COMPARITIVE STUDY ON THE PERFORMANCE, EMISSION & COMBUSTION CHARACTERISTICS OF DIESEL & BIODIESEL BLENDS FROM PONGOMIA PINNATA OIL

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Abstract - *IC engine is the innovation that revolutionized self-propelling machines. Due to the inflating price of petroleum and its derivatives, new ways of enhancing fuel and the system are currently the eyes of the market. The main agenda of this work is using Pongomia Pinnata oil as a substitute of diesel and evaluating the variations in engine characteristics. A 4-stroke single cylinder diesel type-KIRLOSKAR AV1 engine with eddy current dynamometer setup is installed for the performance study. Biodiesel blends of D100, B10, B20, B30, B50 are the scope of study, involving the conversion of Pungai oil using esterification process. A DAQ system is installed for controlling the load acting on the engine and for speed, temperature, combustion calculations. Valve timing diagram of the engine is illustrated. Fuel properties like calorific value, absolute viscosity, flash and fire point are calculated from digital bomb calorimeter, Redwood viscometer and flash point apparatus. Power, speed and efficiency of engine using biodiesel blends are computed for various load conditions. Heat losses are calculated. Using Combustion Analyzer software, values of pressure, volume and heat release rate are calculated for corresponding crank angles. Smoke opacity values are computed using AVL SMOKEMETER and CO, HC, CO2, NO emissions are computed using AVL DIGAS 444N analyzer. Engine characteristic curves are plotted and explicated for results.*

Key Words: **Pongomia Pinnata, KIRLOSKAR AV1, Biodiesel, transesterification, DAQ, bomb calorimeter, Redwood viscometer, Combustion Analyzer, AVL SMOKEMETER, AVL DIGAS 444N analyzer.**

1. INTRODUCTION

Innovations prevail to be the sole-reasons of comforting human lives from ages. Some innovations stand out to be the key for rapid evolution and new scope of research. IC engines are one of the kind. However, there are some drawbacks like rise in oil price, future of oil and its unsustainability. Between 1970 and 2002, global emission of CO_2 increased over 70%. The anthropogenic emission of CO_2 has been the major source of CO_2 emission to the atmosphere with fossil fuel combustion engines and coal-fired power plants as the major contributor. The global temperature rose at an average rate of about 0.13°C per decade, almost twice as fast as the increase of 0.07°C per decade observed over the past 50 years. The global average temperature will increase by about 0.2°C per decade over the next two decades. The warming imbalance caused by greenhouse gases will gradually overcome the thermal inertia of the oceans, and the projected temperature paths will start to diverge with unchecked carbon emissions, leading to several additional degrees of warming by the end of the century [4]. There is a 50% rise in the price of diesel over the past 8 years in India. India's energy demand is projected to be 1,464 million tonnes of oil equivalent by 2035. The Paris Agreement (concluded in December 2015 by 196 countries) aims to keep the global temperature rise in the twenty-first century below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase preferably to 1.5 °C. India has committed to reduce its emission intensity till 2030 by 30–35% below the 2005 levels. PAT (Perform, Achieve and Trade) scheme, upscaling of renewable energy target to 40% by 2030, targeting a changeover to 100% electric vehicles (EVs) by 2030 and the recent announcement to replace all government vehicles with EVs [2]. Finding alternative sources for the existing system is a key to achieve sustainable goals in advance. Ethanol and hydrogen powered vehicles stand next to EVs in future mobility. Biodiesel is also viable and cost effective source that can match the prevalent outcome.

Pongamia Pinnata also known as Derris Indica is a medium sized medicinal plant widely distributed throughout tropical Asia, Seychelles Islands, South Eastern Asia, Australia, India and locally distributed throughout Maharashtra (India). The seeds contain about 28–34% oil with high percentage of polyunsaturated fatty acids [10]. Cropping of pods and single almond sized seeds can occur by 4-6 years and yields 9-90 kg's of seed. The yield potential per hectare is 900 to 9000 Kg/Hectare. As per statics available, Pongamia oil has a potential of 135000 million tonnes per annum and only 6% is being utilized. Methyl esters (biodiesel) are clean burning fuel with no sulfur emission. They are non-corrosive and are produced at low pressure and temperature conditions giving methyl ester (80%) and glycerin (20%) as a byproduct. Although its heat of combustion is slightly lower than that of the petro- diesel, there is no need to modify the engine and there is no loss in efficiency [1]. Conversion of pongomia oil using esterification process and the yield can be blend directly with diesel.

2. RELATED WORKS

i. S.R Arote and P.G Yeole in the paper " Pongomia Pinnata L : A Comprehensive Review" studied the biological, pharmacological, phytochemistry and role of pongmia pinnata in bio-fuel industry. The paper interprets esterification process, FAME and fatty acids present in the seeds of P. pinnata [10].

ii. In the paper " Investigation on performance and emission characteristics of EGR coupled semi adiabatic diesel engine fuelled by DEE blended rubber seed biodiesel" the authors carried an investigation on the performance, in-cylinder pressure and emission parameters of SADE and ODE with both test fuels at different SOI timings [9].

iii. The authors had put forward in the paper "Performance and emission analysis on diesel engine fuelled with neat pongamia biodiesel" that the output power of pongamia biodiesel was comparable with diesel fuel. The brake specific fuel consumption (BSFC) was higher for pongamia biodiesel because of its lower heat content. The exhaust emissions of HC, CO, NOx, and smoke are diminished by 26%, 25%, 6%, and 46% respectively [8].

3. METHODOLOGY

In this study, the fuel is prepared from P. pinnata oil by esterification method. The fuel properties like kinematic viscosity, calorific value, flash and fire point are calculated. Engine setup is installed and the blends of diesel and fuel prepared from the oil are mixed in the ratio of D100 (diesel 100), B10, B20, B30, B50 depicting 0, 10, 20, 30, 50 percentage of biofuel and remaining with diesel in the mix. The engine is fueled with the above biodiesel blends and the performance, emission, heat losses and combustion characteristics are noted.

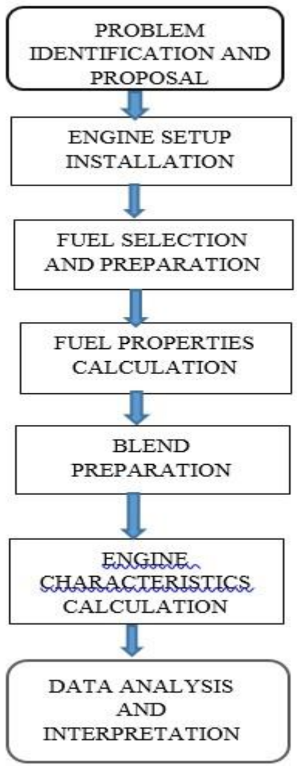


Figure-1: Research methodology

3.1. Engine Setup and Fuel Preparation

The computerized single cylinder diesel engine test rig is installed and the layout is referred in Figure-2. A Kirloskar AV1- single cylinder 4-stroke diesel engine with eddy current dynamometer is used. The engine specifications are mentioned in Table-1. Data Acquisition system is used to interpret temperature and speed of the engine. Dynamometer Control Unit is used to control torque precisely. AVL Smokemeter and AVL Digas 444N Analyzer are used for calculating emission via exhaust gas calorimeter. Combustion Analyzer software is used for determining combustion data.

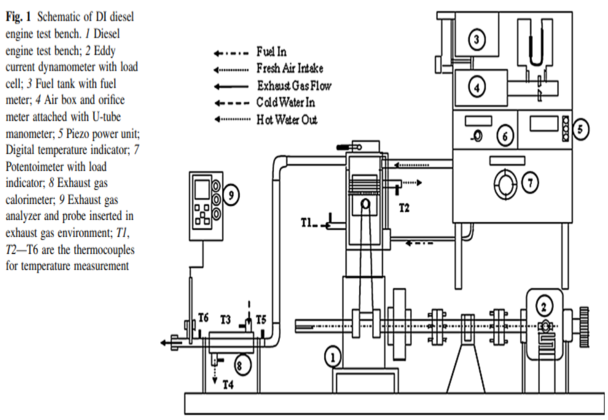


Figure-2: Schematic representation of process [6]

Figure-3: Experimental setup of the process

Table-1: Engine Specifications

S NO	DESCRIPTION	ENGINE SPECIFICATIONS
1	MAKE	Kirloskar
2	POWER	5 Hp
3	No of Cylinders	One
4	Compression ratio	17:5:1
5	Bore	80 mm
6	Stroke	110 mm
7	Type of Ignition	Compression Ignition
8	Speed	1500 Rpm
9	Method of Ignition	Eddy Current Dynamometer
10	Method of starting	Manual Crank Start
11	Method of cooling	Water
12	Injection	Mechanical fuel injection
13	Diameter of Brake Drum	300 mm
14	Orifice Diameter	20 mm

The next motive is to prepare the fuel. Conical flask with 100 ml oil is kept in water bath at 90˚ C for 30 minutes. Another flask of 50 ml methanol and 0.87g of potassium hydroxide is boiled at 60˚ C for 5 minutes. Adding this mixture slowly in oil flask and kept in water bath at 60˚ C for 30 minutes under constant stirring. The mixture is transferred to separating funnel and after 24 hours two separated layers of biodiesel and glycerine are collected. The initial and final stages of pongomia oil and esterification process are depicted in Figure-4. Biodiesel is produced from blends of pongomia oil and diesel in specific ratios.

Figure-4: Esterification of Pongomia oil

Table-2: Blend composition of biodiesel

S NO	BLEND COMPOSITION	DIESEL COMPOSITION	PONGOMIA FUEL COMPOSITION
1	D100	100 %	0 %
2	B10	90 %	10 %
3	B20	80 %	20 %
4	B30	70 %	30 %
5	B50	50 %	50 %

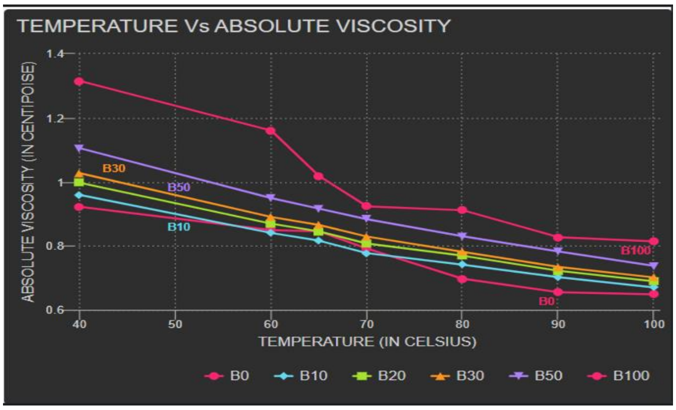
3.2. Fuel Properties Calculation

Flash and fire point of pure diesel and pongomia oil are calculated using flash and fire point apparatus. The readings are shown in Table-3. Kinematic and absolute viscosity values of each biodiesel blends are calculated using Redwood viscometer. The time taken for 50 ml of fuel flow for specific temperatures. The values of density, kinematic viscosity and absolute viscosity are calculated and graphically examined. Plots of Kinematic viscosity Vs Temperature and Absolute Viscosity Vs Temperature are shown in Chart-1.

Table-3: Flash and fire point calculation

S.NO	BLEND COMPOSITION	FLASH POINT (in Celsius)	FIRE POINT (in Celsius)
1	DIESEL	68	76
2	PONGOMIA OIL	59	68

Figure-5: Redwood viscometer test



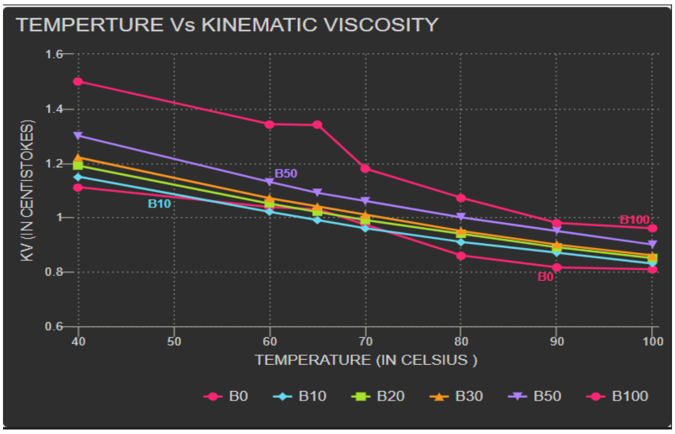


Chart-1: Viscosity graphs

Calorific value of the fuel is calculated using digital bomb calorimeter. The samples of diesel, pongomia oil and biodiesel blend B50 are considered and the initial temperature is noted. After firing, the temperature for every 30 seconds is calculated until the temperature attains a stable point. The calorific value of the samples are tabulated.

$$C.V = \frac{\Delta T(We) - (\text{CVwire} + \text{CVthread})}{\text{Weight of sample in grams}} * 4.184 \ KJ/Kg$$

Where We is the Water equivalent of calorimeter (in J/˚ C)

Table-4: Calorific Value calculations

S.NO	BLEND COMPOSITION	CALORIFIC VALUE (in KJ/Kg)
1	DIESEL	42185.18
2	PONGOMIA OIL	35903.74
3	B50D50	38350.16

Figure-6: Digital Bomb Calorimeter apparatus

3.3. Characteristics of Engine Fuelled by Biodiesel:

The engine is fuelled with the biodiesel blends of B10, B20, B30, B50, D100 and operated under load conditions of 0, 2, 4, 6, 8, 10 N-m torque using Dynamometer Control Unit. Maximum torque for the engine is calculated as 23.74 N-m. The valve timing diagram is shown in Figure-7. The variations in speed, temperature, manometer readings, time taken for 10cc of fuel supply are recorded. Temperature of water inlet and outlet of engine jacket and calorimeter along with exhaust gas temperature are recorded for examining the heat losses. Performance characteristics such as power, specific fuel consumption, mean effective pressure, thermal and mechanical efficiencies are calculated. Air-fuel ratio is also determined and the performance curves are plotted for result analysis. The combustion attributes like pressure, volume, heat release rates to the respective crank angles are recorded using Data Acquisition System and Combustion Analyzer Software.

Emission characteristics such as smoke opacity, CO, HC, CO_2, O2, NO and λ emissions are computed using AVL Smokemeter and AVL Digas 444N analyzer . Also an external pump is used to pump water in and out of the engine and calorimeter. A plot of variations in speed, power and fuel consumption for the corresponding torque value of each fuel blend is interpreted in Chart-2.

Table-5: Valve timing Calculations

S No	POSITION	Before the Nearest Dead Centre	After the Nearest Dead Centre	Distance (X) cm	Angle (degree)
1	Inlet Valve Open	Top Dead Centre		8.4	24.4
2	Inlet		Bottom	13	38.2

	Valve Close		Dead Centre		
3	Exhaust Valve Open	Bottom Dead Centre		10	29.38
4	Exhaust Valve Close		Top Dead Centre	3	8.81

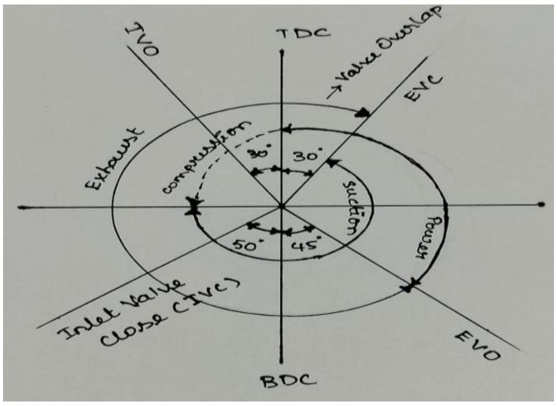


Figure-7: Valve timing diagram

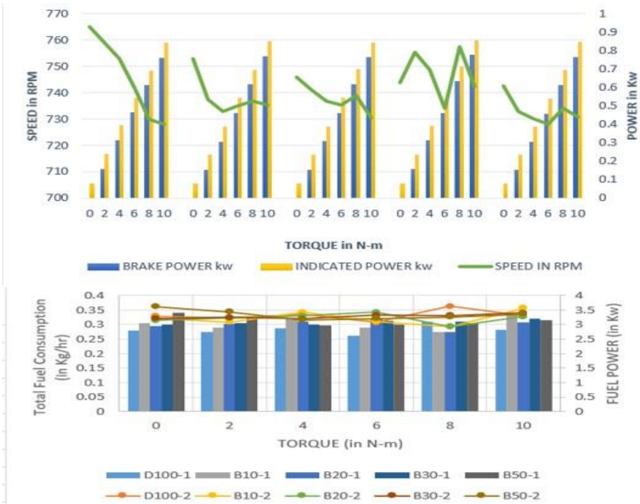


Chart-2: Performance plot

In Chart-2, the graph (above) represents Speed Vs Torque (Primary axis) and Power Vs Torque (Secondary axis) and the graph (below) represents Total Fuel Consumption Vs Torque (Primary axis) and Fuel power Vs Torque (Secondary axis) for D100, B10, B20, B30, B50 biodiesel blends respectively. It is observed that the speed decreases 5% from no load condition to 10 N-m for diesel and 2% for all the other blends. The speed and power attributes of biodiesel is nearly 1% less than that of the diesel. As the blend ratio increases, the Total Fuel Consumption (TFC) also increases.

TFC of blends B10, B20, B30 increases by 8-11% from that of the diesel whereas for B50 the percentage increase is between 12 to 20%. Fuel power of blends B30 and B50 is 1.5-3% more than diesel.

Table-6: Engine performance calculations

S NO	DESCRIPTION	FORMULA
1	Max. load condition	$M.L.C = \frac{2*\pi*N*T}{60000} Kw$ where N max = 1500 rpm
2	Brake Power	$B.P = \frac{2*\pi*N*T}{60000} Kw$
3	Indicated power	Brake power + Friction Power
4	Brake thermal efficiency	$\left(\frac{\text{Brake power}}{\text{Fuel power}}\right) * 100$ in Kw
5	Brake mean effective pressure	$(B.P*60)/(\left(\frac{\pi}{4}\right)*D^2*L*\left(\frac{N}{n}\right)*$ $No.\ of\ cycl.*100)$ $n = 2\ for\ 4\ stroke$

4. RESULTS AND CONCLUSION

4.1. Performance Characteristics

Chart-3: Efficiency and performance curves

In Chart-3, the graph (above) represents Efficiency Vs Brake power (Primary axis) and Air-fuel ratio Vs Brake power (Secondary axis) and the graph (below) represents Brake Specific Fuel Consumption Vs Brake mean effective pressure (Bar chart) and Indicated Specific Fuel Consumption Vs Indicated mean effective pressure (Line chart) for D100, B10, B20, B30, B50 biodiesel blends respectively. From D100 to B50, as the biodiesel blend value increases, the Brake Thermal Efficiency decrease by 3-4%. No significant changes in Mean Effective Pressure,

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Volumetric and Mechanical Efficiency. Indicated Thermal Efficiency decreases by 9% for all the biodiesel blends compared to diesel. For every biodiesel blend ratio increase from diesel to B50, air –fuel ratio decreases by 5%. and specific fuel consumption decreases by 8-10%. From D100 to B50, a 3% increase in kinematic and absolute viscosity is noted and is shown in Chart-1. Nearly 35% increase in the unaccounted heat losses of engine fuelled by biodiesel blends when compared to diesel-run engine heat loss. As the biodiesel blend ratio increases, heat unaccounted losses increase by 2%. The heat losses in engine during the cycle is shown in Chart-4.

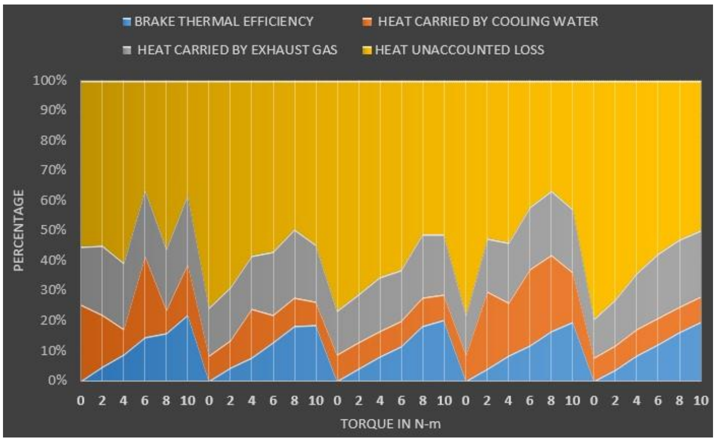
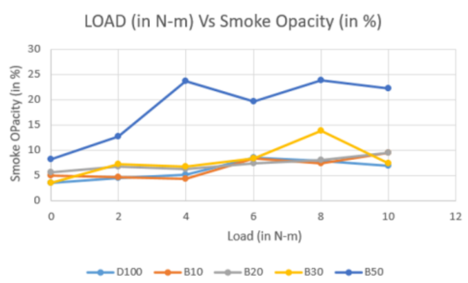


Chart-4: Engine heat losses

4.2. Emission Characteristics

The emission characteristics like Smoke opacity, NO, HC, CO_2, CO emissions are plotted against load (torque in N-m) and is shown in Chart-5. No O_2 and λ emissions are noticed. B20, B30, B50 shows NO emissions of 1-2 ppm. Increase in CO (in % vol.) of 0.01% is detected in B30 and B50 compared to others. HC emissions in B20 is 20% lower than other biodiesel blends which are 9% lower than diesel emissions. CO2 emissions of B20 and B50 are 0.2 (in % vol.) lesser than diesel and other biodiesel blends. Smoke opacity (in %) of B30 and diesel are almost equal whereas 20% increase is seen for other biodiesel blends, as the blend ratio increases.



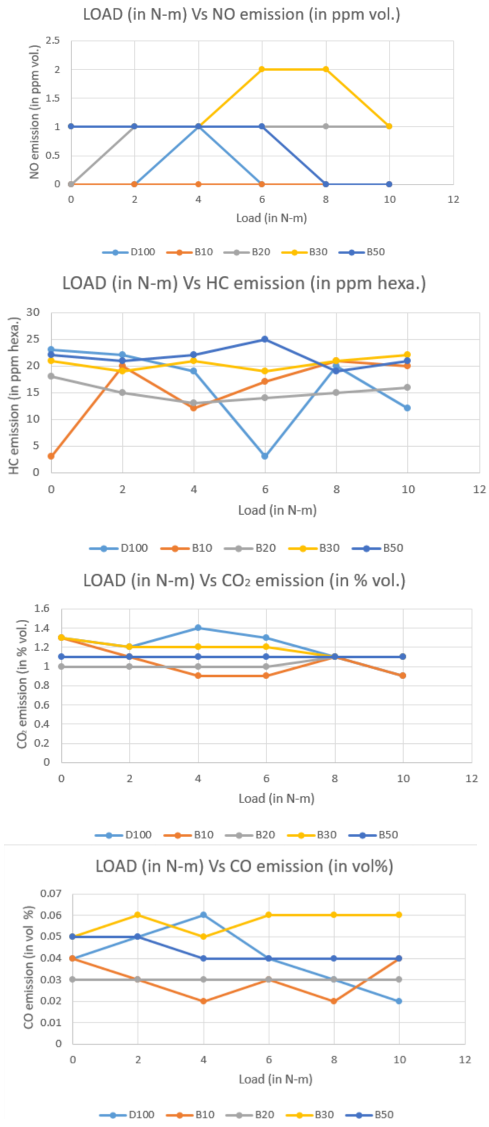


Chart-5: Emission Characteristics

4.3. Combustion Characteristics

In Chart-6, the Rate of Pressure Rise (RoPR) Vs Crank angle, Pressure Vs Volume, Pressure Vs Crank angle, logP Vs logV, Heat Release Rate (HRR) Vs Crank angle and Cumulative Heat Release Rate (CHRR) Vs Crank angle graphs are sequentially plotted and interpreted. The readings noted are similar for different load conditions. The maximum load condition of torque 10 N-m is graphically represented for diesel and biodiesel blends. The peak in-cylinder pressure is maximum for B10. Higher in-cylinder pressure provides improved resistance to knocking and higher compression ratios. HRR of diesel is maximum than that of biodiesel blends. In the ROPR vs Crank angle curve B10 and diesel are better than other biodiesel blends. Higher in-cylinder pressure provides improved resistance to knocking and higher compression ratios.

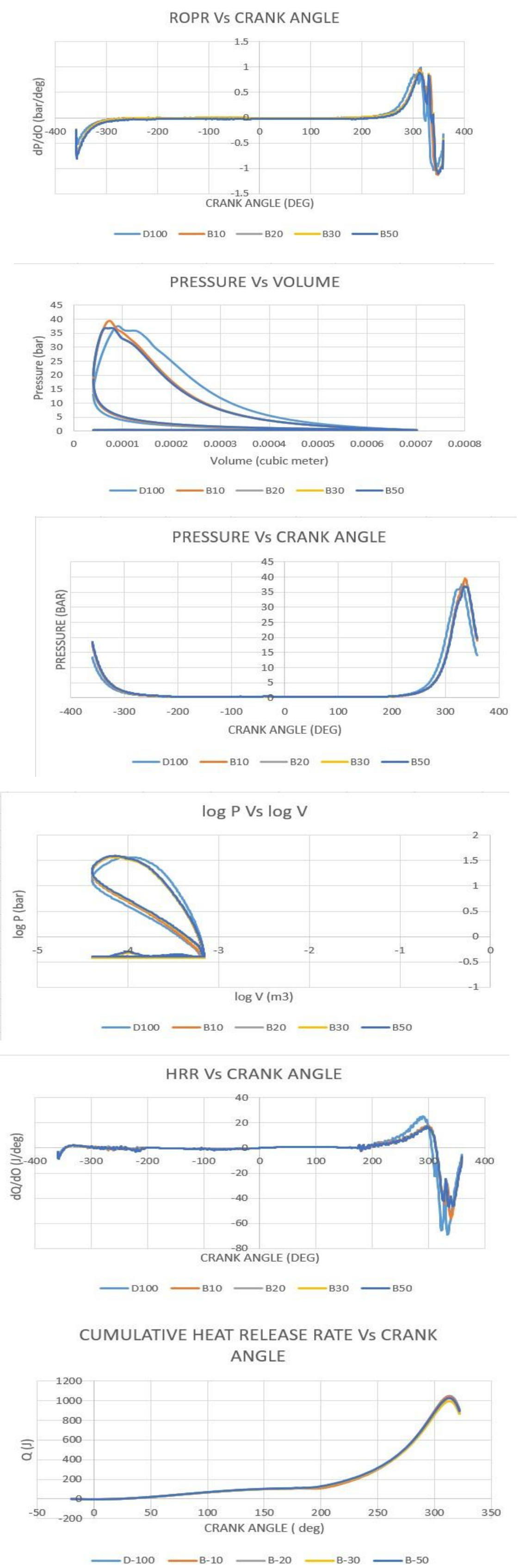


Chart-6: Combustion characteristics

Mass production of biodiesel from pongomia pinnata oil helps to reduce 40 % of fuel cost . Also it also holds the rising demand for crude oil to an extent. The crude glycerine from the biodiesel production can be used for commercial purposes after several stages of refining the impure glycerine or they can be used in boilers for power generation and can be used for fermentation process. From the combustion charasteristics B10 blend of biodiesel is better than other biodiesel blends. From the emission characteristics, B10 has no NO emission and B20 produces lesser CO_2 and HC emissions. From the deviations in the biodiesel aspects compared to diesel. So it is clear that the characteristics of biodiesel are on-par with diesel.

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