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Experimental Investigations of Performance and Emission Analysis of Direct Ignition Diesel Engine Fueled with Refined vegetable oils

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Abstract: - In this research, the refined vegetable oils are investigated to study the Emissions and performance from Kirloskar Direct Injection 4-stroke Diesel engine, single cylinder air-cooled, 4.4 kW, compression ratio 17.5:1 and at constant speed of 1500 rpm,. The Injection pressure, blend percentage, and various loading were used as input parameters. Emissions and Performance like NO_x, CO, HC, CO_2, and Break specific fuel consumption, Brake thermal efficiency were considered as output parameters. Methyl Esters of refined vegetable oils was transesterified with sodium meth oxide as catalyst before blending with diesel. A 3- hole nozzle was used to inject the fuel. The biodiesel and diesel properties are compared with ASTM and BIS standards. The Emission results were studied using AVL gas analyzer. In this study the experimental data showed that the break thermal efficiency of the Refined Palmolein of the biodiesel was marginally higher than diesel fuel. It was also observed that CO, HC, CO_2 & NO_x are less in Refined Palmolein than Refined Corn and Refined Sunflower oil. Also specific fuel consumption of the refined Palmolein oil biodiesel is reduced by 28.57% compared to pure diesel fuel.

Keywords**: -** *Kirloskar Di – Diesel Engine, Injection pressure, Biodiesel, 3 – hole Nozzle, Combustion and Emission characteristics.*

I. INTRODUCTION

In the Present Indian scenario, an alternate fuel becomes most important due to the continuous increase in the diesel fuel price and increasing pollution in the environment due to diesel engine exhaust emissions. Many types of Biodiesel can be used in Diesel Engines. Biodiesel or Vegetable oil reduce the greenhouse emissions and is environmental friendly. The biodiesel is a renewable fuel and reduces the emission in transportation sector. Biodiesel is a very good alternative for fossil fuels and is available in plenty. The properties of the vegetable oils were compared with diesel and analyzed. The vegetable oils cannot be used directly along with diesel, since it is highly viscous. Transesterification process is done in the presence of methanol, and 5% of animal fat is added with sodium meth oxide as catalyst, This improves the performance of the engine and reduces the emissions.

1.1 Background

Similar experiments on biodiesel was conducted by many researchers. The experiments on the DI diesel perkinson engine were conducted by Dorado MP et, al, [1] by using reused olive oil methyl ester to study the effect on combustion efficiency. As a result, oxygen concentration was increased and accelerated the combustion. It was also found that the rate of combustion efficiency in the use of reused olive oil, methyl esters, and the rate of combustion efficiency remains almost constant as in the use of diesel oil. A lower energy rate was seen in the palm oil combustion, done by Tashtoush G et, al, [2]. It was more efficient and higher rate of combustion (66%) seen in burning biodiesel, when compared with the diesel combustion (56%). This is because of the properties like high viscosity, less volatility and density. Sudhir C.V. et, al, [3] conducted test on Diesel Engine using waste cooking oil, the rate of combustion temperature and pressure were low in the operation of biodiesel, and the NOx emissions were also equal to that of diesel. The sulphate emission was very low due to the lesser level of sulphur. The pilot combustion caused the pre-combustion. The observation was that the blending ratio of 15% resulted in reduced smoke opacity. The test conducted in DI stationary engine by yusuf .T. F. et, al, [4] showed that as the blend increases, the brake power and CO increases in variable speed which was less than 1800 rpm. A review was done by shereena et, al, [5] using catalyst along with methanol in the transesterification process, which results in varying fatty acid content of the biodiesel. This could be a good alternative fuel for diesel. The method of varying the engine displacement by Valentin Mickunaitis, et, al, [6] showed the result of mass increase by 6.5% in petrol and 7.5% in diesel. Hence, there is an increase in fuel consumption and CO_2 emission. Mahin pey.N et al., [7] explains that, low sulphur content with neutral CO_2 is essential for transportation and safe handling. The experiments were conducted by Jewel A. Capunitan et al., [8] one of the valuable energy of fuels is the chemical stock produced from pyrolysis processed of corn stover. The various studies made by, Ilknur Demiral et al., [9] on chromatographic and spectroscopic on bio-oil reveals that corncob stock can be classified as a renewable fuel. Significant reduction of about 52.1% in green house gas emissions is evident [Nathan Kauffman] [10]. The literature on production of raw material for biodiesel revealed by Xiao Huang et al., [11] that a corn stove hydrolysate as fermentation feedstock for preparing microbial liquid reduces Nitrogen content. N.N.A.N. Yusuf et al., [12] showed that compared with petroleum diesel, reduction in emissions of biodiesel, on CO_2, SO_2, particulate, CO and the HC and increase of about 10% NO_x is noticed. However blending biodiesel with petroleum diesel reduces NO_x emission with slight increase in other values but are of acceptable criteria. Sources of producing biodiesel include edible oil of corn and canola [Prafulla D. Patil et al.,] [13] by using reused olive oil methyl ester to study the effect on combustion efficiency. As a result, oxygen concentration increases and it accelerates the combustion. It was also found that the rate of combustion efficiency in the use of reused olive oil, methyl esters, and the rate of combustion efficiency remains almost constant as in the use of diesel oil. A lower energy rate was noticed in the palm oil combustion, done by Tashtoush G et, al,.[14]. It was more efficient and higher rate of combustion (66%) seen in burning biodiesel, when compared with the diesel combustion that is (56%). This is because of the properties like high viscosity, less volatility and density. xiulian yin et al., [15] shows that methanol with catalyst produces high yield in shorter time which results in Flat plate ultrasonic irradiation with mechanical stirring (UIMS) & probe ultrasonic irradiation (PUI) than mechanical stirring (MS) & Flat plate ultrasonic irradiation (FPUI) containing lesser quantity catalyst and less energy consumption. In hydro conversion of SF oil Raney Nickel catalyst was investigated by Gyorgy onyestyak etal., [16] and also tested with some of the octanoic acid as model and compounded at 21 bar in the temperature of 280˚ C to 340˚ C, in addition of ln_2O_2 significantly resulted in high alcohol yields. The combustion and emission results in base line fuel and the emission of smoke and nitrogen oxide measured at the engine exhaust while using cottonseed or sunflower oil in different proportions with two speeds and 3 loads tested by D.C. Rakopoulos et al., [17] the blends of sunflower, cotton seed, corn and olive used in six cylinders turbo charged heavy duty DI, Mercedes benz mini bus engine with the amount of two speed and three load conditions with neat diesel resulted in no changes in the thermal efficiency, reduction of smoke and insignificant increase in NOx. M.S shehata [18] conducted experiments on Sunflower oil and Jajoba oil with 80 % PD by varying different engine speed resulted in lower brake thermal efficiency, smoke, CO and HC. The biodiesel must be used within 6 months from the date of manufacture. Cardone M et.al and Çetinkaya M et.al. reveals that, [19,20]. Specific fuel consumption is increased when biodiesel is mixed with diesel oil, whereas exhaust emissions affects the engine parameters.

1.2 Methodology

The Density, Kinematic viscosity of the PM, CF, & SF fuel is within the limits of the Biodiesel Standards. The calorific value of the vegetable oils is slightly less when compared to diesel. The flash point of the vegetable oils is high compared with pure Diesel and is safe to store and transport. The aim of the work is to analyze emissions and the performance of the Diesel engine by using biodiesel. This has been done by varying the injection pressure, fuelled with transesterified refined Palmolein, refined Corn oil & refined sunflower oil (Methyl Esters) combined with pure diesel at different blends (10%,+ 90% PD, 30%+ 70% PD, and 40%+ 60% PD).

1.3 Nomenclature

PM - Biodiesel Refined Palmolein
CF - Biodiesel refined corn oil
SF - Biodiesel Refined Sunflower oil
PD - Pure Diesel
P - Density, kg/m^3
BP - Brake power, kW
BSFC - Break specific fuel consumption kg/kW- hr
η_{bt} - Break thermal Efficiency
N - Engine running speed, rpm
BIS - Bureau of Indian standards
T - Torque, N- m
CV - Calorific Value of the fuel, kJ
R - Radius of the drum, mm
A - Area of the piston, mm^2
K - No. of cylinders
ASTM - American standards of Testing and Materials

II. METHODOLOGY

2.1 Transesterification process

The Methyl Esters are formed by transesterification process. One liter of refined Vegetable oil is treated with 400 gms of methanol and 8 gms of Sodium Meth oxide as catalyst. In the first stage, oil is preheated up to 20 ºC to 40 ºC and is allowed to cool down naturally. Methanol is added to the catalyst in the preheated oil at cold temperature (Atmospheric or lower) and temperature raised to 70 ºC to 80 ºC for reaction while performing Transesterification process of oil is to reduce high viscosity and gives pure methyl esters without any soap content.

CH_2OCOR			CH_2OH		RCOOR
I			I		
CH_2OCOR	+ 3ROH	$\xrightarrow{\text{catalyst}}$	CH_2OH	+	RCOOR
I			I		
CH_2OCOR			CH_2OH		RCOOR
Transesterification	Alcohol	Catalyst	Glycerin		Methyl Esters

2.2 Table 1 - Specification of Test Engine

Type	:	Kirloskar Vertical, 4S, Single acting, High speed, C.I. Diesel engine
Combustion	:	Direct Injection
Rated Power	:	4.3 kW
Rated Speed	:	1500 rpm
Compression Ratio	:	17.5: 1
Injector type	:	Single 3 hole jet injector
Fuel injection pressure	:	210 bar
Dynamometer	:	Eddy current
Dynamometer arm length	:	200 mm
Bore	:	87.5 mm
Stroke	:	10 mm
Connecting Rod	:	200 mm
Cubic Capacity	:	661.5 cm^3
Fuel tank Capacity	:	6.5 liters
Governor Type	:	Mechanical centrifugal type

2.3 Table 2 - Details of Measuring Systems

1.	Pressure Transducer GH 12 D		
2.	Software Version V 2.0	-	AVL 617 Indi meter
3.	Data Analyzer from Engine	-	AVL PIEZO CHARGE AMPLIFIER
4.	To measure pressure	-	AVL 364 Angle Encoder
5.	Smoke meter	-	AVL 437 C Smoke
6.	5 Gas Analyzer (NO_x, HC, CO, CO_2, O_2)	-	AVL DIGAS 444 Analyzer

2.4 Experimental Setup

A stationary kirloskar 4-Stroke, Direct Injection Diesel Engine was used to evaluate the Emission and performance of the various Refined Vegetable oils at various injection pressure and loading. Table – 1 show the specification of the kirloskar 4-stroke diesel engine. The main parameters are to evaluate the Emissions (CO, HC, NO_x, CO_2) and performance of the Brake specific fuel consumption, and Brake thermal Efficiency. The load on the engine was applied using Electrical loading (Dynamometer). The Eddy current dynamometer for loading is coupled to the engine for various loading (0%, 25%, 50%, 75%, 100%) and at various blends (10%PM + 90% PD, 30%PM + 70% PD, 40%PM + 60%PD, 10%CF + 90% PD, 30%CF + 70% PD, 40%CF + 60%PD, 10%SF + 90% PD, 30%SF + 70% PD, 40%SF + 60%PD,) The exhaust gas emissions from the engine measured by using 5 gas analyzer is AVL DIGAS 444 Analyser (NO_x, HC, CO, CO_2, O_2). The brake fuel consumption was measured by fuel flow meter. The complete setup and schematic diagram of the Experimental setp as shown in Figure 1 and Figure 2.

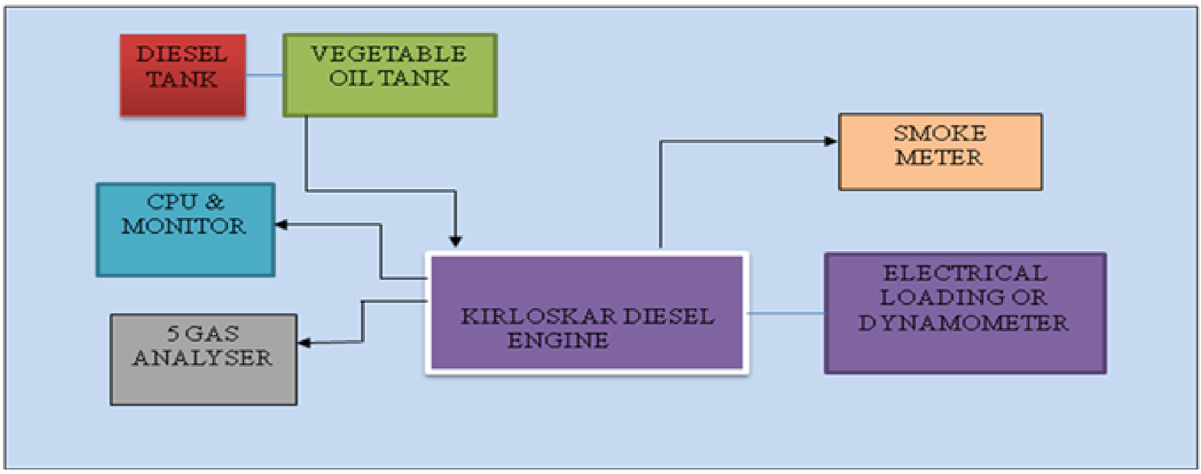

Fig. 1 Schematic Diagram of Experimental setp

1 - Kirloskar Vertical C.I. Diesel Engine, 2 - Fuel Tank, 3 – AVL 437 C Smoke meter, 4 – Electrical loading device, 5 – Engine temperature monitor

Fig. 2 Image of the Experimental setup

2.5 Test procedure

The experiments were conducted at different load conditions, with different Injection pressure at various blends of refined vegetable oil as fuel. The tests were conducted at a constant speed of 1500 rpm. The engine was allowed to run at No load condition for 10 minutes, using each proportion of the blend before applying the load. The loads were increased gradually for each blend in steps of 25 % upto 100% at constant speed of 1500 rpm at different Injection pressures (180 bar, 210 bar, and 240 bar) for various blends .The exhaust gases are measured by 5 gas analyzer from the exhasut stream of the engine. The CO, CO_2, HC, O_2, and NO was measured by 5 gas analyzer as given in Table – 2. Test was conducted to analyze the emissions and performance based on the above conditions. The properties of vegetable oils compared with Diesel, ASTM and BIS standards as given in Table -3

2.6 Table 3 - Comparison of properties of Diesel, Biodiesel standards & Vegetable oils

S.No.	Properties	Diesel	BIS Standard Bio Diesel	ASTM D – 6751(IS 15607:2005)	PM	CF	SF
1.	Cetane Index (min)	46	51	-	36	35	38
2.	Density at 15 ° C kg / m^3	820 – 845	860 – 900	860-900	874	923	923
3.	Kinematic Viscosity at 40 ° C cst	2 – 4.5	2.5 – 6	1.9 – 6	4.9	5.02	4.98
4.	Flash point ° C min	35 ° C	262 ° C	130 ° C	220	162	163
5.	Calroific Value kJ/kg	44,000	-	-	37,037	36,824	39,284

III. RESULTS & DISCUSSIONS

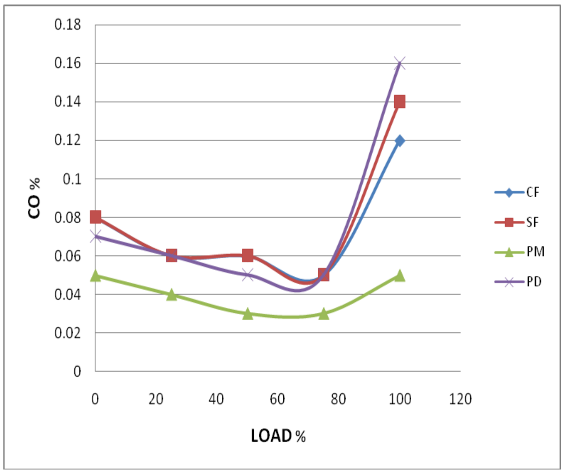

Fig – 3 Variation of CO with respect to various vegetable oils at 240 bar & 30% blend

Carbon mono oxide (CO) :

Fig - 3 shows the CO emissions of 3 refined oils. CO emissions of PM reduces at higher blend ratio (30%PM+70%PD) by 31.25 %, whereas CF and SF reduces at higher loads by 22% and 12.5% when compared to pure diesel. It could be due to higher Injection pressure and effectiveness of the 3- hole nozzle leads to good spray characteristics, According to the literature, the CO emission reduces when compared to diesel. krahl J et al. [21] observed that CO emissions reduced by 50% in rapeseed oil when compared with ultra low sulphur diesel. Ozsezen AN et al. [22] show that WPOME & COME, the CO emissions are decreased by 86.89% and 72.68%. Fontaras et al., [23], CO increases in B50 and B100 in the range of 54% and 95% due to high viscosity and poor spray charecteristics for biodiesel, which lead to poor mixing and poor combustion. Pure biodiesel of karanja and polanga oil reduces the CO emissions compared with diesel. **[**Sahoo PK et al.] [24] reduces the droplet size leads to better combustion. While the difference show that CO emissions of PM is better than CF and SF.

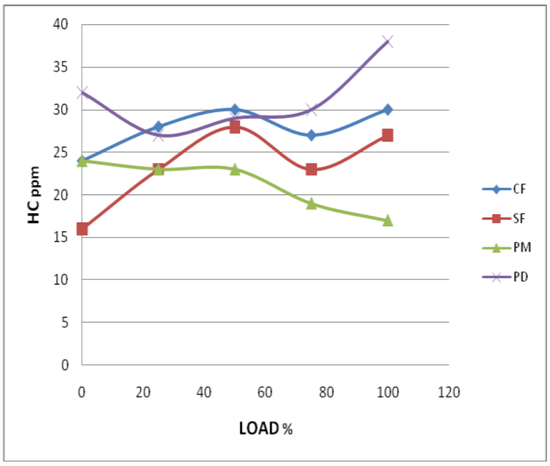

Fig – 4 Variation of HC with respect to various vegetable oils at 240 bar & 30% blend

Hydrocarbon (HC):

It is observed that HC emission reduces in PM by 55.26%, where as in SF is 28.35% and for CF is 18.91% at higher loads at constant speed of 1500 rpm. This could be due to higher injection pressure, the volatility of the fuel increases leads to good combustion, low viscosity leads to increase in gas temperature and better reduction in HC emission. To determine the Emission parameter of unburnt hydrocarbon (HC) is an important parameter. The three test fuels are analyzed and compared with diesel. HC emission shows the variation with respect to Load, injection pressure and blend ratio as shown in fig.4. At high injection pressure the air fuel mixture increases because of high viscosity of rapeseed oil and peak pressures were recorded with different blends. [Canakci M et.al, Devan PK et. al.**]** [25, 26, 27].

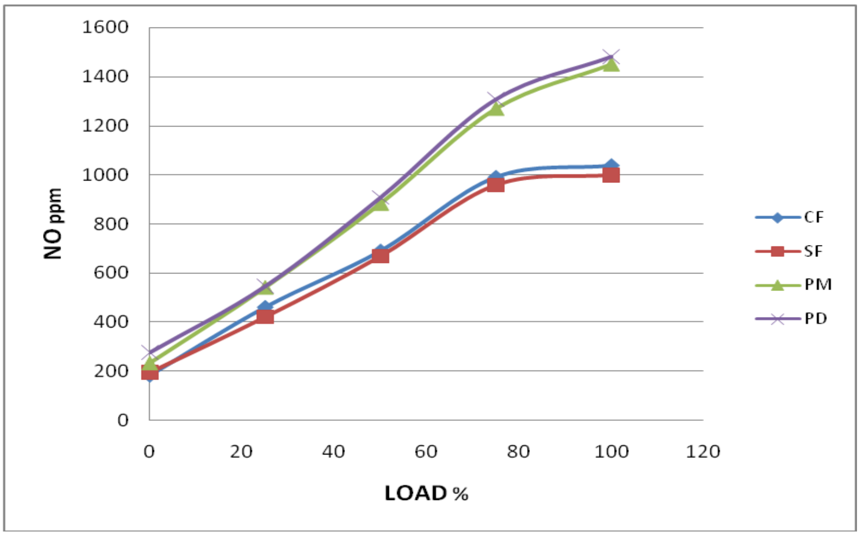

Fig – 5 Variation of NO with respect to various vegetable oils at 240 bar & 30% blend

Nitrogen Oxide (NO):

Fig 5 show the emissions of Nitrogen Oxide (NO) compared with diesel and three types of biodiesel at various injection pressure and loads . The formation of NO is based on combustion temperature. NO emissions are higher at lower injection pressures, However NO emissions are marginally low at 240 bar and 30% blend for PM where as in SF and CF, NO is decreased by 36.66 % & 39.93%. This may be due to the rich air - fuel mixture, reduces combustion temperature Usta N, et at. [28]. The marginal increase in NO due to the presence of oxygen, increases combustion temperature and decreases at lower loads. Cheng AS et al. [29] revials that flame charecteristics of a biodiesel increases the NO formation and reduces the soot heat transfer, resulting increase in flame temperature.

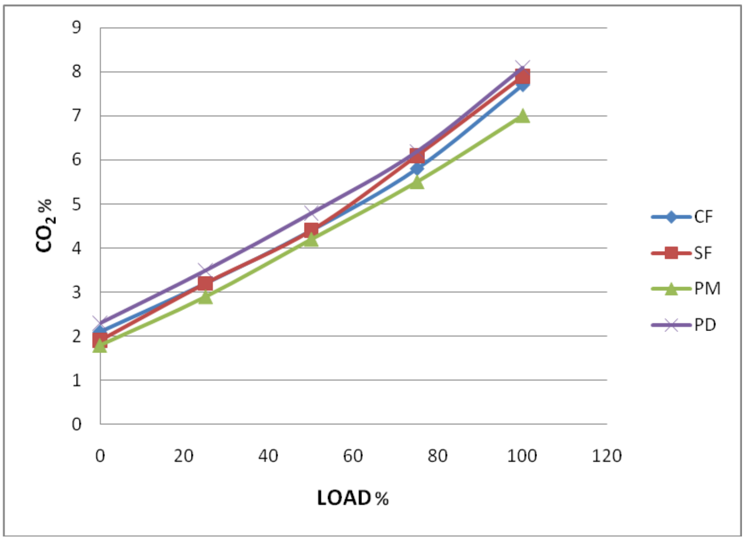

Fig – 3 Variation of CO_2 with respect to various vegetable oils at 240 bar & 30% blend

Carbon di- Oxide (CO_2):

Figure 6 shows the comparision of carbon-di-oxide emissions with three biodiesel fuels with high injection pressure at full load condition under the constant speed of the engine. At lower injection pressure and at various loading there is a marginal increase in CO_2. It is observed that 240 bar and 30% belnds of three biodiesel fuels are decresed in CO_2 when compared to diesel . The emissions of PM, CF and SF reduces by 15.85%, 7.31% and 3.65% respectively. The decrease in CO_2, because of presence of more oxygen atoms in the vegtable oils.

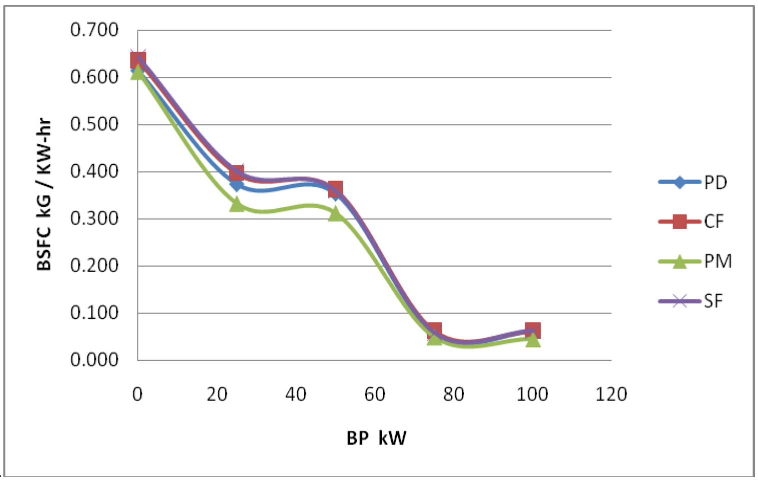

Fig – 8 Variation of BSFC with respect to various vegetable oils at 240 bar & 30% blend

Break Specific Fuel Consmption (BSFC):

The Break specific fuel consumption of the various refined vegetable oils at different injection pressure and loads, compared with pure diesel as shown in fig – 8. The amount of fuel supplied to the engine decreesed at lower loads and at higher loads for PM by 28.57 % at maximum load. There is a increase in CF and SF biodiesel increases by 4.65% at initial load and same as diesel at higher loads when compared with diesel fuel. This shows that PM has lower energy content and higher density of the fuel.

Break Thermal Efficiency (η_{bt}) :

The Break thermal efficiency and performance of the refined vegetable oils as shown in fig-10. It is observed that, the operating conditions of average injection pressure test at each fuel, SF and CF thermal efficiency decreases gradually and same at 3.5 kw and increases at full load by 15.78% compared with pure diesel. The thermal efficiency of the PM is higher than pure diesel. The higher injection pressure increases the atomization of biodiesel using 3-hole nozzle & spray charecteristics (fine spray), and higher oxygen content leads to better combustion, increases the thermal efficiency.

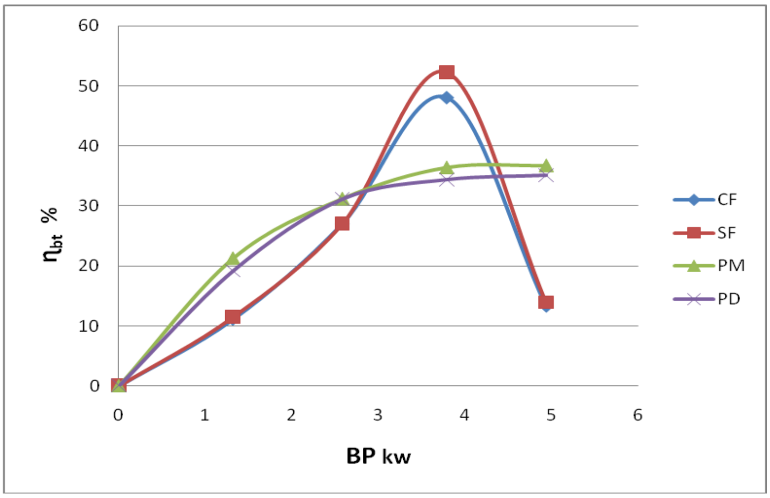

Fig – 10 Variation of η_{bt} with respect to various vegetable oils at 240 bar & 30% blend

IV. CONCLUSIONS

The Engine was tested with various injection pressure, various blends and load. The properties of the biodiesel are analyzed. Following conclusion could be arrived from the graph.

1. It was found that for a blend of diesel of 30% PM, at 240 bar and full load, the CO, HC, CO_2, decreased by 31.25%, 55.26%, 15.85%, and a marginal decrease in NO.
2. BSFC increases with 30% blend at higher injection pressur by 28.57% due to the lower energy content and higher density. The Break power is increased by 15.28%.

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