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Comparative Experimental Investigation on the Performance and Emission of a Diesel Engine fueled with Karanja / Palm Biodiesel Oil and its Blends

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Abstract: This paper investigates the scope of utilizing biodiesel developed from both Karanja and Palm oil as an alternative diesel fuel. The continuous increasing demand for energy and the decreasing petroleum resources has led to the search for alternative fuel which is renewable and sustainable. Vegetables oils are simplest route of biofuel utilization in direct injection compression ignition (DICI) engines however several operational and durability problems are encountered while using straight vegetable oils in CI engines due to their high viscosity and low volatility. The objective is to compare the performance and emission characteristics of Karanja and Palm oil biodiesels on direct injection (DI) diesel engine. Performance and exhaust emissions of diesel engine have been experimentally investigated with Karanja oil (K100) and its blend (K10, K20, K40, K60 and K80) with diesel fuel. Similarly the Performance and exhaust emissions of diesel engine have been experimentally investigated with palm oil (P100) and its blend (P10, P20, P40, P60 and P80) with diesel fuel. Engine performance parameters namely break thermal efficiency, specific fuel consumption (SFC) and mechanical efficiency of CO, HC, CO_2 and NOx were determined for different loading conditions and at constant engine speed of 1500 rpm. From this comparative study it is found that P40 showed better performance and emissions among the tested fuels.

Keywords: Karanja oil, Palm oil, Performance, Emission and Consumption

I. INTRODUCTION

Energy is an essential input for human being to develop in economical, social, and improving the quality of life. Energy demand is also growing at a faster rate with increasing trends of modernization and industrialization, and turned to focus on alternative fuels. Moreover, the availability of fossil resources diminished by day to day which drives to study on conventional diesel engine with the use of alternative fuels. For the past few decades, efforts have been made to commercialize various alternative fuels such as vegetable oil (soya bean oil , rapeseed oil, palm oil, sunflower oil, karanja, jatropha, polanga, rice bran, Moringa oleifera ,Uppage etc.), animal fat (beef tallow etc.),alcohol (Methanol, Ethanol), compressed natural gas, biogas, liquid petroleum gas, hydrogen. Using of Vegetable oils in diesel engines is not a new concept. In 1900, 'Rudolf Diesel' demonstrated his first diesel engine run with peanut oil as fuel at the World Exhibition at Paris. However, due to enormous availability of petro-diesel, research activities on vegetable oil were not seriously pursued. Directly using of vegetable oils as fuel to run diesel engine is made a serious problems such as choking of injector, carbon deposits inside the cylinder more unburnt HC emissions due to its high viscosity. Hence it becomes necessary to convert the vegetable oils as methyl esters or ethyl esters to ensure the standards of ASTM protocol as fuel in diesel engine. Biodiesel fuel is an alternative, renewable, biodegradable, nonflammable, nontoxic green fuel. The common edible oils of biodiesel are palm oil, coconut oil, sunflower oil, and peanut oil etc., whereas Jatropha, Neem, Karanja, Rubber, Rice bran, Mahua, Moringa oleifera Polanga, Uppage etc. are the non-edible oil sources of biodiesel. Biodiesel is a renewable feed stock and as for as environmental concern it is clean burning free sulfur fuel. Biodiesel is an alternative fuel derived from vegetable oils by modifying their molecular structure through a transesterification process [1]. Transesterification involves a reaction in a triglyceride and alcohol in presence of a catalyst to produce glycerol and ester. Most of the researchers have reported that the performance of biodiesel fuelled diesel engine is poor than petro-diesel operated engine. Interestingly, some of the researchers have reported that thermal efficiency is higher with biodiesel than diesel fuel [2].The biodiesel operation reduces the harmful emissions viz., CO, HC and smoke but with little increment of NOx emissions relative to diesel fuel [3]. The biodiesel blends and neat biodiesel in diesel engine reduces carbon monoxides about 3-15% [4] unburnt hydrocarbons about 6-40% [5] and smoke density to 45% [6] compared to ULSD (ultra-low sulfur diesel). However, NOx increased up to 26% [7], BSFC increased by 6-15% [8] decreases in brake thermal efficiency up to 9% [9]. Fujia Wu et al. [10] reported that the NOx reduced in descending order are: CME, PME, SME, WME, and RME; PM emissions reduction varies from 53%-69%. Sahoo et al. [11] concluded that 50% jatropha biodiesel blend showed maximum power with less smoke amongst all the biodiesels and their blends than diesel. Agarwal et al. [12] reported that the rice bran biodiesel fuelled engines produce less CO, unburned HC, and PM emissions compared to diesel fuel but higher NOx emissions. Palash et al. [13] observed that biodiesel blends have strong beneficial impacts on HC, CO and PM emissions but adverse effects on NOx emissions. Similar trends have also been reported by other researchers [14, 15].

II. RELATED WORK

Agarwal [16] conducted an experiment on a diesel engine and observed significant improvement in engine performance and emission characteristics for the biodiesel fuelled engine compared to diesel fuelled engine. Thermal efficiency of the engine improved, brake specific fuel consumption reduced and a considerable reduction in the exhaust smoke opacity was observed. Goering et al [17] studied the characteristic properties of eleven vegetable oils to determine which oils would be best suited for use as an alternative fuel source of the eleven oils tested, corn, rapeseed, sesame, cottonseed, and soyabean oils had the most favourable fuel properties. Altin et al. [18] evaluated the performance and exhaust emissions of a diesel engine using100% refined vegetable oil and their biodiesel. The authors concluded that biodiesel have better performance. Pramanik et al. [19] evaluated the engine performance using the prepared Jatropha blends as fuel. Author reported that significant improvement in engine performance was observed compared to vegetable oil alone. The specific fuel consumption and the exhaust gas temperature were reduced due to decrease in viscosity of the vegetable oil and emission characteristics closer to the diesel fuel. Barabas et al. [20] studied the properties, performance and emissions of the diesel–biodiesel– ethanol blends and comparing them with those of diesel fuel. They reported that, performances decrease, especially at low engine loads. CO emissions decrease significantly due to an increase of CO_2 emissions, as a result of a prolonged oxidation process. The objective of the present study is to compare the performance and emission characteristics of a 4-stroke single cylinder water cooled constant speed diesel engine using neat Karanja oil (K100), Palm oil (P100) and Diesel fuels.

III. MATERIALS AND METHODS

Test Fuels

The test fuel samples in the present study have chosen as neat Karanja oil (K100), Palm oil (P100) and compared the results with Diesel fuel. The Karanja oil and Palm oil are the most suitable feedstock among the non-edible feed stocks in India.

Table 3.1-Properties of the Karanja and Palm Oil Biodiesel

Properties	Test values	
	Karanja Oil	Palm Oil
Density (kg/m^3)	860	876
Kinetic viscosity @ 40^{0}C (mm^2/s)	5.2	4.8
Acid value (Mg of KOH/gm)	0.81	0.30
Pour point (^{0}C)	15	17
Cloud point (^{0}C)	6	13
Flash point (^{0}C)	174	130
Calorific value (KJ/Kg)	37000	38600
Cetane no	41.7	62.8

Experimental Test Setup and Method

The experimental work carried out to investigate the performance and exhaust emission characteristics at different load conditions and compared with diesel fuel. neat Karanja oil (K100), Palm oil (P100) and pure Diesel fuels were used to test a single-cylinder, four-stroke, and water cooled diesel engine with eddy current dynamometer having a rated output of 3.5kW at a constant speed 1500 rpm. The technical specifications of the engine are given in Table 3.2, and the schematic of the experimental setup is shown in Figure 3.1. The power output of the engine was measured by an eddy current dynamometer that was coupled with the engine. The exhaust emissions like HC, CO, and NOx were measured by ARO exhaust gas analyzer. For exhaust gas temperature and smoke measurement ARO smoke meter was used. Temperature indicator was used for the measurement of exhaust gas temperature. The engine and dynamometer were interfaced to a control panel, which is connected to a computer. This computerized test rig was used for calculating the

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engine performance characteristics like brake thermal efficiency and for recording the test parameters like fuel flow rate, temperatures, air flow rate, load etc.

Table 3.2: Specification of engine

Engine manufacturer	Apex Innovations (Research Engine test set up)
Software	Engine soft Engine performance analysis software
Engine type	Single cylinder four stroke multi fuel research engine
No. of cylinder	1
Type of cooling	Water cooled
Rated power	3.5 kW @ 1500 rpm
Cylinder diameter	87.5 mm
Orifice diameter	20 mm
Stroke length	110 mm
Connecting rod length	234 mm
Dynamometer	Type: eddy current, water cooled, with loading unit

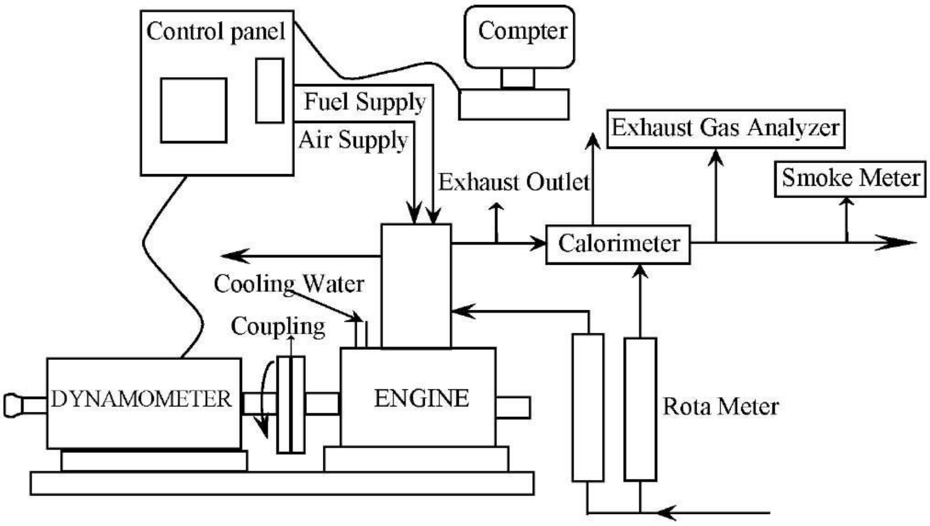

Figure 3.1: Schematic diagram of experimental setup

IV. RESULTS AND DISCUSSION

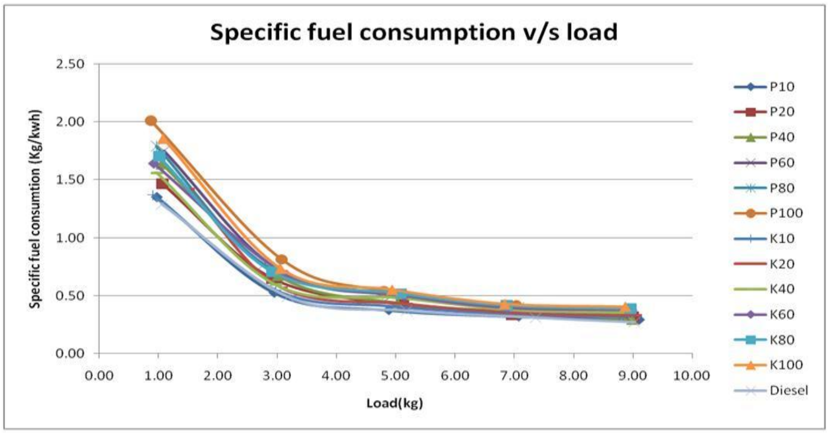

Figure 4.1 Comparison of SFC (kg/kWh) of engine for various palm biodiesel and karanja biodiesel blends with diesel (for different load)

Result:-

Figure 4.1 shows as load increases SFC (specific fuel consumption) decreases for all blends. Comparing SFC of diesel engine for pure diesel to K10, K20, K40, K60, K80, K100, P10, P20, P40, P60, P80, P100 fuel increases in SFC of

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engine at partial load are 10.81%, 16.22%, 29.73%, 35.14%, 40.54%, 48.65%,1.51%, 14.51%, 18.03%, 35.72%, 38.86%, 46.78% and at full load are 18.52%, 22.22%, 29.63%, 40.74%, 44.44%, 51.85%,15.07%, 18.54%, 8.67%, 22.32%, 29.77%, 37.04% respectively so at partial load for P10 blended fuel and full load **P40** blended fuel minimum increases in SFC of engine and its near to diesel fuel. It is also seen that at partial load Less increase of SFC for K20 then P20. And at full load less increase of SFC for P20 Then K20 blended fuel

Analysis and validation:-

The variation in brake specific fuel consumption with load for different fuels shows decline with increase in load due to more increase in brake power with load as compared with fuel consumption. The BSFC in case of blends were higher compared to diesel in the entire load range, due to its lower heating value, greater density and hence higher bulk modulus. The higher bulk modulus results in more discharge of fuel for same displacement of the plunger in injection pump, there by resulting increase in BSFC.[23]. It is also known that biodiesel contains oxygen content, which results in the lower heating value [25]. Thus for the same energy output from the engine, it requires larger mass fuel flow, which increases SFC to compensate the reduced chemical energy in the fuel [26, 27].

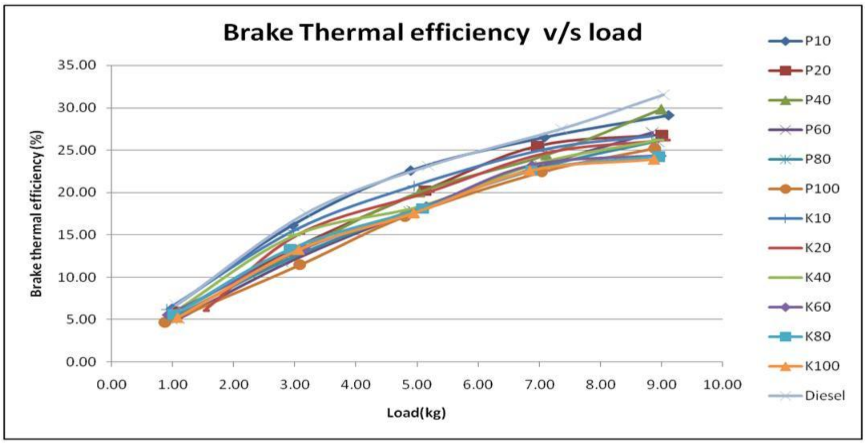

Figure 4.2 Comparison of BTE (%) of engine for various palm biodiesel and karanja biodiesel blends with diesel (for different load)

Result:-

Figure 4.2 shows as load increases BTE (break thermal efficiency) increases for all blends. Comparing break thermal efficiency of diesel engine for pure diesel to K10, K20, K40, K60, K80, K100 ,P10, P20, P40, P60, P80, P100,fuel Decrease in BTE of engine at partial load are 8.46%, 11.47%, 18.68%, 19.07%, 20.21%, 22.64% ,0.48%, 10.89%, 11.68%, 21.55%, 21.71, 24.37% and at full load are 14.37%, 15.78%, 15.85%,21.68%, 21.92%, 23.10%, 6.31%, 13.87%, 4.02%, 12.91%, 16.18, 18.95% respectively so at partial load as well as full load for **P10** minimum decrease in BTE of engine and it is near to diesel fuel as fuel it is also seen that for **P40** blended fuel BTE is not considerably decreases for full load so its near to diesel fuel.

Analysis and validation:-

In general the thermal efficiency depends on the combustion process which is a complex phenomenon that is influenced by several factors such as design of combustion chamber, type of injection nozzle, injection pressure, spray characteristics and fuel characteristics such as cetane number, volatility, viscosity, homogeneous mixture formation, latent heat of vaporization, calorific value etc. The BTE of different fuels is shown as a function of load. The variation in brake thermal efficiency for various blends was less at part load than at higher load due to the raised temperatures inside the cylinder. The brake thermal efficiencies of diesel and the blends of biodiesel with diesel were seen increased with increase in load but tended to decrease with further increase in load. It is evident that diesel fuel has the higher brake thermal efficiency compared to biodiesel and its blends. Due to its higher calorific value the amount of heat produced in the combustion chamber is more, further the combustion is complete and produced higher temperatures. The efficiency of diesel is 31.10%, K20 blend is 26.19% and P20 is 26.79% [22] The BTE of blends were lower than with diesel throughout the entire range showing the poor combustion characteristics of methyl ester due to high viscosity and poor volatility. The BTE of B10, B20 of KOME / POME are closer to that of diesel. At full load conditions BTE of B20 KOME is about 13.87% less than that of diesel. The BTE of B10, B20 of KOME/POME are found better [23].

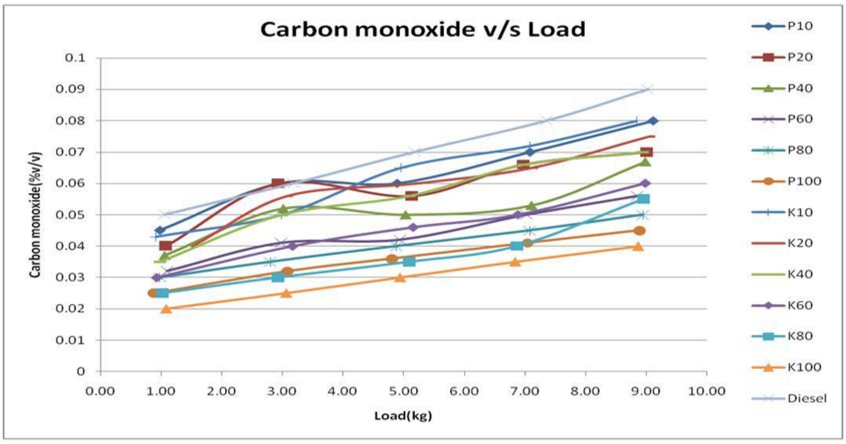

Figure 4.3 Comparison of CO (%v/v) of engine for various palm biodiesel and karanja biodiesel blends with diesel (for different load)

Result:-

Figure 4.3 shows the variation of carbon monoxide emissions as load increases CO (Carbon monoxide) Emission increases for all blends. Comparing CO Emission of diesel engine for pure diesel as fuel to K10, K20, K40, K60, K80, K100, P10, P20, P40, P60, P80, P100 fuel CO emission decreases at partial load are 7.14%, 14.29%, 20%, 34.29%, 50%, 57.14%, 14.29%, 20.00%, 28.57%, 40.00%, 42.86%, 48.57% and at full load are 11.11%, 16.67%, 22.22%, 33.33%, 38.89%, 55.56%, 11.11%, 22.22%, 25.56%, 37.78%, 44.44%, 50.00% respectively. At partial load as well as at full load K100 fuel minimum engine CO emission. It is seen that at partial load as well full load K80, P100 also less CO emission.

Analysis and validation:-

It is observed that the variation of CO emission with engine loading. It was observed that CO emissions are increased with increase in engine load. . Further it can be seen that volume of CO initially decrease but increase at full load indicating better burning conditions at higher temperature assisted by improved spraying qualities with uniform charge preparations of biodiesel.[23] the CO emission is lower for karanja/Palm biodiesel blends as compared with diesel. With the higher combustion chamber temperatures, the combustion in the engine is more complete and the oxidation of carbon monoxide is also improved. Hence carbon monoxide present in the exhaust due to incomplete combustion reduces drastically. Due to the lower calorific value and higher viscosity of bio diesel, the combustion in the diesel engine is insufficient. Thus the temperature produced in the chamber is less and in turn increases the CO emissions. But the oxygen presents in the bio diesel acts as a combustion promoter during the combustion process, which results better combustion and compensate the increase in the emissions.[22] due to some extra oxygen contents, which convert CO to CO_2 and resulted in complete combustion of the fuel [28]. In another study, it has been reported that higher cetane number of biodiesel blends; results in the lower possibility of formation of rich fuel zone and thus reduces CO emissions [21].

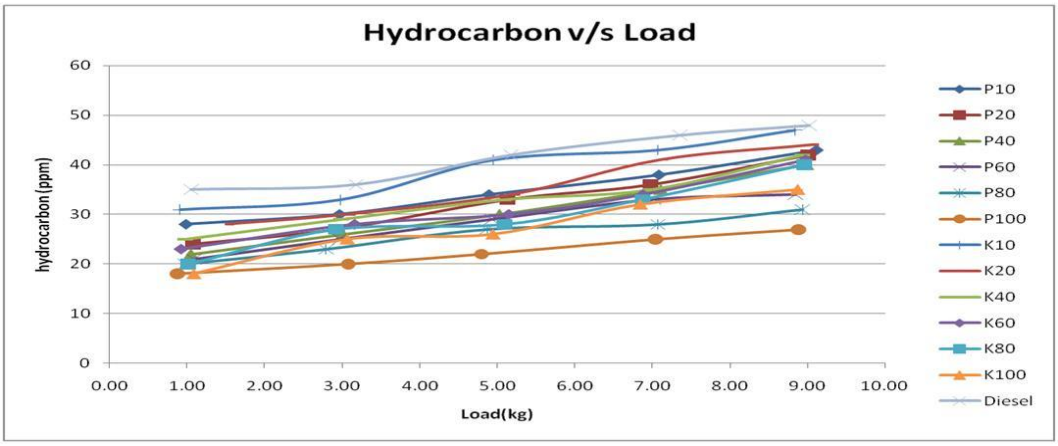

Figure 4.4 Comparison of HC (PPM) of engine for various palm biodiesel and karanja biodiesel blends with diesel (for different load)

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Result:-

Figure 4.4 shows as load increases HC (Hydro carbon) Emission increases for all blends. Comparing HC Emission of diesel engine for pure diesel as fuel to K10, K20, K40, K60, K80, K100, P10, P20, P40, P60, P80, P100 fuel HC emission decreases at partial load are2.38%, 19.05%, 21.43%, 28.57%, 33.33%, 38.10%,19.05%, 21.43%, 28.57%, 30.95%, 35.71%, 47.62% and at full load are 2.08%, 8.33%, 12.50%, 14.58%, 16.67%, 27.08% , 10.42%, 12.50%, 16.67%, 29.17%, 35.42%, 43.75% respectively at partial load and at full load P100 fuel maximum decreases in HC emission and it is seen that for partial load K100,P80 fuel also less emission of HC and its near to P100.

Analysis and validation :-

The HC emissions depend upon mixture strength i.e. oxygen quantity and fuel viscosity in turn atomization. The variations of HC emission for diesel and biodiesel are shown in the figure. The HC emission increases with increase in load on the engine. It is observed from the figure that the decrease in hydro carbon emissions with increase in biodiesel content in the blend. Lower heating value leads to the injection of higher quantities of fuel for the same load condition. More the amount bio diesel leads to more viscosity. Viscosity effect, in turn atomization, is more predominant than the oxygen availability, either inherent in fuel or present in the charge When compared to diesel, it has been reported that the oxygenated compounds(the oxygen availability in the bio diesels)available is more in the blends improve the fuel oxidation and thus it reduces HC emissions **[29].** The emissions of unburnt hydrocarbon for biodiesel exhaust lower than that of diesel fuel the increased gas temperature and higher cetane number of biodiesel could be responsible for this decrease. Higher temperature of burnt gases in biodiesel fuel helps in preventing condensation of higher hydrocarbon reducing unburnt HC. The higher cetane number of biodiesel results decrease in HC emission due to shorter ignition delay. [22, 23, 30, 31]

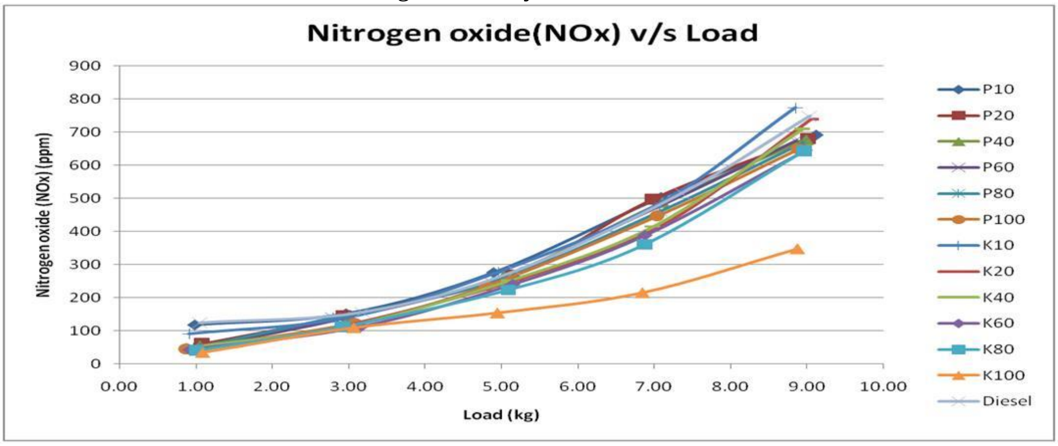

Figure 4.5 Comparison of NO_x (PPM) of engine for various palm biodiesel and karanja biodiesel blends with diesel (for different load)

Result:-

Figure 4.5 shows as load increases NO_X (Nitrogen oxide) Emission increases for all blends. Comparing NO_X Emission of diesel engine for pure diesel as fuel to K20, K40, K60, K80, K100, P10, P20, P40, P60, P80, P100 fuel NO_X emission decreases at partial load are 9.29%, 10.71%, 14.29%, 20.36%, 45.00%,1.43%, 4.29%, 5.00%, 7.86%, 12.14%, 16.07% and at full load are 1.20%, 5.07%, 13.89%, 14.15%, 53.54% , 7.74%, 9.08%, 9.48%, 9.88%, 10.68%, 13.22% respectively . so at partial load and at full load B100 fuel maximum decreases in NO_X emission. It is seen for K10 blends at partial load NO_X emission decrease by1.07% and at full load its increases by3.43%

Analysis and validation:-

The NOx emissions are highest for diesel fuel compared to bio diesels and its blends. It has been reported that formation of NOx emissions are strongly dependent upon the equivalence ratio, oxygen concentration and burned gas temperature. According to Beatrice et al. [32] and Song et al. [33] increased oxygen levels increase the maximum temperature during the combustion, and thus increase NOx formation. It is also agreed that in the production of NO_x, the fuel borne oxygen is more effective than the external oxygen supplied with the air [34]. The exhaust gas temperature with blends having high percentage of Karanja/Palm oil is high as compared to diesel at higher loads. The slower burning character of the fuel causes a slight delay in the energy release, which results in higher temperature in later part of power stroke and exhaust stroke. Increased exhaust gas temperature is due lower heat transfer and the fact that biodiesel has some oxygen content in it which facilitate NOx formation [24].

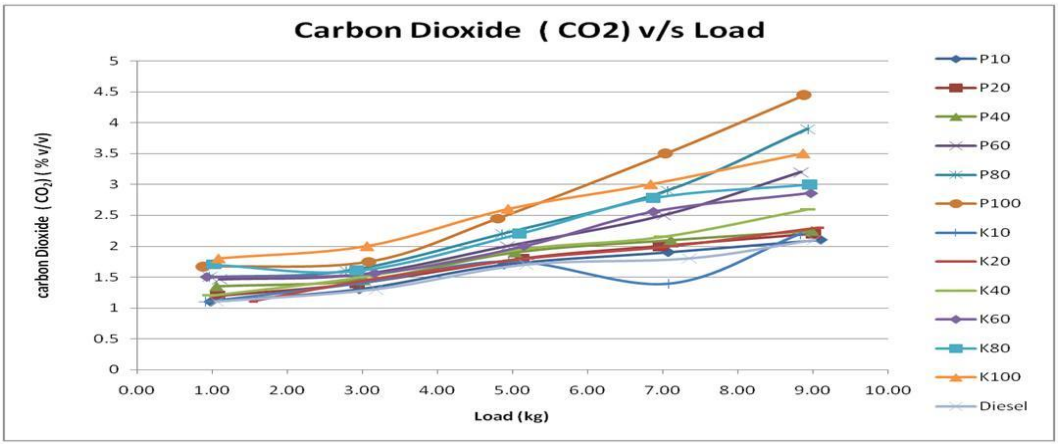

Figure 4.6 Comparison of CO_2 (%v/v) of engine for various palm biodiesel and karanja biodiesel blends with diesel (for different load)

Result:-

Figure 4.6 shows as load increases CO_2 (carbon dioxide) Emission increases for all blends. Comparing CO_2 Emission of diesel engine for pure diesel as fuel to K10, K20, K40, K60, K80, K100, P10, P20, P40, P60, P80, P100 fuel CO_2 emission increases at partial load are 2.94%, 5.88%, 14.71%, 17.65%, 29.41%, 0.00%, 5.88%, 11.76%, 17.65%, 29.41%, 44.12% 52.94% and at full load 4.76%, 9.52%, 23.81%, 36.19%, 42.86%, 66.67%,0.00%, 4.76%, 7.14%, 52.38%, 85.71%, 111.90% respectively . at, partial load and at full load P10 no increase in CO emission and it is seen that forK10 fuel minimum Increases in CO_2 emission.

Analysis and validation:-

It can be observed that CO_2 increases with increases in load for all fuels tested. The trends observed may be because of more fuel being burnt at higher loads due to which more carbon is available to form CO_2.It can be noted that the CO_2 emissions for biodiesel blends increased compared to diesel fuel. This may be attributed to the oxygen content in biodiesel which reacts with unburned carbon atoms during the combustion and increases the formation of CO_2. More amount of CO_2 in exhaust emission indicates the complete combustion of fuel [29].

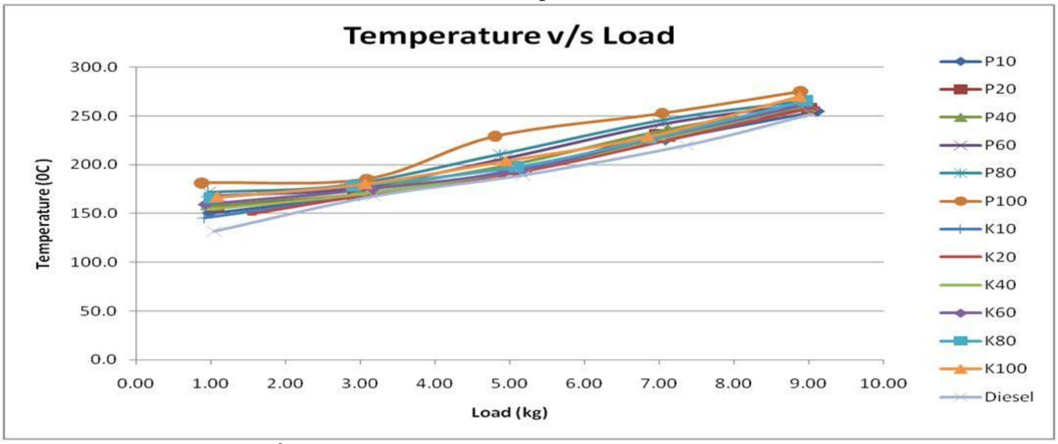

Figure 4.7 Comparison of EGT (^{0}C) of engine for various palm biodiesel and karanja biodiesel blends with diesel (for different load)

Result:-

Figure 4.7 shows as load increases EGT (Exhaust Gas Temperature) increases for all blends Comparing EGT of diesel engine for pure diesel as fuel to K10, K20, K40, K60, K80, K100, P10, P20, P40, P60, P80, P100 fuel EGT increases at partial load are 2.03%, 2.04%, 2.37%, 2.71%, 4.41%, 7.63%,0.61%, 2.22%, 5.76%, 9.03%, 11.16%, 20.95%, and at full load are 3.13%, 2.60%, 3.22%, 4.05%, 5.32%, 7.10%,1.00%, 2.15%, 2.99%, 3.65%, 5.27%, 9.16% respectively . At, partial load and at full load for P10 fuel minimum increases in EGT. It is also seen for partial load and K10, K20, K40, K60 blends and for full load K20, K40; P20 blends not considerable increase in EGT.

Analysis and validation:-

The exhaust gas temperature in the combustion chamber depends on the calorific value, latent heat and viscosity of the fuel injected. The exhaust gas temperature increases with the load for all fuel samples. It is observed that, if the quantity of biodiesel in the blend increases the exhaust gas temperature is also increases. Higher cetane number of biodiesel shortens ignition delay advancing combustion and Due to low calorific

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value of biodiesel and it requires more fuel to generate same power. The combustion of more fuel causes to increase the combustion temperature and in turn exhaust gas temperature [22, 23].

5. CONCLUSIONS

During the present investigation several tests were carried out on a four stroke single cylinder inject diesel engine using diesel, karanja biodiesel and Palm biodiesel at different proportions. From the experimentation following conclusions were drawn.

i. Break thermal efficiency (BTE) in case of diesel, K10, K20, K40, K60 and K80 & P10, P20, P40, P60 and P80 the thermal efficiency, decreases with increasing proportion of biodiesel in the test fuels. This is due to the higher viscosity, density and lower heat value than the diesel fuel.

ii. Brake specific fuel consumption (BSFC) for diesel, K10, K20, K40, K60 and K80 & P10, P20, P40, P60 and P80 decreases for all the test fuels with increase in load. It is seen that BSFC is highest for pure biodiesel and lowest for diesel because of high viscosity, density, low volatility and low heat content of pure biodiesel when compared with that of diesel. Exhaust gas temperature is found highest for pure biodiesel. This may be due to high combustion temperature of biodiesel because of high oxygen content.

iii. Hydrocarbon emission increases with that of load for all prepared test fuels. It is understood that biodiesel produces less HC emission in comparison to that of diesel because of better combustion of the test fuel and its blend with additive due to presence of oxygen.

iv. Hydrocarbon emission increases with that of load for all prepared test fuels. It is understood that biodiesel produces less HC emission in comparison to that of diesel because of better combustion of the test fuel and its blend with additive due to presence of oxygen.

v. It is observed that CO emission decrease with increase in load for all prepared test fuels. CO emission is highest for pure biodiesel because of poor spray characterization that results in improper combustion which gives rise to CO formation.

vi. Without engine modifications (i.e. at 210bar standard engine pressure)K20, P20 and P40 gives the best results both in performance and emissions

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