Influence of Biodiesel Blends on Compression Ignition Engine Performance, Emission and Combustion Characteristics

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Abstract

In a country like India the majority vehicles are running on ICE for which propulsion is derived from petro diesel products. Over the years it is observed that petro diesel resources are depleting in nature. On the other hand, the pollution levels are increased tremendously. To overcome these problems researcher have concentrated on alternative fuels in place of petro diesel fuels. The biodiesel properties are closer to diesel. In this work palasa seed oil is used as substitute fuel with various blend combination. Palasa seed oil is combined with regular diesel in the amounts of B10, B20, B30, and B40. The research is being conducted on a direct injection single cylinder four stroke diesel engine. Among the evaluated blends, B20 has the closest performance and emission characteristics to diesel. When compared to B0 blend, the brake thermal efficiency of B20 mix is enhanced by up to 13.41%. Further the HC, CO emissions are reduced with B20 compared to standard diesel. However, the oxides of nitrogen emission levels are slightly increased compared to B0 blend.

Keywords: Palasa seed oil blends, emission, combustion, performance, transesterification, diesel engine

1.Introduction:

The high expensive growth of conventional fossil fuels and their related effects of use were very important concerns in world wide. The fossil fuels consumption was increased day to day and the supply of fuel rapidly decreases and demand increases. The high demand of fossil fuels like natural gas, petroleum and coal does not meet the requirement. In world wide researchers are working on to improve the fuel characteristics and quality of emissions of IC engines. Further the researchers also concentrate on development of alternative fuels in place of fossil fuels that can be used in IC engines without main engine design alterations.

The coal, electricity and petroleum products are the most common commercial energy products. They were utilized for power generation in industrial, transportation, commercial and agriculture sectors. In modern countries commercial fuels were placed an important source not only for economic benefit but also for domestic needs of the population. The noncommercial energy sources play an important role in the market. The noncommercial energy sources which include cattle dung, agriculture waste and logs were conventionally collected and not purchased at a particular price in rural areas [1].

Bio fuel is a type of fuel produced from natural products like seeds, oils, algae. By the name it can be understood that it is biologically friendly fuel. Bio fuel is green fuel which has very low percentages of emissions then conventional diesel. Based on the material biofuels are classified into four generations [2].

1. First Generation Bio-fuels were derived from agricultural crops and seeds.
2. Second Generation Biofuels were produced from crops that are non edible (like neem oil, cotton seed oil), waste vegetable oils.
3. Third generation Biofuels were extracted from algae by chemical processing.
4. Fourth Generation Biofuels extracted from genetically altered species like algae [3].

The utilization of vehicles in the country has increased significantly and the consumption of fuel has risen. This condition directs to the depletion of petroleum products in the country [4]. The impact of B100, B40, and B20 mixture of Roselle biofuel was utilized in the research. The minimization of delay period and smoke opacity, the indicated thermal efficiency (ITE), temperature of exhaust gas and cylinder pressure were increased [5]. By the early injection of biodiesel, the combustion process of duration decreases which improves the indicated thermal efficiency about 50.7% [6]. The algae blends showed better peak pressure compared to diesel and was about 11% high. The heat release rate obtained for algae blends was 15% more compared to base fuel [7]. The brake thermal efficiency was reduced up to 17.39% even as maximizing in BSFC up to 29.15% for 10% mixture of diethyl ether as correlated to base fuel .The impact of different additives like dimethyl, dimethyl carbonate and diethyl ethers was evaluated. The BTE of diethyl ether was increased up to 12% compared other additives [8].

The engine test was conducted with fish oil blends on common rail diesel engine. The soot emissions, hydrocarbon emissions, carbon monoxide and engine power were reduced 17.5%, 26.2%, 14.3% and 3% with B30 blend respectively. In other side the NOx pollutants & BSFC were raised by 5.1% & 3.4% respectively correlated to base fuel [9]. The SFC, BTE increased with BD75 and reduced up to 1.95% with BD100. The amount of CO reduced upto 34.28%, HC and smoke decreased about 17.49% and 50.95 % respectively [10].

The water emulsion test results indicated that the engine torque improved up to 28.4% with B20E5(20%blend and 5% water) and the brake specific fuel consumption was reduced upto 7.27% respectively. The oxides of nitrogen pollutants were lowered upto 26.17% with B20 blend and 30% water content [11].

The research conducted on four strokes, water cooled, naturally aspirated, 1- cylinder base engine using binary blends of heptanol/biodiesel. The un burnt hydro carbons and CO emissions were reduced while other hand NO_X and O_2 emissions were increased compared to standard fuel [12]. The CO emissions were minimized with grape seed oil blend (20 ppm) compared to diesel fuel [13].

The utilization of waste cooking bio diesel reduces the environmental issues and minimize the dependence of fossil fuels. The HC and CO pollutants were reduced compared to standard fuel [14]. The specific fuel consumption for B100 was 15% more than standard fuel for jatropha oil [15].

The emission characteristics of a four stroke one-cylinder water-cooled diesel engine were studied experimentally. Blends of ethanol, cotton seed oil, eucalyptus oil, and micro algae were utilized. The pollutants of CO_2, CO, smoke and oxides of nitrogen were reduced by 22%,2.3%,6.54% and 0.97% respectively [16]. The main oil blend was the combination of 10% pine oil, 10% Eucalyptus oil and 80% diesel(P10E10D80). The P10E10D80 blend was used in CI engine in place of conventional fuel. The viscosity and cetane number of P10E10D80 was low compared diesel. At 20% to 100 percent load the utilization of methanol could substitute 39 to 56 percent respectively. Further it enhances the brake thermal efficiency about 2.56%, brake specific energy consumption 17%, exhaust gas temperature 8.92% respectively at full load condition [17].

The study was carried out on turbocharged CI engine operated with dual fuel mode using waste palm oil and bamboo leaf oil. The temperature of the exhaust gas and brake thermal efficiency were reduced by 10.81% and 14.08% while the specific energy consumption was increased by 46%. Further the emission parameters like nitric oxide and smoke intensity were lower about 91.71% and 63.59% respectively but the CO and HC emissions were increased 65.71% and 40.63% respectively at 100 percent load condition [18].

The purpose of this research is to establish the performance, emission, and combustion characteristics of a compression ignition engine utilizing palasa seed oil blends and diesel. The blends like B10, B20, B30 and B40 are considered in this study.

2.**Materials and Methods**

2.1 Materials

The Palasa tree and seeds are shown in Fig.1. Palasa tree belongs to pea family of tree species. It is type of flowering plant that comes into genus of butea. The scientific name of this flowering plant is Butea Monosperma.

Fig.1: Palasa Tree and seeds

Palasa tree is a deciduous tree that is grown at tropical areas like India, Sri Lanka, and Vietnam. Their flowers are orange-red color by which it is also called “Flame of Forest”. The main uses of the tree are: tannin, dye, medicine. As these seeds are not edible, the oil extracted from them can be considered as nice source for biofuel production [19].

2.2 Transesterification process

Fig.2: Transesterification process

Transesterification is a chemical process for conversion of triglycerides in to biofuel. One litre palasa seed oil is collected in a flask and about 60^oC for a given length of time. After attaining the required temperature, the oil is collected into the beaker and 15 ml distillation water and 10 gm KOH/NaOH are added to it. Sediments are settled down at the bottom of the flask after one hour duration. Again, the oil is collected and heated upto 60^oC. Then 250 ml/litre methanol/ethanol and 20gm KOH/NaOH are added to oil. The oil is stirred continuously for 10 min and then stirred oil is collected into the beaker [20]. After these two processes performed the mixture is left for a long time still. Due to variation present in density of glycerin and ester they form two distinct layers. Glycerin, having high density settle bottom. It can be separated and utilized for any application. The left-over product is the ester formed during these processes. It is washed and shaken vigorously with warm water to remove the products of saponification [21]. The transesterification process is shown in Fig.2.

2.3 Test fuels

The biodiesel used in this experimentation is palasa seed oil produced via transesterification process. The prepared test biofuels are named as B0-100% diesel, B10- diesel 90%, and palasa seed oil 10% , B20- diesel 80% and palasa seed oil 20%, B30- diesel 70% and palasa seed oil 30%, B40- diesel 60% and palasa seed oil 40%. The properties of palasa seed fatty acid composition are indicated in table-1. The phase changes of fuel blends are stored in glass breakers. The properties of the selected fuel are determined by using EN and ASTM standards as shown in table-2.

Fatty Acid	Composition (wt %)
Stearic(18:0)	4.5
Palmitic(16:0)	24.5
Linoleic(18:2)	40.3
Oleic(18:1)	23.9
Linolenic(18:3)	0.5
Gondoic(20:1)	0.7
Arachidic(20:0)	0.8
Lignoceric(24:0)	1
Behenic(22:0)	2.9

Table 1: Palasa seed oil Fatty acid composition

Properties	Palasa seed oil					EN 14214	ASTM D6751	Method
	B10	B20	B30	B40	B100			
Kinematic viscosity at 40^0 C (cst)	3.6	3.73	3.85	4.1	4.7	3.4 to 4.9	1.8 to 5.9	ASTM D445
Acid number	0.84	0.78	0.66	0.61	0.44	<0.5	<0.5	AOCS Ca 5a-40
Density (g/cm^3)	0.80	0.82	0.83	0.84	0.85	0.85 to 0.89	-	ASTM D4052
Calorific value(K Cal/ Kg)	10095	10000	9534	9432	8175	-	-	ASTM D240
Flash point(^{0}C)	68	72	86	98	148.5	>120	>135	ASTM D93
Iodine Value(g/100g)	110.2	106.4	98.3	93.4	74.35	≤ 120	-	AOCS Cd 1-25
Cetane number	44.3	44.9	45.3	46	44	-	-	ASTMD613

Table 2: Properties of Biodiesel prepared from palasa seed oil as per EN and ASTM standards

2.4 Test Engine

Four-stroke, naturally-aspirated, variable-compression diesel engine with eddy current dynamometer was used for the experiments. Smoke meter & MARS 5-gas analyzer are used in this experimentation. The pollutants such as NO_X, CO_2, HC & CO are computed. with MARS 5-gas analyzer. The smoke pollutants are deliberated with smoke meter. The total experiments are conducted at 1500 rpm speed by different load conditions. Test engine is run with base diesel for 20 min to obtain steady state condition then emission, combustion and performance parameters are noted. Similarly, the above said parameters are recorded for various palasa biodiesel blends. The engine layout and test engine are shown in Fig.3 and Fig.4. Specifications of the engine shown in table 3. The uncertainty analysis is shown in Table 4

Parameters	**Specifications**
Test engine	Research engine setup, 4 stroke water cooled engine
Piston Shape	Cylindrical
Piston dimensions	87.5 mm – 87.6 mm
Make	Kirloskar
Number of cylinders	1
Rated Speed and Rated Power	1500 rpm and 3.5 kW
Stroke Length	110 mm
CR Range	12:1 to 18:1
Type of Cooling	Water Cooled
Connecting rod length	234 mm
Orifice diameter	20 mm
Dynamometer arm length	185 mm, Eddy current Dynamometer
Injection point variation	0 to 25^o BTDC
Type of starting	Key or Crank start

Table 3: Engine Specifications

Parameters	**Instrument uncertainty**
Speed(rpm)	±1
Time(s)	±0.1
Load(N)	±0.2
Temperature(^{o}C)	±1
Brake Power(kW)	±0.5
Pressure(bar)	±1
CO(%)	±0.025
CO_2(%)	±0.025
NO_x(ppm)	±8
HC(ppm)	±9

Table 4: Uncertainty Analysis

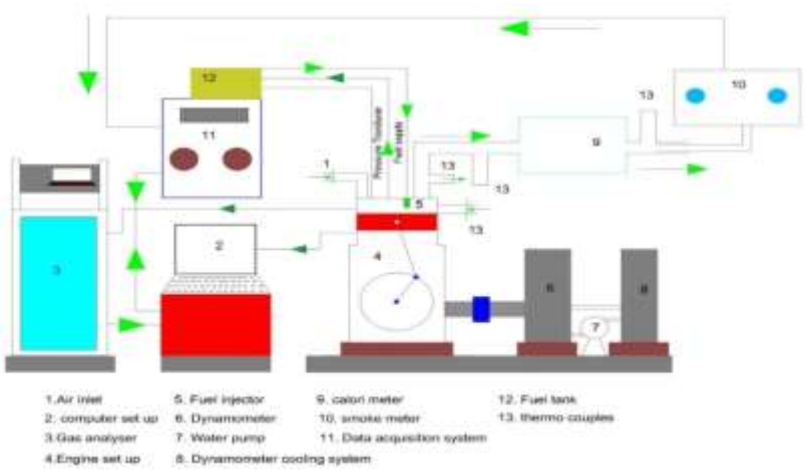

Fig.3: Test Engine Setup lay out

Fig.4: Test Engine Setup

3. Results and discussion

Many elements influence the combustion process in diesel engines, including cetane number, rate of fuel evaporation, fuel quality, combustion chamber design, fuel optimization, injection time, compression ratio, and pressure [22]. Optimization of above said parameters combustion process may be enhanced and therefore utilization of fuel as well as pollutants from combustion can be minimized. Cetane number and combustion efficiency is important factor that has influence on engine exhaust emissions, combustion and performance of base diesel engine [23].

Fig.5 illustrates the mechanical efficiency (ME), brake thermal efficiency (BTE) graph based on brake power for biodiesel fuel blends & diesel fuel. The BTE for B10, B20, B30 and B40 fuels efficiency are 28.5%, 29.5%,26.94% and 27.69% respectively. The highest brake thermal efficiency obtained for B20 is 13.41% correlated to standard fuel. The remaining fuels BTE are increased for B10, B30 and B40 are 9.57%, 3.57% and 6.45 respectively compared to B0 blend. The BTE gradually improved from zero load condition to 100% load condition. The mechanical efficiency (ME) of B10, B20, B30 and B40 fuels efficiency are improved by an average of 3.33%, 10%, 6.66% and 7.5% respectively when correlated to B0 fuel. In detail, Because of its higher cetane number and oxygen content, biodiesel fuel has a lower calorific value than normal diesel; yet, biofuel facilitates excellent combustion, especially at rich fuel air mix ratios.

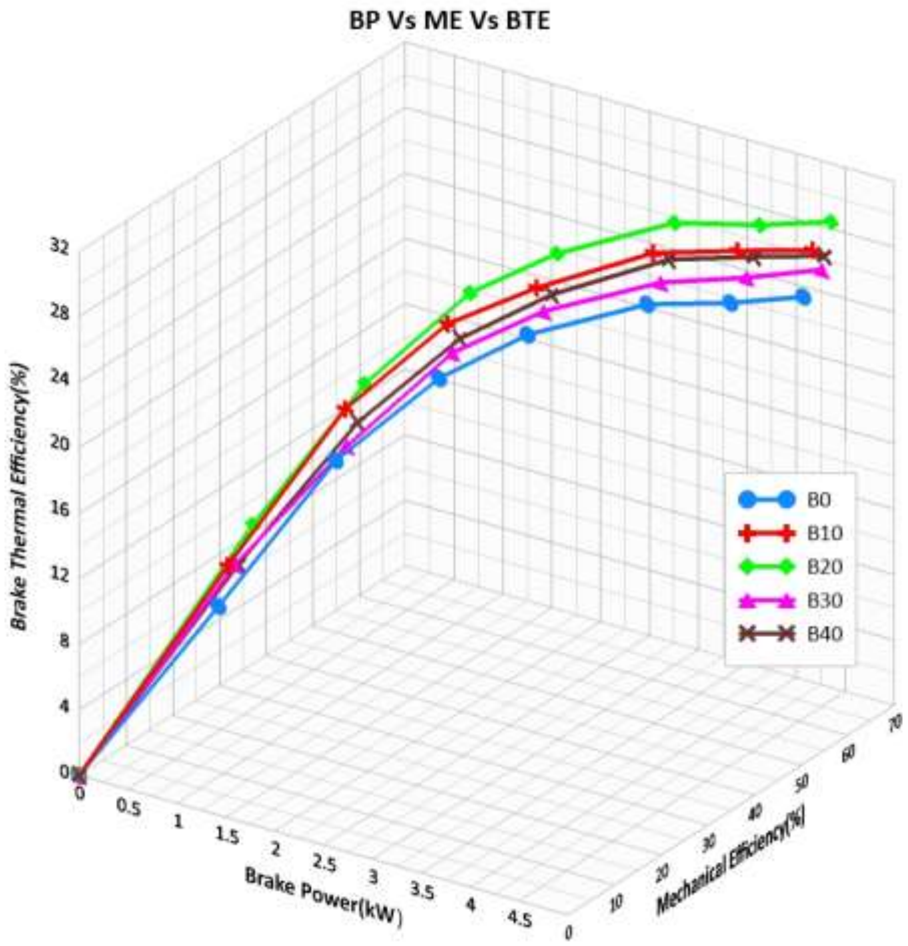

Fig.5: BP Vs BTE Vs ME

Fig. 6 indicates the volumetric efficiency and specific fuel consumption (SFC) graph based on break power for diesel and biodiesel fuel blends. The SFC is lowered for zero to maximum load condition. The SFC for B20 is lowered correlated to the B0 fuel and is about 43.4% respectively. According to the brake power, the SFC for B10, B30 and B40 fuel blends reduced by 32%, 10% and 22.2% correspondingly when correlated to B0 fuel. The density, viscosity and lesser heating value of fuel influence on fuel depletion. The lesser heating value of biofuel is lesser than base fuel & more amount of fuel is injected by pump to achieve the equal power than diesel fuel produces led to a growth the specific fuel consumption. Generally, the volumetric efficiency rises with effective induction of air charge during the stroke and reduces with speed. The volumetric efficiency reduced from no load to rated load condition [24].

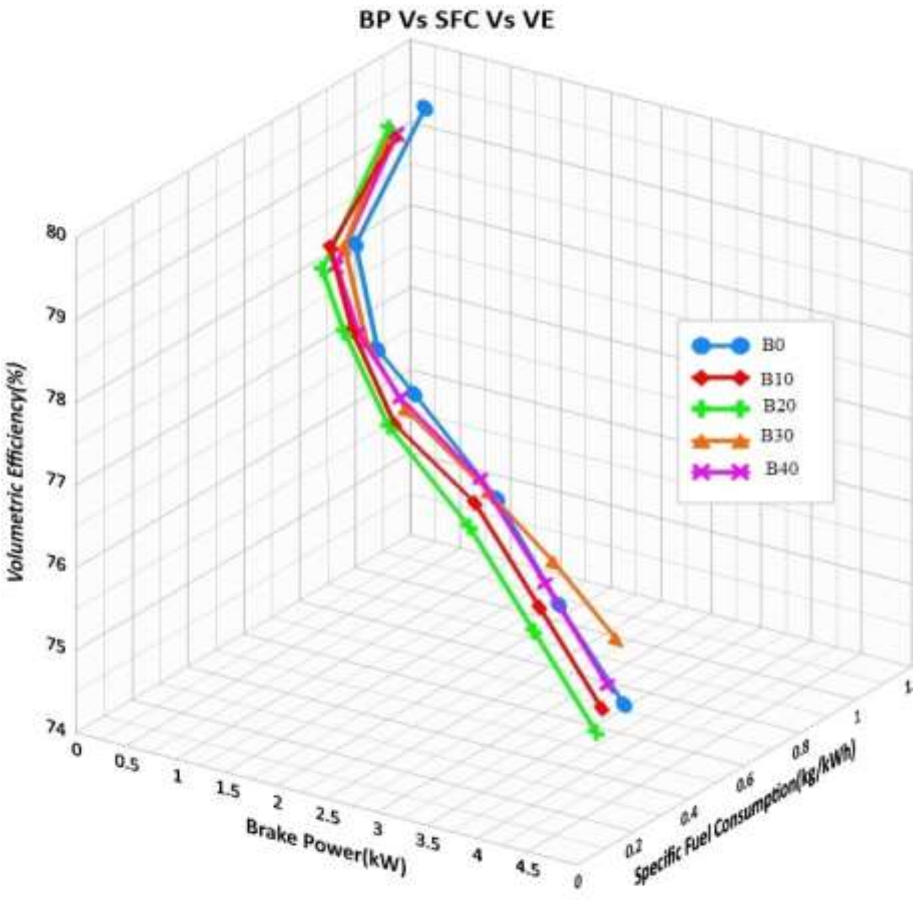

Fig.6: BP Vs SFC Vs VE

Fig.7 demonstrates the deviation of Carbon dioxide (CO_2) and Carbon monoxide (CO) based on brake power for biodiesel and diesel blends. According to the brake power the CO emissions for B40 is lowered compared to B0 blend and is about 26.28%. Based on the brake power the carbon monoxide emissions for B10, B20 and B30 are 8.5%, 14% and 18.09% respectively less compared to the B0 blend. One of the main reason for carbon monoxide development in the engine is incomplete combustion. The diesel engine principle, engine running with excess air the formation of CO in the cylinder is low correlated to standard diesel [25]. Generally, biodiesel having more oxygen substance and high cetane number effects the complete combustion it caused the carbon monoxide emission are decreased 26]. The CO_2 emissions are higher from zero load to 100% load condition.

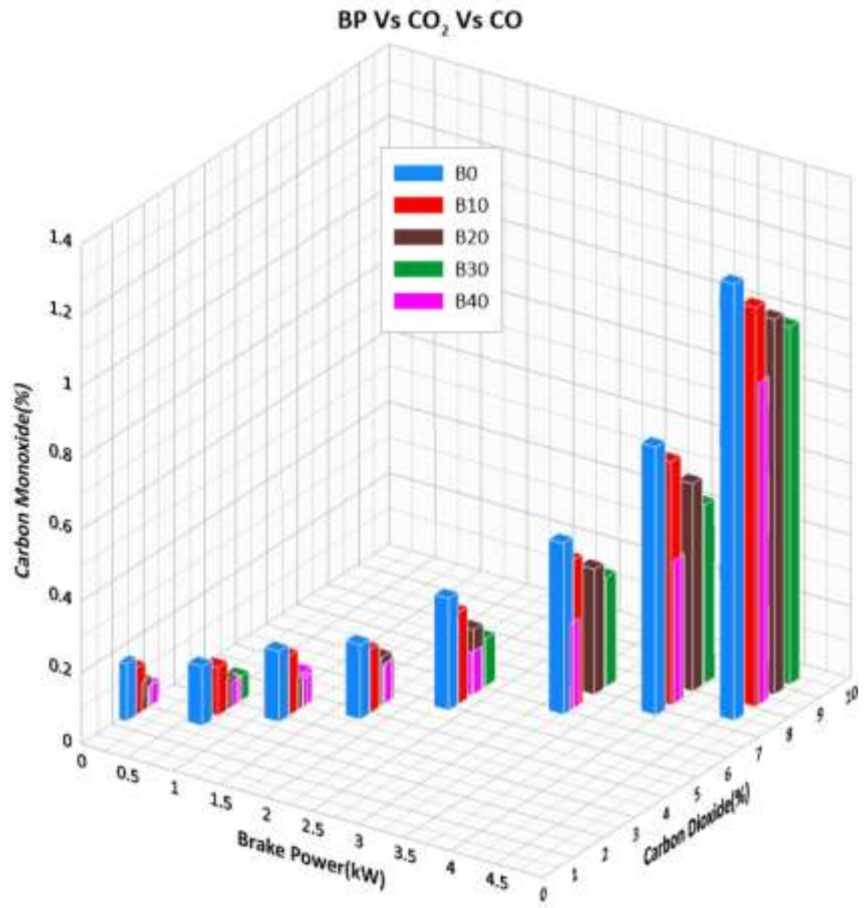

Fig.7: BP Vs CO Vs CO_2

Fig.8 illustrates NO_x and HC pollutant variations for diesel and biodiesel blends based on the brake power. In IC engines nitrogen oxide pollutants is the effect of oxygen with nitrogen at higher temperatures. The NO_x emission is developed by the reaction of nitrogen and oxygen molecules [27]. Based on brake power the NO_x emissions of B10, B20, B30 & B40 are 6.77%, 10.16%, 13.55% & 18.64% respectively more compared to B0 blend. The more oxygenated fuel vaporization plays a major role in the combustion process that indicates less combustion temperature and there by less nitrogen oxide formation. Unburnt hydrocarbon emissions are produced due to incomplete combustion, its major parts are cylinder volume and nozzle area [28]. The HC emissions obtained for B10, B20, B30 & B40 are 62 ppm, 60 ppm, 64 ppm and 66 ppm respectively. The B20 blend produced minimum HC emissions compared to diesel and all remaining blend proportions. The hydrocarbon emission for B10, B20, B30 & B40 are 8.8%, 11.76%, 5.88% and 2.94% more compared to B0 blend at maximum load condition. The main reason for declined unburnt hydrocarbon pollutants is high igniting behavior of biodiesel blends.

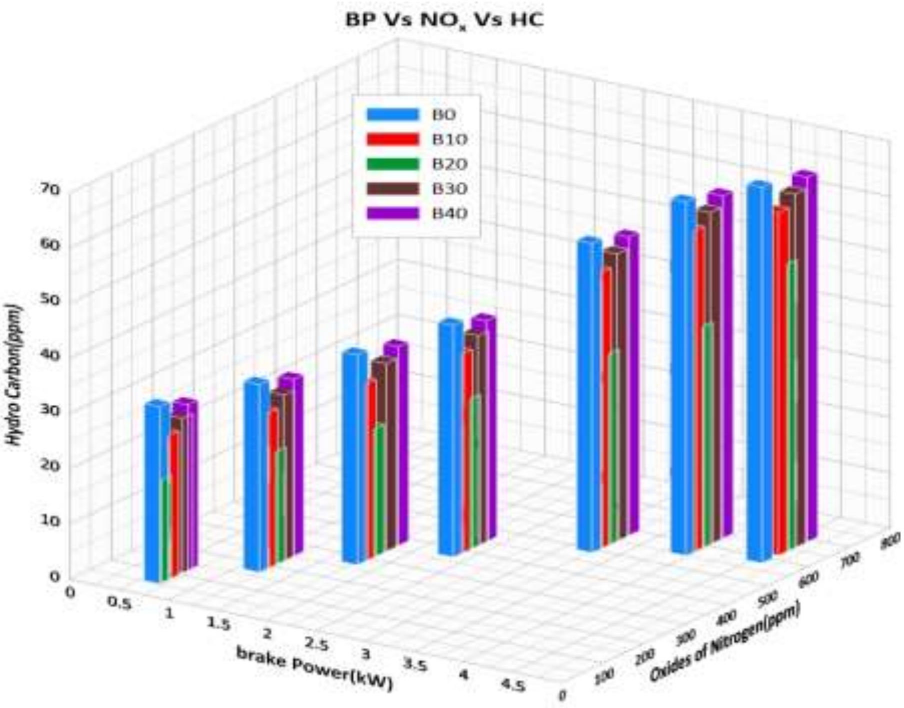

Fig.8: BP Vs NO_x Vs HC

The variation of brake power vs smoke opacity for the investigated fuels like diesel and biodiesel blend is shown in the Fig.9 The opacity of smoke values are indicated in percentage variations. The opacity of smoke is minimized when fuel and air mixture burned totally in the piston geometry [29]. The tested results for B0 and B10, B20, B30 & B40 are 45%, 49%, 52%, 55% and 58% respectively. The smoke opacity for diesel is low correlated to all mixtures. The values for B10, B20, B30 & B40 are 8.8%, 15.5%, 22.2% and 28.8% more correlated to B0 blend. The formation of rich air fuel mixture at more pressure & temperature in combustion results smoke opacity formation.

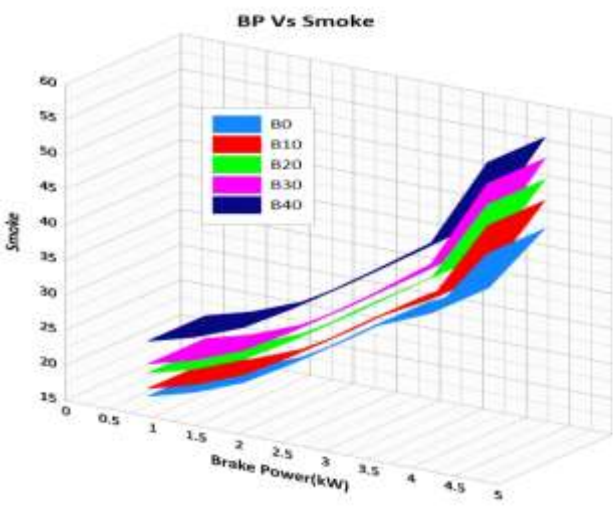

Fig.9 : BP Vs Smoke

Cylinder pressure measurements act as an important role in combustion analysis. The in-cylinder pressure data is used in work transfer analysis form gas to piston. The analysis is a basic parameters for evaluating engine efficiency as it is independent of no.of cylinders, engine displacement and speed. The disparity of crank angle vs cylinder pressure of B0 and biofuel blends is shown in Fig.10. It indicates clearly the maximum pressures increased as the load applied are increased. Which effects to maximized the amount of fuel inject in the cylinder. The fuel having high amount of carbon atoms, these effects increased heating value of biodiesel blends, it directs to peak pressure [30]. The maximum pressure obtained for B0 and remaining blends for all load conditions.

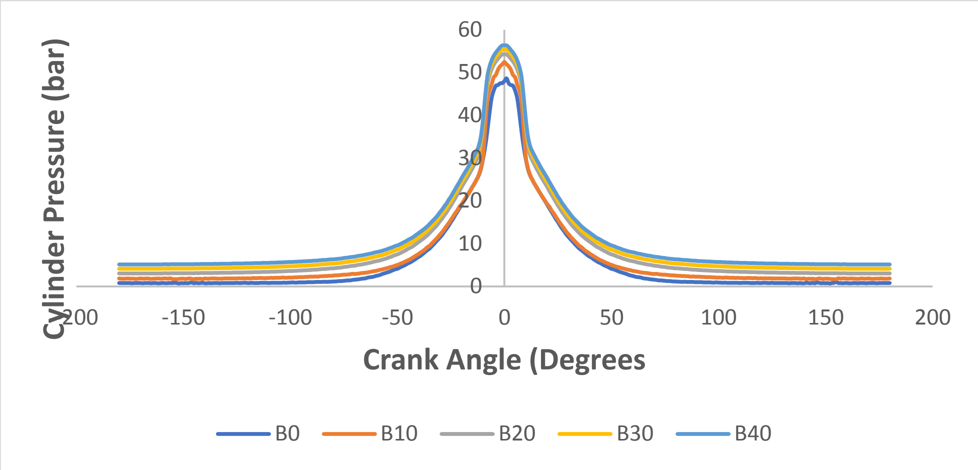

Fig.10: Crank angle Vs Cylinder pressure

Heat release rate is one of the important factor in CI engine. Heat release rate depends on calorific value, density, latent heat viscosity and combustion temperature. The HRR consists of controlled combustion, premixed combustion and late combustion [31]. Fig.11 indicates the crank angle vs HRR for biodiesel and diesel blends. The HRR shows the composition of chemical energy exists in the tested fuel. The plot shows with the increase of engine load, the HRR for B0 and all biodiesel blends are increased. The heat release rate for B10, B20, B30 and B40 are almost equal or higher when correlated to B0 blend. The low heating value and high viscosity of biofuel increases the ignition delay stage when correlated to base diesel.

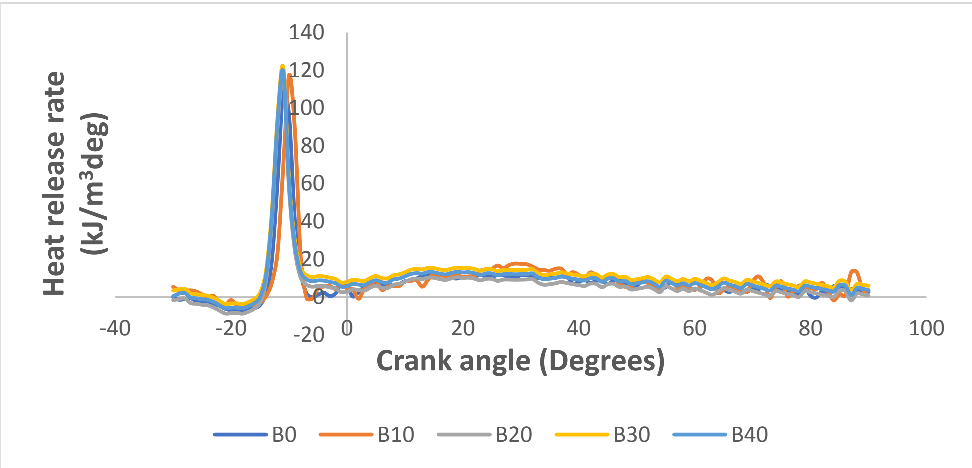

Fig.11: Crank angle Vs Heat release rate

4.Conclusions

The biofuel derived from palasa seed is tested in a direct injection, water-cooled CI engine in this study. The chemical and physical properties of palasa seed oil are examined in the preliminary investigation. Further the experiments are conducted on CI engine with varied load conditions.

- The brake thermal efficiency obtained for B20 is 13.41% more compared to B0 blend.
- The SFC reduces for all blends with increase of brake power. The SFC for B20 is 30.3% low compared to B0 blend at full load condition.
- The oxides of nitrogen pollutants are maximized from no load to full load condition. The NO_x emissions of diesel are slightly low compared to all blends.
- Regarding unburnt hydrocarbon emissions for B20 blend is 11.7% less correlated to standard fuel at higher load.
- The CO emissions for B40 blend is 26.28% less compared to B0 blend at maximum load condition.
- From the investigations it was found that B20 blend gives better performance and low emission characteristics.

Nomenclature:

NO_x: Oxides of nitrogen
BTE: Brake thermal efficiency
ME: Mechanical efficiency
VE: Volumetric efficiency
CO: Carbon monoxide
HC: Hydro carbon
CO_2: Carbon dioxide
HRR: Heat release rate
SFC: Specific fuel consumption
CP: Cylinder Pressure
B0: Diesel
B10: 10% Palasa seed oil + 90% diesel
B20: 20% Palasa seed oil + 80% diesel
B30: 30% Palasa seed oil + 70% diesel
B40: 40% Palasa seed oil + 60% diesel

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Disclosure statement

The author has declared no conflicts of interest.

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