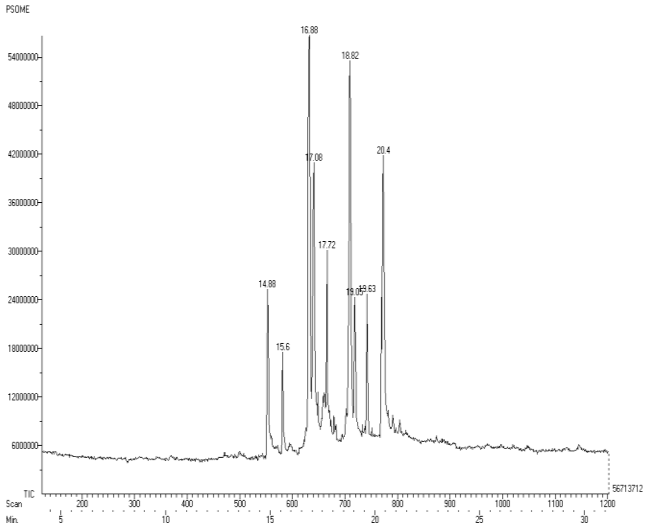

Figure 3: GC-MS Spectrum of Palm Stearin Biodiesel

Amongst the subsequent fatty acids, short chain HC amid C16:0 and C18:0 consist of a composition which is the main mass section. GC-MS Spectra of PSME biodiesel is displayed in Figure 3. The changes in various characteristics such as combustion, performance, and exhaust emission with output power are obtained graphically and conversed below.

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Performance Analysis

The analysis of engine performance provides knowledge regarding the consumption of fuel by the diesel engine. The combustion analysis provides sufficient information on the phenomenon of combustion when the fuel-air blend is burnt in the cylinder.

- **Brake Thermal Efficiency (BTE)**

Thegraph (Fig. 4) is plotted for BTE of normal diesel and biodiesel blends in terms of brake power variations. The BTE represents the efficiency of an engine in converting the heat energy liberated during combustion of the fuel into brake power. BTE is the highest for diesel fuel (26.79%) and lowest for biodiesel blend B40 (21.81%) which is visualized in the above graph. Normally, the BTE is inversely proportional to the concentration of Palm Stearin Methyl Ester in the fuel blends. The lesser calorific value and the higher viscosity and density of PSME blends cause poor fuel atomization that reduces the BTE of the diesel engine. Blend B20 shows better efficiency (25.35%) within the blends.

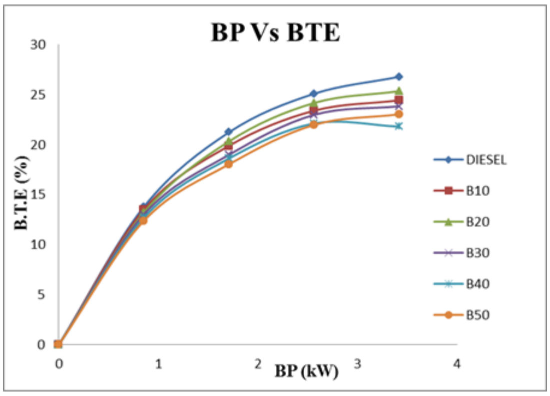

Figure 4: Changes in BTE with BP

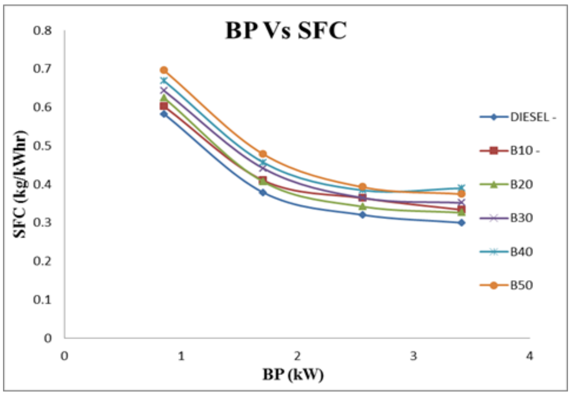

Figure 5: Changes in SFC with BP

- **Specific Fuel Consumption (SFC)**

SFC indicates the quantity of fuel expended by the engine for delivering unit power output. Figure 5 visualizes the changes in SFC for diesel & different biodiesel blends with variation of output power.The SFC of an engine is inversely correlated to the output (brake) power produced. As load increases, the output (brake) power generated by the engine also increases to the rated value. Therefore, fuel usage is better and the fuel consumption rate is reduced drastically at 100% load. Diesel recorded the lowest Specific fuel Consumption of 0.30 kg/kWhr followed by B20 (0.326 kg/kWhr), B10 (0.333 kg/kWhr), B30 (0.351 kg/kWhr), B50 (0.374 kg/kWhr) & B40 (0.389 kg/kWhr). The reduced heating value of palm stearin methyl ester raises fuel consumption for biofuel blends and hence leads to an increase in SFC.

- **Mechanical Efficiency (M.E)**

The ratio of brake power generated in an engine to the indicated power developed in the cylinder (by the combustion of fuel) is defined as mechanical efficiency.

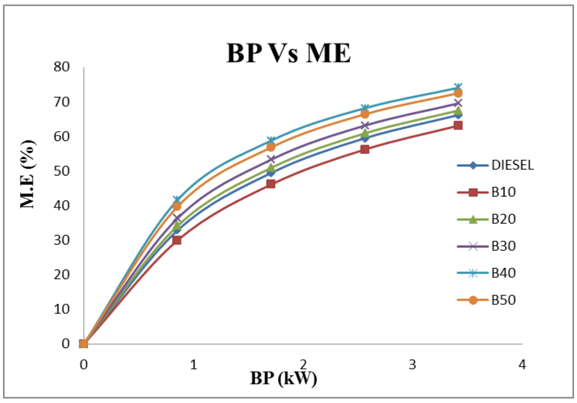

Figure 6: Changes in ME with BP

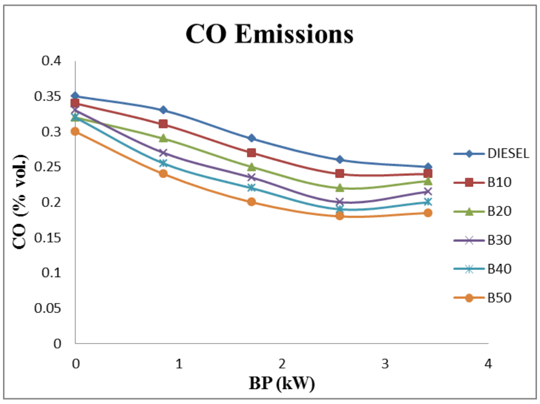

Figure 7: CO Emissions with Brake power

Figure 5 indicates the changes of mechanical efficiency with different brake power for various blends of biodiesel & diesel. When the frictional power developed in an engine is less, higher mechanical efficiency is obtained. Biodiesel fuel has better lubricating features than normal diesel. Usage of biodiesel blends results in reduced frictional power (frictional losses) and thereby the engine's M.E is improved. From the above graph, Blend 40 shows the greatest mechanical efficiency (74.02%) than diesel (66.15%).

Emission Analysis

The emission study investigates the measurement of fuel impact by the IC engine on the atmosphere.

- **Carbon monoxide emissions (% vol.)**

The CO emission with changes in output power for normal diesel and PSME blends are displayed in Figure 7. CO is formed from the incomplete process of oxidation/ combustion of the hydrocarbon fuel. During complete combustion, the carbon molecules present in the hydrocarbon fuel gets fully converted into CO2 through oxidation. The CO emission decreases with load, as visualized in the above figure. From the graph it is clear that at 100% engine load, the CO emissions of PSME B50 (0.18%), PSME B40 (0.20%), PSME B30 (0.21%), PSME B20 (0.23%), and PSME B10 (0.24%) are less when compared to Diesel (0.25%). The diminished CO emissions may be a result of the higher O_2 content present in the PSME fuel that increases the combustion rate and thereby reduces the formation of CO emissions.

- **Hydrocarbon emissions (ppm)**

The emission (HC) of the diesel engine is based on the fuel concentration & its combustion characteristics. The HC emission level with brake power variation for pure diesel and PSME blends is displayed in Figure 8

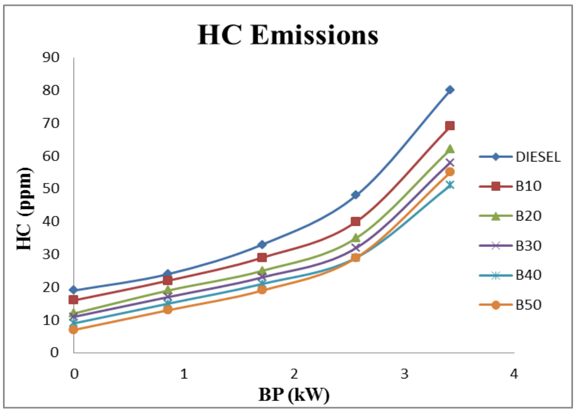

Figure 8: HC Emissions with Brake power

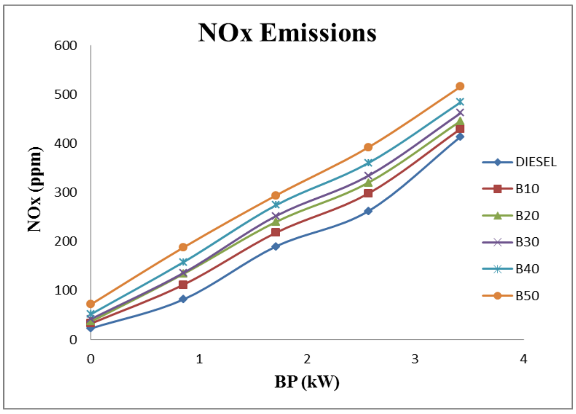

Figure 9: NOx Emissions with Brake power

It is noticed that emission (HC) is decreased by 25ppm with biodiesel B40 blend at 100% load. On observing the graph, the blend B40 produces less HC emission than other blended fuels and diesel at full load. More complete combustion is obtained owing to the O_2 existing in the PSME fuel blends.

- **NOx Emissions (ppm)**

At extremely high temperatures developed during combustion, the nitrogen present in atmospheric air and the oxygen react together to form NOx emissions. NOx emissions can be a significant source of air pollution leading to global warming phenomenon. NOx emission from an engine is based on the concentration of O2, time taken for the combustion process and its temperature. The NOx emissions for diesel and PSME blends at different brake powers are demonstrated in Figure 9. Above figure proves the emission of nitrogen oxides is directly correlated to the proportion of biodiesel present in the fuel blends. The maximum emission of NOx is observed for biodiesel blend B50 (516ppm) and is minimum with diesel (414ppm) at full load. It can be observed that as the percentage of PSME in the fuel blend increases, the nitrogen oxide emissions from the CI engine also increases due to increased combustion rate leading to higher combustion temperatures.

- **Smoke Intensity (Hatridge Smoke Units)**

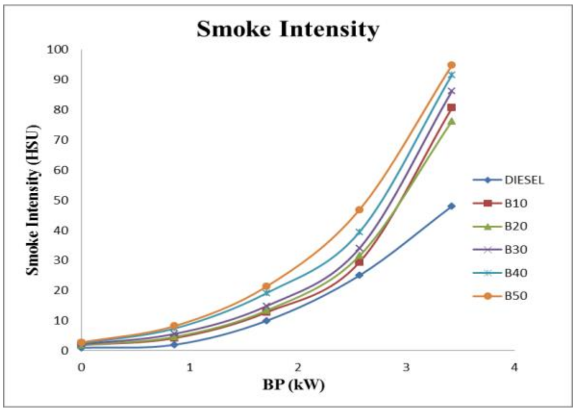

Figure 10: Smoke Emissions with Brake power

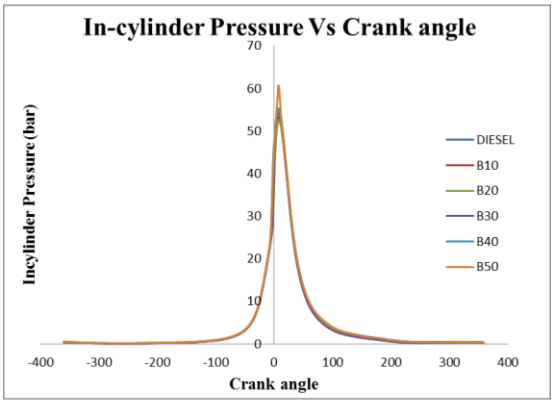

Figure 11: In-cylinder Pressure vs. Crank angle

The smoke intensity for diesel and PSME blends are displayed in Fig. 10. The lowest smoke emissions are observed with diesel usage (48HSU) followed by PSOME B20 (76.20 HSU), B10 (80.60 HSU), B30 (86.20 HSU), B40 (91.60 HSU) and B50 (94.80 HSU). Smoke emissions from an engine mainly consist of solid particles of Carbon, often referred to as soot. When the combustion zone is not having sufficient oxygen molecules, the fuel oxidation will not be done properly and smoke will be formed in the exhaust. Even though PSME is an oxygenated fuel, poor fuel atomization resulting from increased viscosity of the PSME may be the cause for increased Smoke emissions as displayed in the above figure. All the tested blends show that the smoke emissions are proportional to the output power.

Combustion Characteristics

- **In-cylinder Pressure**

Figure 11 displays the changes of in-cylinder pressure with CA for biodiesel blends as related to Diesel at 100% load. B50 recorded the highest cylinder pressure of 60.67 bar, followed by B40 (55.3 bar), B30 (54.66 bar), B10 (54.27 bar), Diesel (53.33 bar) and B20 (52.31bar) at 100% load. The biodiesel consists of more oxygen which causes the peak pressures to be much greater than that for normal diesel.

- **Heat Release Rate (HRR)**

Figure 12 illustrates the changes of net HRR in accordance with CA at full load. The HRR are 43.46 J/deg.CA, 42.52 J/deg.CA, 41.77 J/deg.CA, 40.37 J/deg.CA, 37.11 J/deg.CA & 35.55 J/deg.CA for B20, B50, B40, B30, diesel & B10 respectively. PSME blend B20 recorded the highest value of net HRR. The HRR for biodiesels exceed that of Petro-Diesel by virtue of the increased O_2 concentration of biodiesel that supports more complete combustion.

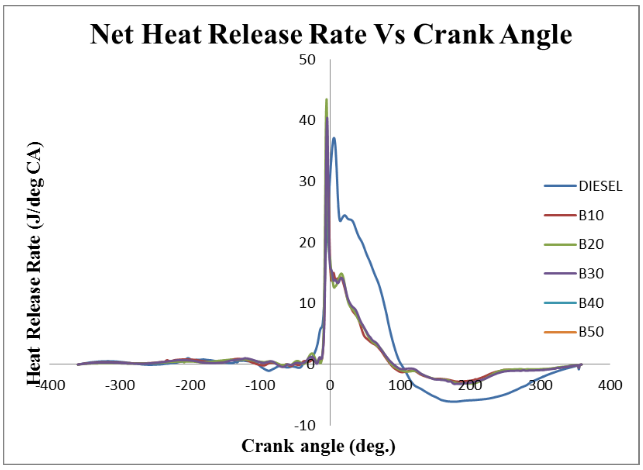

Figure 12: Net Heat Release Rate vs. Crank angle

CONCLUSION

The investigation on diesel-PSME blends as the fuel in a Compression Ignition engine is being concluded. The following are the main findings of the study;

- BTE is inversely proportional to the concentration level of biodiesel in the blends, and the BTE of B20 (25.35%) is quite comparable to diesel (26.79%). Diesel fuel provides the highest conversion efficiency of fuel energy into brake power.

- SFC for diesel (0.30 kg/kWhr) is lower than the SFC for PSME biodiesel fuels at 100% (full) load conditions. PSME B20 fuel blend recorded the lowest SFC (0.325 kg/kWhr) among the biodiesel blends at the standard compression ratio (17.5:1).

- For biodiesel fuels, the in-cylinder temperatures and pressures are comparatively greater because of enhanced combustion rates compared to petro-diesel. For the biodiesel blend B50, the peak pressure noticed is 60.67 bars at 10^o aTDC.

- Heat Release rates for PSME biodiesel blends exceeds the rates for petro-diesel due to enhanced combustion rates resulting from greater fuel oxygen content. The highest HRR was observed for B20 blend (43.46 J/deg.CA) at 8^0 bTDC.

- The emission of CO and HC are significantly decreased by the use of PSME fuel blends. B50 recorded minimum CO emissions (0.185%) while B40 recorded the least HC emissions (51 ppm) at full load.

- Smoke and NOx emissions are directly proportional to concentration of PSME fuel blends. The lowest value of Smoke and NOx emissions were recorded by Petro-Diesel (414ppm and 48 HSU respectively).

- When Palm Stearin biodiesel blends are fed to CI engines, the HC and CO emissions are decreased significantly while the combustion characteristics and performance characteristics are enhanced.

When certain emission control strategies like Exhaust Gas Recirculation (EGR) are employed, emissions of NOx from the engine could be reduced tremendously. The research work shall be conducted with more parameters like variation of compression ratio, injection pressure and timing, preheating of intake air and exhaust gas recirculation in future.

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