

Analysis of Performance, Combustion and Emission Characteristics of Multi-Cylinder CRDI Engine using Palm Oil Methyl Ester (POME) as a Fuel

Kalaiselvam V*, Rajesh S, Sivakkumar G

Assistant Professor, Department of Mechanical Engineering, R.M.K. Engineering College.

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Abstract

The world is affronted with some serious environmental issues and depletion of fossil fuels at a faster rate with rapid growth in automotive sector. This led many researchers to churn out a renewable and environmental friendly alternative fuel. Biodiesel is recognized as one such solution to this crisis. Biodegradability, low volatility, high cetane number, no sulphur emissions strengthens the claim. Though many researches have been done in this area with wide variety of non-edible oils in various blends with diesel, all those researches are mostly carried out in constant speed agricultural Compression Ignition (CI) Engines. But only few experiments' have been done in automotive engines (i.e.) multi-cylinder variable speed Common Rail Direct Injection (CRDI) Engines. Hence our research work reports the preparation of Palm Oil Methyl Ester (POME) by trans-esterification of Palm Oil (PO) and detailed experimental and comparative investigation of Performance, Combustion and Emission characteristics of automotive engine (TATA Vista) run with various blends of biodiesel prepared (POME B5, B10, B15, B20) as a fuel. Based on the experimental works we could infer that Palm Oil Methyl Ester (POME) as biodiesel proves to be a good prospect as an alternative fuel to power automotives with its sustainability and lower HC, CO, NOx emissions.

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I. INTRODUCTION

In earlier times, the main energy source was wood by regular deforestation; however, the reliability on wood as a fuel had a serious concern. After that, an alternative to wood was discovered i.e. coal. Later on petroleum products were identified i.e. petrol, diesel etc. In the initial phase, it seems that the problem of energy needs had been completely resolved. However, the population growth along with lifestyle changes increases global energy demand. Later, it is realized that the fossil fuels resources are also limited. One of the main consumers of energy is automobile sector as 600 million cars are used in the world [1] and primarily runs in diesel engines.

According to [4] Society of Indian Automobile Manufacturers (SIAM) report, around 23.3 million vehicles were produced in India registering a growth of 8.68% over the previous year. Also [5] Make in India survey claims that Automotives account for 45% of country's

manufacturing GDP. On the other hand Institute For [6] Energy Research reports that 44.9% of the refined fossil fuel is used as diesel in automotives and considering the raise in rate of the consumption of fossil fuels particularly diesel it claims that the half of the fossil fuel reserves will become extinct by 2030.

On the environment point of view, these fossil fuels contribute to the global warming at a alarming rate and the global countries have signed a treaty in global summits to reduce the environmental pollution. Recently, countries like India, Supreme Court banned registration of diesel cars due to its adverse environmental emissions. So it's high time for us to switch to a cleaner and renewable alternative fuel which gives a sustainable solution for our crisis. This situation has forced the researchers to work on utilization of renewable energy sources.

To fulfill this escalating demand, there are two methods: first is to make the engines more

fuel-efficient and second is to use alternative compatible fuel to the engine [6]. The second method seems to be more appropriate as already there are huge numbers of existing engines. Bio-fuels will also bring down the transportation cost along with GHG emissions [7]. The biodiesel is one of the alternative fuels found to be most suitable renewable and environment friendly for CI engines [8]. The biodiesel has the ability to substitute diesel as most of its properties are closer to diesel [9].

Since the main aim of this research is to study the performance, emission and combustion characteristics of biodiesel in a variable speed multi-cylinder engine we would like to first study it with the first generation biodiesel i.e, with the biodiesel prepared from the edible oil and later on proceeding further this research work, engine will be tested with biodiesel prepared from non-edible oil .Alternatively a non-edible part or surplus byproduct from a food plant can also be used as a bio-fuel, without affecting food supply.

II. METHODOLOGY

1. Palm Oil Methyl Ester Preparation

Trans-esterification method proves to be the most productive way of preparing biodiesel from Palm Oil from various literature reviews we too will be preparing biodiesel by trans-esterification process.

To decide the stage requirement for the trans-esterification of palm oil we first tested the oil for its properties in lab. The reports suggested that Palm Oil has low fat contents. We could infer from the test report that Crude Palm Oil needs only a single trans-esterification stage and hence the Crude Palm Oil Methyl Ester is cheaper to produce. For the present study Crude Palm Oil is procured from the market.

The process parameters selected to carry out the trans-esterification process are as follows

Process Parameter	Selected Value
Alcohol Type	Methanol
Catalyst Type	Base Catalyst
Base Catalyst	NaOH
Reactants Molar Ratio	6:1

Reaction Temperature	65°C
Alcohol Addition	130ml for 500ml oil
Reaction Time	1 hour
Stirring Speed	1000 rpm
Settling Time	6 hours
Yield	74 percent

Table 1: Process Parameters

The first step in the trans-esterification process is methanoxide preparation. Na-OH which is the base catalyst in our current study is procured in the palette form from the market and powdered very finely and mixed with the methanol (9.1g of Na-OH to 130ml of methanol) and stirred well in order to make a homogeneous mixture called methanoxide. This process of preparing methanoxide is called methanolysis.

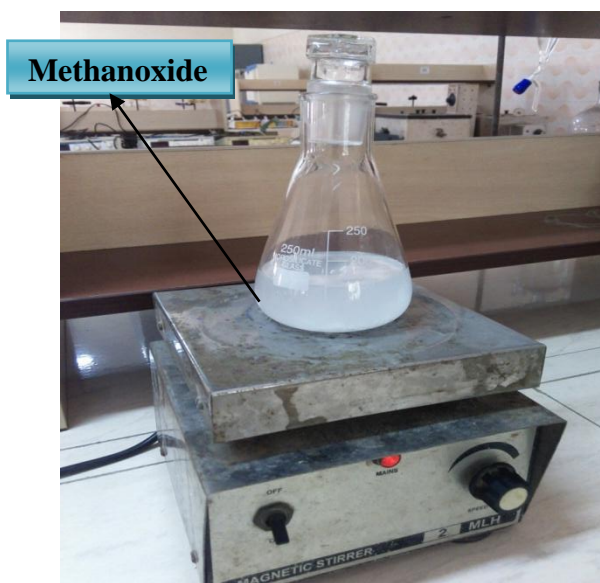


Fig 1: Methanoxide (Methanol & Na-OH)

The next step is the base catalyzed trans-esterification of raw oil. The raw oil procured from the market is first filtered in order to remove the impurities present in them and then they are preheated to about 50°C for about 5 – 10 minutes in order to remove the moisture present in the oil.

Then both the preheated oil and the homogeneous methanoxide are mixed in the manner that each 500ml of oil is mixed with 130 ml of methanoxide. Then the mixture is stirred at 1000rpm using the hot plate magnetic stirrer and

the mixture is maintained at the temperature of 65°C for an hour. During this period of one hour, trans-esterification process takes place where the triglycerides present in the raw oil is converted into the glycerine.

Then it is transferred to the separating beaker where the glycerine formed during the trans-esterification process is allowed to settle down during the time of 6 hours and the trans-esterified oil to go on top of the glycerine and then it is removed out.

Then the purified oil is heated to about 100°C to vaporize the remaining water contents in the oil. Thus the Crude Palm Oil Methyl Ester is prepared from the Crude Palm Oil.

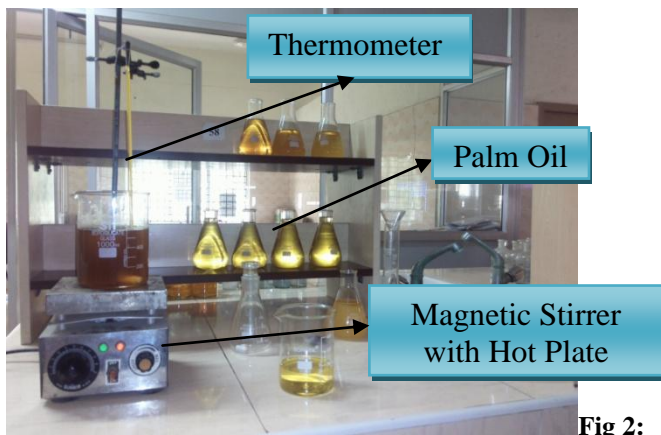


Fig 2: Transesterification of Palm Oil

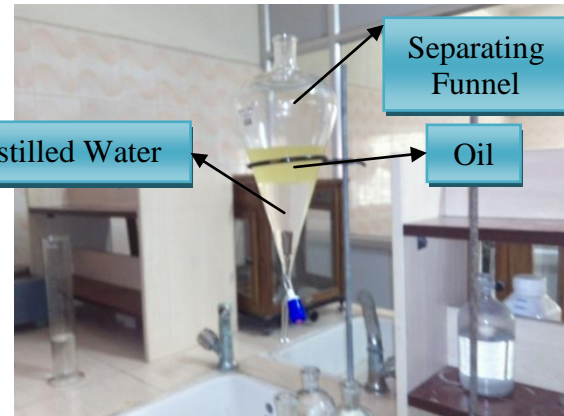


Fig 4: Water Washing



Fig 3: Palm Oil after Transesterification (Settling Process)

After we get the trans-esterified oil, we need to purify it in order to remove the unreacted reactants from the oil. In order to do it distilled water is used to water wash the oil.

First distilled water is preheated to about 70°C and then added to trans-esterified oil in the separating funnel in the ratio of 150ml of water for 500ml of oil. Now the oil floats over the distilled water and the unreacted reactants (Na-OH and Methanol) get dissolved in the distilled water and the distilled water is tapped out from the separating funnel.

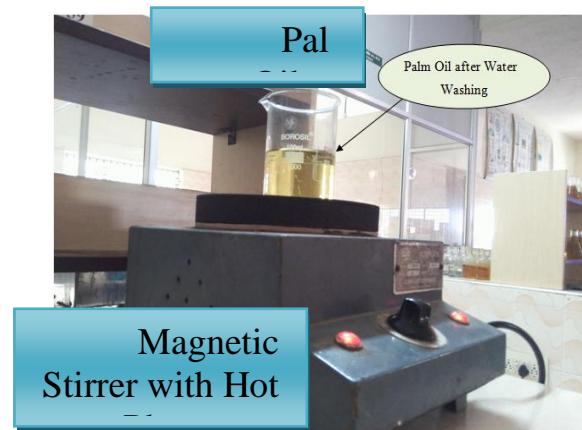


Fig 5: Heating after water wash

2. Experimental Procedure

Test fuels were prepared by blending Palm Oil Methyl Ester (POME) with diesel at different percentages by volume. The blending ratio chosen was B10, B20, B30 i.e. 10 percent Palm Oil Methyl ester with 90 percent Diesel, 20 percent Palm Oil Methyl ester with 80 percent Diesel, 30 percent Palm Oil Methyl ester with 70 percent diesel respectively so that data could be generated over wide range of biodiesel blends.

Engine equipped with Pal instrumented instrumentation and data acquisition system was used to measure various parameters to give the performance parameters like Gly Fuel Consumption (BSEC), Brake Thermal Efficiency (BTE), and Exhaust Gas Temperature (EGT) etc. Emission characteristic were measured with the help of gas analyzer and smoke meter.

The engine was mounted on sturdy base frame. The engine and the dynamometer were coupled using standard coupling. A standard air tank was fitted with a mass air flow sensor for measuring the actual volume of air drawn into the cylinder. The thermocouples and necessary signal conditioner for the measurement of temperature at various points were suitably provided. Windows based powerful software was used for real time data measurement, auto zoom and analog and digital display of data in the computer. The system can store large number of graphs for analysis.

The exhaust gas composition was measured using the Exhaust Gas Analyzer. It

measures the NO_x, CO₂, HC, CO and O₂ in the exhaust gases. The opacity of the exhaust gases was measured by smoke meter. The short term performance and emission characteristics were evaluated by testing the engine fueled with prepared test fuels to determine how each fuel would perform under identical engine load conditions. The experimental test set up for Common Rail Direct Injection (DI) Multi Cylinder diesel engine is shown in the figure. The engine tested in this study was the CRDI Multi-cylinder TATA Vista make.

3. Experimental Setup

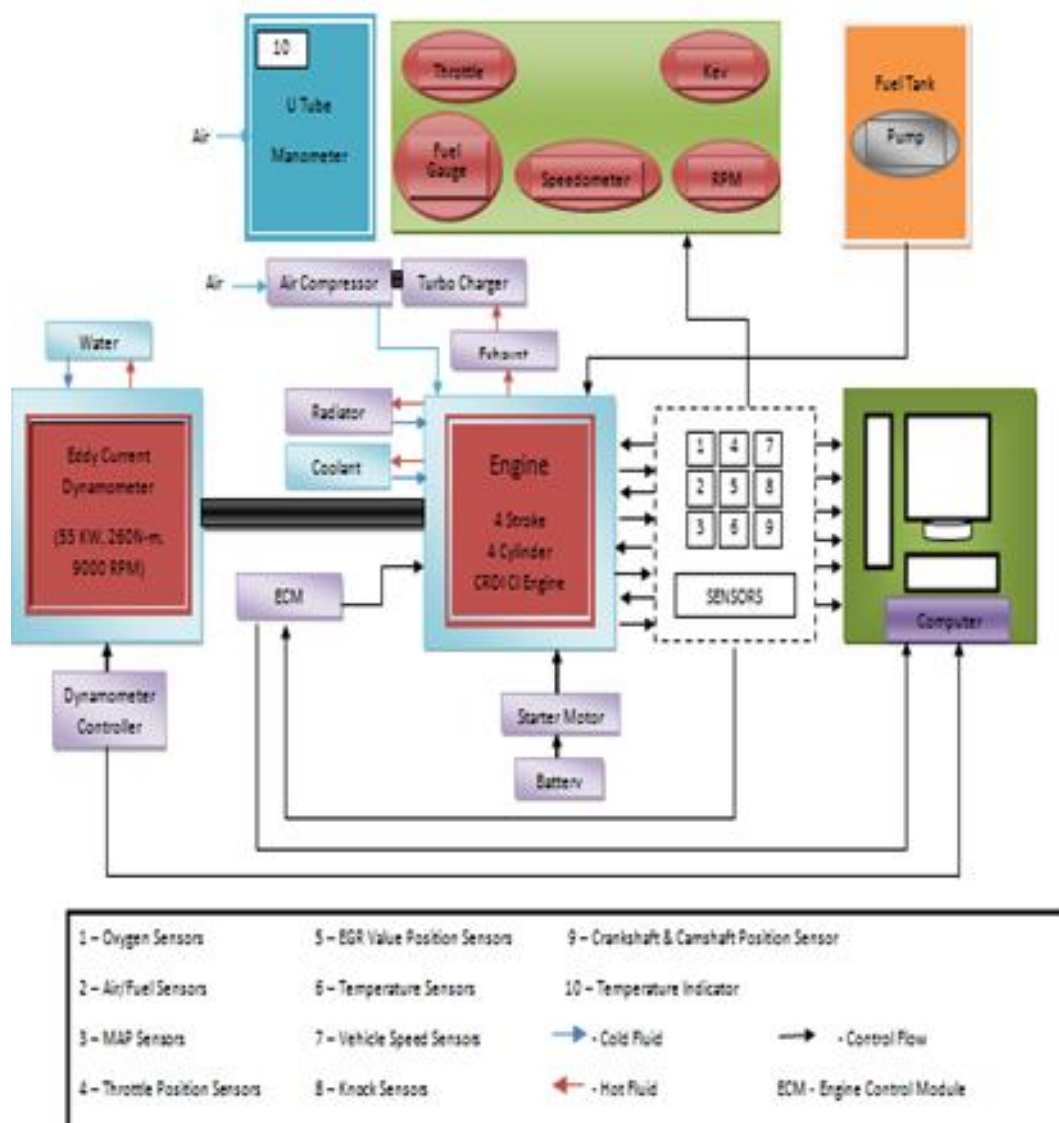


Fig 6: Experimental Setup Line Diagram

4. Fuel Properties

Property	Unit	Diesel	POME	POME (B10)	POME (B20)	POME (B30)
Density	kg/m ³	844	870	849.8	879.5	877.5
Cetane Number		53	56.5	40.3	44.3	47.4
Kinematic Viscosity	mm ² /s	2.0	4.5	1.4	1.96	2.45
Flash Point	°C	98	174	64	65	71
Pour Point	°C	15	16	-	-	-
Cloud Point	°C	18	16	-	-	-
Calorific Value	kJ/kg	46800	41300	45011	45011	44711
Gross Heat of Combustion	kJ/kg	45800	40135	44752	44752	44543
Sulphur Content	% wt	0.10	0.04	0.02	0.02	0.03

Table 2: Properties of fuel

4. Engine Specifications

Make	Indica Vista (CRDI)
Type	4 Stroke Cycle, Water Cooled
No of Cylinder	4
Piston Displacement	310.02 cc
Bore Size	69.2 mm
Stroke	82 mm
Max Engine Output	55.2 kW @ 4000rpm
Max Torque	190Nm @ 1750 – 3000rpm

Table 3: Engine Specifications

III. RESULTS AND DISCUSSION

SSI

1. Performance Characteristics

Torque Vs Brake Thermal Efficiency

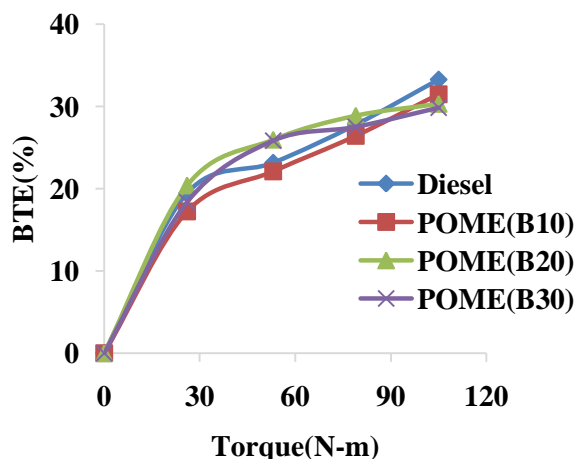


Fig 7: Torque Vs Brake Thermal Efficiency

The variation of brake thermal efficiency of the test fuels with respect to torque. Brake thermal efficiency of all the fuels increased as the load increased. This could be explained as the load increases suction pressure developed will be more which might have resulted in efficient combustion in the engine. At 80% torque, brake thermal efficiency of Diesel, POME (B10), POME (B20), POME (B30), were 33.29%,

31.47%, 30.325% and 29.87% respectively. The brake thermal efficiency decreases as the blend percentage increases to 80% of torque. But, for the blend of POME(B20) and POME(B30), the brake thermal efficiency were increased more than diesel at 40% torque; this may be due to the higher oxygen content in the biodiesel blends than diesel resulting in complete combustion. The POME (B10) shows the overall decrease in brake thermal efficiency at all loads. And at the 80% torque, the POME (B20) and POME (B30) blend with higher latent heat of vaporization leads to incomplete combustion thus resulting in decrease in brake thermal efficiency.

Torque Vs Brake Specific Fuel Consumption

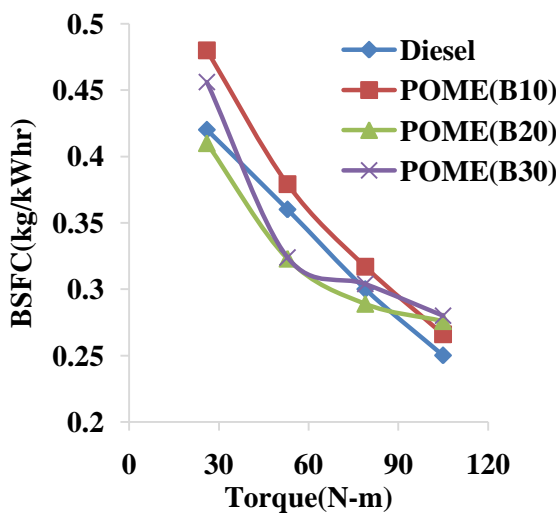


Fig 8: Torque Vs BSFC

Fig.10 shows the BSFC of diesel and blends of POME with diesel at various torque. For POME (B10), the BSFC is more than diesel because of lower calorific value of the blend. In POME (B20) and POME (B30) the BSFC is 0.323 kg/kwhr, 0.324 kg/kwhr, at 40% torque; were lower than diesel 0.36kg/kwhr as the oxygen content is more in the blend makes the better combustion. But at 80% as the load increases the BSFC of all the blends were higher than diesel. This would be due to the lower calorific value of the blend and the incomplete combustion occurs as the more fuel is burned in the expansion stroke than during combustion and the reduction in lower heating value of the fuel blends leads to increase in the volume of injected to maintain the same engine power. Therefore, these factors will lead to increase of BSFC at increased loads.

2. Emission Characteristics

Torque Vs Hydrocarbon Content

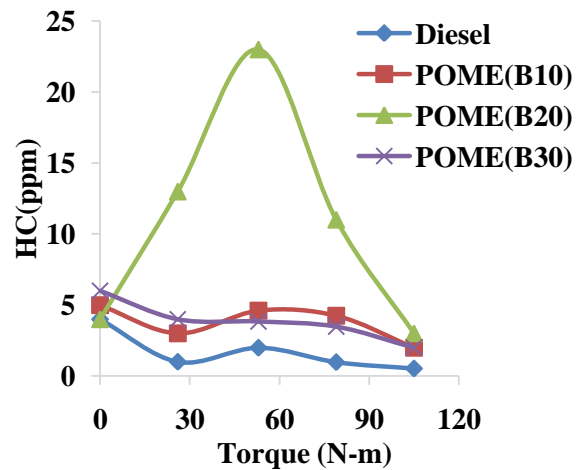


Fig 9:

Torque Vs Hydrocarbon

Hydrocarbon emission of the diesel and palm oil methyl ester blends with diesel was depicted in Fig 11. For the blends of POME (B10), POME (B20) and POME (B30) the increased emission is noted than the diesel, this is because, the unburned mixture of fuel released to the exhaust. The POME (B20) blend releases more hydrocarbon than other blends as the unused oxygen profile (Fig 31) shows the amount of oxygen is liberated more in this without combustion resulting in release of excess hydrocarbon. Because of the lower calorific value and the ignition delay of the fuel blends most of the fuel molecules do not tend to attain the homogeneous proportion and the combustion takes place after the power stroke leads to release the high amount of hydrocarbon. From literature, it is noted that palm oil methyl ester blends of proportion more than 50% shows the lower hydrocarbon emissions than diesel due to its increased gas temperature and higher cetane number.

Torque Vs Carbon monoxide content

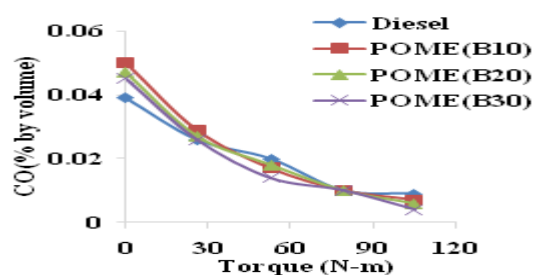


Fig 10: Torque Vs Carbon monoxide

Fig.12 depicts the variation of carbon monoxide emission for the test fuels at various loads. Carbon monoxide is usually formed when there is no sufficient oxygen to oxidize the fuel. Diesel engines are usually operated at excess air as the carbon monoxide emissions in diesel engine are lower than that of gasoline engine. The CO emission at 40% torque and at 80% torque shows the significant decrease in the CO emission of palm oil methyl ester than diesel. For 40% torque the CO emission for POME (B10), POME (B20) and POME (B30) were 0.017%, 0.018% and 0.014% respectively lower than diesel which is accounted as 0.02. At 80% torque the CO emissions were 0.009%, 0.007%, 0.006% and 0.004% for diesel, POME (B10), POME (B20) and POME (B30) respectively. As the load increases the CO emission decreases due to complete combustion as the excess oxygen molecules oxidizes the CO into CO₂.

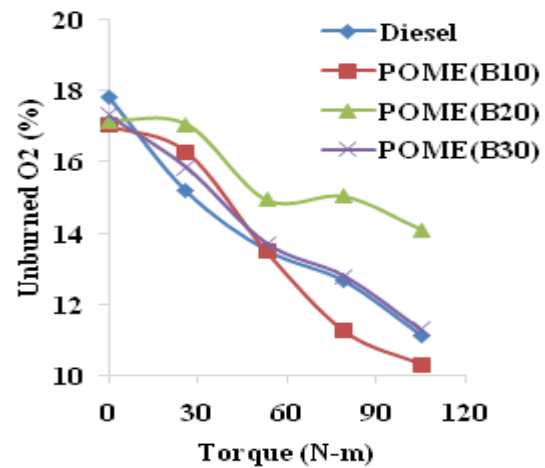


Fig 12: Torque Vs Unburned O₂

The unused oxygen after the combustion. The remaining oxygen molecules after the combustion process are released in the exhaust as unused oxygen molecules. The unused O₂ of the palm oil methyl ester blend is more than the diesel because of excess oxygen content in the fuel. In the blends of POME (B10), POME (B20) and POME (B30), the POME (B20) blend releases more unused O₂ than POME (B10) and POME (B30). This may be of the excess oxygen that has not been burnt in the combustion process. Thus, the hydrocarbon in the POME (B20) was unburned and the release of more amount of unburned hydrocarbon was noticed in the hydrocarbon profile.

Torque Vs Carbon dioxide Content

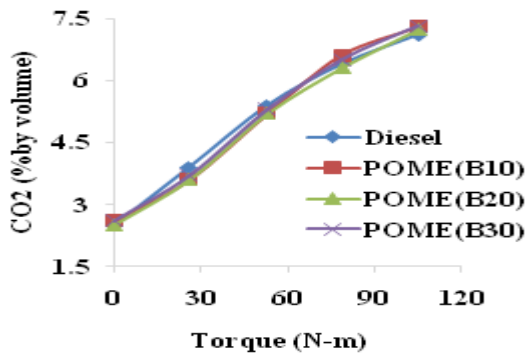


Fig 11: Torque Vs Carbon dioxide

The variation of carbon dioxide emission of test fuels in the CRDI engine. CO₂ emission of the palm oil methyl ester blends compared to diesel is almost equal with small variations in percentage as the blends show the increased CO₂ emission up to 0.3% than diesel. The increase in load increases the level of CO₂ emission due to intake of more amount of fuel. As the oxygen molecules in the palm oil methyl ester blends are more, the combustion of the fuel is easier. This relates the complete combustion of the fuel and the oxidation of carbon molecules with oxygen by decreasing the level of CO emissions to the atmosphere in POME (B10), POME (B20) and POME (B30) than diesel.

Torque Vs Unburned Oxygen

3. Combustion Characteristics

Crank Angle Vs Cylinder Pressure

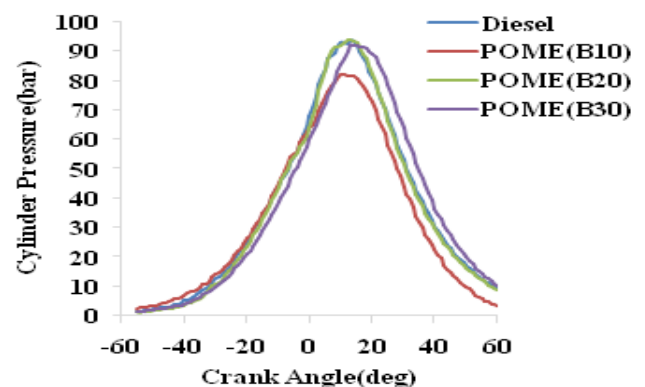


Fig 13: Crank Angle Vs Cylinder Pressure

The cylinder pressure with respect to crank angle at 80% torque is shown in fig 29. It is noted

that the cylinder pressure is higher for the POME (B20) as 94.12 bar. Peak pressure for POME (B10) and POME (B30) is 81.87 bar and 92.25 bar respectively whereas diesel have 93.74 bar. The peak cylinder pressure increases as the load increases. For all the test fuels peak pressure occurred only after top dead center so, there was knocking in the CRDI engine with these fuels. H. Sharon et al. obtained cylinder pressure higher than diesel, when he tested used palm oil based biodiesel in diesel engine. The same was obtained in this study as POME (B20) resulting in higher peak pressure than diesel.

Crank Angle Vs Heat Release Rate

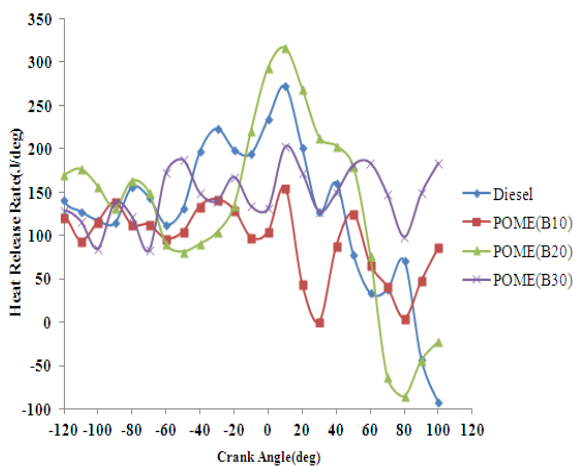


Fig 14: Crank Angle Vs Heat Release Rate

The heat release rate profile of the test fuels at 80% of torque applied to the engine. It clearly explains the effect of ignition delay. Negative heat release rate was due to vaporization of accumulated fuel during ignition delay. For the blend of POME (B20) the heat release rate is more compared to diesel and other blends as the injected fuel may get accumulated inside the chamber for some time and it exploded suddenly which caused the higher heat release rate for the blend POME (B20). But for the blend POME (B10 & B30) the heat release rate is lower than that of diesel and POME (B20) because the controlled combustion had taken place and the heat release rate of the blends got decreased.

IV. CONCLUSION

Experiments were conducted on a Variable Speed, Multi-Cylinder, Water Cooled, Common Rail Direct Injection and Four Stroke Automotive

(Vista) Diesel Engine using various blends of palm oil methyl ester B10, B20, B30 with diesel fuel. Based on the experimental investigations the following conclusions were arrived:

1. The brake thermal efficiency with POME (B20) and POME (B30) fuel at 40% torque increases by 3.8% absolute than diesel.
2. The heat release rate of POME (B20) fuel increases by 16.5% than diesel at 80% torque applied to the engine.
3. The CO content of the biodiesel decreases with respect to diesel up to 50% for the blends POME B20 & B30 in 40% and 80% torque applied to the engine.
4. The CO₂ content with respect to diesel also decreases up to 8.3% for biodiesel blends.

On the whole it is concluded that 20% and 30% palm oil methyl ester blended with diesel fuel combustion gives best performance and significant reduction in CO and CO₂ emission which makes palm oil blends B20 & B30, a suitable biodiesel to be used in the automotive engines.

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