Extraction and Optimization of Biodiesel Produced from Waste Cooking Oil and Comparing the Performance and Emission Characteristics with Diesel at Different Compression Ratios

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Abstract*- In this present research work, waste cooking oil biodiesel combined with diesel fuel blends were used as alternative fuels for diesel engines. The three different types of blends namely B10, B20 and B30 were prepared. The optimization of production of biodiesel from waste cooking oil from tranesterification process was evaluated on varying the various parameters such as reaction time, KOH concentration and molar ratio. An experimental investigation was carried out to evaluate the performance and emission characteristics of a cooking oil biodiesel blends at various compression ratios like 12, 14 and 16 on a compression ignition engine and important fuel properties were determined. The performance parameters analyzed include BP (Brake Power), BSFC (Brake Specific Fuel consumption), BTE (Brake Thermal Efficiency) and exhaust gas concentration including oxides of nitrogen, HC and CO. The calorific value of optimized waste cooking oil biodiesel was lower than diesel fuel. The flash and fire point of waste cooking oil biodiesel were determined to be 154°C and 160°C respectively which are higher than diesel fuel. The experimental results also showed that the smoke emissions were reduced for all biodiesel mixtures and hydrocarbon (HC) and NO_x emissions of B10 blend is lowest among all. There is a slight increase in the carbon monoxide (CO) emission for the B10 blend as compared to B20 and B30. From all the results it was concluded that B10 blend of waste cooking oil biodiesel act as best alternative fuel among all tested fuel at full load condition.

I. INTRODUCTION

Due to scarcity and increasing costs of conventional fossil fuels, biodiesel as a fuel has become more attractive fuel. Experts suggested that current oil and gas reserves would tend to last only for few decades. To fulfil the rising energy demand and replace reducing oil reserves renewable fuel like biodiesel is within the forefront of other technologies. Biodiesel has proved to be a possible alternative for diesel in compression ignition engine. Biodiesel burns like petroleum diesel as it involves regulated pollutants. Diesel fuel can be replaced by biodiesel made from vegetable oils. The major components of vegetable oils and animal fats are triacylglycerols (TAG). Chemically, TAG are esters of fatty acids (FA) with glycerol (1, 2, 3-propanetriol; glycerol is often also called glycerine).The TAG of vegetable oils and animal fats typically contain several different FA.Thus, different FA can be attached to one glycerol backbone. The different FA that are contained in the TAG comprise the FA profile (or FA composition) of the vegetable oil or animal fat. Because different FA have different physical and chemical properties, the FA profile is probably the most important parameter influencing the corresponding properties of a vegetable oil or animal fat. Biodiesel is now mainly being produced from soybean, rapeseed, and palm oils. India enjoys some special advantages in taking up plantation of tree-borne oil seeds for production of bio diesel due to vast unutilized land. The use of biodiesel results in substantial reduction of un-burnt carbon monoxide and particulate matters. It has almost no sulphur, no aromatics and more oxygen content, which helps it to burn fully. Its higher cetane number improves the combustion. Sunflower and rapeseed are the raw materials used in Europe whereas soyabean is used in USA. Thailand uses palm oil, Ireland uses frying oil and animal fats. In India vast research has been done on biodiesel from jatropha oil. It is proposed to use non-edible oil for making biodiesel, as consumption from edible oil is very high in India. Increase in the molar ratio of alcohol to vegetable oil increases the yield of methyl ester from vegetable oil up to a particular limit. After a higher molar ratio than a particular limit the glycerol becomes difficult to separate. Amount and type of catalyst also affects the conversion rate from vegetable oil to methyl ester. For oils having less fatty acid content alkaline transesterification is used and for oils having higher fatty acid content acid transesterification is used. Stirring helps in higher conversion rate of methyl ester from vegetable oil. Impurities present in vegetable decreases the conversion rate into methyl ester. The proposed study has been carried out with biodiesel derived from cooking oil with the following objectives

- Optimization of production of biodiesel extracted from waste cooking oil through transesterification process.
- Determination of the properties of optimized biodiesel produced from waste cooking oil.
- Evaluation and comparison of the various performance parameters of waste cooking oil biodiesel such as brake power, brake specific fuel consumption, brake thermal efficiency, mechanical efficiency with diesel fuel.
- Evaluation and comparison of various emission characteristics of waste cooking oil biodiesel such as hydrocarbon emissions, carbon dioxide emissions, carbon monoxide emissions and nitrogen oxide emissions with diesel fuel.

II.EXPERIMENTAL SET UP AND PROCEDURE

The experiments were conducted on a single cylinder, water cooled variable compression ratio ignition engine whose specifications are given table no 1 and the engine was coupled with an eddy current dynamometer to measure power and torque. With the help of a load cell connected to the dynamometer ,various loads i.e. 0 kg, 2 kg, 4 kg, 6 kg were applied on the engine. Load sensor was connected with load cell which indicated the load on the load indicator. The exhaust emission parameters were analyzed by the horiba and flue gas analyzer. The exhaust emissions parameters with their respected test methods are given in Table 2

Table no 1
Engine Specification

MODEL	TV1(KIRLOSKAR)
TYPE	Single cylinder 4 strokes,
Compression ratio	12 to 18
Rated power	3.5 KW @1500 rpm
Bore	87.5 mm
Stroke length	110 mm
Connecting rod length	234 mm
Orifice diameter	20 mm
Dynamometer	Eddy current type
Dynamometer arm length	145 mm
Load indicator	Digital, Range 0-50 Kg,
Load sensor	Load cell, type strain gauge
Speed indicator	Digital with non contact type speed sensor
Rota meter	Engine cooling 40-400 LPH; Calorimeter 25-250 LP

Table 2
Emission parameter test methods

S.NO.	Parameters	Test methods
1.	Hydro carbon as HC (ppm)	Horiba analyzer.
2.	Carbon monoxide as CO	Flue gas analyzer
3.	Nitrogen oxides (NO)	Flue gas analyzer
4.	Carbon dioxide as CO2 (%)	Flue gas analyzer

Experimental procedure for performance parameters described below:

- Firstly the diesel was filled in a fuel tank.
- Initially the compression ratio of 12:1 was adjusted.
- After setting the water supply, the cooling water and calorimeter flow was set up at 300 LPH and 70 LPH respectively.
- All the election connections were checked properly and then the electric supply was started.
- The engine performance analysis software package "Engine soft" for on screen performance analysis was opened.
- Then the valve provided at the burette was opened to supply the diesel to the engine.
- Then engine was started and ran for few minutes at no load conditions.
- The log option of the software was selected after that fuel supply was turned on. After one minute the display was changed to input mode and then value of flow of water in cooling jacket and calorimeter was entered. The first reading for the engine was noted for no load condition. Then the fuel knob was turned back to regular position.
- The same steps were repeated for different loads.
- All the readings were saved and then same procedure was done for 14:1 compression ratio.
- The compression ratio was changed by changing the screw arrangement.
- The same procedure was done for 16:1 compression ratio
- After noting all the readings engine was brought to no load conditions and after that engine and computer was turned off to stop the experiment. The fuel supply was also stopped after some time.

Experimental procedure for emission parameters described below:

- Sensors were inserted into the provided outlet for exhaust gases for the required load condition.
- The analyzer was attached to the exhaust outlet and the exhaust gases were passed to the analyzer with the help of sensors.
- After this the displayed three readings on the digital screen of analyzer were noted.
- Mean value of these three readings were calculated.
- Then the sensors were removed.
- The above steps are repeated for different fuels and different load conditions.

III. RESULTS AND DISCUSSIONS

Optimizing of tranesterification of waste cooking oil

The optimization of production of biodiesel from waste cooking oil from tranesterification process was evaluated on varying the various parameters such as reaction time, KOH concentration and molar ratio. The reaction temperature for transesterification process was kept at 60^{O}C. On comparing these samples on the basis of minimum viscosity, maximum yield and minimum fatty acid content, the optimized result was obtained at molar ratio of 5:1, 0.5% KOH and at a reaction time of 60 minutes. The maximum yield of 98% was obtained at these conditions.

The FFA content and viscosity at the optimized conditions were evaluated as 0.0705 and 4.376 centi poise respectively. It was observed that properties of waste cooking oil biodiesel given in Table No. 3 were conforming to the latest biodiesel standards. The calorific value of optimized waste cooking oil biodiesel was 9262 kcal/kg which is 7.9 % lower than diesel fuel. The flash and fire point of waste cooking oil biodiesel were observed to be higher than of diesel fuel. The cloud and pour point were also observed to be lower for biodiesel fuel.

Table no. 3
Properties of fuel

Property of oil	ASTM standards	Diesel	Waste cooking oil (B100)biodiesel
Density kg/m3	------------	850	875.8
Kinematic viscosity	1.9-6.0	2.049	4.336
Flash point, OC	>130	78	154
Fire point, OC	>53	83	160
Cloud point, OC	-3 to 12	<10	-2
Pour point, OC	-15 to 10	-6	-6
Calorific value, kJ/kg	> 33000	42000	38896.2
Carbon residue, (%)	<0.05	0.0214	0.0179%
Ash content,%	0.02% max	0.02	0.02

Performance characteristics

BP was observed to be decreased with the amount of blend in the diesel. This is due to the low heating or calorific value of blends. The brake power of diesel was observed to be higher than the biodiesel blends. The BP of B10 was higher than other blends due to its more calorific value. It was observed that at higher loads the variation in BP is less due to less heat losses at higher loads. It was also observed that as the load increased the brake power increases, due to increase in torque with load. The variation of brake power (BP) with load and blend proportion at CR16, CR 14 and CR 12 is illustrated in Fig 1, 2, 3 respectively. It is seen that engine brake power increased, as the compression ratio was increased. This is due to the increase in brake torque at high compression ratios. Increase in compression ratio induces greater turning effect on the cylinder crank. This means that the engine is giving more push on the piston, and more torque is generated. The effect of varying compression ratio on brake bower of B10 blend is illustrated in the Fig 4. It was observed that the BP with CR16 was higher than with CR14 and CR12 at all loads. The brake specific fuel consumption of three different blends of waste cooking oil biodiesel i.e. B10, B20, and B30 were compared with the diesel fuel. It was observed that BSFC decreased sharply with load for all fuels and at any compression ratio. The main reason for this can be that 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. The BSFC of all biodiesel blends was found to be higher than diesel fuel. As the proportion of biodiesel blend increased, the BSFC was observed to be increased. The BSFC of LB30 was higher than all other fuels. This is due to the higher density of waste cooking oil biodiesel. As the percentage of blend increases the density also increases. The higher densities of biodiesel blends caused higher mass injection for the same volume. Due to high density of biodiesel the fuel consumption is more. The variation of BSFC of diesel and different blends with load at CR16 is shown in the Fig 5. The variation of BSFC at full load was less as compared to part loads. This was due to less variation in brake power (BP) at full loads. The variation of BSFC with load for CR14 and CR12 is illustrated in Fig 6 and 7 respectively. The brake specific fuel consumption was observed to be decreased with the increase in compression ratio from 12 to 16.The brake specific fuel with CR 16 was found to be less than that of CR14 and CR12. This is mainly due to the increase in brake power with compression ratio. The higher compression ratio induces better combustion due to increase in temperature inside the combustion chamber which led to improved combustion and hence increase in brake power and therefore decrease in brake specific fuel consumption. The variation of brake specific fuel consumption with increase in compression ratio of B10 blend is illustrated in Fig 8. The brake thermal efficiency was observed to be low at part loads. The brake thermal efficiency was improved with the load for the main reason that relatively less portion of the power is lost with increasing load. Also, brake thermal efficiency is found to decrease with the increase in blend content .This is due to the higher viscosity of blends which led to the poorer atomization and poor combustion. The another reason for the decrease in brake thermal efficiency with the blend content is due to the increase in fuel consumption which is mainly due to higher density of blends. The variation of the brake thermal efficiency with load and blend content at different compression ratio is illustrated in fig 9, 10, 11. At CR 16 the highest brake thermal efficiency was found to be 21.9% with diesel fuel and among blends, the brake thermal efficiency of B10 i.e. 21.4% was the highest. With the increase in compression ratio the brake thermal efficiency was found to be increased. The brake thermal efficiency with the compression ratio16 was found to be highest at all loads. The trend is observed because at higher compression ratio, the air temperature is high which results in better combustion of fuel. The variation of brake thermal efficiency with load and compression ratio for B10 blend is illustrated in the Fig 12. The mechanical efficiency of diesel fuel was observed to be lowest at all loads. With increase in load the mechanical efficiency increases due the increase in brake power. Blended fuels exhibited better mechanical efficiency compared to the neat diesel fuel. This is due to better lubricating properties of blended fuels compared to diesel. The mechanical efficiency of B30 blend was observed to be the highest among all fuels i.e. Diesel, B10, B20.This is due to more viscosity, B30 blend have better lubricating properties. The mechanical efficiency of B30 was 35.7% while that of diesel was 34.4% at full load at CR14 and at CR16 it was 39.1% and 36.5% Comp. ratio with B30 and diesel respectively. The variation in mechanical efficiency with load at different compression ratio is illustrated in Fig 13, 14, 15.It was observed that with increase in compression ratio the mechanical efficiency increases. The mechanical efficiency of at CR 16 was higher than at CR14 and CR12 at all loads. The mechanical efficiency of B30 at CR 16 at full load was 39.1% while that at CR14 and CR12 was 35.7% and 33.9% respectively. The variation of mechanical efficiency of B30 blend at all compression ratios is illustrated in Fig 16. This increase in mechanical efficiency is observed due to the increase in brake power with the increase in compression ratio. Since the brake power at CR 16 is higher than at CR14 and CR 12 therefore mechanical efficiency is higher at CR 16.

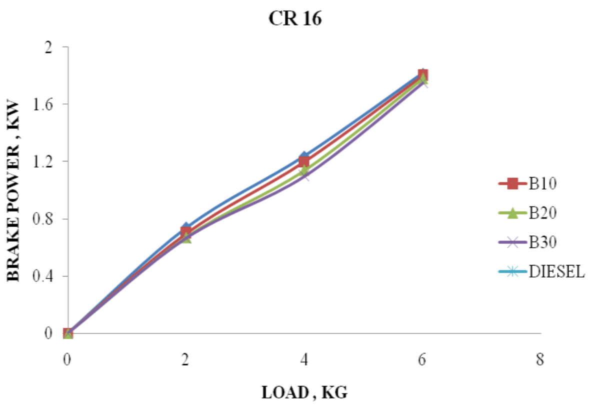

Fig 1: Variation of brake power with load at compression ratio 16

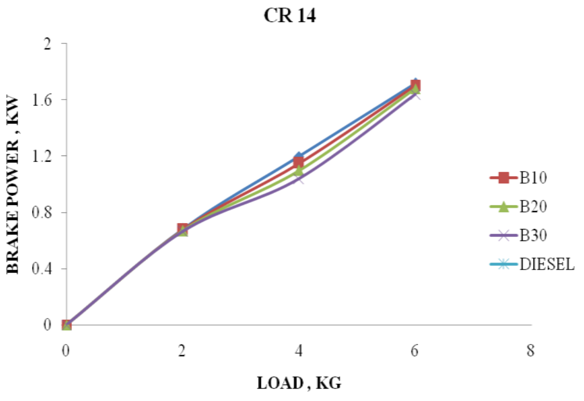

Fig 2 Variation of brake power with load at compression ratio 14

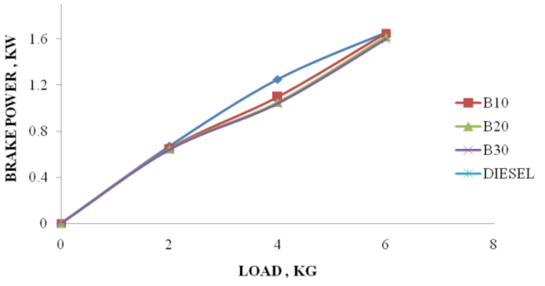

Fig 3: Variation of brake power with load at compression ratio 12

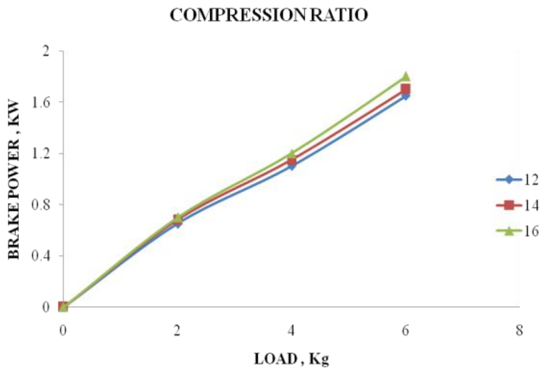

Fig 4: The variation of brake power with load at different compression ratios for B10 blend

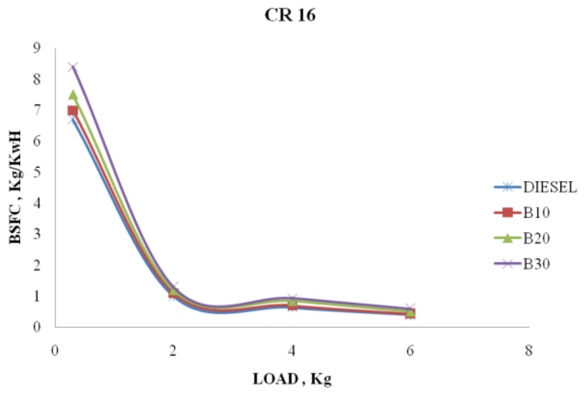

Fig 5: Variation of BSFC with load at compression ratio 16

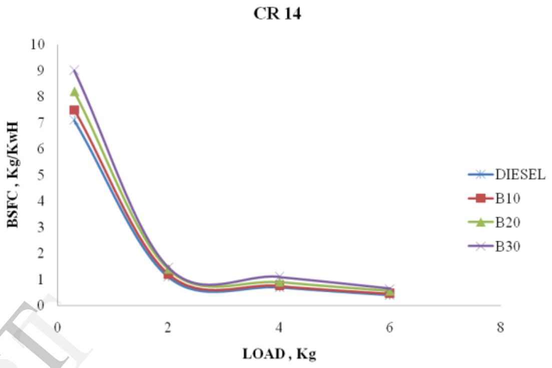

Fig 6: Variation of BSFC with load at compression

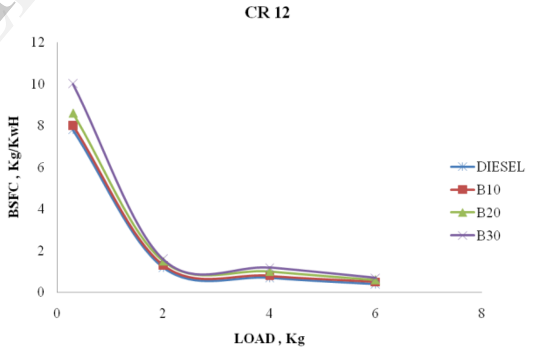

Fig 7: Variation of BSFC with load at compression ratio 14

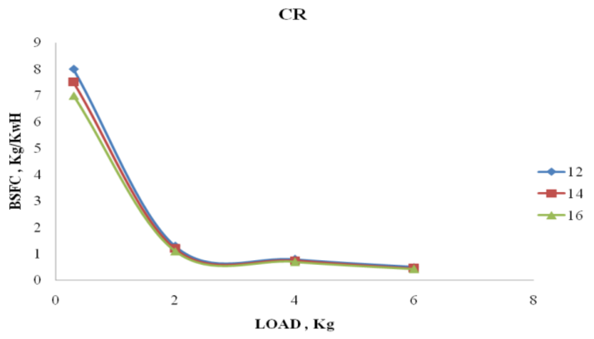

Fig 8: Variation of BSFC with load at different compression ratio for B10 blend

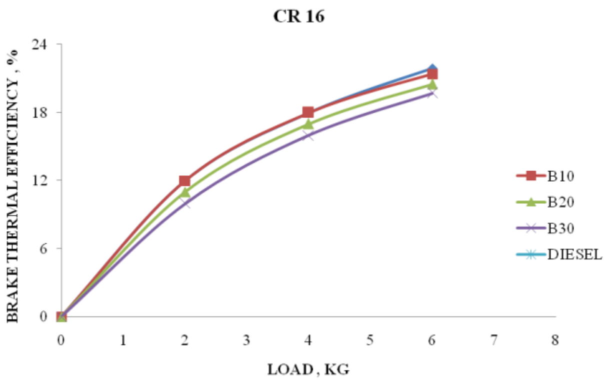

Fig 9: Variation of Brake Thermal Efficiency with load at compression ratio 16

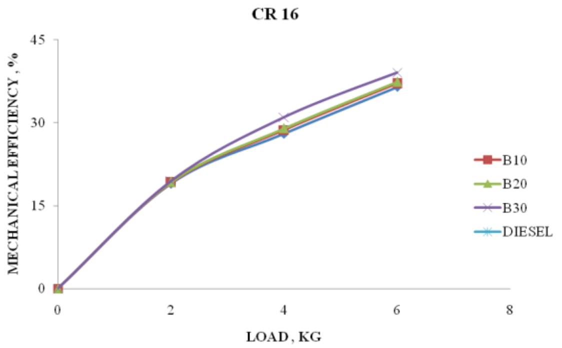

Fig 13: Variation of Mechanical Efficiency with load at compression ratio16

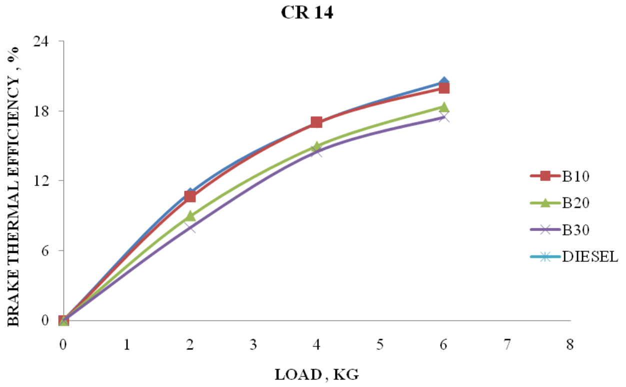

Fig 10: Variation of Brake Thermal Efficiency with load at compression ratio 14

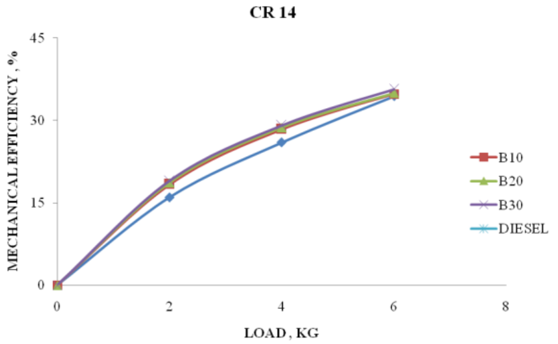

Fig 14: Variation of Mechanical Efficiency with load at compression ratio14

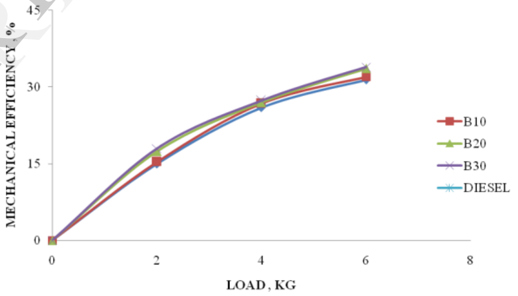

Fig 15: Variation of Mechanical Efficiency with load at compression ratio12

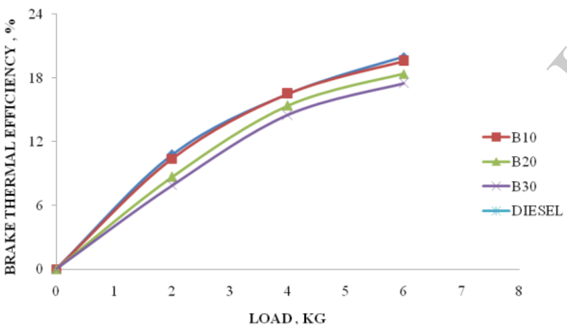

Fig 11 V:ariation of Brake Thermal Efficiency with load at compression ratio 12

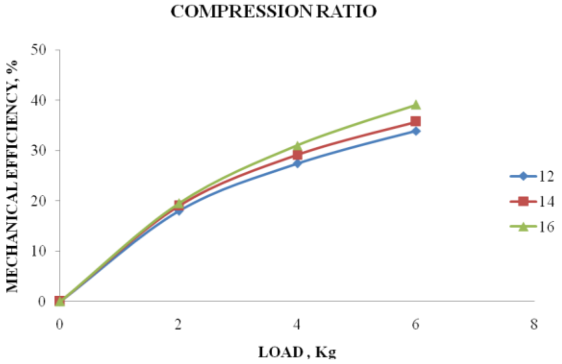

Fig 16: The variation of mechanical efficiency of B20 blend at all

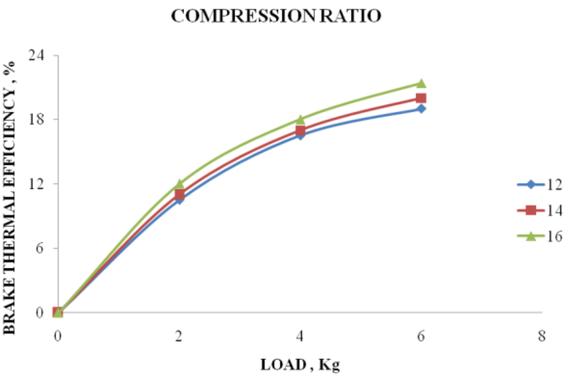

Fig 12: The variation of brake thermal efficiency with load at different compression ratios for B10 blend

Emission Characteristics

The variation of hydrocarbon emissions with load for diesel, B10, B20, B30 are compared at two different compression ratios. It was observed that with increase in load the hydrocarbon emission increases .It is due to entering of rich fuel air mixture in the combustion chamber because of increase in fuel consumption. This leads to improper combustion due to which unburnt hydrocarbon emissions increases. It was also observed that with increase in blend content the HC emission decreases. This is due to the high cetane no. of biodiesel blends. Higher cetane no. lowers the combustion delay which improves the combustion. Another reason for low hydrocarbon emission with the increase in blend content is due to more oxygen content than diesel fuel. It was observed that HC emissions for diesel fuel were highest and for B30 blend it was lowest. The HC emissions for different fuels with load at CR 16 and CR 14 are illustrated in the Fig 17 and 18 respectively. The carbon monoxide emissions results from incomplete combustion. The CO emissions for diesel fuel, B10, B20, B30 with load are compared at CR16 and CR14. It was observed that with increase in load the CO emissions increased .This is due the injection of rich air fuel mixture which led to incomplete combustion of fuel. It was observed the CO emissions of B10 blend were nearly same as that of diesel fuel. But with further increase in blend content the emissions were observed to be decreased. This may be due to the higher oxygen content which leads to complete combustion. The CO emissions were decreased with increase in compression ratio because of increase in air temperature which lowers the delay period and improves the combustion. The CO emissions for the B30 blend at CR16 were found to be the lowest among all fuels. The CO emissions for Diesel, B10, B20, and B30 with load at CR14 compression ratios are illustrated in the Fig 20. The NO_x emissions of diesel, B10, B20, B30 with load at compression ratios CR14 and CR16 were compared. NO_x emissions are temperature dependent. It was observed that NO emissions increase with increase in load. This is because of increase in temperature inside combustion chamber at high loads. NO_x emissions were observed to be increased with increase in blend content. This is because of high oxygen content in the biodiesel fuel. Nitrogen from air can easily mix with oxygen and produces the NO_x emissions. These emissions were observed to be increase with compression ratio due to lower ignition delay which increases the peak pressure and temperature. The NO_x emissions for diesel, B10, B20, B30 with load at CR16 and CR14 are illustrated in the following Fig 21 and 22 respectively. It can be seen from the figures that NO_x emissions for the diesel were lowest at both compression ratios. The NO_x emissions of B20 blend were observed to be highest at all loads and both compression ratios. The CO_2 emissions for diesel, B10, B20, B30 with load at CR16 and CR14 were compared. It was observed that with increase in load the CO_2 emissions increases due to better combustion at high loads. The CO_2 emissions with diesel were highest .As the blend content increased, the CO_2 emissions were decreased. Carbon dioxide is formed on complete combustion of the fuel in oxygen. Here, carbon dioxide formation is less due to the fact that biodiesel in general is a low carbon fuel and has a lower elemental carbon to hydrogen ratio than diesel fuel. The CO_2 emissions were observed to be increased with the compression ratio this is due to the lower ignition delay that led to better combustion. The variation of CO_2 emissions with load at CR16 and CR14 are illustrated in the Fig 23 and 24 respectively. It was observed that CO2 emissions were lowest for B30 blend at all loads for both compression ratios.

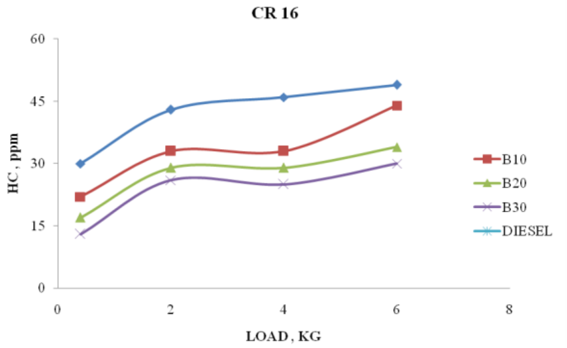

Fig 17: Variation of hydrocarbon emissions with compression ratio 16

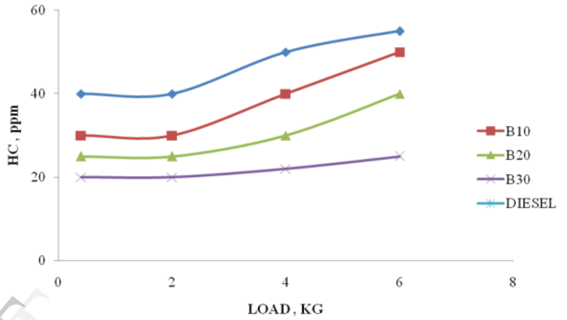

Fig 18: Variation of hydrocarbon emissions with compression ratio 16

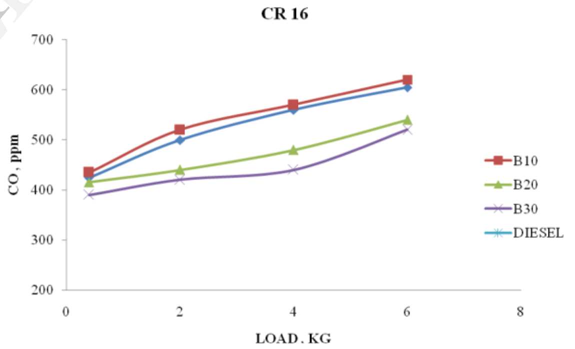

Fig 19: Variation of CO emissions with compression ratio 16

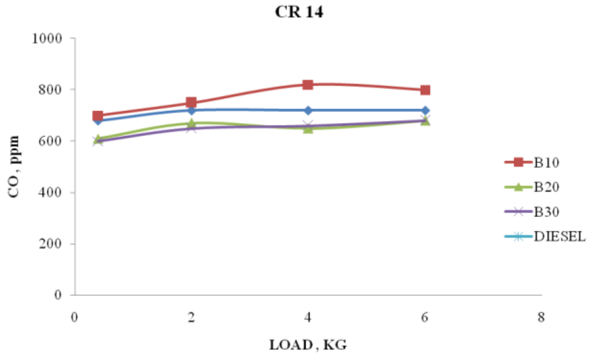

Fig 20: Variation of CO emissions with compression

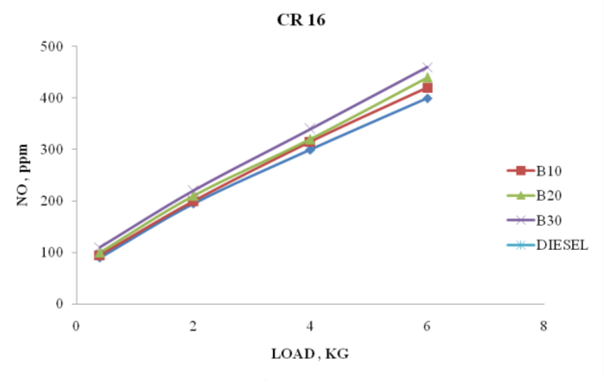

Fig 21: Variation of NO emissions with compression ratio 16

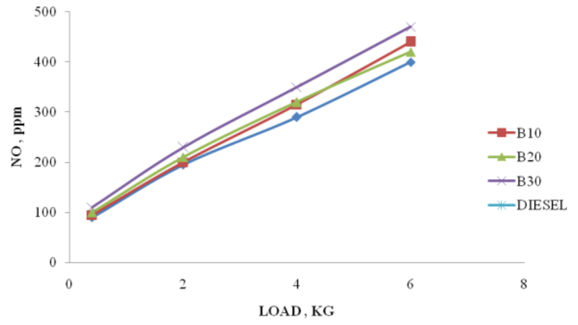

Fig 22: Variation of NO emissions with compression

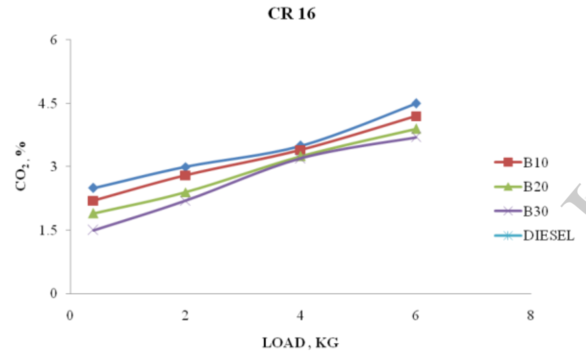

Fig 23: Variation of CO$_2$ emissions with compression

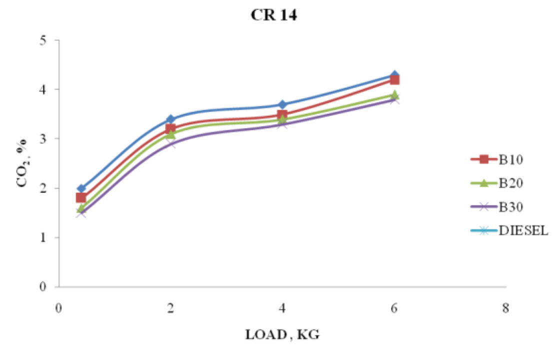

Fig 24: Variation of CO$_2$ emissions with compression

IV. CONCLUSION

The optimization of biodiesel production from waste cooking oil was evaluated using tranesterification process .The performance and emission parameters for diesel fuel were compared with B10, B20, and B30.The following conclusions can be drawn from the present study:

- The optimum conditions for maximum biodiesel production were obtained at molar ratio of 5:1, reaction time 60 minutes and .5% KOH concentration. A maximum yield of 98% was determined.
- The fuel properties of optimized biodiesel were found to be comparable to diesel and were conforming to the latest biodiesel standards.
- The calorific value of optimized waste cooking oil biodiesel was 9261 Kcal/Kg which is 7.9% lower than diesel fuel.
- The flash and fire point of waste cooking oil biodiesel were determined to be 154°C and 160°C respectively which are higher than diesel fuel.
- The cloud and pour point were also observed to be lower for biodiesel fuel.
- The performance parameters such as BP, brake thermal efficiency, with B10 were observed to be nearly similar to diesel fuel at all loads.B10 have better performance parameters than other blends .At higher compression ratio the performance of VCR engine was better. The BSFC of B10 blend was lowest among the blends.
- The emissions parameters of B10 blend such as CO, CO, and HC were nearly similar to diesel fuel. With increase in blend content these emissions were observed to be decreased. Among all blends, these emissions from B20 blend were observed to be lowest. The NO$_x$ emissions for B10 blend were observed to be lowest. The CO and HC emissions were lowered at higher compression ratio while NO$_x$ and CO$_2$ emissions were higher at high compression ratio.

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