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Research Paper

PERFORMANCE AND COMBUSTION CHARACTERISTICS OF CI ENGINE WITH VARIABLE COMPRESSION RATIO FUELLED WITH PONGAMIA AND JATROPHA AND ITS BLENDS WITH DIESEL

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In the present world it is essential to find an alternate fuel source due to the increased industrialization and depletion in natural resources. The method of obtaining biodiesel from various sources and blending them with diesel is adopted in many economically developed and developing countries around the world. This paper investigates the utilization of jatropha and Pongamia Pinnata Methyl Ester (PPME) blends with diesel in Variable Compression Rratio (VCR) CI engine. The performance and combustion characteristics of B10,B20 and B30 blends of jatropha and pongamia with diesel for various compression ratios (13, 14, 15, 16, 17.5) have been studied and it is found out that the blends of biodiesel like jatropha and pongamia with diesel could substitute in the place of pure diesel and be used as an alternate source of fuel in the near future, thus saving the natural resources for the future generation. Performance parameter like brake thermal efficiency, specific fuel consumption, mechanical efficiency, brake power is evaluated and final conclusion is drawn.

Keywords: Biodiesel, Jatropha, Pongamia Pinnata Methyl Ester (PPME), Variable compression ratio CI engine

INTRODUCTION

In the modern society having much advancement in technology there is also some issues relating to an alternate source of fuel to sustain the transportation sector for the future generation. However our dependence is on diesel and petroleum for fueling the transportation sector and if this continues then this could threaten our energy resource, affect our economy and even affect our environment

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so badly that it may even take hundreds of years for a seed to sprout. Thus we are in search of a alternate source of fuel to have a sustainable economy. This is possible with the use of Biodiesel which is a renewable source of energy. Though it is not possible to run a CI Engine on 100% biodiesel like Jetropha and Pongamia without any major modifications in the presently available engine, when blended with diesel in various proportions it would make the world wonder with its Eco-friendly nature. Biodiesel is nothing but long-chain alkyl esters which is obtained from animal fat and plant seeds. They are regarded as carbon sink as they absorb 78.5% of carbon in the atmosphere as they burn and even considered as cleaner than fossil fuels.

As per Jehad *et al.* (2012), the use of waste oil biodiesel has showed an increase of 4.75% in fuel density compared to pure diesel and also there was a 13.43% decrease in calorific value of fuel and 7.24% for unused oil biodiesel. The biodiesel showed improvement in the power, thermal efficiency, torque and reduction in the specific fuel consumption. Mohammed and Medhat (2013) did study on the usage of waste cooking oil from restaurants and found out that through transesterification process pure biodiesel could be produced. Their study on combustion characteristics with different blends and various compression ratios shows that with increase in compression ratio the torque for all blends increases and in contrary the BSFC decreases and with increased blends the BSFC increases at all compression ratios. The ignition delay is lower for biodiesel. Pugazhvadivu and Jeyachandran (2005) study shows that when waste frying oil heated to about 135 °C brings down the viscosity to that of diesel at 30 °C and it could be used as an alternative fuel in diesel engine for short time operation of engine. An *et al.* (2013) study on the performance and combustion characteristics of biodiesel and its blend fuels shows that biodiesel/blend fuels have high break specific fuel consumption of about 42% at 25% engine load and low engine speed. There was an increase in brake thermal efficiency of biodiesel compared to pure diesel at 50% and 100% load. Lower peak heat release rate was observed for biodiesel. Horng-Wen Wu *et al.* (2010) used Taguchi method on combustion performance of a diesel engine with biodiesel blends and found out that fine brake thermal efficiency and brake specific fuel consumption are achieved for biodiesel blend of B20. In Avinash (2007) study he has mentioned that from Masjuki *et al.* (1996) investigated preheated Palm Oil Methyl Esters (POME) in the diesel engine it is seen clearly that preheating palm oil methyl esters above room temperature has in turn improved the brake power output and engine performance. Avinash (2007) has also mentioned that from Scholl and Sorenson study it is known that ignition delay, pressure rise and peak pressure were close to diesel combustion at the constant engine load and speed. Altin *et al.* (2001) worked with biodiesel blends in a single cylinder, four stroke diesel engine and found out that specific fuel consumption values of the methyl esters were less than that of the raw vegetable oils and high specific fuel consumption in vegetable oils is due to lower energy content. Hanbey and Huseyin (2010) in their study have blended Raw Rapeseed Oil (RRO) with diesel in various blends like O50 and O20 and have found out that preheating fuel to 100 °C has lowered RRO's viscosity, avoids clogging in fuel filter, preheating of fuel decreases mass fuel consumption. Sureshkumara *et al.* (2008) did an experimental investigation on replacement of diesel with Pongamia Pinnata Methyl Ester (PPME) and came to a conclusion that diesel with PPME (40%) could possibly replace diesel for diesel engine applications for getting better performance, less emission, energy economy and environmental protection. Tompkins *et al.* (2012) in his study has mentioned that from Nogueira LAH. Does biodiesel make sense? Energy, biodiesel could further improve the global energy consumption.Biodiesel is a mixture of glyceride free mono-alkyl esters of long chain fatty acids obtained from biologically based oils and fats (Agarwal, 2007; Demirbas, 2007; and Knothe, 2009). Jiafeng Sun *et al.* (2010) study report that there is some inconsistencies in the NOx emission behavior among petroleum diesel and biodiesel and may be linked to differences in technology and design of engine. Rakopoulos *et al.* (2011) study shows that there was only some minor effect on the transient performance of the turbo charged diesel engine and also in the combustion noise radiation when biofuels blends are used. Qi *et al.* (2010) did a detailed study on the effects of using methanol as an addictive to biodiesel blends and found that the BD50 combustion is quicker than BDM5 and BDM10 at low and high engine load. Even the power and torque outputs are better in BD50 than in BDM5 and BDM10. Sharanappa *et al.* (2009) study shows that using methyl ester of mahua oil and by increasing the blending ratios of biodiesel there is reduce in HC, slight increase in NOx emission and fuel consumption, brake specific energy consumption decreases when 20% biodiesel is used. Hossain and Davies (2010) study on plant oils as fuel for diesel engine showed that raw plant oil when compared to biofuel and fossil diesel has better potential to reduce GHG emissions. Avinash and Atul (2013) study on performance and combustion characteristics of Karanja oil blends with mineral diesel showed in an unmodified diesel engine Karanja oil's higher blends concentration are not suitable as alternate fuel but lower concentration (upto 20%) can be used. The most suitable way of converting vegetable oil into fatty acid methyl eser is transesterification process. But the keeping in the difficulty in acquiring the required chemaicals for transesterification process, the karanja oil was used in a diesel engine for electricity generation, irrigation. Karanja (also known as Pongamia Pinata) is available in India and Australia (Bajpai *et al.*, 2009; Agarwal and Rajamanoharan, 2009; and Agarwal and Dhar, 2010). Jindal et al. (2010) study showed that BTHE increases and BSFC reduces when injection pressure and compression ratio increases. Sharanappa *et al.* (2010) study on performance of a kirloskar diesel engine with fish oil methyl esters showed no major deviation as an alternate fuel but showed that it has environmental benefits and good combustion properties. Ismet (2011) did a study on diesel engine running on dimethyl ether and diethyl ether and concluded that there is a decrease in lower cylinder pressure and temperature and thus low performance of engine and more fuel consumption compared to diesel but there is slight increase in brake power and brake thermal efficiency compared to diesel. Geng *et al.* (2012) did a study on diesel engine with diesel-azides blends and found out that diesel-azides blends have high heat release rate peak of premixed combustion, improves efficiency of cycle, potential for rapid combustion but has a shorter combustion duration. Azoumah *et al.* (2009) study showed that for evaluating the optimum load to be supplied to that engine exergy and gas emission analyses is a effective methods. Murari *et al.* (2013) did a investigation on diesel engine with biodiesel-diesel and canola oil-diesel blends and found out that pure and used canola biodiesel-diesel blends showed similar performance, emission and fuel properties but CO and HC emissions are less than neat diesel in biodiesel-diesel blends. Edwin *et al.* (2012) did experimental analysis of biofuel as alternative fuel for compression ignition engines and found out that adding small amount of diesel with biofuel shows performance similar to that of neat biofuel and there is also reduction in NOx emission. Manuela *et al.* (2011) study on biobutanol from food wastes as biofuel showed that there is an increase in CO, hydrocarbons- and acrolein-emissions at various loads and running the engine on lower loads emit lesser NOx contents.

MATERIALS AND METHODS

Preparation of Biodiesel

Sodium hydroxide (12 grams) is mixed with methanol (200 ml) and then vegetable oil (1000 ml) is added to the mixture in a three way flask and stirred for 1 hour at 60 °C. Now the solution is transferred to a beaker and allowed for 4 hours undisturbed to settle down the glycerin at the bottom. The floating methyl ester (coarse biodiesel) is heated to 110 °C and kept for 15 minutes to remove the methanol. Finally the impurities are removed by washing with 360 ml of water and pure methyl ester is obtained.

Properties of Biodiesel

Table 1: ASTM Standards and Fuel Properties of Pongamia, Jatropha Biodiesels

Parameters	ASTM D975	ASTM D6751	PBD	JBD	Unit
Flash point	52 min	130.0 min	126	169	°C
Water content and sediment	0.050 max	0.050 max	0.0322	0.05	% vol
Kinematic viscosity 40 °C	1.9 – 4.1	1.9 – 6.0	6.06	5.4	mm^2/sec
Sulfated Ash	0.01 max	0.020 max	0.01	0.02	% mass
Sulfur (Grade No.2 – Low sulfur/S 500 grade)	0.05 max	0.05 max	0.0013	0.0006	% mass
Copper strip corrosion	No. 3 max	No. 3 max	2	1	_
Cetane	40 min	47 min	62.0	53	_
Carbon residue	0.35 max	0.050 max	0.02	0.058	% mass
Acid number	-	0.80 max	0.3	3.2	Mg KOH/g
Free glycerin	-	0.020 max	0.01	0.02	% mass
Total glycerin	-	0.240 max	0.12	0.25	% mass
Phosphorous contents	-	0.001 max	0.0001	0.0001	% mass
Distillation temperature	282-338	360 max	242	330	° C
Aromaticity	35 max	-	-	-	% vol.

Experimental Setup

Table 2: Engine Specification

Product	Engine test setup 1 cylinder, 4 stroke, diesel (Computerized)
Engine	Make: Kirloskar, Type: 1 cyl., 4 stroke diesel, water cooled, power 3.5 kW at 1500 rpm, stroke 110 mm, bore 87.5 mm, 661 cc, CR 17.5, modified to VCR engine: CR 12 to 18.
Dynamometer	Type: Eddy current, water cooled.
Air box	M S fabricated with orifice meter and manometer
Propeller shaft	With universal joints
Fuel tank	Capacity 15 lit with glass fuel metering column
Calorimeter	Type: Pipe in pipe
Piezo sensor	Range 5000 PSI, with low noise cable
Crank Angle Sensor	Resolution 1 Deg, Speed 5500 RPM with TDC pulse.
Temperature Sensor	Type: RTD, PT100 and Thermocouple, Type K
Load indicator	Digital, range 0-50 Kg, supply 230 VAC
Load sensor	Load cell, type strain gauge, range 0-50 Kg
Software	"EngineSoft" engine performance analysis software
Rotameter	Engine cooling 40-400 LPH; Calorimeter 25-250 LPH
Pump	Type: Monoblock
Overall Dimensions	W 2000 x D 2500 x H 1500 mm

Procedure

Using pongamia and jatropha oil in the variable compression ratio engine at a rated speed of 1,500 rpm, the performance analysis is carried out. In every test, volumetric efficiency and specific fuel consumption are measured. From the initial measurement, brake thermal efficiency, specific fuel consumption, brake power, brake mean effective pressure, mechanical efficiency, with respect to compression ratios 17.5:1 to 13:1 are calculated and recorded. At each operating conditions, the performance Characteristics and combustion characteristics are performed and the same procedure is repeated for other loads also.

RESULTS AND DISCUSSION

Brake Thermal Efficiency

Figures 1-3 shows the variation of brake thermal efficiency with load for biodiesel

Figure 1: BTHE % vs. Load at CR 17.5

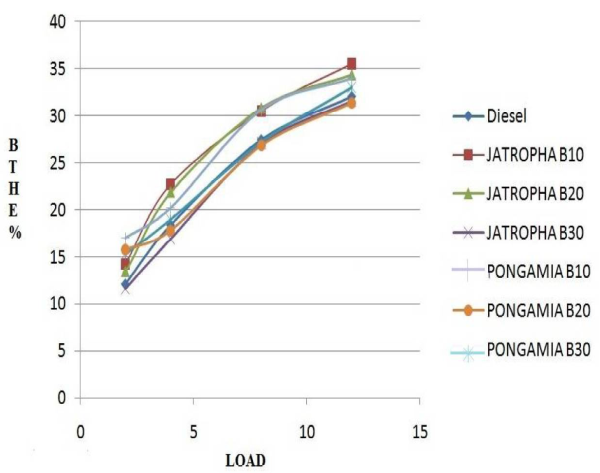


Figure 2: BTHE % vs. Load at CR 16

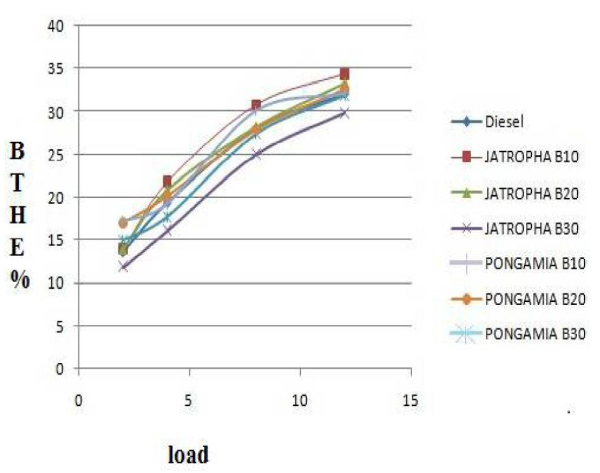
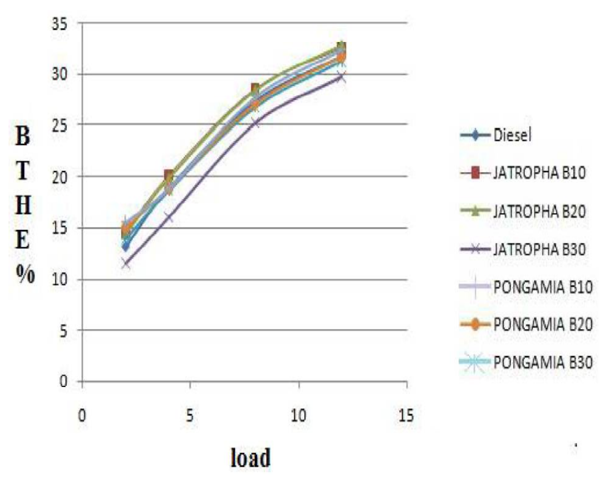
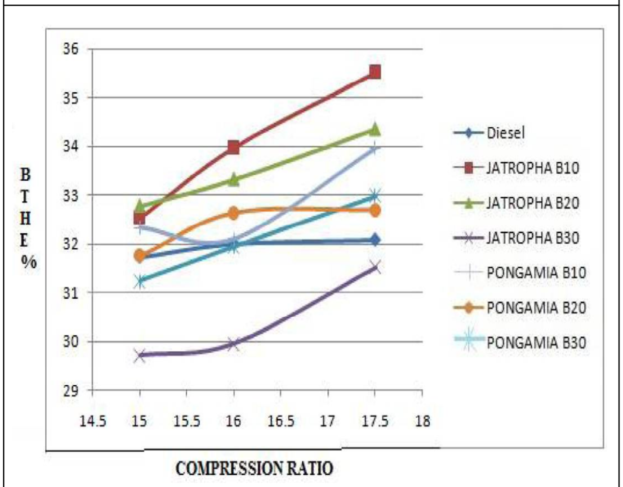


Figure 3: BTHE % vs. Load at CR 15



blends like jatropha B10, B20, B30 and pongamia B10, B20, B30 compared with pure diesel at compression ratio 17.5, 16, 15 and Figure 4 shows the variation of brake thermal efficiency with compression ratio at maximum load.Brake thermal efficiency is increasing with increasing loads for all blends of biodiesels and diesel. It may be due to reduction in heat loss and increase in power. Brake thermal efficiency of jatropha B10 and B20 is greater than the diesel whereas the brake thermal efficiency of jatropha B30 is similar to diesel.

Figure 4: BTHE% vs. Compression Ratio at Maximum Load



It may be because of the presence of oxygen in biodiesel which enhance the combustion as compared to diesel and biodiesel is more lubricant than diesel that provides additional lubrication. Jatropha oil biodiesel has higher viscosity, higher density and lower calorific value than diesel. Higher viscosity leads to decreased atomization, fuel vaporization. These may be the possible reasons of jatropha B30 to have lowest brake thermal efficiency for all loads. The highest value of brake thermal efficiency is obtained at 12 kg load for all the fuels. Similarly in pongamia oil, the brake thermal efficiency is maximum for B10 blend and the brake thermal efficiency of blend B10 and B20 is similar to diesel. This may due to lower heating or calorific value of the pongamia oil than diesel.

Brake Specific Fuel Consumption

The Variation in Brake Specific Fuel Consumption (BSFC) with load for different fuel samples at different compression ratios of 17.5, 16, 15 is shown in Figures 5-8 shows the variation of Brake Specific Fuel Consumption (BSFC) with compression ratio at maximum load. The specific fuel consumption when using biodiesel fuel is expected to increase as compared to the consumption of diesel fuel. BSFC decreased sharply with increase in load for all fuel samples at all the compression ratio. The main reason for this may be that the percent increase in fuel required to operate the engine is less than the percent increase in brake power due to relatively less portion of the heat losses at higher loads. As the BSFC is calculated on weight basis, higher densities resulted in higher values of BSFC. But unexpectedly BSFC of jatropha B10 is slightly

Figure 5: BSFC vs. Load at CR 17.5

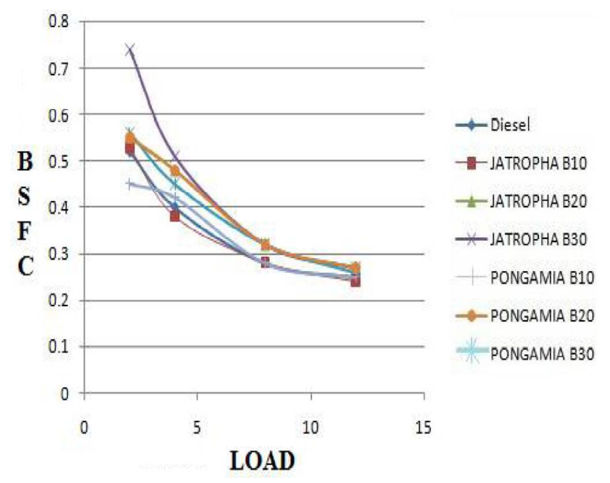


Figure 6: SFC vs. Load at CR 16

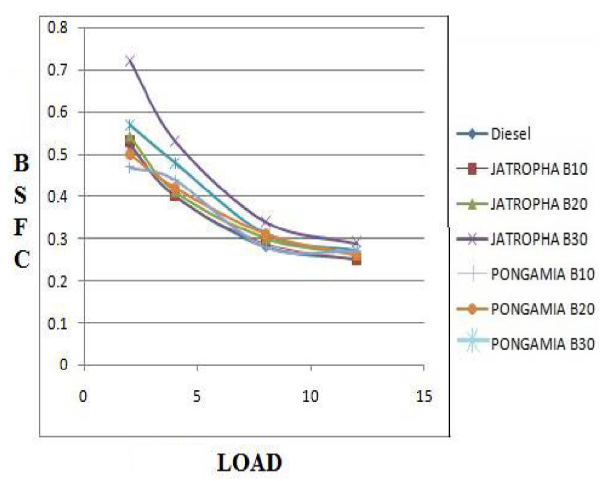


Figure 7: SFC vs. Load at CR 15

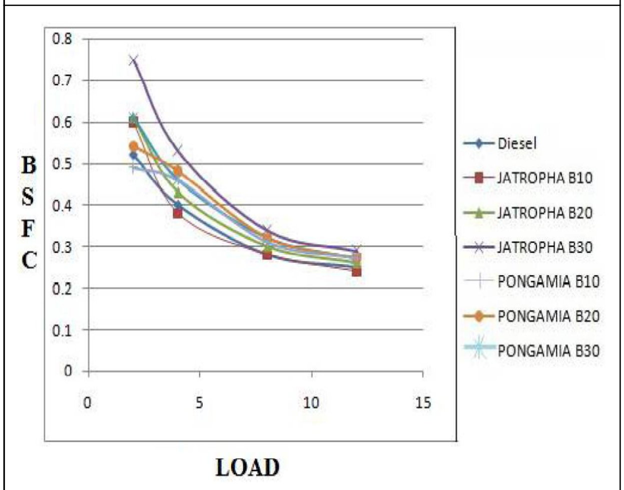
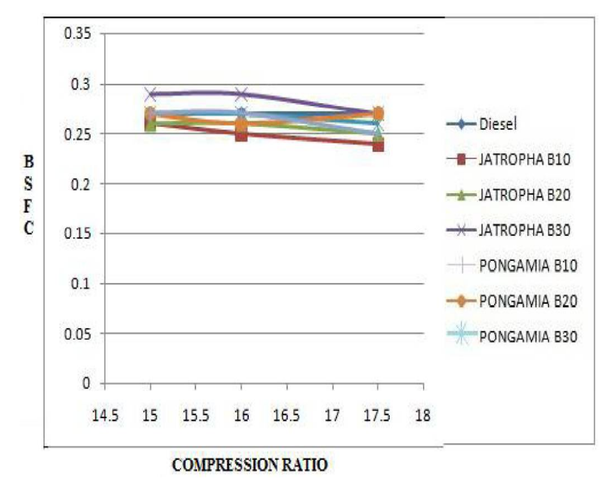


Figure 8: BSFC vs. Compression Ratio at Maximum Load



lesser than the diesel. From the graph it is clear that the jatropha B30 shows the maximum BSFC followed by pongamia B20 and B30.

Mechanical Efficiency

Figures 9-12 shows the variation of mechanical efficiency with load for different fuel samples at different compression ratios of 17.5, 16, 15. Mechanical efficiency measures the effectiveness of the machine in transforming the energy and power that is input to the device into output force. Mechanical efficiency increases with increase in load for all type of fuel blends. This may due to increase in the brake power. Mechanical efficiency of the biodiesel is greater than the diesel at all the compression ratios. Pongamia B10 and jatropha B10 have the maximum mechanical efficiency of 62.77% and 62.20% respectively. Diesel has the minimum mechanical efficiency of 55.49%. The increase in efficiency for all the biodiesel blends may be due to improved quality of spray, high reaction activity in the fuel-rich zone and decrease in heat loss due to lower flame temperature of the blends than that of diesel.

Figure 9: MECH % vs. Load at CR 17.5

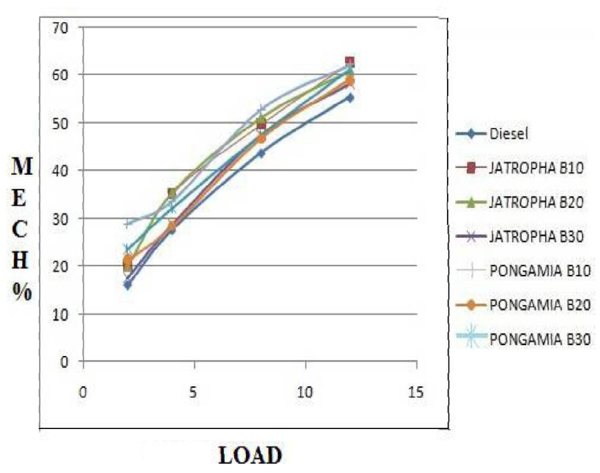


Figure 10: MECH % vs. Load at CR 16

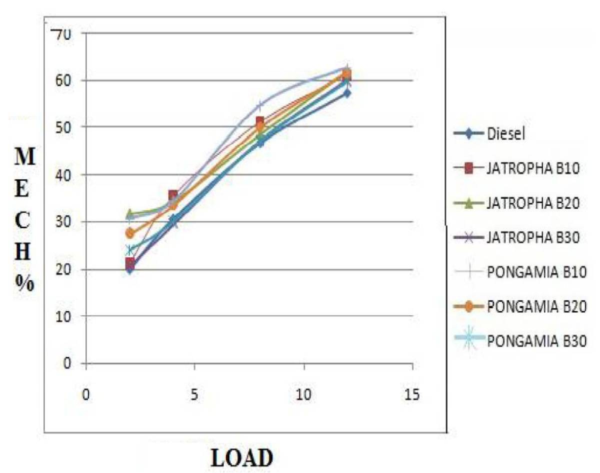


Figure 11: MECH % vs. LOAD AT CR 15

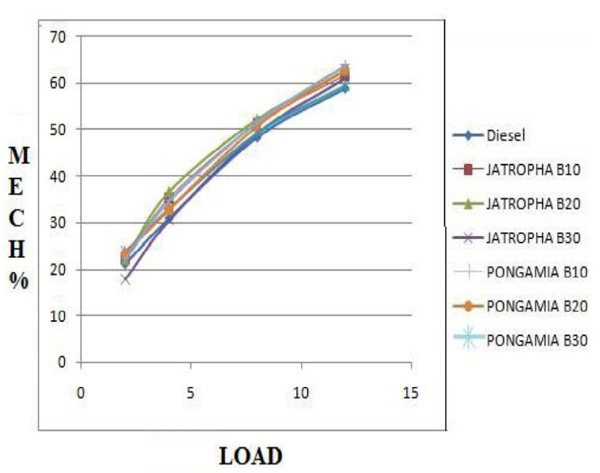
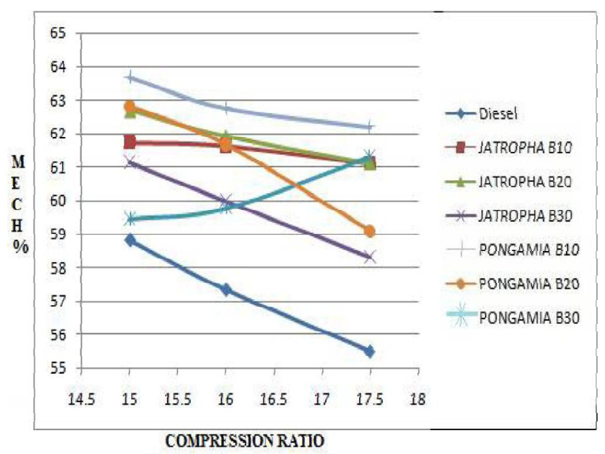


Figure 12: MECH % vs. Compression Ratio



Variation of Pressure with Respect to Crank Angle

The variation of cylinder pressure with respect to crank angle of all biodiesel blend and diesel is shown. Figures 13 and 14 shows the *P*-θ diagram of idling and maximum load condition at compression ratio 17.5 and Figures 15 and 16 shows the *P*-θ diagram of idling and maximum load condition at compression ratio 16 and Figures 17 and 18 shows the *P*-θ diagram of idling and maximum load condition at compression ratio 16 respectively. It is observed from the graph that at CR 17.5 the maximum pressure attained during idling is around 47 bars by diesel whereas at maximum load maximum pressure (60.8 bars) is attained by jatropha B30. At compression ratio 16 the maximum pressure (49 bars) in idling condition is attained by diesel whereas at maximum load condition the maximum pressure (62 bars) is attained by jatropha 30. At compression ratio 15, the maximum pressure (31.19 bars) in idling condition is attained by jatropha B10whereas at maximum load condition the maximum pressure (62 bars) is attained by jatropha B30.

Figur 13: *P-θ* Diagram of Idling at CR 17.5

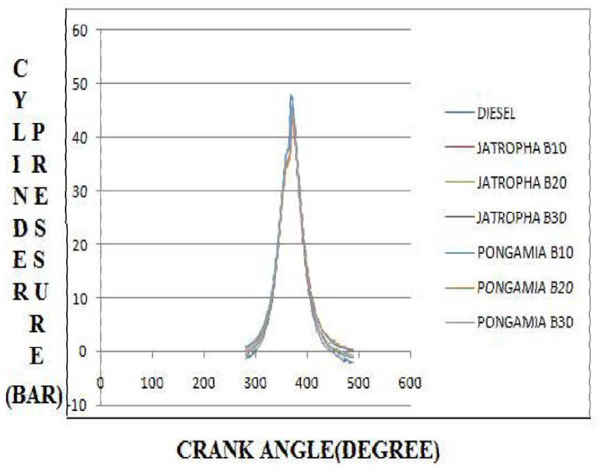


Figure 14: *P-θ* Diagram of Maximum at CR 17.5

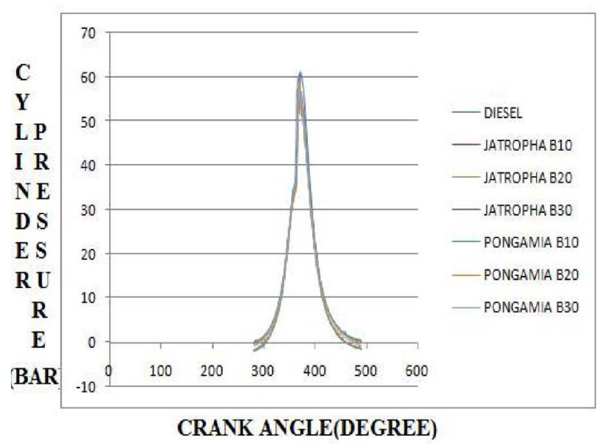


Figure 15: *P-θ* Diagram of Idling at CR 16

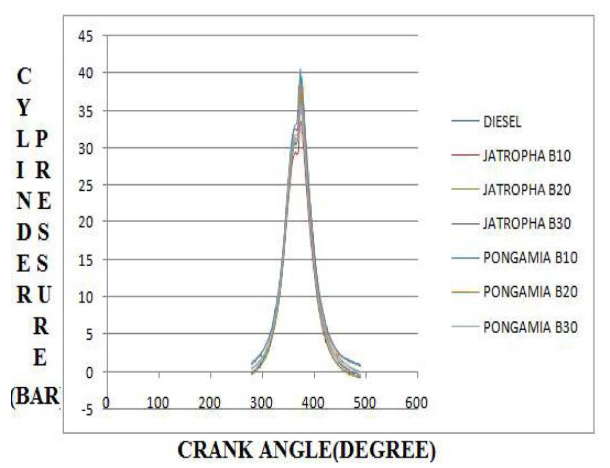


Figure 16: *P-θ* Diagram of Maximum at CR 16

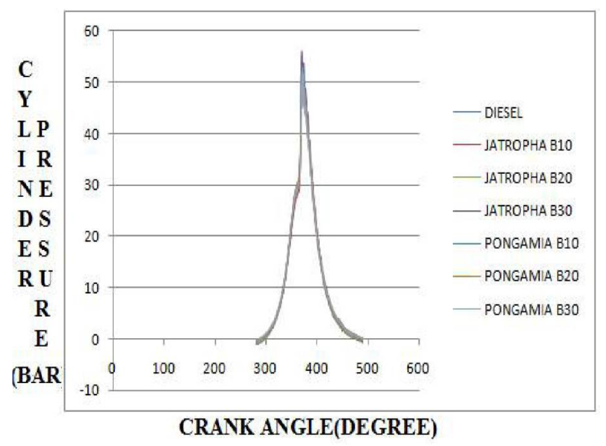


Figure 17: *P-θ* Diagram of Idling at CR 15

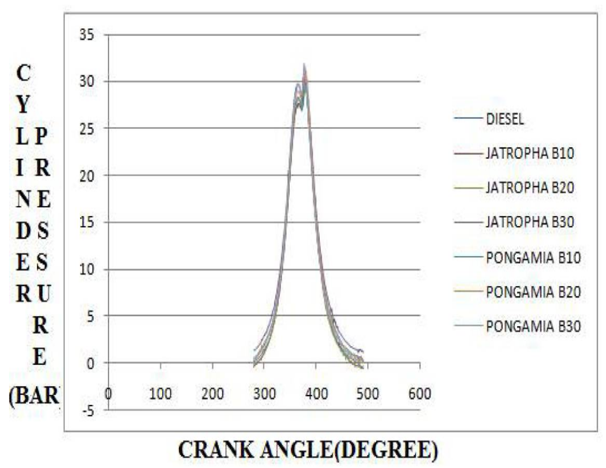
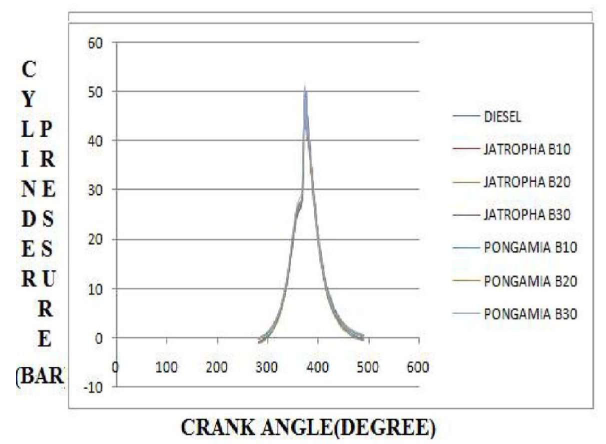


Figure 18: *P-θ* Diagram of Maximum at CR 15



CONCLUSION

The aim of the investigation was successfully carried out and the following conclusions were drawn:

Biodiesel produced from Pongamia, Jatropha oils can be successfully used as alternative fuels in existing diesel engines without any major modifications.

The properties of Pongamia, Jatropha biodiesels which are prepared through a series of processes including transesterification, are within the specifications and close to conventional diesel.

The compression ratio 17.5 showed highest brake thermal efficiency, and hence, may be considered as optimum compression ratio for variable compression ratio diesel engine. Better fuel economy was observed at 17.5 compression ratio compared to other compression ratios. Brake power is maximum at 17.5 compression ratio.

Jatropha B10 and Pongamia B10 show the maximum brake thermal efficiency followed by jatropha B20. Jatropha B30 shows the least brake thermal efficiency. Jatropha B10 shows 17% increase in brake thermal efficiency than the diesel. Pongamia B10 shows 10% increase in brake thermal efficiency than the diesel. Brake thermal efficiency is maximum at compression ratio 17.5 for all the fuel.

The BSFC decreases with increase in load and compression ratio. Jatropha B10 and Pongamia B10 have the brake specific fuel consumption almost equal to diesel. For rest of the biodiesel BSFC is very much higher than the standard diesel. This is due to high density and high viscosity properties of the biodiesel.

Mechanical efficiency increases with increase in load for all type of fuel blends. This may due to increase in the brake power. Mechanical efficiency of the biodiesel is greater than the diesel at all compression ratios. Pongamia B10 and Jatropha B10 have the maximum mechanical efficiency of 62.77% and 62.20% respectively. Diesel has the minimum mechanical efficiency of 55.49%.

It is concluded that the blends of pongamia and jatropha are safe to use as an alternative fuel in a VCR engine in whine Jatropha B10 and Pongamia B10 shows the optimum performance and emission characteristics.

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