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EVALUATION OF VCR CI DI ENGINE FOR PERFORMANCE AND EMISSIONS WITH BLEND OF METHYL ESTERS OF PALM STEARIN-DIESEL

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ABSTRACT
Methyl esters of vegetable oils are becoming preferred alternative to petro-diesel run engines. Palm Stearin is obtained upon fractionation of palm Olien oil. In the present work experimental investigations are conducted on a direct injection diesel engine under two compression ratios of (16.5 and 19) with different fuel injection pressures (190, 210 and 230 bars) at a constant speed of 1500 rpm employing 60% Palm Stearin methyl ester blend. The results were compared with the baseline data on the performance of the engine, when it was run with petrol-diesel at a rated FIP of 190 bar and CR 16.5. The results indcated that the trends of BTE with PSME60 were found to be similar to the baseline results. It was observed that the BTE was high at injection pressure of 210 bar and CR 16.5 with respect to other PSME60 trends of 190 and 230 bar.However, the engine performance was superior with CR19 at the rated injection pressure of 190 bar. The peak pressures with higher CR were observed to higher. The engine emissions in terms of HC, CO and Smoke opacity were lower but the NOx were found to be increased due to the better combustion. The study revealed that palm stearin could be explored as a source for producing biodiesel in order to utilize palm derived oils effectively with environmental concern. It is observed that compression ratio has a dominant effect on performance where as fuel injection pressure as played a vital role in the reduction of emissions.

Keywords: CI Engine, PSME60 Blend, Fuel Injection Pressures, Compression Ratios, Engine Performance, Exhaust Emissions

Nomenclature	
Baseline	Petro-diesel
BTE	Brake Thermal Efficiency
BSFC	Brake specific fuel consumption
CO	Carbon Monoxide
CR	Compression Ratio
EGT	Exhaust Gas Temperature
FIP	Fuel Injection Pressure
HC	Hydro Carbons
NaOH	Sodium Hydroxide
NO_x	Nitrogen Oxides
PSME60	60% Palm Stearin Methyl Ester Blend

INTRODUCTION
Diesel fueled compression ignition engines are invariably used in light, medium and heavy duty applications. On a large scale, they are being used in the transportation and agricultural applications due

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to their high efficiency and reliability. The versatility of diesel engines is due to its high fuel conversion efficiency, lower fuel cost, safety operation and high reliability. The increased automotive population over the past two decades has raised the pollution at alarming levels. Moreover, the heavy dependence on petroleum derived fuel (diesel fuel) is not only draining country's exchequer but also raising the doubts of its availability in future years. Thus the twin problems of large scale exploitation of petroleum derived fuels and associated pollution has made the researchers to find viable alternate fuels. The intensive research has led to the development of various alternate fuels like, alcohol fuels, natural gas, hydrogen, vegetable oils etc.

Among these alternate fuels, vegetable oils are best suited for diesel fuel since its properties are close to petro-diesel. Though, vegetable oils offer advantages such as renewable, self sustainability, however, their straight use in engines is restricted mainly due to its high viscosity. The vegetable oils are mainly classified as edible and non-edible oils. Edible oils are sunflower oil, groundnut oil, coconut oil, olive oil, palm oil etc. Neem oil, Jatropha oil, Cotton seed oil, Linseed oil, Mahua oil, Pongamia oil and castor oil are few examples of non-edible oils. Since there is a demand for edible oils from domestic uses, fuels should be explored from non-edible oils.

Reviewed attempts made by the researches to reduce the viscosity of vegetable oils and animal fats and subsequent its use led to processes such as micro emulsion, pyrolysis, preheating, blending and transesterification. Among these, transesterification has gained wide acceptance by the research community for conversion of untreated oil to esterified oil and its subsequent use in engines. They observed that transesterification improved fuel properties over those of unprocessed vegetable oils. The converted vegetable oils from raw oil to corresponding methyl/ethyl esters popularly called as BIODIESEL (Ali and Hanna, 1994).

Investigations on the effect of temperature on the viscosity on the performance and emission characteristics of a compression ignition engine of karanja oil and also reducing viscosity of karanja oil and its blends through the specially designed heat exchanger yields lower emissions and improved engine performance (Agarwal and Rajamanoharan, 2009)

Experiments were conducted and using karanja oil as fuel on the performance of CI engine was evaluated under various operating conditions, Engine when operated at higher compression ratios has yielded lower emissions and better performance (Amarnath and Prabhakaran, 2012).

Experiments were conducted and using the n-pentane at different proportions by volume with diesel on the performance of DI engine. At full load conditions, It was concluded that NO_x emissions reduced (Balamurugan and Nalini, 2014).

Yeld and production cost of various methyl esters, in general produced from non-edible oils have been in literature (Barnwal and Sharma 2005).

They were conducted experiments with fish oil methyl ester (FOME) blends and varying EGR rates to control the particulate matter and NO_x emissions in a single cylinder constant speed diesel engine. Their experimental results yielded that 20% FOME delivered almost same brake thermal efficiency with lower HC, CO and soot emissions, but higher NO_x emissions when compared to diesel fuel (Bhaskar *et al.,* 2013).

Variation of injection pressure reduced the emissions and maximized the performance at both full and part loads on the engine performance and exhaust emissions of turbocharged diesel engine (Ismet, 2003).

They were described in their work that alkyl esters, namely ethyl and isopropyl esters of crude palm oil and crude palm stearin were synthesized via chemical transesterification reactions and subsequently evaluated for their fuel properties. These alkyl esters are much safer than petroleum diesel in terms of safety for storage and transportation as they possess high flash points. They may find applications in the fuel industry besides utilization as oleo-chemicals (Choo *et al.,* 2005).

A study on the comparison of the properties of special biofuels from palm oil and its fractions synthesized with various alcohols and described that palm oil and its crystallization fractions, olein and stearin oils, with methyl, ethyl, isopropyl and benzyl alcohols, and investigated the effect of alcohol on the cold properties, thermal stability, density and viscosity of the resulting biofuel. The products were

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characterized by GC and H NMR spectroscopy. Biofuels produced from the olein oil fraction have superior cold properties compared to those synthesized from palm oil and the palm stearin oil fraction. They opined that the use of benzyl alcohol yields a biofuel with high thermal stability but also high viscosity and density values (Claudia *et al.,* 2014).

Waste cooking oil produced by transesterification has been used as an alternative to diesel fuel by Kannan *et al.,* (2011). They observed that biodiesel decreased brake thermal efficiency when compared to diesel fuel, it has significantly reduced CO, HC, soot and NO_x emissions. They opined that this is due to the reduced ignition delay, heat release rate and slightly longer combustion duration.

The tests were conducted on the effect of waste plastic oil and diesel blends on the performance and emissions of a CI engine. They concluded that waste plastic oil yielded 80% higher thermal efficiency, 25% higher NO_x, 5% higher CO, and 15% higher HC emissions when compared with diesel fuel. Finally, they reported that 100% waste plastic oil can be used to run the engine (Mani *et al.,* 2010).

Different methods have been considered to discussed the production of palm olein (cooking oil) and refinery process.

They stated that the refinery process consists of two units: (1) Refinery unit (2) Fractionation unit. Palm Olein is used mainly as cooking oil in households; whereas, palm sterin is used to produce shortenings and margarine (Polprasert *et al.,* 2015).

The direct used canola oil methyl esters (COME) -diesel fuel blends to study the effect of fuel injection pressure on combustion and performance characteristics of a single cylinder naturally aspirated DI diesel engine. They observed advanced injection timings with COME for its complete combustion. They concluded that the brake specific fuel consumption, brake specific energy consumption for COME is higher than diesel (Cenk *et al.,* 2012).

From the literature review, most of the research work carried out biodiesel resources and production technologies. They mentioned that fractionation is used in the oils and fats industry to physically separate oils into high-melting 'stearin' fractions and lower-melting 'olein' fractions. Palm oil is most widely fractionated. The main triglycerides in palm oil can be grouped into three groups produced from palm oil-stearin (PS), mid-fraction, and olein (POo).

A common fractionation process is the separation of palm mid fraction from palm olein. Palm olein (PO) is the liquid fraction derived from the fractionation of palm oil, and palm stearin (PS) the high-melting (hard) fraction. Palm stearin and palm kernel olein are both products of the palm oil industry that presently have limited use (Salvi and Panwar, 2012).

In this study, described that heterogeneous transesterification of vegetable oils offers an environmentally more attractive option for biodiesel production compared to the conventional homogeneous processes. They employed metal doped methoxide catalyst was developed in the present study which aims to improve the transesterification of low cost palm stearin (PS) and reduce the generation of waste. Through the X-ray diffraction (XRD), field emission scanning electron microscopy (FESEM), etc. observed that better catalytic activity of the aforementioned catalyst in the biodiesel reaction could be attributed to the presence of optimal number of catalytically active acid site density on its surface (Kok *et al.,* 2015).

It is observed from the literature that various researchers have contributed to the implementation of processed or methyl/ethyl ester vegetable oils in engines by adopting higher injection pressures for making blends. Efforts were made by researchers to lower the NOx emissions from the biodiesel fuelled engines with the addition of EGR and other oxygenated additives. Palm stearin is obtained upon fractionation of palm olien oil.

Though it finds applications in shortenings and margarine. Very few have explored its use as source for production of biodiesel and its subsequent use in engines. Few researchers also made use of heterogeneous method of producing biodiesel using metal doped methoxides.

In the present study an attempt is made to utilize neat methyl esters obtained from non-edible oil derived from Refined, Bleached & Deodorised (RBD) Palm Stearin. For this purpose experimental studies were carried out by varying compression ratio and fuel injection pressure with an objective of improving the performance and reducing the harmful emissions of the engine.

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MATERIALS AND METHODS

Preparation of Methyl Esters from Palm Stearin

From the literature review, it is found that most of the research works have been carried out on a number of alternative fuels especially biodiesel produced from different kinds of vegetable oils and animal fats. To begin with laboratory samples of Palm Stearin methyl esters of Refined, Bleached & Deodorized (RBD) Palm Stearin were prepared by adopting standard transesterification process described by Fangrui and Milford (1999). In the present case methanol and NaOH as ingredients were used. The procedure of making oil from Palm stearin to final biodiesel is presented in the form of flow chart, Figure 1 and Photograph Figure 2 as given below. Table 1 gives the comparison of important properties of fuels under consideration.
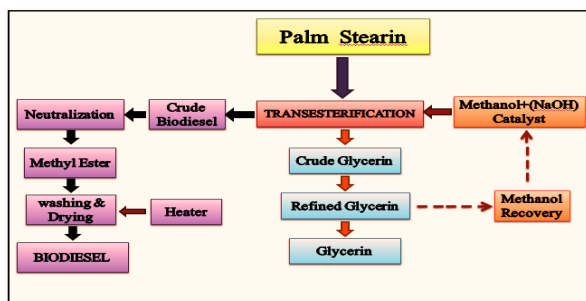
Figure 1: Flow Chart of Biodiesel Production from Palm Stearin

Figure 2: Photograph of Biodiesel production

Preparation of Blend (PSME60)

From Figure 3, the blend PSME60 is prepared by mixing 60% by volume Palm stearin methyl ester and 40% by volume Petro-diesel. A separate emulsifier is used to mix both petro-diesel and Palm stearin methyl ester in molecular level. PSME60 fuel is made just before the commencement of the experiment to avoid the possible oxidation of the blend if stored for longer durations.

Figure 3: Emulsifier for blend preparation

Table 1: Properties of Palm Stearin Methyl Ester blend and Petro-diesel

| Sr. No.	Fuel property	Unit	Petro-diesel	PSME60
1	Cetane number	- - -	45	48.6
2	Specific gravity@15ºC	Kg/m^3	830	855.8
3	Calorific Value	MJ/kg	42.5	40.100
4	Flash Point	ºC	49	97.6
5	Kinematic Viscosity@40ºC	$_cSt$	3.52	4.29

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Experimental Programme
Figure 4 shows the purpose of experimental investigations, a stationary type single cylinder, four stroke, variable compression ratio, direct injection CI engine.

Table 2: Test Engine Specifications

Parameter	Details
Model and Engine type	Kirloskar AV1-Computer Based Four Stroke, Single Cylinder, Variable Compression Ratio, Multi Fuel, Water Cooled, Direct injection, Compression Ignition Engine
Supplier	Tech-Ed, Bengaluru
Rated Power	3.7kW(5hp)
Rated Speed	1500 rpm
Bore & Stroke	80 mm & 110 mm
Connecting rod length	234 mm
Swept volume	551 cc
Compression Ratio	5:1 to 20:1
Injection Timing	24º btdc
Loading device	Eddy Current Dynamometer
Rated torque & Arm lengh	2, 4, 8 kg-m & 175 mm
Starting	Self Starter/ Canking
Orifice Diameter	20 mm
Recommended Fuels	Diesel, Petrol, Bio diesel, LPG, Ethanol, Various oils blended with diesel
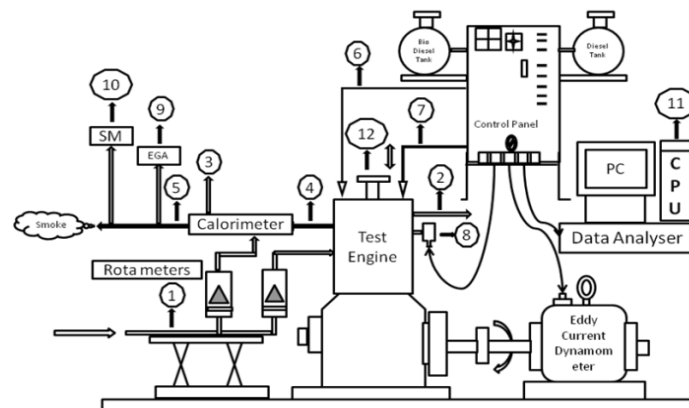
Figure 4: Computer Based Four Stroke Single Cylinder Variable Compression Ratio Multi Fuel Engine with Eddy Current Dynamometer

The detailed specifications of the engine are given in Table 2, initially the experiments were performed with Petro-diesel maintaining rated fuel injection pressure, rated compression ratio and rated speed of 190bar, 16.5 and 1500 rpm respectively. During the experiments, the engine speed (1500rpm) and engine coolant outlet temperature (65^0C) were maintained constant so as to obtain a steady state condition of the engine. The results with these details were treated as baseline data. The equipment/instrumentation employed is schematically shown as Figure 4. The smoke opacity of the exhaust gas was measured by smoke Opacity meter (Make: INDUS Smoke Meter; Model: OMS-103). Exhaust gas composition was measured using MORTH/CMVR/TAP-115/116 Part-VIII based exhaust gas analyzer (Make: INDUS Scientific Pvt Ltd, 5-Gas Analyzer; Model: PEA-205). This analyzer measures CO, HC, CO_2, O_2, and NO_x in the exhaust gas. The measurement range and accuracy of the exhaust gas analyzer are given in

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Table 3. Further experiments were continued with neat PSME60 by varying fuel injection pressures from 190 bar to 230 bar in steps of 20 bars and a higher compression ratio of 19.

1. Water inlet to the calorimeter and engine (T_1^0C)	7. Fuel flow
2. Water outlet from the engine jacket (T_2^0C)	8. Pressure Transducer
3. Water outlet from the calorimeter (T_3^0C)	9. Exhaust gas Analyzer
4. Exhaust gas inlet to the calorimeter (T_4^0C)	10. Smoke Meter
5. Exhaust gas outlet from the calorimeter (T_5^0C)	11. Personal Computer
6. Atmospheric air temperature ((T_6^0C)	12. VCR Lever

Table 3: Exhaust Gas Analyzer and Smoke meter Specifications

A) Exhaust gas analyzer specification			
Gases measured	**Measurement Range**	**Data Resolution**	**Accuracy**
Carbon Monoxide (CO)	0-15.00%	0.01%	±0.06% Vol
Hydrocarbon (HC)	0-30,000 ppm	1 ppm	±12 ppm Vol
Carbon Dioxide (CO_2)	0-20.00%	0.01%	±0.5% Vol
Oxygen (O_2)	0-25.00%	0.01%	±0.1% Vol
Oxides of Nitrogen (NO_x)	0-4000 ppm	1 ppm	± 3 ppm Vol
B) Smoke meter specification			
Smoke Opacity	0-99.9% HSU	HSU:0.1%	±0.1m^{-1}

RESULTS AND DISCUSSION
In the present study, Constant speed, performance and emission related experiments are performed on a Kirlosker AV1, single cylinder, four stroke, water cooled, direct injection CI engine with petro-diesel and 60% Palm Stearin methyl ester blend by varying fuel injection pressures(190, 210 and 230 bars) and Compression Ratio 16.5 and 19 of the engine. The baseline data represent the information on the performance of the engine when it was run with petrol-diesel at rated FIP of 190 bar and CR = 16.5. The effect of fuel injection pressure and CR are investigated on the important characteristics of an engine and the same are plotted and discussed appropriately.

*Performance Characteristics for PSME60 of the Engine at different FIPs and CRS*
Effect of Injection Pressure at CR 16.5
As can be observed from Figure 5.1 which represents the variation of BTE and BSFC of the engine with the load when the engine was run with 60% Palm Stearin methyl ester blend by varying the FIP from 190 bar to 230 bar in steps of 20 bar. The brake thermal efficiency of the engine is an important non-dimensional performance parameter that represents the percentage of power developed by the engine to the amount of heat supplied.

Thus, it is reciprocal of BSFC of the engine. It can also be observed that for a compression ratio of 16.5, BTE for an injection pressure of 210 bar is higher than those with 190 and 230 bar with respect to baseline data. It is seen that BTE of PSME60 slightly lower than that of petro-diesel fuel at all load levels. As the methyl esters of Palm Stearin blend have higher viscosity, density and low calorific value than the diesel fuel, the higher viscosity leads to decreased atomization, fuel vaporization and combustion, and hence the thermal efficiency of bio-diesel is lower than that of diesel fuel. It is interesting to note that as the FIP was increased, the BTE and BSFC values are decreasing. But the values with 210 bar are close to baseline values. It is required to adopt higher injection pressures when a fuel with a higher viscosity is used compared to petro-diesel.

This is also due to fact that as the FIP was increased smaller and smaller size droplets should have produced and which in turn mixed thoroughly with available here and let near complete combustion. Further, an increase in pressure beyond 210 bar has not helped. Therefore, for this engine configuration it can be inferred that 210 bars could be an optimum injection pressure.

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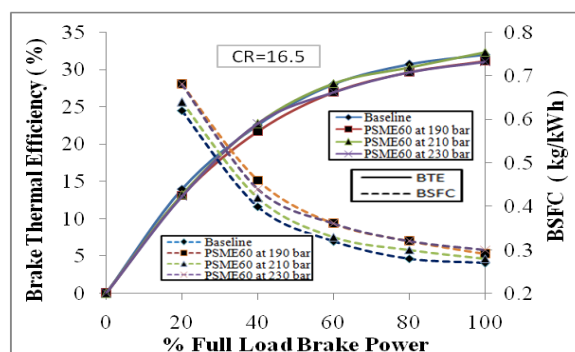
**Figure 5.1: BTE and BSFC vs % Full Load Brake Power at CR =16. 5**

Effect of Injection Pressure at CR19

Further tests were performed on the engine with a compression ratio of 19. The FIPs are again maintained as 190 bar to 230 bar. Figure 5.2 shows the variation of BTE and BSFC of the engine with the percentage of full load power when it was from with 60% Palm Stearin methyl ester blend. In the same Figure the baseline data is also compared. The BTE of PSME60 blends were lower than diesel for the entire load. It is obvious from the BTE and BSFC values for an FIP of 190 bars are close to baseline data. It was observed that higher compression ratio has played a vital role in obtaining better performance with Palm Stearin methyl ester blend. It is oblivious from the two figures that engine operation with 60% Palm Stearin methyl ester blend is better to increase in compression ratio.
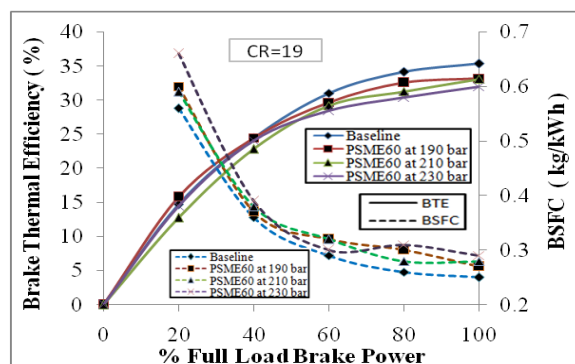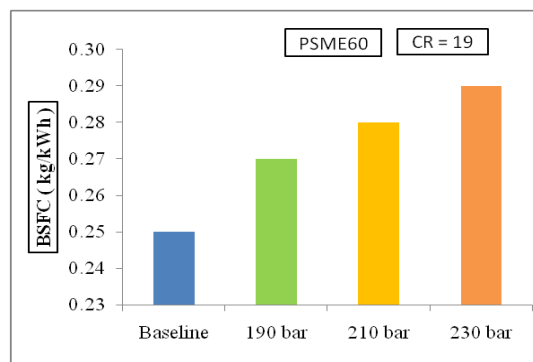

Figure 5.2: BTE and BSFC vs % Full Load Brake Power at CR=19

*Comparison of BSFCs of Engine for different FIPs and CRs*
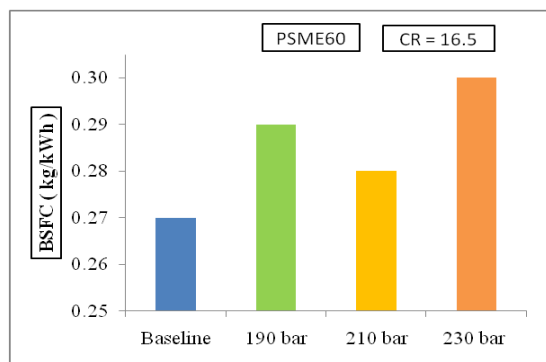
Figure 5.3(a): Variation of BSFC for PSME60 under Full Load conditions for different FIPs and CR=16.5

Figure 5.3(b): Variation of BSFC for PSME60 under Full Load conditions for different FIPs and CR=19

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From Figure 5.1 and Figure 5.2 the BSFCs of the engine for load operation are extracted and compared in Figure 5.3(a) and Figure 5.3(b). In order to observe the role of compression ratio, the best BSFCs obtained with CR= 16.5 and CR=19 respectively are redrawn as Figure 5.3(c).
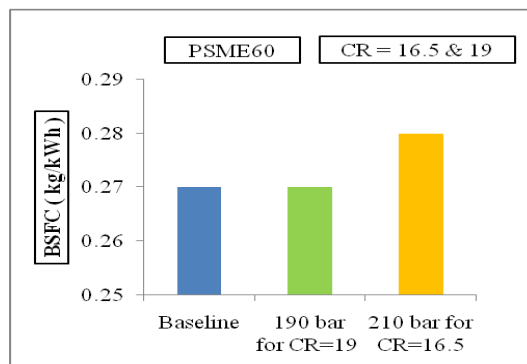
Figure 5.3(c): Comparison of lowest BSFCs of engine with PSME60 under Full Load conditions

From Figure 5.3(c) it can be noticed that compression ratio has played a dominant role in achieving better performance. It can be concluded at this stage, injection pressure can be varied, maintaining the rated CR as it is or compression ratio can be increased by retaining the rated FIP. Therefore, it is estimated that either an increase in compression ratio of about 15% or an increase in FIP of about 10% is required to achieve the performance of the engine with 60% Palm Stearin methyl ester blend in line with petro-diesel fuel operation of the respective rated FIP and CR.

Comparison of Cylinder Pressure (bar) –Crank Angle (Deg) of Engine for different FIPs and CRs
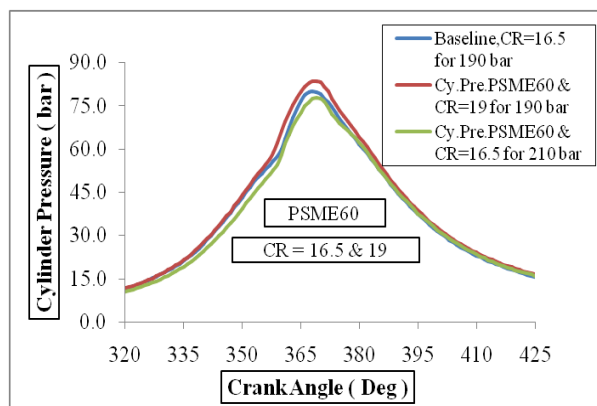
Figure 5.3(d): Comparison of best P-θs of engine with PSME60 under Full Load conditions

Figure 4.3(d) shows the variation of Cylinder pressure with crank angle under full load conditions for different CRs and FIPs. The results were compared with the baseline data on the performance of the engine, when it was run with petrol-diesel at a constant FIP of 190 bar and CR 16.5. From the results, it was observed that , 60% Stearin methyl ester blend give higher combution pressure at high compression ratio due to longer ignition delay, maximum rate of pressure rise when compared to petro-diesel. The cylinder peak pressures, was seen lower(2.58%) at an injection pressure of 210 bar and CR of 16.5 where as in peak pressure was higher(4.3%) for CR of 19 at the rated injection pressure of 190 bar.

*Emission Characteristics for PSME60 of the Engine at different FIPs and CRs*
It was observed the effects of FIP and CR on the engine performance. During the entire load range of operation, the emissions of the engine were also measured. Since the emissions of the CI engine will be significant at full load operation, therefore, to observe the effect of FIP and CR, the emission levels are compared for CO, HC, Smoke Opacity and NO_x in Figures 5.4, 5.5, 5.6 and 5.7 respectively.
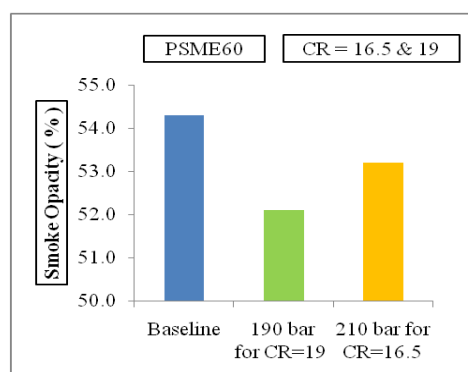
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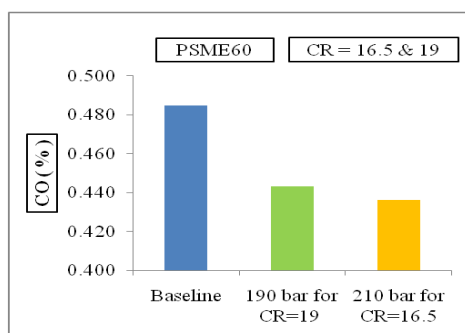
Figure 5.4: Comparison of lowest CO Emissions of engine with PSME60 under Full Load conditions
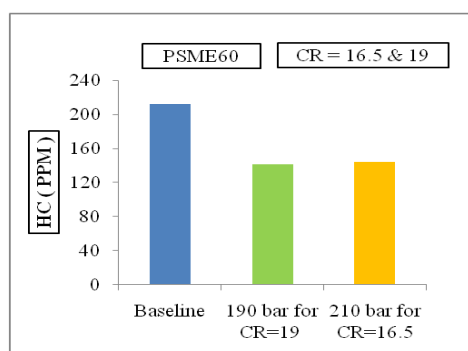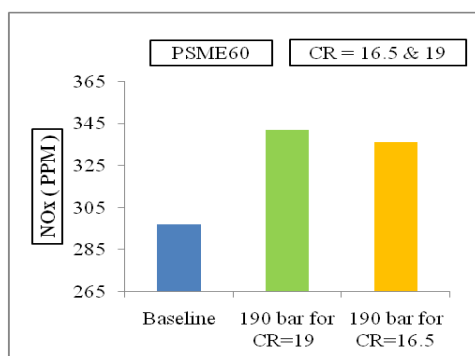

Figure 5.5: Comparison of lowest HC Emissions of engine with PSME60 under Full Load conditions

Figure 5.6: Comparison of the lowest Smoke Opacity of engine with PSME60 under Full Load conditions

It can be observed that again CR has played a dominant role in reducing CO, HC and Smoke Opacity. With an increase in compression ratio, the levels of CO, HC and Smoke opacity are significantly reduced. This can be due to the fact that factors affecting for formation of CO, HC and Smoke Opacity are almost similar. It can also be observed that the levels of these emissions with 60% Palm Stearin methyl ester blend or far lower when compared to emissions obtained with petro-diesel operation.

Figure 5.7: Comparison of lowest NO$_x$ Emissions of engine with PSME60 under Full Load conditions

Figure 5.7 shows the levels of NO$_x$ for different conditions. It is interesting to notice that NO$_x$ levels are higher with biodiesel compared to petro-diesel operation. This is well established in the literature that NO$_x$ emissions increase with biodiesel operation due to the reactive nature of biodiesel molecule of higher

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temperature and oxygen present in its structure. Since the biodiesel molecule contains oxygen in its structure, the amount of oxidizer required by the engine gets reduced.
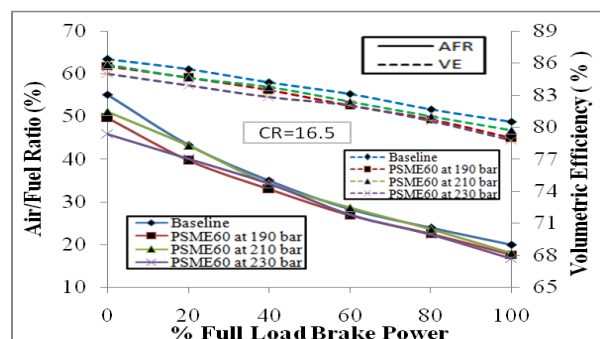

Figure 5.8: AFR and VE vs % Full Load Brake Power at CR =16. 5

Figure 5.8 and Figure 5.9 shows the variation of AFR and VE of the engine when it was from with PSME60. Fuel consumption is higher in the engine due to increased temperature and completes combustion. Air fuel ratio decreases with increase in load because air fuel mixing process is affected by the difficulty in atomization of biodiesel due to its higher viscosity. This can be understood with the lowest values of volumetric efficiency obtained by Palm Stearin biodiesel blend operation.
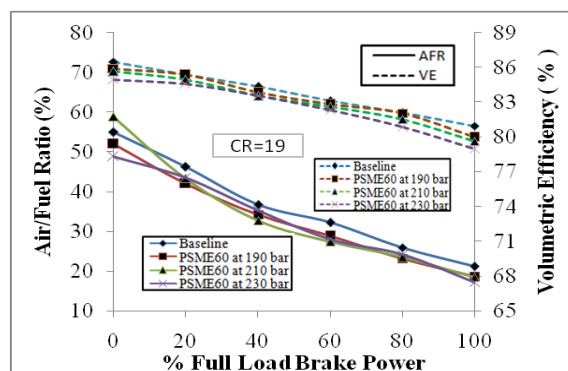

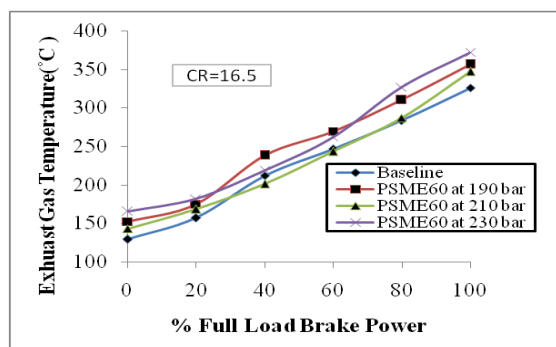**Figure 5.9: AFR and VE vs % Full Load Brake Power at CR =19**

Figure 5.10(a): EGT vs % Full Load Brake Power at CR =16.5
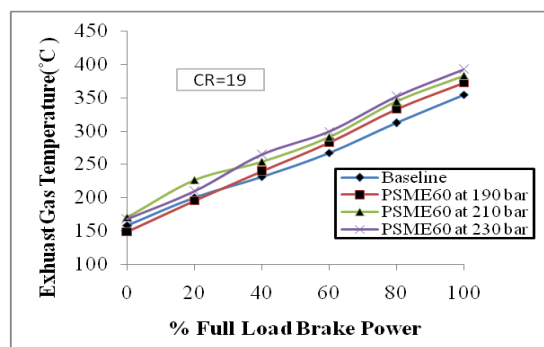
Figure 5.10(b): EGT vs % Full Load Brake Power at CR =19

Also, because of its reactive nature the in-cylinder temperatures with biodiesel operation would be higher. This is also a reason for higher NO_x levels, since the in-cylinder temperatures are higher and yields higher exhaust temperatures. Figure 5.10(a) and Figure 5.10(b) show the variation of EGTs for CR=16.5 and

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CR=19 respectively. It can be observed that with a biodiesel operation the EGTs are higher. These variations can be attributed to the increase in thermal efficiency.

Conclusion

The effects of compression ratio and fuel injection pressure were studied experimentally when Kirloskar AV1,single cylinder, four stroke,water cooled,dierct injection, multi fuel CI engine was run with 60% Palm Stearin methyl ester blend. Based on the present work the following conclusions are drawn.

i. About 98.10% yield of Palm Methyl Esters was obtained from Refined , Bleached & Deodorised (RBD) Palm Stearin.

ii. The Brake thermal efficiency, was observed to be higher at an injection pressure of 210 bar and CR of 16.5 where as efficiency was higher for CR of 19 at the rated injection pressure of 190 bar.

iii. Under full load operation and CR 16.5, the percentage reduction in CO, HC, Smoke Opacity were observed to be about 10.10%, 32.08% and 2.03% respectively in comparison with baseline operation.

iv. Under full load operation and CR 19, the percentage reduction in CO, HC, Smoke Opacity were observed to be about 8.66%, 33.49% and 4.05% respectively in comparison with baseline operation.

v. Under full load operation and CR 16.5,A percentage reduction of about 2.58% was observed in Peak pressure with PSME60 compared to Petro-diesel operation

vi. Under full load operation and CR 19,A percentage increase of about 4.30% was observed in Peak pressure with PSME60 compared to Petro-diesel operation

vii. The volumetric efficiency of the engine was relatively low with Palm Stearin Methyl Esters blend compared to petro-diesel operation.

viii. Under full load operation and CR 16.5,A percentage increase of about 13.13% was observed in NO_x emission with PSME60 compared to Petro-diesel operation

ix. Under full load operation and CR 19,A percentage increase of about 15.15% was observed in NO_x emission with PSME60 compared to Petro-diesel operation.

x. It is observed that compression ratio has a dominant effect on performance where as fuel injection pressure as played a vital role in the reduction of emissions.

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