# INFLUENCE OF VARYING INJECTION PRESSURE ON PERFORMANCE AND EMISSION CHARACTERISTICS OF BLEND OF SAPOTA SEED BIODIESEL IN CI ENGINE

S.Sathya narayanan[1] ,V.Sivaraj[2] , E.Samuel joshua[3] , J.Srinivas[4]

[1,2,3,4]Department of Mechanical Engineering, Panimalar Engineering College, Chennai, Taminadu, India

narayanansathya249@gmail.com[1] , sivara569@gmail.com[2] , samueljoshuae@gmail.com[3] , jayaramansrinivas@gmail.com[4]

***Abstract:*** Diesel engines are majorly preferred for their durability, robustness and low fuel consumption. In order to achieve the higher efficiency of the engine, there will be an increase in the pollutant gases which are directly associated with adverse health or environmental impacts. Low heat rejection of diesel engine also plays vital role on improving combustion efficiency and reduce the harmful pollutant gases. The Bio diesel is the solution for the above factors and the problems associated with biodiesel fruit seed oils are high viscosity, low volatility and high reactivity, but at the same time their higher Cetane number, lower Sulphur content , higher oxygen concentration are the desirable properties to use a fuel in compression ignition engine. The high viscosity of the fruit seed oils can be reduced by the Transesterification process. This work focused on the analysis of the effect of varying the injection pressure on performance, combustion and emission parameters of CRDI diesel engine using bio-diesel (Blend of Sapota seed oil and diesel). Variation of injection pressure was conceded as 500bar, 550bar and 600bar. The effect of the injection pressure on engine characteristics were obtained at different load condition and these results were compared with Diesel fuel which has the injection pressure of 500bar. The output result shows that the increasing of injection pressure used to improve the performance, combustion and emission characteristics of diesel engine.

***IndexTerms*:** **Sapota seed oil, Compression Ratio, Engine Characteristics, Injection Pressure, CRDI Diesel Engine**

## I. INTRODUCTION

Combating climate change causes the planet to look for sustainable and low-carbon energy and fuel sources. Cities' traffic is one of the main and most important sources of greenhouse gases, or carbon emissions. At the same time, the world's population is projected to rise to 8 or even 10.5 billion by 2050, owing to significant economic growth in emerging economies Emerging economies' growth would result in a large rise in energy usage. We need to use natural or renewable resources more effectively and efficiently, as well as increase the use of alternatives like biofuels, to meet this increasing demand. It provides a way to minimise traffic-related carbon emissions, while electric vehicles are not an option due to high vehicle costs compared to current fuels, there are fewer vehicle charging stations and EV batteries have a smaller energy storage density. One of the key reasons we need biofuel is that it can be used in our current engines with only minor modifications right away. Different fruits and their fruit seed oils are depicted in Figure 1. It can also be used in blended or pure form with a number of other ingredients.

Fig.1 Fruits and Seed oils

A. Raj Kumar et.al, [1] have conducted an experiment on Emission and Performance Characteristics of Diesel Engine Using Mamey Sapote Biodiesel the fuel used here is Mamey Sapote oil in a compressed ignition engine. This study gives the comparative measures of Emission characteristics of Sapota Biodiesel blends of 5, 10, 15 and 20% ratio with diesel fuel. From this investigation, it can be concluded that the biodiesel can be used as an alternative to diesel in a compression ignition engine without any engine modifications. M.R. Indudhar et.al, [2] have conducted an experiment on Effect of injection timing and injection pressure on the performance of biodiesel ester of Hongeoil fuelled common rail direct injection (CRDI) engine. This experiment discusses the feasibility study on the utilization of biodiesel ester of Honge oil (EHO) in common rail direct injection (CRDI) engine. Existing single cylinder diesel engine fitted with conventional mechanical fuel injection system (CMFIS) was suitably modified to operate on Common Rail Direct Injection (CRDI) facilities. The experiments were conducted to study the influence of IP on CRDI engine operation using electronic control unit.

K. Rajasekhar et.al, [3] has conducted an experiment on Experimental Evaluation of Injection Pressure and Injection Timing on Diesel Engine. It is an experiment to evaluate the Performance and Emission characteristics. The experiments were conducted at different Load conditions of 0%, 25%, 50%, & 75% and Full Load by varying injection pressures of 200 and 220 Bar with different injection timings at19°, 23° and 27° BTDC. Output results shows that engine operating at 220 bar pressure gives more brake thermal efficiency than lower pressure irrespective of the injection timing whereas brake specific fuel consumption is found to have significant changes at the initial conditions. It is also shows that the CO emissions decrease with increase in injection pressure. The NOx emissions increase with increase in injection pressure. Mahantesh M. Shivashimpi et.al, [5] have conducted an experiment on Effect of Injection Parameters: Injection Timing and Injection Pressure on the Performance of Diesel Engine Fuelled with Palm Oil Methyl Ester. This experimental study paper investigation mainly focused on CI engine performance with using the palm oil methyl ester. The final results were reported for optimized parameters of diesel engine with engine speed 1500 rpm and CR 17.5. The experimental results of diesel engine performance improved in terms of brake thermal efficiency (BTE) and substantial reduction of harmful emissions. S. Rostami et.al, [7] have conducted an experiment on Effect of the injection timing on the performance of a diesel engine using Diesel-Biodiesel blends. Different experiments were carried out on the diesel engine at different engine speeds. The injection timing was regulated for three different crank angles before top dead centre. The experimental results of engine torque, brake specific fuel consumption (BSFC), cylinder pressure, and exhaust gas temperature for fuel blends at different engine speeds and injection timings were recorded. The results showed that an ANN is a good tool to predict engine performance.

Cenk Sayin et.al, [9] has conducted an experiment on Effects of injection timing on the engine performance and exhaust emissions of a dual-fuel diesel engine

## II. TEST FUEL: SAPOTA SEED BIODIESEL

Today, Sapota seed oil is being reassessed beyond artisanal applications and has been analyzed in greater detail, for example, it is acquiring an interesting position as a source of triterpene alcohols, whose properties are interesting for applications in cosmetics (it is commonly considered to be effective in skin care and its healing, to improve tolerance to UV radiation, etc.) and pharmacology (anti-inflammatory capacities, erythematic and sunburn treatments, etc.). One aspect that sparsely addressed is the potential use of this oil in the food sector because of its characteristics. It could be an interesting source of vegetable fats with specific phase properties obtained by means of oil fractionation or oil mixing processes.

The Sapota seed oil is important in the ongoing efforts to replace fats that currently are produced through industrial processing with the partial hydrogenation of oils, this results in fats with high contents of trans fatty acids which compounds with serious objections from nutritional and public health points of view .

Fig.2 Mamey Sapote Seed


Fig.3 Sapota biodiesel

Mamey Sapote popularly known as sapodilla, a forest tree with long life span is mostly found in southern Mexico, Caribbean and Central America. It is also cultivated in larger scale in India, Thailand, Cambodia, Malaysia, Indonesia and Bangladesh mainly for its fruit... The soils can be slightly alkaline, well dried with medium textured loams. Its normal growth can reach up to around 30 m height with the maximum diameter of trunk 1.5 m. Even though the tree flowers and fruits are available throughout the year, maximum yield occurs during the period of March to June. The Fig.2 represents the Sapota Seed oil known as the biodiesel. The seeds are not utilized for any major purpose except seedling. The seeds are covered by a juicy sweet brownish flesh which can be eaten raw or made into jam and juice. The Fruits seeds have a rough brownish skin with 1–4 seeds of colour brown or black. Mamey Sapote seeds have oil contents of 25–30% and hence this underutilized oil seed can be Considered for the biodiesel production. Our study is also based on use of the Sapota seed for biodiesel production.

The fractionation of vegetable oils is a process that has been strongly revalue due to the fact that it can produce vegetable fats from oils without severe thermal treatments in recent decades, thus achieving more natural and healthy products. Figure 1.4 denotes the Mamey Sapote oil for pharmacology purpose. The dry fractionation of vegetable oils also has significant advantages from Sapota seed oil .The required amount of seeds was collected from the Fruits and the collected seeds were washed using clean water to remove the sticky fruit pulps. After washing, they were dried in sunlight for nearly a day for the easy removal of the shells from the seeds. The extraction of Sapota seed Oil can be extracted from the seeds in many ways like extraction using mechanical presses, solvent extraction using chemicals and extraction using screw expellers etc. Out of these, extraction using screw expeller is very economical and best suitable for batch type process. Both the methods have their own pros and cons and we need to choose the best method based on our constrained. The brief explanation about the processes will be discussed below

### 1.1 TRANSESTERIFICATION PROCESS

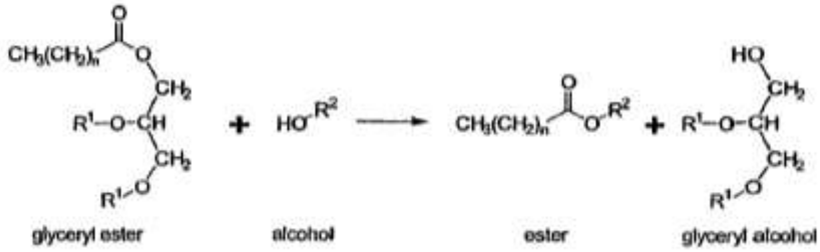


Fig.4 Chemical reaction of Transesterification process

Transesterification is also called as alcoholysis and is a chemical reaction of an oil or fat with alcohol in the presence of a catalyst to form esters and glycerol. Transesterification is the feasible method known for reducing viscosity and the preparation of biodiesel. Biodiesel is the alkyl ester of fatty acids made by the transesterification of oils or fats from plants or animals using small chain alcohols such as methanol and ethanol in the presence of catalyst. Glycerine is a by-product of biodiesel production. Transesterification involves a series of three repeated reversible reactions where triglycerides are transformed into diglycerides and then diglycerides are changed to monoglycerides followed by the transfer if monoglycerides to glycerol. The Figure 1.7 represents the chemical reaction of the Transesterification process. In every Step, the ester is formed and consequently three esters molecules were formed from one molecules of triglyceride. Alcohols like methanol, ethanol, propanel, Butanol and amyl alcohol can be used in the transesterification process.

The Major factor for this Transesterification process is the FFA content of the Fruit seed oil and the FFA stands for Free Fatty Acids. Usually, Non-edible oils having high FFA content, which is not suitable for normal Transesterification process. If the FFA content of the oil is less than 2.5%, then one step Transesterification process with a base catalyst should be used and if it exceeds 2.5%, two-step Transesterification process should be used. The FFA content of Mamey Sapote was 1.86% hence single step Transesterification process has been selected.

## III. EXPERIMENTAL SETUP AND PROCEDURE

Fig.5 Diesel engine

Fig.6 Fuel measuring instrument

The setup consists of single cylinder, four stroke, CRDI VCR (Variable Compression Ratio) engine connected to eddy current dynamometer. CRDI VCR engine works with programmable Open ECU for Diesel injection, fuel injector and common rail with rail pressure sensor and pressure regulating valve, crank position sensor, fuel pump and wiring harness. The setup enables study of CRDI VCR engine performance with programmable ECU at different compression ratios and with different EGR. Table 3.1 represents the complete specification of the Engine setup. These type of setup will have several features which includes Performance optimization with Open ECU, Can test at different CR and EGR conditions, Plotting of Torque and Power Curves, Determination of Specific Fuel Consumption with ease, Determination of Volumetric Efficiency and Air – Fuel Ratio, Determination of Mechanical Efficiency, Determination of the Frictional Power, Heat Balance Sheet and Performance Test under different Load, PΘ and PV Diagram, Combustion analysis. Engine Soft is Lab view based software package developed by Apex Innovations Pvt. Ltd. for engine monitoring system.. The software evaluates power, efficiencies, fuel consumption and heat release. Various graphs are obtained at different operating condition.

## IV. RESULTS AND DISCUSSION

The performance parameters including the specific fuel consumption (SFC), the brake thermal efficiency, energy content of variation of the pressure rise, the heat release rate, the emission parameters like carbon monoxide (CO), hydrocarbons (HC), nitrogen oxide (NOx), and the smoke opacity, of the Sapota seed oil biodiesel blends SOBD 40 and the neat diesel, were analyzed as follows.

### 1.2 BRAKE SPECIFIC FUEL CONSUMPTION

Variation of injection pressure of Bio diesel at 500, 550 and 600Bar and Diesel at 500Bar effect on SFC is given in the figure 5.1. The Figure 5.1 illustrates the variation in Specific fuel consumption with the change in load. For all blends and diesel tested, SFC decreased with increase in load. One possible explanation for this reduction is the higher percentage of increase in brake power with load as compared to fuel consumption and it is well known that specific fuel consumption is inversely proportional to the brake thermal efficiency. The result showed that the injection pressure 550Bar has reduced SFC in all load condition compared with other cases. In 550Bar injection pressure measured SFC in an average value of 0.325kg/kWh which has 0.06 kg/kWh lower than the base diesel. In case of biodiesel mixtures at the 3 different fuel injection pressures, the SFC values were determined to be lower than that of the diesel fuel at all loads. Among the four different blends of biodiesel, 550Bar Biodiesel has the lowest value of specific fuel consumption and the value is 0.25 Kg/Kwh at 100% load.

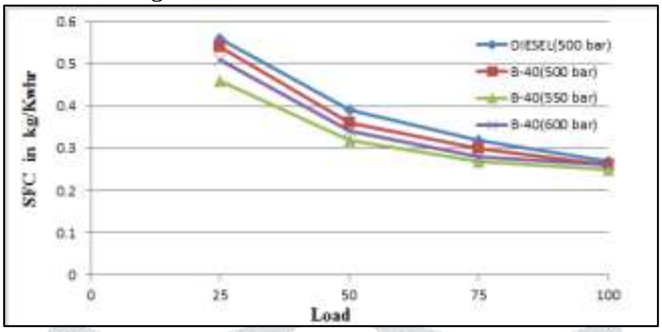


Fig.7 Load Vs BSFC

### 1.3 BRAKE THERMAL EFFICIENCY

Variation of injection pressure of Bio diesel at 500, 550 and 600bar and Diesel at 500bar which effects on Break Thermal Efficiencies is given in the figure 5.2. Among the three different injection pressures of the biodiesel and 500Bar of diesel, 550 bar of B40 Biodiesel has higher brake thermal efficiency in all Load Conditions. In 550Bar of Biodiesel at 25% load, the efficiency is 12.73%, at 50% load the efficiency is 9.75%, at 75% the efficiency is 12.84% and at 100% load, brake thermal efficiency is 14.32% higher when compared to the Diesel.

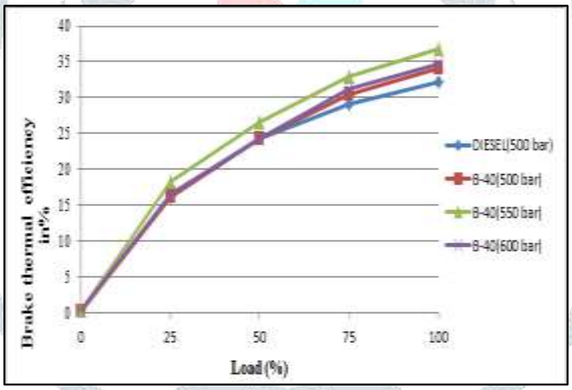


Fig.8 Load Vs BTE

### 1.4 CYLINDER PRESSURE

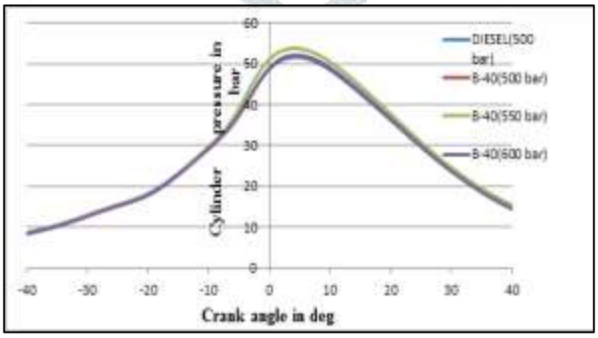


Fig.9 Crank angle Vs Cylinder pressure

The different testing conditions of the in-cylinder pressure elevation are depicted in the figure 5.3. The Biodiesel at 500Bar, 550Bar and 600Bar along with the Diesel at 500Bar of injection Pressures were involved the testing. The peak pressure of Biodiesel B40 at 550bar Fuel injection pressure is 53.76Bar which is 2.41Bar higher than the Diesel. The other reason is identified as low viscosity and low calorific value of Bio Diesel used in the Engine. The reason for high peak pressure in the Sapota Seed oil biodiesel fuel was due to its lower calorific value. The fuel with higher calorific value necessitates that low quantity of fuel is sufficient for the combustion process [18]

### 1.5 HEAT RELEASE RATE

The variation of heat release rate for the different test conditions are plotted in the figure 5.4. The Figure 5.4 represents the Graph of Heat release rate of the fuels with respect to the Crank angles. The Different test conditions are the different fuel at different Fuel injection pressures. The plot reveals the maximum heat release rate of Sapota seed oil biodiesel is at 550Bar of fuel injection pressure and the value is 22.48 J/deg CA. The Biodiesel of all three Fuel injection pressures out performs the diesel at all load condition [16].

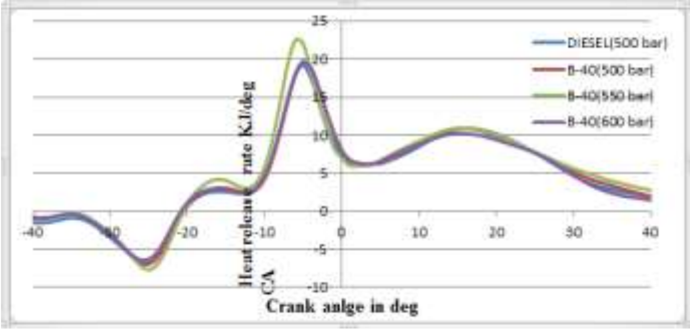


Fig.10 Crank angle Vs Heat Release rate

### 1.6 CO EMISSION

Variation of injection pressure of 500Bar, 550Bar and 600Bar of Biodiesel and 500Bar of diesel effect on co emission efficiency is given in the figure5.5. By varying the injection pressures, 550Bar of Biodiesel has less CO emission when compared with Diesel at 500Bar. . The average value of CO emission by the Biodiesel is decreased by 0.18% compared to the Diesel. In 550Bar, at 25% load the CO emission efficiency is 0.017%, at 50% load the CO emission efficiency is 0.023%, at 75% load the CO emission efficiency is 0.056% and at 100% load the co emission efficiency is 0.44% lower than that of the Diesel [13-15].

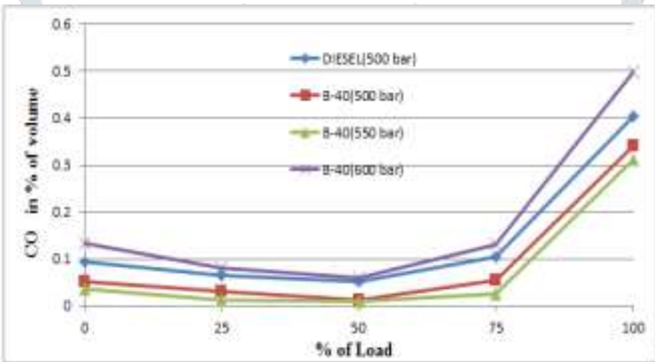


Fig.11 Load Vs CO Emission

### 1.7 HC EMISSION

Fig.xxx depicts the variation of Hydro carbon (HC) emissions of the Diesel at 550Bar, 550Bar and 600Bar Sapota seed oil biodiesel in different load conditions. The average value of HC emission of Biodiesel at 550Bar is 20ppm which is lower than the Diesel at 500Bar.

The increased oxygen content caused complete and cleaner combustion and the higher Cetane number reduced the combustion delay which in turn proved to be responsible for the low HC emission in Sapota seed oil Biodiesel. The Biodiesel of 500Bar and 550Bar of injection pressure outperforms the Diesel.

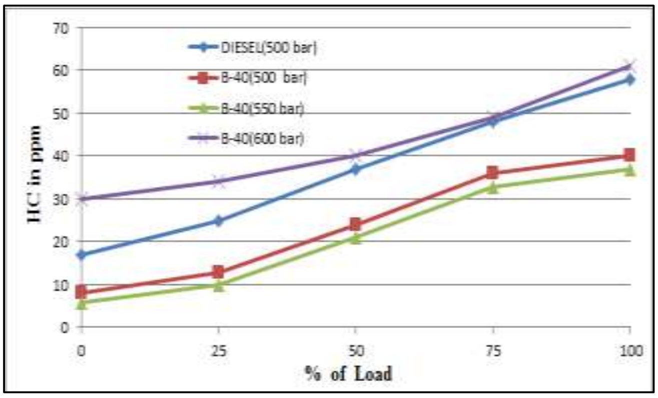


Fig.12 Load Vs HC emission

### 1.8 NOx EMISSION

Nitrogen oxide emission variations under various test condition are shown in figure 5.7. NOx emission mainly depends on the peak temperature, ignition delay, stoichiometric, engine design and operating conditions. By varying the injection pressure, the NOx emission in Sapota seed oil biodiesel at 550Bar of injection pressure is reduced by 30ppm when compared to Diesel at 500bar of injection pressure. Due to high oxygen content, Bio Diesel shows higher NOx emission than diesel [17].

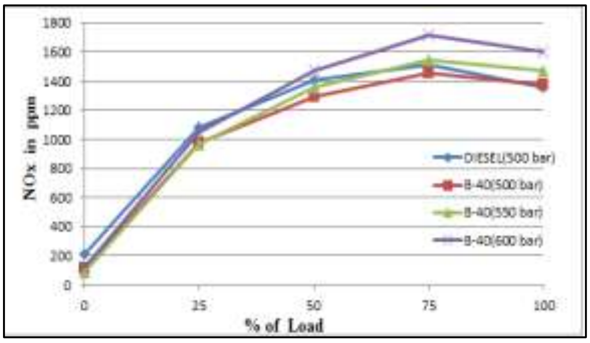


Fig.13 Load Vs NOx emission

But the NOx emission of the biodiesel at 550Bar is lower only at 0% load and the emissions are higher in all other load cases. The Biodiesel at 550bar shows less NOx emissions in all cases. In 550bar at 25% load NOX emission is 971ppm, at 50% load NOX emission is 1359ppm, at 75% load NOX emission is 1547ppm and at 100% load NOX emission is 1472ppm which is lower than the Diesel at 500Bar of injection pressure [10-12].

### 1.9 SMOKE EMISSION

The smoke emission variations of the diesel at 500Bar and 550Bar, 550Bar and 600bar of the biodiesels were indicated in the figure 5.8. The smoke emission of Biodiesel of 550Bar Injection pressure at 25% load smoke emission was 12.6%, at 50% load smoke emission was 19.2%, at 75% load smoke emission was 20.9% and finally at 100% load smoke emission was 28.1% lower than the Diesel at 500bar of fuel injection pressure. The reason for high smoke emission in the diesel is due to the increased hydrocarbon content in the fuel. This is found to generate rich mixture during the combustion process rendering it incomplete [8-9].

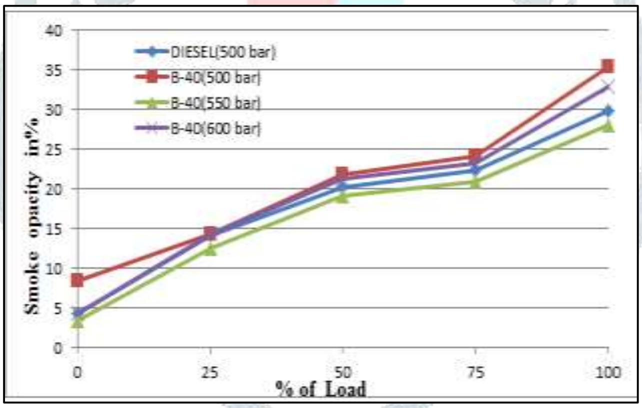


Fig.14 Load Vs Smokeemission

## V. CONCLUSION

From the experimental tests conducted with the Biodiesel using Sapota seed oil and diesel oil operations in CI engine at different fuel injection pressures, the following conclusions were made at 100% load conditions:

1. At 550Bar of fuel injection pressure, SFC is lesser than other two injection pressures of biodiesel and diesel. SFC at 550Bar is 0.25kg/kWh which shows 3.7% and 7.4% reduction from the 500Bar fuel injection pressure of the Diesel and 600Bar Fuel injection pressures of Biodiesel respectively.
2. Brake thermal Efficiency at 550Bar Fuel injection pressure of biodiesel is comparatively high. The 550Bar of the Biodiesel shows the value as 36.88% which is 12.5% and 7.5% greater than the fuel injection pressure of 500Bar of Diesel and 600Bar of biodiesel respectively.
3. Amount of heat release rate is comparatively high at 550Bar of Biodiesel when compared to the competition of 500Bar of the Diesel and 600Bar Fuel injection pressure of Biodiesel.
4. In cylinder pressure rise is comparatively high in 550Bar Fuel injection pressure of Biodiesel and it results in complete combustion of biodiesel that the Fuel injection pressure of 500Bar Diesel and 600Bar Biodiesel respectively.
5. Carbon Monoxide emission in 550Bar of Fuel injection pressure of the biodiesel was comparatively less than the comparisons
6. Hydrocarbon emission at 550Bar injection pressure is also comparatively less among the competition. The 550Bar biodiesel is nearly shows a value of 37ppm, which is 3.6% and 7.5% lesser than fuel injection pressures of 500Bar Diesel and 600Bar Biodiesel respectively.

7. Nitrogen Emission is comparatively high at 550Bar and the values comes to 1472ppm which is 8.6% lesser than the Biodiesel at fuel injection pressure of 600Bar.On the other hand, it shows 6.6% higher than the Diesel at 500Bar Injection Pressure and 7.4% higher than the Biodiesel at 500Bar of Fuel injection pressure.
8. Smoke Emissions were also low which comes for the 550Bar injection pressure of the biodiesel to 28.1% and among competition, 20.6% and 14.5% lesser that the Diesel at 500Bar of fuel Injection pressure and Biodiesel at 600Bar respectively.

Thus the Sapota seed oil Biodiesels operated diesel engines showed higher performance as compared with the Diesel Operated engine. The overall experimental works depicted that the 550Bar of injection pressure of Sapota seed oil biodiesel shows enhanced BTE and reduced pollution except for the Nitroxide emissions. Hence Sapota seed oil Biodiesel can be used as an alternative fuel in diesel engines to save huge amount of fossil fuel requirement and reduces the large amount Pollution in our country as well as worldwide.

## REFERENCES

[1] A. Raj Kumar et.al, (7th July 2015). “Emission and Performance Characteristics of Diesel Engine Using Mamey Sapote Biodiesel as Alternate Fuel”, International Journal of Innovative Research in Science, Engineering and Technology, Volume-4.

[2] .M.R. Indudhar et.al, (4th Nov, 2015). “Effect of injection timing and injection pressure on the performance of biodiesel ester of Honge oil fuelled common rail direct injection (CRDI) engine”, International Journal of Engineering, Science and Technology, pp. 37-48.

[3] K. Rajasekhar et.al, (January, 2019). “Experimental Evaluation of Injection Pressure and Injection Timing on Diesel Engine”, International Journal of Engineering and Advanced Technology, Volume-8.

[4] Avinash Kumar Agarwal “Effect of Fuel Injection Pressure and Injection Timing of Karanja Biodiesel Blends on Fuel Spray, Engine Performance, Emissions and Combustion Characteristics”, Combustion Engine and Energy Conversion Laboratory School of Mechanical Engineering, College of Engineering, Hanyang University.

[5] Mahantesh M. Shivashimpi et.al, “Effect of Injection Parameters: Injection Timing and Injection Pressure on the Performance of Diesel Engine Fuelled with Palm Oil Methyl Ester”, European Journal of Sustainable Development Research.

[6] Mario Sremec et.al “Numerical Investigation of Injection Timing Influence on Fuel Slip and Influence of Compression Ratio on Knock Occurrence in Conventional Dual Fuel Engine”, Journal of Sustainable Development of Energy, Water and Environment Systems, Volume 5, issue 4, pp 518-532.

[7] Rostami et.al, (December, 2014). “Effect of the injection timing on the performance of a diesel engine using Diesel-Biodiesel blends”, International Journal of Automotive and Mechanical Engineering (IJAME) ISSN: 2229-8649 (Print); ISSN: 2180-1606 (Online); Volume 10, pp. 1945-1958.

[8] R.Sathiyamoorthi, S. Chezhian Babu, V. Rajangam, L.S. Tamizhselvan. Evaluation of Neem oil biodiesel with 2-Ethyl Hexyl Nitrate (2-EHN) as Cetane improver on performance and emission characteristics of a DI Diesel engine. International Journal of Engineering Research & Technology (IJERT) ISSN: 2278-0181 (2018), Vol 6, Issue 02. DOI: http://dx.doi.org/10.17577/IJERTCON071

[9] M.D. Mohan Gift, C. Karthikeyan, M. Dinesh Babu, R. Sathiyamoorthi, 2020 “Analysis and Optimization of Vehicle Rim Cooling Criteria with Air Knife”, International Journal of Research and Analytical Reviews (IJRAR), Vol. 7 (2), pp. 31-35.

[10] Sathiyamoorthi, R & Sankaranarayanan, G 2014 ‘Experimental Investigation of Performance, Combustion and Emission characteristics of neat Lemongrass oil in DI diesel engine’, International Journal of Current Engineering and Technology, INPRESSCO, vol.3, pp.25-30.

[11] Hariraman.M, Jefrin John.J, Deepthakumar A.R, Sathiyamoorthi. R, Vinoth kumar.C. Performance and emission analysis of nano additives ($SiO_2$ and MgO) using Bio-fuel driven single cylinder diesel engine. Journal of Applied Science and Computations, Vol. VI, Issue IV, April 2019, 486-491.

[12] R.Sathiyamoorthi, A.Anbarasu, M.Dinesh Babu, V. Rajangam. Optimization of Injection parameters and compression ratio on a single cylinder diesel engine fuelled by Azadirachta Indica (Neem) biodiesel using Response Surface Methodology (RSM), Journal of Applied Science and Computations, Vol. VI, Issue IV, April 2019, 21-28.

[13] B.Maheswaran, S. Senthil, R.Sathiyamoorthi ‘Comprehensive design and FEM analysis of Piston and Connecting rod using ANSYS for two wheeler engines’, Journal of Innovation in Mechanical Engineering, Vol. 2(1), pp. 10-16 (2019), Guru Nanak Publications, India.

[14] R.Ravisankar, V.S.K. Venkatachalapathy, K. Velmurugan, N. Alagumurthi, R.Sathiyamoorthi, Comparative assessment on heat transfer characteristics of a Truck Radiator using various nano-additives, Aut Aut Research Journal, Vol, XI (X), pp. 1-14 (2020), Aut publications

[15] R.Sathiyamoorthi, G.Sankaranarayanan, B. Nithin Siddharth, M.V. Natarajan (2020). Effect of Alumina Nanoparticles on Performance and Emission Study of DICI Engine Fuelled by Cymbopogon Flexuosus. Recent Trends in Mechanical Engineering (Springer Book series), pp. 29-42. DOI: https://doi.org/10.1007/978-981-15-1124-0_3

[16] Sathiyamoorthi, R & Sankaranarayanan, G 2015 ‘Combustion characteristics of DICI engine on various injection parameters using neat lemongrass oil-diesel blends’, Journal of Chemical and Pharmaceutical Sciences, vol.9, pp. 103-108.

[17] Sathiyamoorthi, R & Sankaranarayanan, G 2015 “Effect of various injection pressures and timings on emission characteristics of DI diesel engine with neat lemongrass oil-diesel blend”, International Journal of Applied Engineering Research, vol.10, no. 19, pp.14916-14920.

[18] R.Sathiyamoorthi, M.Puviyarasan, B.Bhuvanesh kumar, D.Breslin Joshua, 2016 ‘Effect of $CeO_2$ nano additive on performance and emission characteristics of diesel engine fuelled by neem oil-biodiesel’, International Journal of Chemical sciences, Vol. 14(S2), pp. 473-484, ISSN 0972-768X.