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Experimental studies on a VCR Diesel Engine using blends of diesel fuel with Kusum bio-diesel

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Abstract – The endless scenario of fast depletion of fossil fuel resources and the unavoidable hike in fuel prices and to replenish the demand, attention has been focused towards alternate fuels for use in diesel engines. The vegetable oil has become popular, economic and implementable source among the various fuel alternatives. The Kusum bio-diesel is a non-edible, biodegradable fuel suitable for diesel engines. Kusum bio-diesel has been prepared by transesterification method. An experimental investigation is made to evaluate the use of Kusum bio-diesel in a direct injection (D.I), Computerized Variable Compression Ratio (VCR) engine. The tests are conducted using different blends of the neat diesel and Kusum bio-diesel at different compression ratios, with the engine working at constant speed. Fuel consumption, and exhaust gas emissions such as carbon monoxide and total unburned hydrocarbons are observed. The variation of performance of engine, combustion and exhaust emissions from the engine with reference to neat diesel fuel and the Kusum bio-diesel are determined and compared. The experimental results show that mechanical efficiency of the engine is more for the B15blend of Kusum oil with diesel at all loads and for B25 at high loads. The brake thermal efficiency of the engine with Kusum methyl ester-diesel blend was significantly better than that with neat diesel fuel.

Key Words - VCR engine, Emissions, Combustion, Kusum bio-diesel and Neat diesel.

1. INTRODUCTION

Fast depletion of the fossil fuels, serious threat to the environment from exhaust emissions and global warming have led to incline towards alternate fuels for engines all over the world. In this context of fast depletion of fossil fuels and increase in diesel engine vehicles, Importance has been given to renewable fuels like vegetable oils. Among many usage applications commercial transportation, agricultural machinery require diesel, for its easy operation. The consumption of diesel oil is several times higher than that of petrol. The increasing number of auto mobiles has led to increase in demand for fossil fuels. For developing countries, the import bill has become a concern and hence paying serious attention towards renewable energy resource. Besides this, fossil fuel sources have finite life and the ever increasing cost of these have led towards searching renewable fuels, for ensuring energy security and environmental protection. Various sectors like transportation, agriculture and industries are using diesel fuel as a major source of power. Biodiesel is a cleaner fuel replacement for diesel available from natural sources such as virgin and used vegetable oil, algae and animal fats.

Biodiesel has become one of the most energy-efficient environmental friendly options in recent times to fulfill the future energy needs. Biodiesel can be obtained from both vegetable oils and animal fats. But getting biodiesel from animal fats is costly and laborious. During the last 15 years, biodiesel has progressed from the research stage to a large scale production in many developing countries. In Indian context, non-edible oils are emerging as a preferred feedstock and several field trials have also been made for the production of biodiesel.

This work examines the interactions resulting from the application of the kusum bio- diesel on a practical heavy-duty VCR diesel engine system, with the aim of understanding their impact on emissions and performance. The aim of this experimental study is to assess the new fuel contributions to potential performance and efficiency penalties An extensive investigation encompassing the performance, emissions is taken up to evaluate the engine under the conditions of different fuel blends and compression ratios. The merits and the demerits of the kusum bio-diesel fuel implementation with the neat diesel application are discussed.

2. LITERATURE REVIEW

S. K. Acharya et.al, [1] studied the effect of preheated Karanja and Kusum oil and its emission characteristics. This investigation was done on a single cylinder, four stroke, water cooled diesel engine with constant compression ratio (16.5:1) and 1500 rpm. Preheating of Kusum oil resulted in the reduction of the exhaust gases such as carbon monoxide, hydrocarbon, and carbon dioxide. Muralidharan et.al, [2] experimented the performance, emission and combustion characteristics of waste cooking oil methyl ester. In these investigations, the authors used four different biodiesel blend fuels (B20, B40, B60 and B80). This work was done on a four stroke, single cylinder VCR engine at constant speed 1500 rpm and at a compression ratio 21:1 under different loads. It has been observed that the reduction in carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbon (HC) and increment in oxides of nitrogen when blends were used as fuel. It was observed that mostly the same combustion characteristics were observed for waste cooking oil methyl ester and its blends followed by standard diesel fuel.

Sharma et.al, [3] examined that the Kusum seed oil is an ideal feedstock for preparation of bio-diesel. In this experiment, the authors have used acid esterification and alkaline transesterification processes for bio-diesel preparation and bring to down acid value of vegetables oils. Biodiesel obtained from vegetable oils in a common diesel engine leads to more reduction in un-burnt hydrocarbons, carbon monoxide and particulate matter and emissions of oxides of nitrogen are either increased or reduced slightly depending on the cycles and testing methods. Many studies on exhaust emissions using vegetable oils and biodiesels have reported reduction of emissions of un-burnt hydrocarbons, carbon monoxide, smoke and particulate matter with a small increase of oxides of nitrogen.

Nobukazu Takagi and Koichiro Itow [4] conducted experiments on a single cylinder Direct Injection diesel engine with palm oil, rapeseed oil and the blends of palm oil and rapeseed oil with ethanol and diesel fuel at different fuel temperatures. They found acceptable performance and engine exhaust emissions with the vegetable oils and their blends for short-period operation. Compared to diesel, the methyl esters of palm oil and rapeseed oil offered lower smoke, emissions of nitrogen, engine noise and higher thermal efficiency.

Wang et.al.,[5] experimented with blends of neat diesel and vegetable oil and found higher carbon monoxide, lower carbon dioxide, lower HC emissions, except at 50% vegetable oil blend, due to higher oxygen content in the vegetable oil. Lower emissions of oxides of nitrogen were reported as compared to neat diesel due to lower calorific value of vegetable oil. H. Raheman and A.G. Phadatare.,[6] examined that the blends of esterified Kusum oil with diesel up to 40% by volume can substitute neat diesel for getting lower emissions. The reduction in exhaust emissions together with an increase in torque, brake power, brake thermal efficiency and reduction in brake-specific fuel consumption made the blends of Kusum esterified oil (B20 and B40) a suitable alternative fuel for diesel and could help in controlling air pollution.

Kalligeros et.al.,[7] conducted experiments on a single cylinder direct injection diesel engine using olive oil and sunflower oil as fuels in different proportions with marine diesel. They found lower un-burnt hydrocarbon, carbon monoxide, nitrogen oxide and particulate matter with blends compared to neat diesel oil. Nwafor et.al.,[8] examined the emission characteristics of a diesel engine operating on rapeseed methyl ester and found that rapeseed methyl ester and its blends with diesel fuel emitted more carbon dioxide than with diesel fuel. Hydrocarbon emissions were observed to decrease drastically when running on rapeseed methyl ester. Hydrocarbon emissions are observed to increase with increased amount of diesel fuel in the blend. Senatore et.al.,[9] experimented and found that with rapeseed oil methyl ester, heat release always takes place earlier than that with mineral diesel, because fuel injection starts earlier for biodiesel blends due to their higher density, leading to higher peak cylinder temperatures.

McDonald et.al.[10] experimented with soya bean oil methyl ester as a fuel and obtained the heat release from the actual pressure angle diagram in an indirect injection diesel engine and concluded that the overall combustion characteristics were more similar to diesel operation except shorter ignition delay for soya bean methyl ester. Niehaus R. A et.al [11] experimented and found that with thermally decomposed soybean oil produced slightly less power than diesel fuel and also produced low levels of hydrocarbons and NO_X emissions. With thermally cracked soybean oil, the heat release rate was lowered as compared to diesel. They observed and suggested that by advancing the injection timing, combustion temperatures can be increased. Besides this, a higher rate of cylinder pressure rise and higher levels of premixed burning with the oil can be achieved with advancing injection timing.

3. EXPERIMENTATION

3.1 Experimental set up

Direct Injection, VCR Diesel engine is utilized for the experimentation. Experimentation is carried out at various engine loads (Engine Loading device is eddy current dynamometer) to record the cylinder pressure and finally to compute heat release rates with respect to the crank-angle. Engine performance data is acquired to study the performance and engine pollution parameters.

The exhaust gas analysis of different components of exhaust gas are measured and compared and engine performance is analyzed for the parameters mentioned above with the implementation of blends of neat diesel with kusum bio- diesel at different compression ratios. The engine setup is shown in fig.1 and 1a.

Fig.1, Computerized VCR engine test rig

Fig.1a, Computerized VCR engine test rig

Table 1, Specification of the DI-Diesel Engine

Rated Horse power:	6 kW
Rated Speed:	1500rpm
No of Strokes:	4
Mode of Injection	Direct Injection
Injection pressure	200 kg/cm^2
No of Cylinders:	1
Stroke	116 mm
Bore	102 mm
Compression ratio	17.5:1 and 21:1

This experimental investigation was carried out on a Kirloskar made VCR engine. It was connected with the control panel unit which consist rotameter, water temperature indicator, loading switch, speed indicator and fuel flow transmitter etc. The engine performance and combustion parameters such as brake power (BP), brake specific fuel consumption (BSFC), brake thermal efficiency (BTE), mechanical efficiency (MEFF), heat balance, cylinder pressure and heat release rate were determined by engine performance analysis software.

3.2 INDUS PEA 205, (Exhaust Gas Analyzer)

The PEA 205 [fig.2] measures the exhaust emissions such as Carbon Monoxide (CO), Carbon Dioxide (CO_2), Hydro Carbon (HC), and Oxygen (O_2) by means of Non-Dispersive infrared (NDIR) measurement.

Fig.2, Indus pea 205 Exhaust Gas Analyzer

3.3 Transesterification Process

Transesterification of natural glycerides with methanol to methyl esters is a technically important reaction that has been used extensively in the soap and detergent manufacturing industry worldwide for many years. The transesterification process is the reaction of a triglyceride with an alcohol to form esters and glycerol. During the Transesterification process, the triglyceride is reacted with alcohol in the presence of a catalyst, usually a strong alkaline like sodium hydroxide. The alcohol reacts with the fatty acids to form the mono-alkyl ester, or biodiesel, and crude glycerol.

3.3.1 Production of Kusum oil Methylester

Kusum oil is a bio-diesel produced by using raw Kusum seed oil. Due to high content of FFA of Kusum oil, the objective has been achieved in two steps namely (i) acid esterification, (ii) alkaline esterification.

3.3.2 *Acid esterification*

The acid esterification was carried out at 4:1-6:1 molar ratio with varied H_2SO_4 (0.5- 2.0%) at 50-60°C and 60-90 min reaction time. Preheated oil, methanol and acid H_2SO_4 were mixed together as per desired proportion and stirred at 200 rpm. After completing the acid esterification reaction, treated was taken into beaker (Fig. 4 (a)) and heated up to 60°C.

3.3.3 Alkaline *esterification*

After acid treatment, 50 g oil was taken in a 250 ml flask and preheated up to 100°C to eliminate dissolved moisture content in the Kusum oil. The required amount of methanol (4:1, 6:1, 8:1) were mixed with distinct percentage of KOH catalyst concentration (0.5, 1.0, and 1.5). This homogeneous mixture of methanol and catalyst KOH was mixed with the Kusum oil and stirred with 200 rpm at varied reaction temperature 50-60°C. The reaction was stopped after 60, 75 and 90 min. After completion of trans esterification reaction, Kusum oil methyl ester was separated from glycerol by separating funnel (Fig.(4b)) and then the separated methyl ester was washed with hot distilled water. At last biodiesel was heated in the hot air oven to remove excess water content, and collected in jar as shown in the fig 4(c).

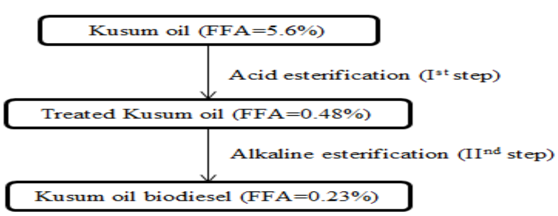

Fig. 3: Process flow diagram Kusum oil treatment

Fig. 4a, Acid Esterification

Fig. 4b, Alkaline Esterification

Fig.4C, Kusum bio-diesel

3.4 Experimental Procedure

The experimentation is conducted on a single cylinder direct injection VCR diesel engine operated at normal room temperatures of 28^0C to 33^0C.

The series of exhaustive engine tests were carried out on a compression ignition diesel engine using diesel and Kusum oil biodiesel blends. Several blends of varying concentration of Kusum oil methyl ester (biodiesel) with diesel were prepared as follows:

B10- This is the blend containing 10% bio-diesel and 90% neat diesel

B15- This is the blend containing 15% bio-diesel and 85% neat diesel

B20- This is the blend containing 20% bio-diesel and 80% neat diesel

B25- This is the blend containing 25% bio-diesel and 75% neat diesel

Performance and emission tests were conducted under different loading condition on these various diesel-biodiesel blends. The optimum blend was found out from the graphs based on maximum thermal efficiency, minimum brake specific energy consumption and safe emission at all load.

4. RESULTS & DISCUSSIONS

CVD (Calorific value of diesel) = 44,631 kJ/kg
CVB10 (Calorific value of B10) =44,201.6kJ/kg
CVB15 (Calorific value of B15) =43,986.9kJ/kg
CVB20 (Calorific value of B20) =43,772.2kJ/kg
CVB25 (Calorific value of B25) =43,557.5kJ/kg

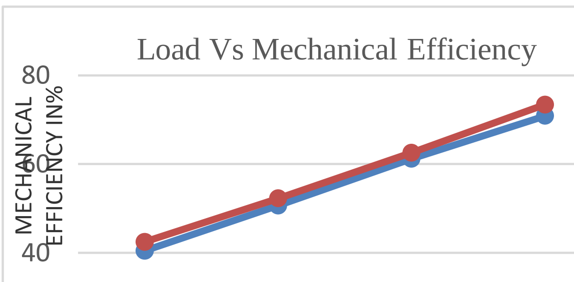

Fig.5, Load Vs Mechanical Efficiency graph with Neat Diesel at various loads.

The maximum mechanical efficiency of the engine was increased with increase in the compression ratio and the maximum mechanical efficiency for diesel was found to be 73.412 at 24 kg load (fig.5).

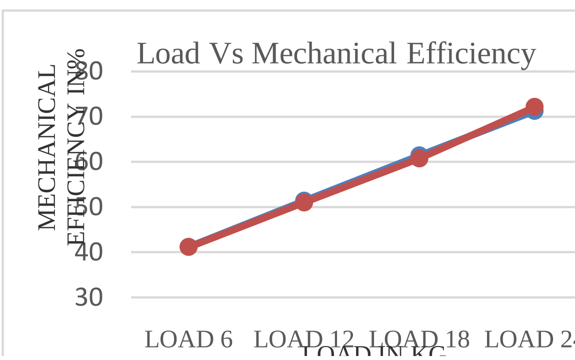

Fig.6, Load Vs Mechanical Efficiency graph with B10 blend of kusum bio-diesel at various loads.

The maximum mechanical efficiency of the engine was increased with increase in the compression ratio and the maximum mechanical efficiency for B10 was found to be 72.125 at 24 kg load (fig.6).

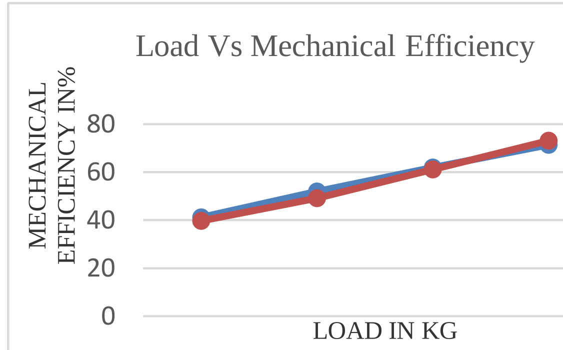

Fig.7, Load Vs Mechanical Efficiency graph with B15 blend of kusum bio-diesel at various loads.

The maximum mechanical efficiency of the engine was increased with increase in the compression ratio and the maximum mechanical efficiency for B15 was found to be 73.14 at 24 kg load (fig.7).

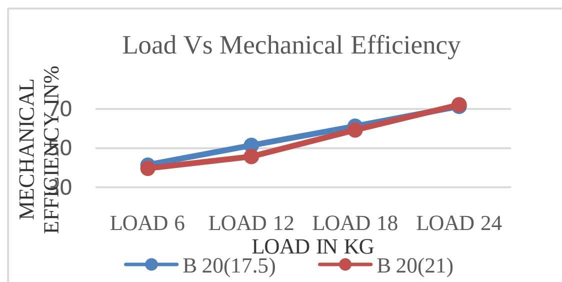

Fig.8, Load Vs Mechanical Efficiency graph with B20 blend of kusum bio-diesel at various loads.

The maximum mechanical efficiency of the engine was increased with increase in the compression ratio and the maximum mechanical efficiency for B20 was found to be 72.173 at 24 kg load (fig.8).

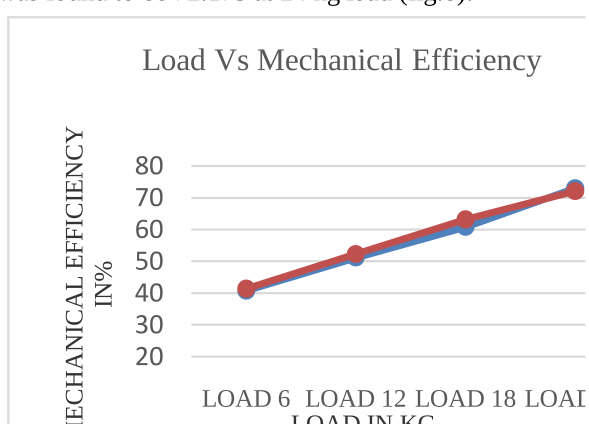

Fig.9, Load Vs Mechanical Efficiency graph with B25 blend of kusum bio-diesel at various loads.

The maximum mechanical efficiency of the engine was increased with increase in the compression ratio and the maximum mechanical efficiency for B25 was found to be 72.11 at 24 kg load (fig.9).

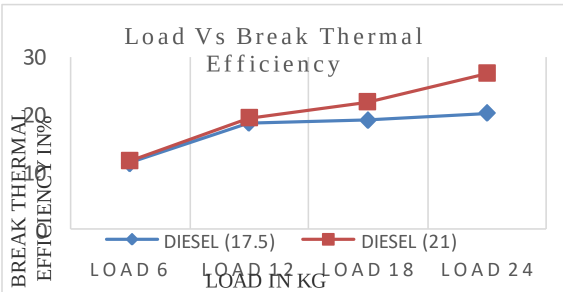

Fig.10, Load Vs Break Thermal Efficiency graph with Neat Diesel at various loads.

The maximum brake thermal efficiency of the engine was increased with increase in the compression ratio and the maximum brake thermal efficiency for diesel was found to be 27.202 at 24 kg load (fig.10).

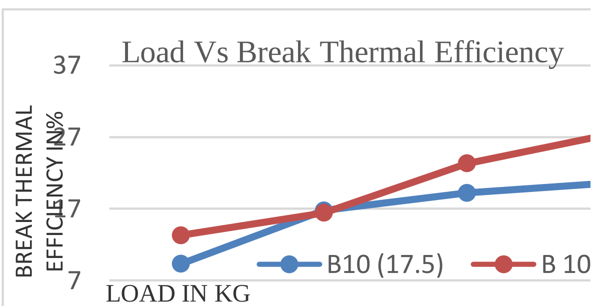

Fig.11, Load Vs Break Thermal Efficiency graph with B10 blend of kusum bio-diesel at various loads.

The maximum brake thermal efficiency of the engine was increased with increase in the compression ratio and the maximum brake thermal efficiency for diesel was found to be 27.405 at 24 kg load

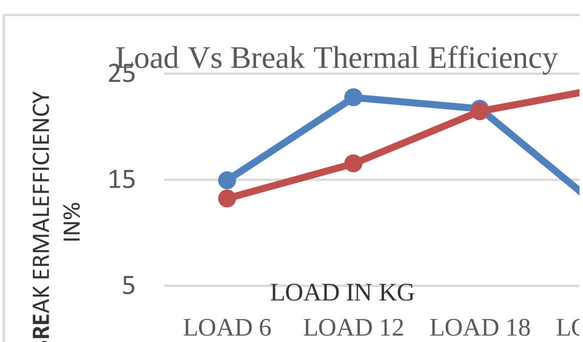

Fig.12, Load Vs Break Thermal Efficiency graph with B10 blend of kusum bio-diesel at various loads.

The maximum brake thermal efficiency of the engine was increased with increase in the compression ratio and the maximum brake thermal efficiency for diesel was found to be 23.19 at 24 kg load (fig.12).

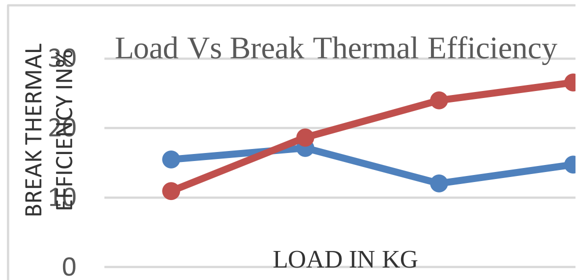

Fig.13, Load Vs Break Thermal Efficiency graph with B15 blend of kusum bio-diesel at various loads.

The maximum brake thermal efficiency of the engine was increased with increase in the compression ratio and the maximum brake thermal efficiency for diesel was found to be 26.56 at 24 kg load (fig.13).

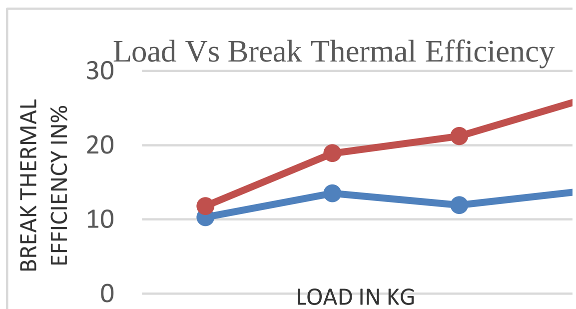

Fig.14, Load Vs Break Thermal Efficiency graph with B25 blend of kusum bio-diesel at various loads.

The maximum brake thermal efficiency of the engine was increased with increase in the compression ratio and the maximum brake thermal efficiency for diesel was found to be 26.323 at 24 kg load (fig.14).

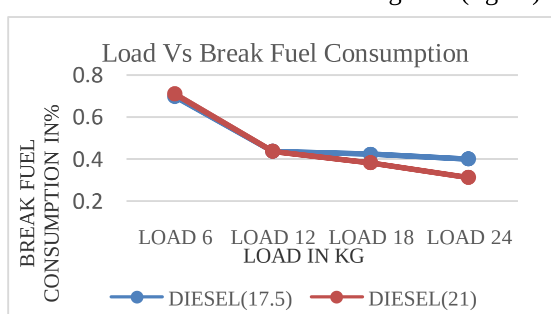

Fig.15, Load Vs Break Fuel Consumption graph with Neat Diesel at various loads.

The minimum brake fuel consumption of the engine was decreased with increase in the compression ratio and the minimum brake fuel consumption for diesel was found to be 0.312 at 24 kg load (fig.15).

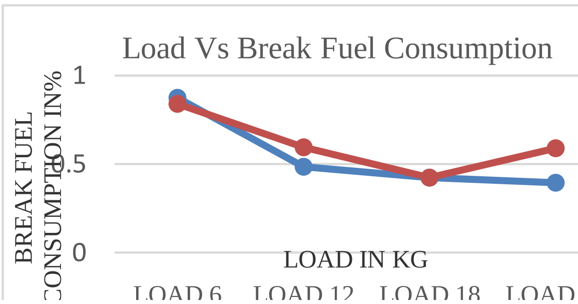

Fig.16, Load Vs Break Fuel Consumption graph with B10 blends of kusum bio-diesel at various loads.

The minimum brake fuel consumption of the engine was decreased with increase in the compression ratio and the minimum brake fuel consumption for diesel was however found to be 0.59 at 24 kg load (fig.16).

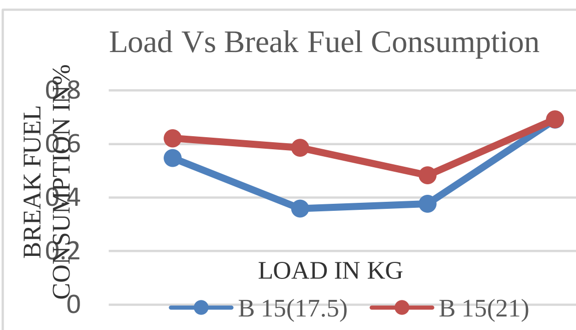

Fig.17, Load Vs Break Fuel Consumption graph with B15 blends of kusum bio-diesel at various loads.

The minimum brake fuel consumption of the engine was decreased with increase in the compression ratio and the minimum brake fuel consumption for diesel was found to be 0.692 at 24 kg load (fig.17).

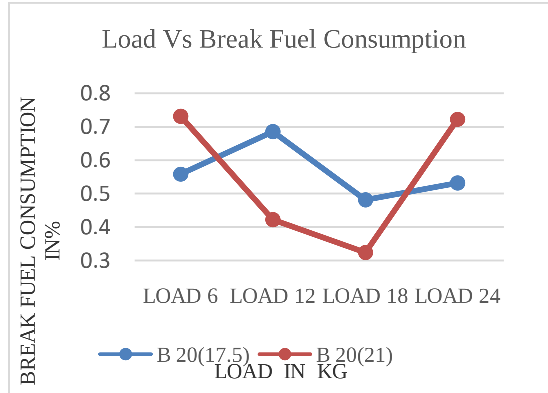

Fig.18, Load Vs Break Fuel Consumption graph with B20 blends of kusum bio-diesel at various loads

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The minimum brake fuel consumption of the engine was decreased with increase in the compression ratio and the minimum brake fuel consumption for diesel was found to be 0.723 at 24 kg load (fig.18).

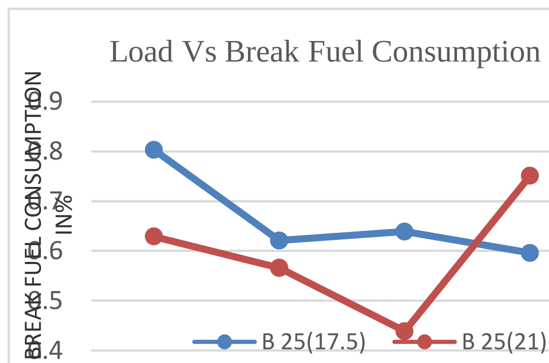

Fig.19, Load Vs Break Fuel Consumption graph with B25 blends of kusum bio-diesel at various loads.

The minimum brake fuel consumption of the engine was decreased with increase in the compression ratio and the minimum brake fuel consumption for diesel was found to be 0.751 at 24 kg load (fig.19).

The emissions obtained during the experimentation at different loads are obtained by using a 4- gas emission analyzer. The experiment is done by neat diesel, Kusum bio-diesel blends and pure Kusum bio-diesel. The emission analysis for CO, CO_2, HC are shown in the figures 20 to 22 for diesel and kusum bio-diesel blends.

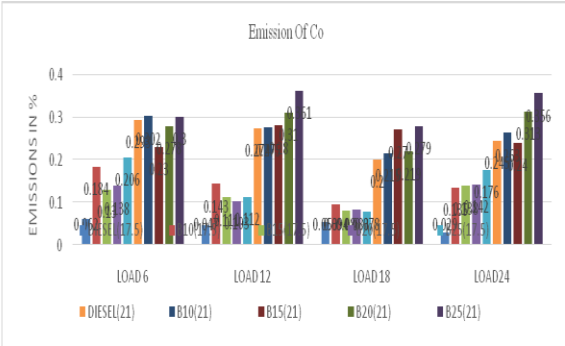

Fig.20, Load Vs Co graph with blends of Kusum bio-diesel and with Neat Diesel.

The variation of carbon monoxide with load and compression ratio of the engine is shown in fig.20. It is observed that carbon monoxide emission decreases when compared to neat diesel. It means that proper combustion has not carried out for bio-diesel. The minimum carbon monoxide emissions were obtained for neat diesel.

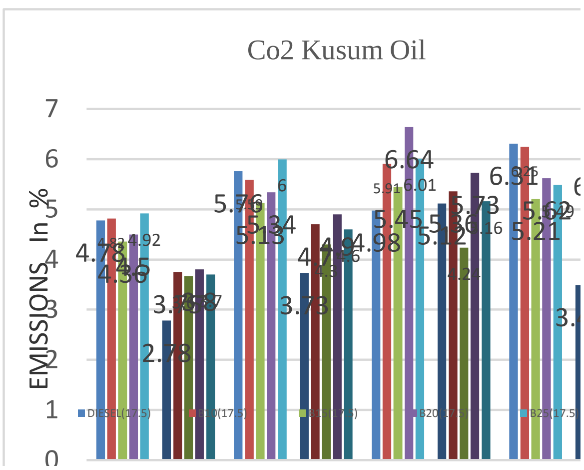

Fig.21, Load Vs Co_2 graph with blends of Kusum bio-diesel and with Neat Diesel.

The variations of carbon dioxide emission for various blends at varying loads are shown in figure 21. The carbon dioxide emissions for the blends are higher than diesel for all loads and blends and decreases with compression ratio. Carbon dioxide is formed on complete combustion of the fuel in oxygen. As the calorific value of the fuel is low, more fuel needs to be burnt to get equivalent power output. So combustion of more carbon compounds leads to higher carbon dioxide emissions.

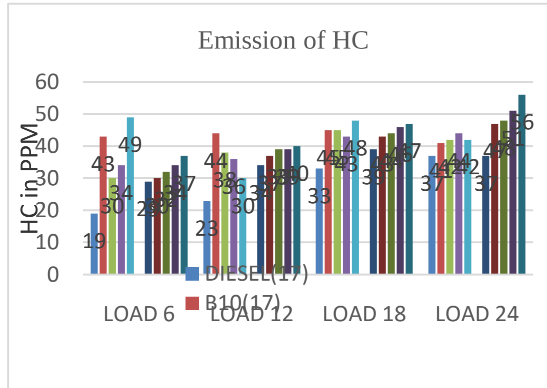

Fig.22, Load Vs HC graph with blends of Kusum bio-diesel and with Neat Diesel.

The hydro carbons variation with load for the Kusum bio-diesel and diesel are shown in fig. 22. The hydro carbons are higher for all the blends for the Kusum bio-diesel compared with neat diesel. The results depend on oxygen quantity and fuel viscosity in turn atomization.

5. CONCLUSIONS

A single cylinder computerized variable compression ratio engine was operated successfully using Kusum bio-diesel and its blends of Kusum oil methyl ester. It is observed that the Engine works smoothly on Kusum oil with performance comparable to neat diesel operation. The mechanical efficiency of the engine is more for the B15blend of Kusum oil with neat diesel at all loads and for B25 at high loads. The brake thermal efficiency of the engine with Kusum methyl ester-diesel blend was marginally better than that with neat diesel fuel. The brake thermal efficiency of the engine for neat diesel, B10, B15 and B20 at 24kg load was found to be at a higher value. The Brake specific fuel consumption is low for Kusum methyl ester-diesel blends than diesel at all loads. With the increase in load, the mechanical efficiency of B25 is increased in 17.5:1 compression ratio. With the increase in load, brake thermal efficiency of B10 increases in 17.5:1 compression ratio. With the increase in load, Specific fuel consumption of B15 decreases in 17.5:1 compression ratio. With the increase in load, Mechanical efficiency of B15 increased in 21:1 compression ratio. With the increase in load, break thermal efficiency of B10 increases in 21:1 compression ratio. With the increase in load, Specific fuel consumption of B25 decreases in 21:1compression ratio. Hence with B10, the VCR engine works by giving lowest values of CO, CO_2 and HC at the two compression ratios i.e 17.5:1 and 21:1.

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