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Characterization of biodiesel blends on emission and performance characterization of IC engine

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ABSTRACT

This study explores the emission of different pollutants formed by using different blends in IC engine. Biodiesel was synthesized from Jatropha, Thumba and Undi oil by applying homogeneous catalyst to investigate performance and emission of engine. Further the same biodiesel was preceded for emission analysis on single cylinder IC engine with various blending ratios as well as load. Blends (i.e. mixture of biodiesel + fossil fuel) of B00% (i.e. diesel fuel), jatropha methyl esters like JB5%, JB10%, JB15%, JB20%, JB30%, and JB100% were prepared at 40^0C; in the same way blends of remaining two biodiesels were prepared. The emission parameters like Oxides of nitrogen (NO_x), Carbon monoxide (CO), Hydrocarbon (HC) etc. and performance parameters like Brake specific fuel consumption (BSFC), and Brake thermal efficiency (BTE) were studied and compared with fossil fuel. Result showed that among all methyl ester and blends thumba TB20% blend shows lower emissions as well as performance as assimilated with running diesel fuel at all load.

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I. INTRODUCTION

Diesel fuel is largely utilized in the transport, agriculture, commercial, domestic, and industrial sector for generation of power and substitution of even a small fraction of total consumption by indigenous alternative fuels particularly of bio origin will have significant impact on economy, the environment, the development of agro based industries in the region of the alternative fuels. Biodiesel obtained from vegetable oils is considered to be promising alternative fuel resulting in numerous environmental, economic and social benefits.

Biodiesel benefits include bio-degradable, non-toxic, free from Sulphur (< 0.001%) and 60% less net carbon dioxide emissions[1] and can be synthesized using vegetable oils and fats [2]. In addition it has high flash point (greater than 160oC) which helps biodiesel for transportation and storage safe. The important quality that biodiesel possess is that it decomposes more easily when they expose to environment and most importantly they can be produced easily compared to petrol and diesel.The lubrication property of biodiesel dominates more when compared to diesel fuel and increases the engine life. Biodiesel causes less emission of carbon dioxide, hydrocarbon and particulate matter, which are dominating factors while compared to diesel. The only drawback is that NOx emission is to be increased upto 15-20% [3].Most of the researchers studied performance and emission parameters of methyl ester on various engines, speeds, loads and biodiesel blend ratios. These results proved that the engine performance is affected by percent biodiesel in diesel fuel, while they agreed with decrease in CO and HC emissions but increase in NOx and CO_2emissions. The CO and HC emissions depends upon aromatic content of fuel while increase inNOx and CO_2 indicates more oxygen atom in biodiesel fuel[4-12].

In India, Ministry of New and Renewable Energy (MNRE) prepared National Biofuel Policy in 2008. As per MNRE report, about 20% blend with diesel fuel of biofuels (like bioethanol and biodiesel) will be used commercially by 2017. [13]. So it becomes most important to search/ identify for new and potencialfeedstocks for biodiesel preparation. Indian Government focusedon non-edible oil (NEO) seeds plants like JatrophaCurcus [14] and Pongamiapinnata (Karanja) [15].Government has been planted these plants on road side, along railway tracks and in forests. These two plants has potential to grow in bare lands with minimum inputs of irrigation and fertilization. Along with that researchers has been concentrated on Madhucaindica [16], Calophylluminophyllum [17],[18],Castor [19],Citrullus colocynthis [20] and more NEO's for biodiesel synthesis.

Vegetable oil reported some engine durability issues such as severe engine deposits, piston ring sticking, injector choking, gum formation and lubricating oil thickening. These problems are primarily attributed to high viscosity and poor volatility of straight vegetableoils due to large molecular weight and bulky molecular structure. Higher viscosity of vegetable oil as compared to mineral diesel leads to unsuitable pumping and fuel spray characteristics. For long running, straight vegetable oils are not suitable as fuels for diesel engines; they have to be modified to bring their combustion related properties closer to diesel. Undoubtedly, transesterification is well accepted and best suited method of utilizing vegetable oils in CI (compression ignition) engine but this adds extra cost of processing because of the transesterification reaction involving chemical and process heat inputs.

Chavanet. al [17], [20]synthesized thumba ethyl ester and calophyllum (undi) methyl ester by using 0.75wt%, 1.2wt% of potassium hydroxide (KOH), 1:8 molar ration of oil to alcohol at 65^{o}c reaction temperature and 650rpm stirring speed.

Bavane R.K. [21] used undi biodiesel for VCR engine, he proved that engine performance improved with slightly reduction in emissions like HC, CO and NOx.Baste S.V. et.al[22]has been reported that blending of diesel with 20% Pongamiapinnata oil methyl ester can be used safely in a conventional CI engine without modifications in engine.Mohammed et.al. [23]had studied engine performance using jatropha biodiesel and its blends on IC engine. He reported better performance (of BSFC and BTE) using JB10, B20, JB30, JB50 than diesel fuel. The CO emissionsdecreased consequently with increase in engine speed up to 1700rpm while NOx emissions increased for all blends.

The main objective of present work was to synthesize biodiesel using sodium methoxide as a solid homogeneous catalyst (instead of potassium hydroxide and sodium hydroxide) and methyl alcohol and the synthesized biodiesel use to analyze the engine Performance and Emission characteristics of diesel engines fuelled with biodiesel produced from Jatropha, Thumba and Undi oil and/or its blends with diesel fuel, which will help in both the direction of reducing emission problems and search of alternative fuel for CI engines without engine modification

The Jatrophacurcas Linnaeus plant belongs to the family euphorbiaceae.It is a hardy shrub that can grow on poor soils and areas of low rainfall.The oil content of Jatropha seed ranges from 25% to 30% by weight. Fresh Jatropha oil slow-drying, odorless and color less oil, but it turns yellow after aging.Non-edible oil generally contains about 3-4 %wax and gum. De-waxing and degumming of plant oils is required not only for smooth running of the CI engine but also to prevent engine failure even if plant oils are blended with diesel. It is therefore necessary to remove wax and gum from the fresh oil before it could be used in CI engine[24-27].

Undi is a species of family Guttifereae (Clusiaceae), native to India, East Africa, Southest Asia, Australia and South Pacific. Commonly it is called as „Indian laurel", Alexandrian Laurel, Beach calophyllum. The oil content of undi seed ranges from 55% to 60% by weight. The greenish yellow oil with disagreeable odour contains 28.08mg of KOH/gmFFA.Theundi oil obtained from the calophyllumseeds was used as alternative to candlenut oil in lamps [17], [18].

Thumba is planted/ grown naturally in rainy season and its fruits / seeds are available in winter.Commonly it is called as 'Bitter apple' (in English), Thumba (in Marathi), Indrayan (in Hindi), It is a creeper, short period cropgrown naturally wild in Indian arid zone (Western Rajasthan).Thumba is planted/ grown naturally in rainy season and its fruits / seeds are available in winter. It has annular and rough stem, rough leaves that are 3-7 lobed, 5-10cmlong in middle, flowers are monoleceios and have yellow rounded fruit.The averageseed yield is about 2500-3500 kg of seeds/ ha. Seeds contains 12% to 20% of golden yellow- brown oil. Currently all extracted oil is consumed by saponification industries [20].

II. METHODOLOGY

a A. Biodiesel synthesis-

The two stage process was used to transfer triglyceride to its respective ester, first step was esterification and transesterification carried out afterwards. The principal role of esterification is to reduce free fatty acid (FFA) value of oil [14].

The 1000 ml Jatropha oil first heated to 50^{o}C then 1.7% (by wt. of oil) sulfuric acid was to be added to heated oil and methyl alcohol about 1:8 molar ratio (by wt of oil) added afterwards. The reaction started with stirring speed about 650 rpm and temperature was controlled at 55-60 ^{o}C for 60 min with regular analysis of FFA every after 25-30 min. Finally the FFA was reduced upto 1.5% then the excess methyl alcohol was removed by distillation and esterified oil was transferred into settling tank. The trace quantity of moisture was formed in this step, which was removed. The major obstacle to acid catalyzed esterification for FFA is the water formation. Water can prevent the conversion reaction of FFA to esters from going to completion [28]. Afterwards the esterified oil were fed to the transesterification process [29]

1000ml of esterified jatropha oil was measured and poured into a 2000 ml three necked round bottom flask & it was heated up to 40^0c. In the separate 250 ml beaker 1.2wt % of sodium methoxide dissolved with methyl alcohol (8 mol of that oil) at 40^0c, then this mixture was slowly added to heated oil & reaction started for 90 min with stirring speed about 650 rpm and at 55-60 ^oC temperature. After reaction completion i.e. when FFA reduced up to 0.7% the trans esterified oil was again transferred to distillation afterwards to separating funnel. The three distinct layer of methyl ester, glycerol and unreacted oil were formed. The glycerol settled at bottom of funnel due to gravity and jatropha methyl ester were settled at the top of funnel. The unreacted oil settled in between glycerol and methyl ester layer. The glycerol was separated manually.Then the product i.e. jatropha methyl ester was washed with the help of hot distilled water to remove dissolved sulphric acid, sodium, methyl alcohol and glycerol. The wasted biodiesel were dried over anhydrous sodium sulphate. The purified methyl ester were proceeded for quality testing, Table-II. The undi methyl ester and thumba methyl ester were synthesized as per protocol given by Chavanusing potassium hydroxide as a strong base catalystand methyl alcohol [17], [20].

The diesel fuel and biodiesel blends were prepared, considering MNRE report.For comparative study with diesel fuel (DB00), the blending of biodiesel has been prepared by volume as JB10 (i.e.10% jatropha biodiesel and 90% diesel fuel), JB20 (20% jatropha biodiesel and 80% diesel fuel), JB30 (30% jatropha biodiesel and 70% diesel fuel) and JB100 (100% jatropha biodiesel. In the same way other biodiesel blends i.e. undi and thumba were prepared at 40 ^{o}c.

B. Experimental Test Rig

Theengine tests were conducted on a four-stroke-singlecylinder direct-injection water-cooled CI engine whosespecifications are given in Table I. The engine was alwaysoperated at a rated speed of 850 rev/min.

TABLE I
Engine Specifications

SR.NO.	Description	Specification
1	Make	Field Marshal
2	Bore	114.30mm
3	Stroke	139.70mm
4	Rated RPM	850
5	Power	8/5.9 HP/kW
6	Compression Ratio	17:1
7	Fuel Oil	High Speed Diesel
8	NO. of Cylinders	1
9	Engine Cooling Method	Water Cooled

The engine is started with diesel and once the engine warmsup, it is switched over to biodiesel blends with diesel of Jatropha, Thumba and undi biodiesel one by one. After the completion of readings of blends engine again runs with diesel after that it again run on 100% biodiesels of Jatropha, Thumba and Undi oils.For this purpose, several blends of varying concentrations were prepared ranging from 0% (mineral diesel) to 100% (Pure Biodiesel) through 5%,10%, 15%, 20%, 30%. These blends were then subjected toperformance and emission tests on the engine. The performanceand emissions data were then analysed for all experimentsand the results are reported in the following section.

III. RESULT & DISCUSSION

A. a *Biodiesel characterization*

TABLE I
Physico-chemical properties of Biodiesel

Properties	ASTM STD.	Jatropha B100%	Undi B100% [18]	Thumba B100% [20]
Density	D1972	0.872	0.892	0.870
Viscosity in Cst	D667-06	3.82	3.87	3.80
Calorific value	D6751	38.00	37.18	37.00
Flash pt in ^{O}c	D93	164	176	164
Fire pt in ^{O}c	D93	171	182	172

B. *Performance characteristics*

1) *Brake specific fuel consumption:* The results for the variation in the brake specific fuel consumption (BSFC) with increasing load on the engine for the various biodiesel blendswere shown in Figure 1.1 to 1.6. For allbiodiesel blends and diesel, the specific fuel consumption falls with increasing load. The brake specific fuel consumption (BSFC) decreases with the increase in load, as this was because of; at higher load power generated is more, with respect to fuel consumption rate. The increase in biodiesel fuel consumption is mainly due to its low heating value, as well as its high density and high viscosity[30]The different feedstock of biodiesel with different heating valueand carbon chain length, or different production processes andquality, also have an impact on engine economy. As the percentage of biodiesel increase in the blends the brake specific fuel consumption also increased. Biodiesel blends B15, B20 shows nearly similar performance to diesel.Biodiesel B100 blends shows poor brake specific fuel consumption performance as compare to the diesel and other blends.

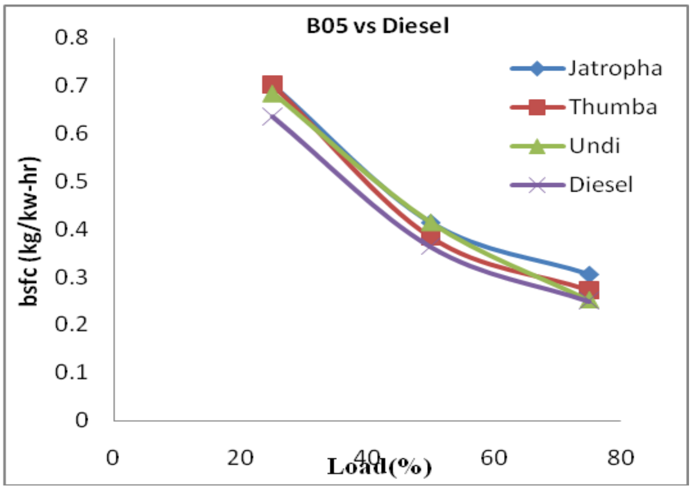

Fig. 1.1- Variation of Load vs BSFC of JB5, TB5,UB5 with diesel fuel

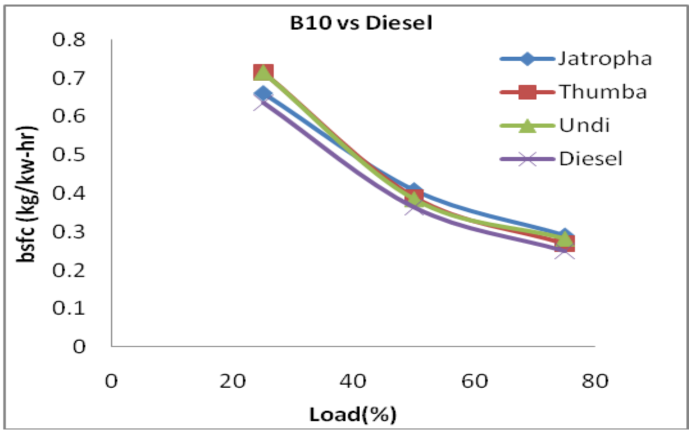

Fig. 1.2- Variation of Load vs BSFC of JB10,TB10,UB10 with diesel fuel

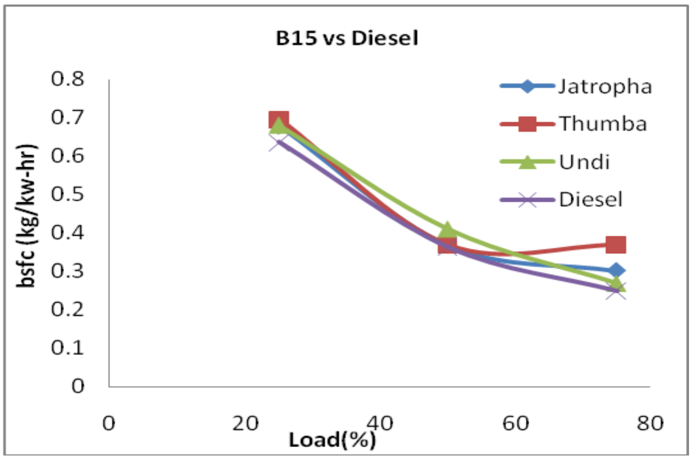

Fig. 1.3- Variation of Load vs BSFC of JB15,TB15,UB15 with diesel fuel

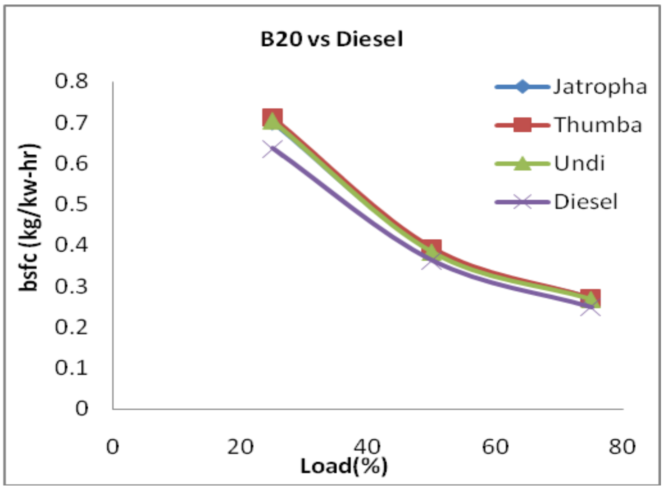

Fig. 1.4- Variation of Load vs BSFC of JB20,TB20,UB20 with diesel fuel

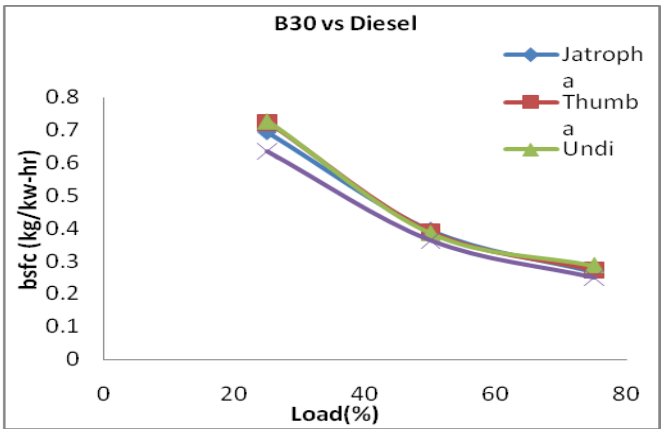

Fig. 1.5- Variation of Load vs BSFC of JB30,TB30,UB30 with diesel fuel

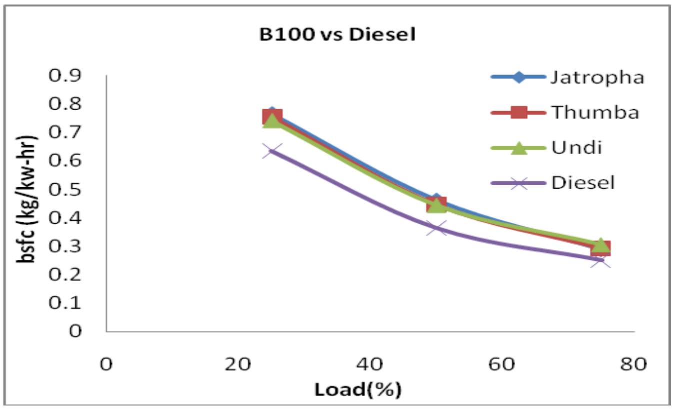

Fig. 1.6-Variation of Load vs BSFC of JB100, TB100,UB100 with diesel fuel

2) *Brake thermal efficiency (BTE):*The variation in BTE with increasing load on the engine for the various biodiesel blends and for diesel fuel were shown in Figure 2.1 to 2.6Biodiesel and its blends resulted in decreased brake thermal efficiency as compared to diesel fuel. This wasdue to oxygen (11%) present in the biodiesel molecules that improves the combustion characteristics but poor volatility result in poor atomization and poor spray characteristics. The poor spray characteristics may affect the homogeneous air-fuel mixture formation which in turn lower the heat released rate thereby reduction in brake thermal efficiency

[30].Also the lower heating value of biodiesel leads to injection of higher quantities of fuel as compared to diesel for the same load conditions hence, decrease in brake thermal efficiency. B20 biodiesel blends shows very similar brake thermal efficiency to the diesel compared to the other biodiesel blends.

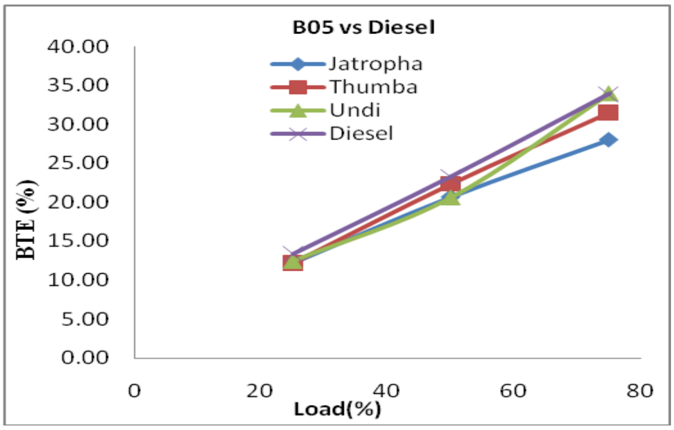

Fig. 2.1- Variation of Load vs BTE of JB5,TB5,UB5 with diesel fuel

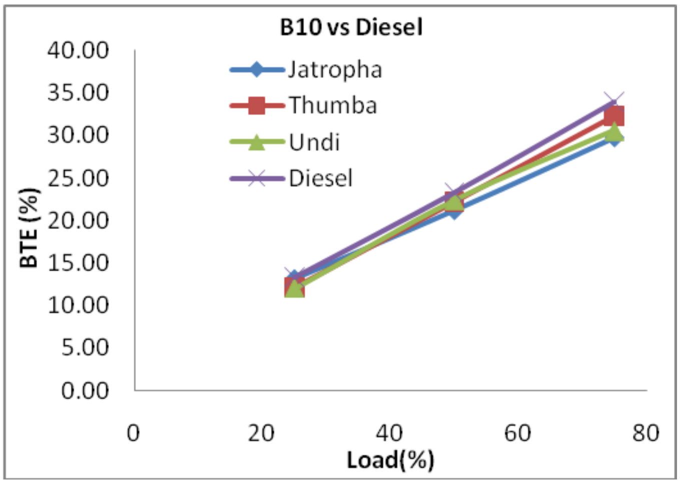

Fig. 2.2- Variation of Load vs BTE of JB10,TB10,UB10 with diesel fuel

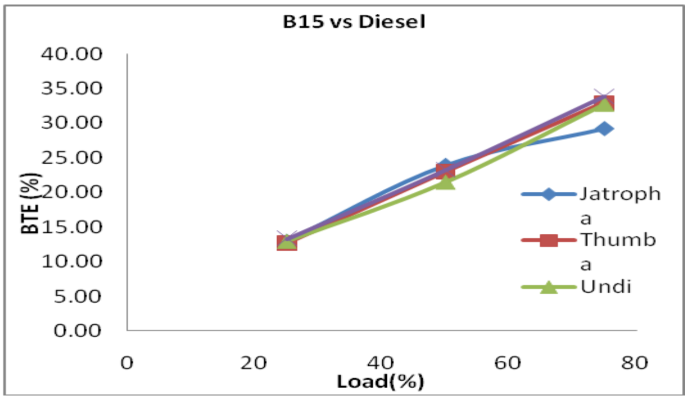

Fig. 2.3- Variation of Load vs BTE of JB15,TB15, UB15 with diesel fuel

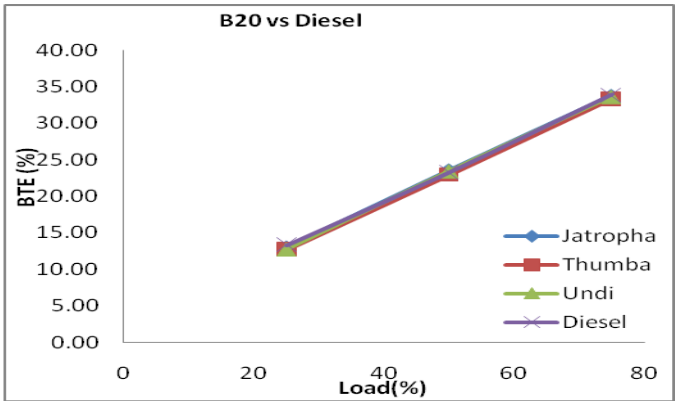

Fig. 2.4- Variation of Load vs BTE of JB20,TB20, UB20 with diesel fuel

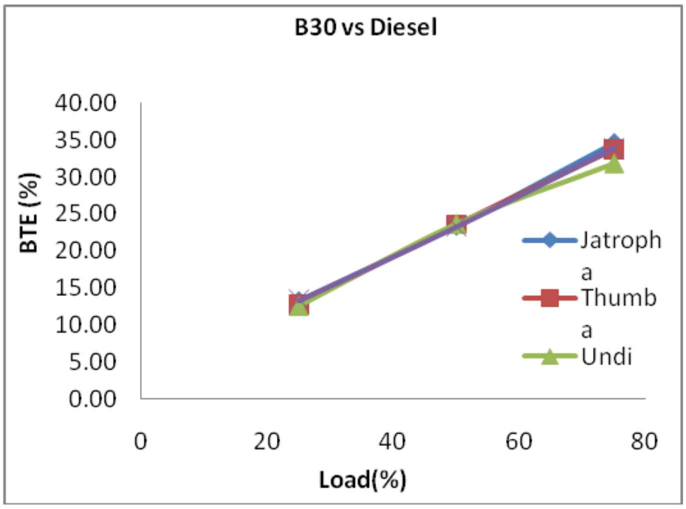

Fig. 2.5- Variation of Load vs BTE of JB30,TB30, UB30 with diesel fuel

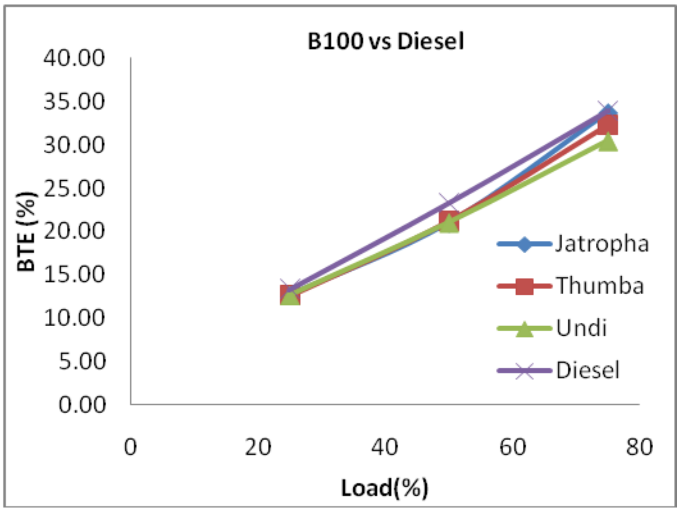

Fig. 2.6- Variation of Load vs BTE of JB100,TB100, UB100 with diesel fuel

B. *Emission Characteristics*

1) *CO emissions:*CO is one of the compounds formed during the intermediate stages of fuels and is formed mainly due to incomplete combustion of fuels. If combustion proceeds to completion, CO is converted to CO_2. If the combustion is incomplete due to shortage of air or low gas temperature, CO will be formed.The variations of CO emissions were shown in Figure 3.1 to 3.6.In case of

biodiesel blends, CO emissions were lower than that of diesel fuel, due to some extra oxygen contents, which convert CO to CO_2 and resulted in complete combustion of the fuel. Higher cetane number of biodiesel blends; results in the lower possibility of formation of rich fuel zone and thus reduces CO emissions.At full load, the oxygen content of the blends and pure biofuels seems to play an important role in reducing CO emissions [30], [31].At partial loads,CO emissions of diesel fuel are comparable to or even lower than all the other fuels. At very low load (25%), emissions of CO from the conventional diesel fuelled engine are higher than the others.Explanation for this behavior is that at full load the oxygen content of the different biofuels helps to complete the oxidation of carbonaceous species during combustion [30].At partial load, there is enough oxygen available for complete combustion anyway. CO emissions are high at low load (25%), probably due to the lower gas temperatures inside the cylinder which prevent CO being converted to CO_2. In this case, CO emissions of biodiesel blends are lower than conventional diesel fuel, probably due to their lower carbon content.

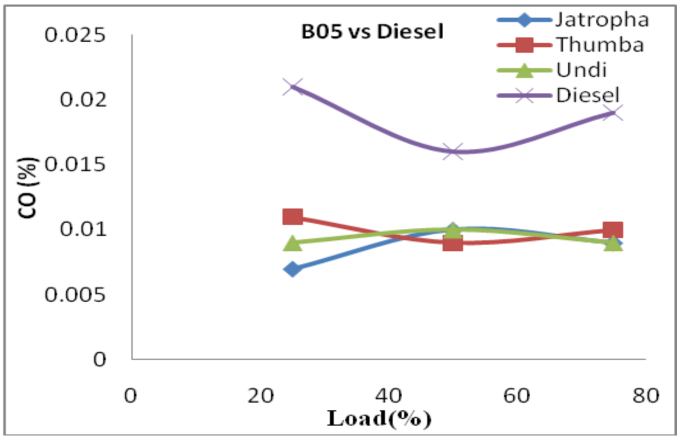

Fig. 3.1- Variation of Load vs CO of JB5, TB5, UB5 with diesel fuel

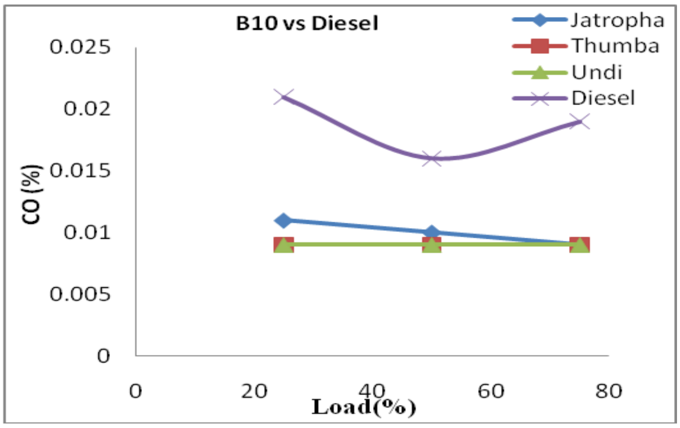

Fig. 3.2- Variation of Load vs CO of JB10,TB10, UB10 with diesel fuel

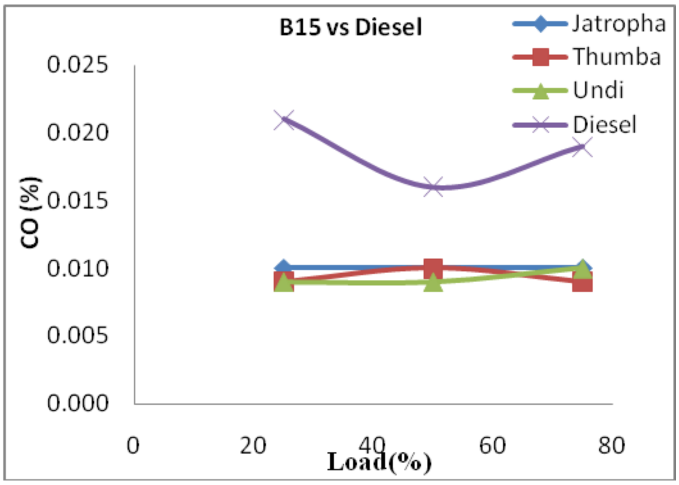

Fig. 3.3- Variation of Load vs CO of JB15,TB15, UB15 with diesel fuel

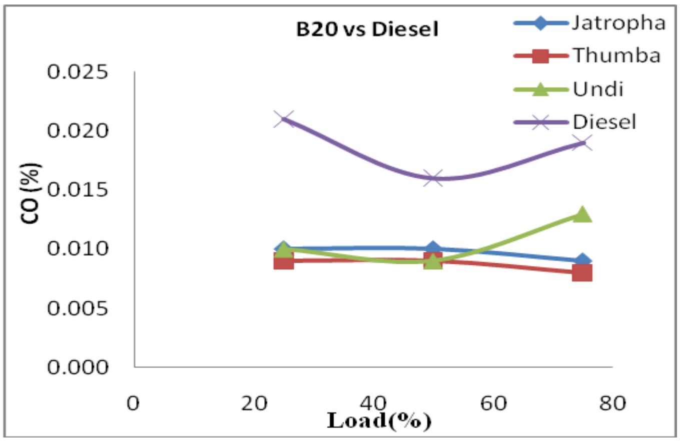

Fig. 3.4- Variation of Load vs CO of JB20,TB20, UB20 with diesel fuel

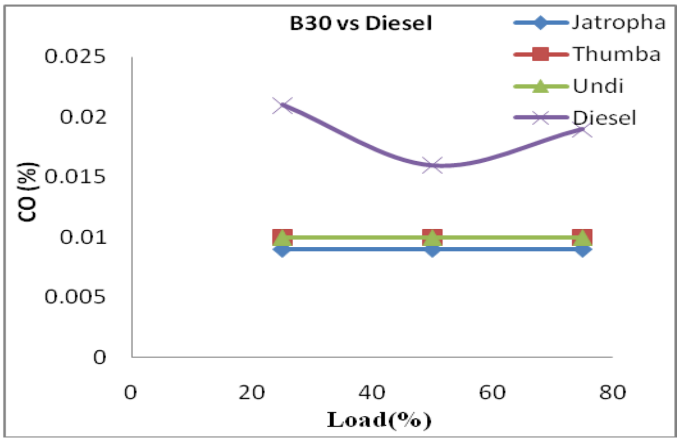

Fig. 3.5- Variation of Load vs CO of JB30,TB30, UB30 with diesel fuel

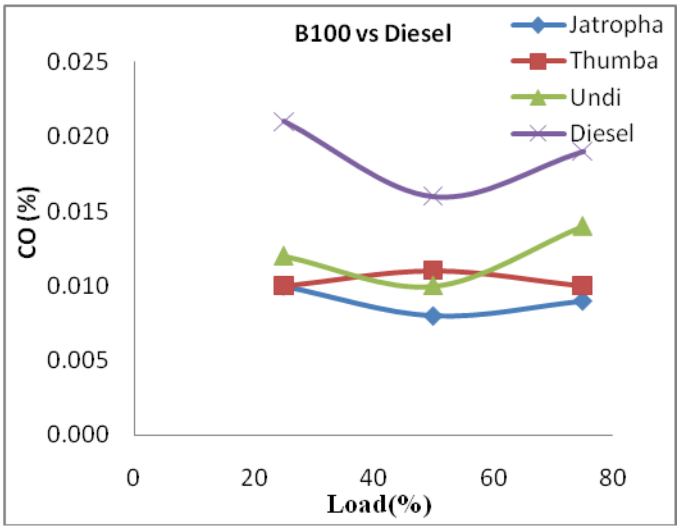

Fig. 3.6- Variation of Load vs CO of JB100,TB100, UB100 with diesel fuel

2) *NOx emissions:*The NOx emissions increased with increase in biodiesel concentration in diesel fuel. They are tempreture dependent. (This increase is mainly due tobiodiesel of vegetable oil contains higher oxygen content [30].Moreover, cetane number and different injection characteristics also have an impact on NOx emissions for biodiesel. The content of unsaturated compounds in biodiesel could have a greater impact on NOx emissions. The unsaturated compound shows reduction inNOx emissions. The larger engine load is, the higher the level of NOx emissions for biodiesel which is as the results of higher combustion temperature due to higher engine load. As load is increased, the overall fuel-air ratio increased which resulted in an increase in the average gas temperature in the combustion chamber and hence NOx formation which is sensitive to temperature increases [3]. The NOx formation is highly dependent upon temperature, due to the high activation energy needed for the reactions involved. Hence the most significant factor that causes NOx formation is high combustion temperatures[1].Nitrogen oxides (NOx) emissions decrease can be observed as speed and load are increased. This is probably due to the increase in turbulence inside the cylinder, which may contribute to a faster combustion and to lower residence time of the species in the high temperature zones.The variation of NOx emissions were shown in Figure 4.1 to 4.6. As shown, almost every biofuel produced higher amounts of NOx than conventional diesel. Thumba and Undi oil biodiesel blends show low NOx emissions compared to Jatropha biodiesel blends but higher than diesel fuel.

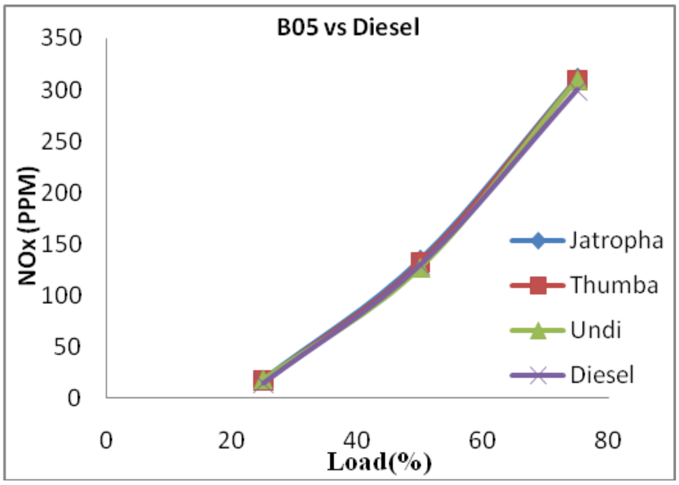

Fig. 4.1- Variation of Load vsNOx of JB5,TB5, UB5 with diesel fuel

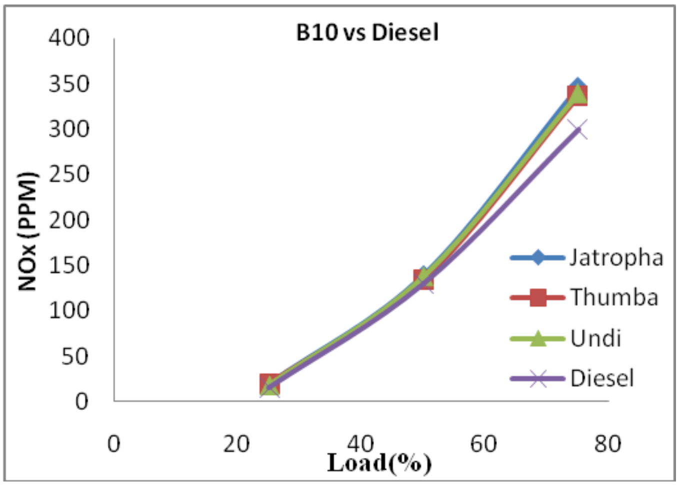

Fig. 4.2- Variation of Load vsNOx of JB10,TB10, UB10 with diesel fuel

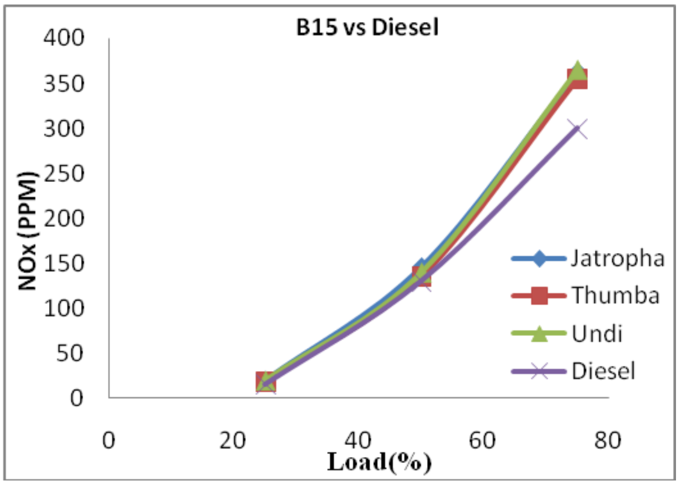

Fig. 4.3- Variation of Load vsNOx of JB15,TB15, UB15 with diesel fuel

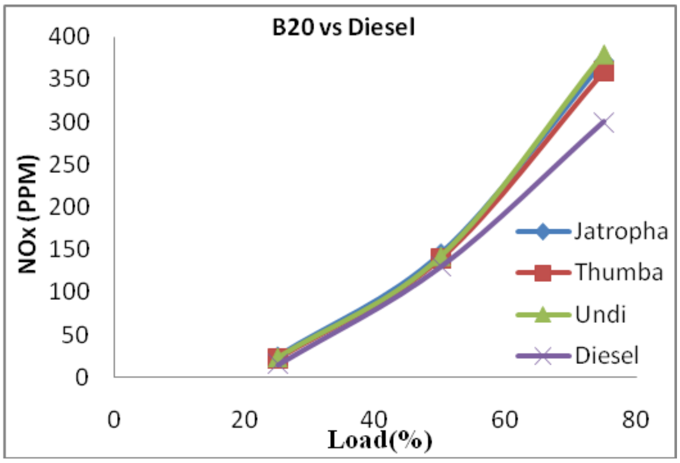

Fig. 4.4- Variation of Load vsNOx of JB20,TB20, UB20 with diesel fuel

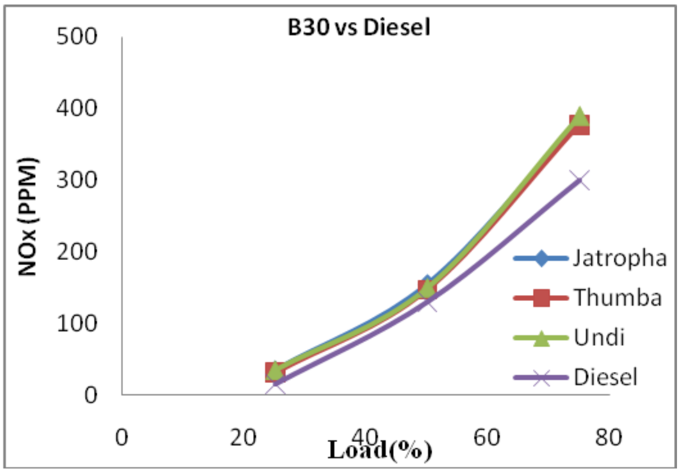

Fig. 4.5- Variation of Load vsNOx of JB30,TB30, UB30 with diesel fuel

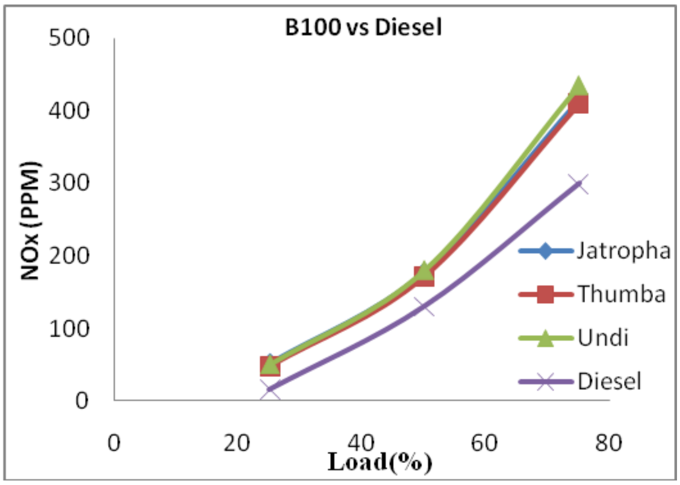

Fig. 4.5- Variation of Load vsNOx of JB100,TB100, UB100 with diesel fuel

3) *HC emissions:*The variation of HC emissions were shown in Figure 5.1 to 5.6.The oxygenated compounds available in the blends improve the fuel oxidation and thus it reduces HC emissions. When the oxygen content of fuel blend is increased, it requires less oxygen for combustion. However, oxygen content of fuel is the main reason for complete combustion and HC emission reduction. Furthermore, cetane number of biodiesel blends reduces the combustion delay, and such a reduction has also been related to decreases in HC emissions. The presence of higher HC emissions indicates the chemical energy of the fuel which is not utilized during combustion process. Jatropha biodiesel blends showed highest HC emissions compared toundi and thumba biodiesel while undi biodiesel showed lowest HC emission with all loads.Among all biodiesel blend UB20% showed lowest HC emission.

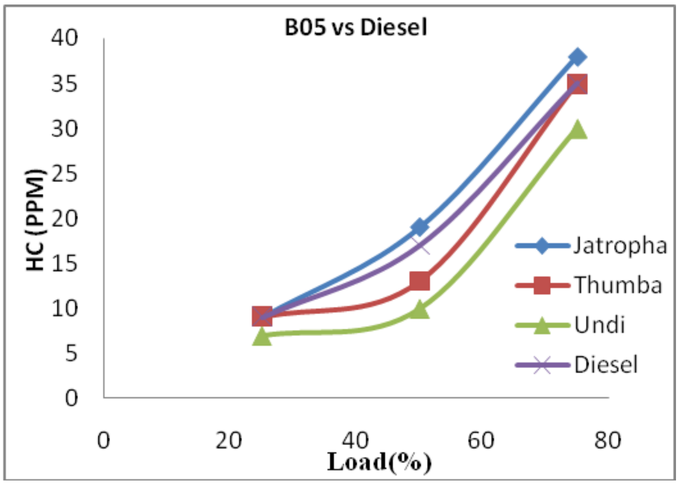

Fig. 5.1- Variation of Load vs HC of JB5,TB5, UB5 with diesel fuel

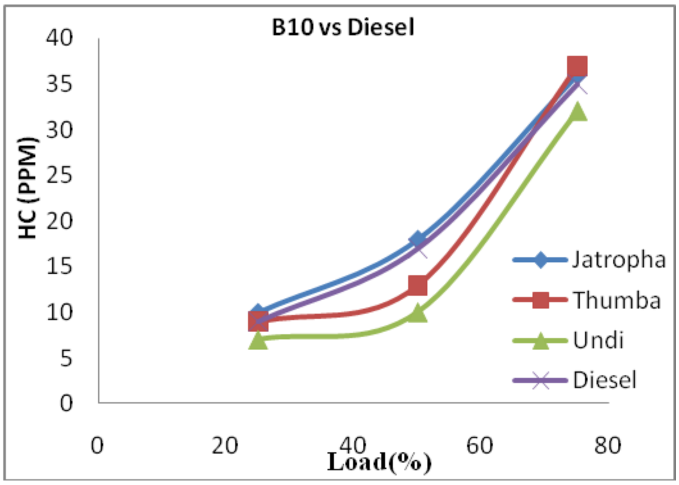

Fig. 5.2- Variation of Load vs HC of JB10,TB10, UB10 with diesel fuel

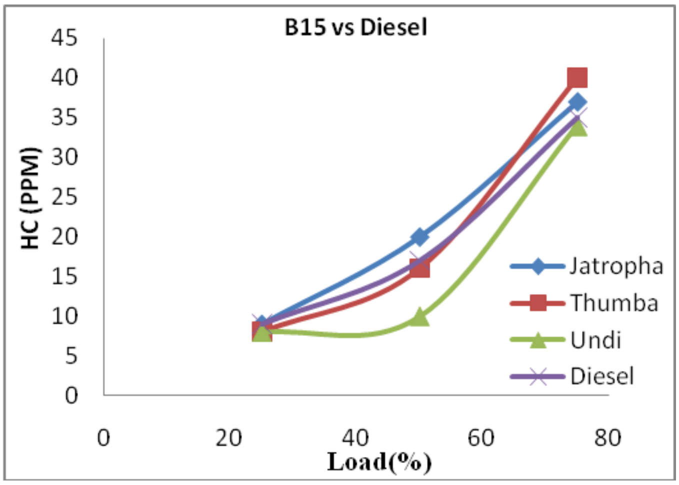

Fig. 5.3- Variation of Load vs HC of JB15,TB15, UB15 with diesel fuel

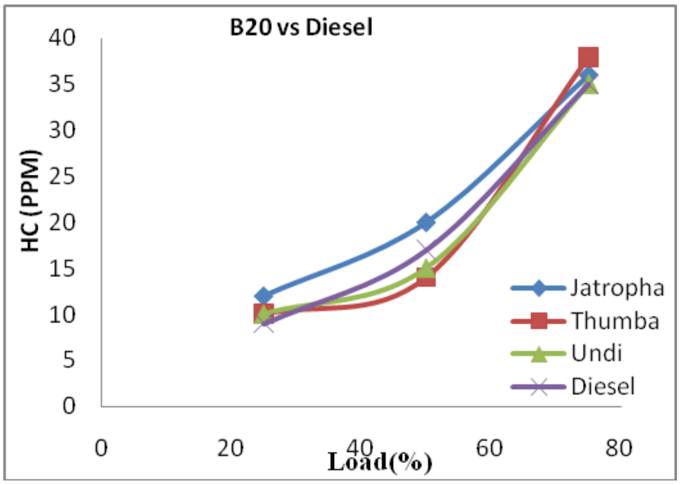

Fig. 5.4- Variation of Load vs HC of JB20,TB20, UB20 with diesel fuel

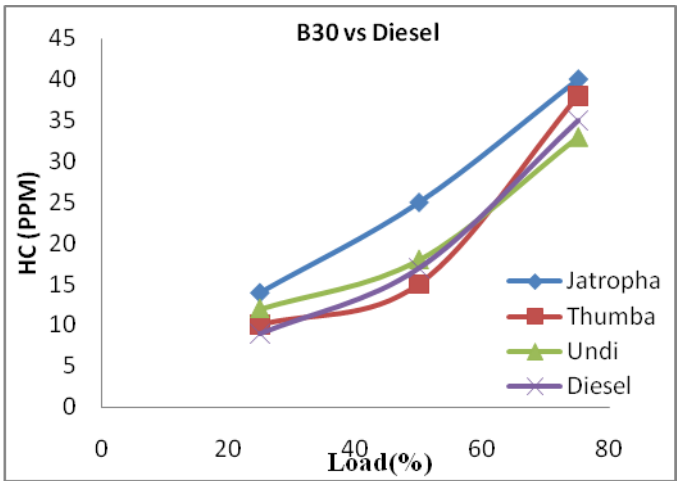

Fig. 5.5- Variation of Load vs HC of JB30,TB30, UB30 with diesel fuel

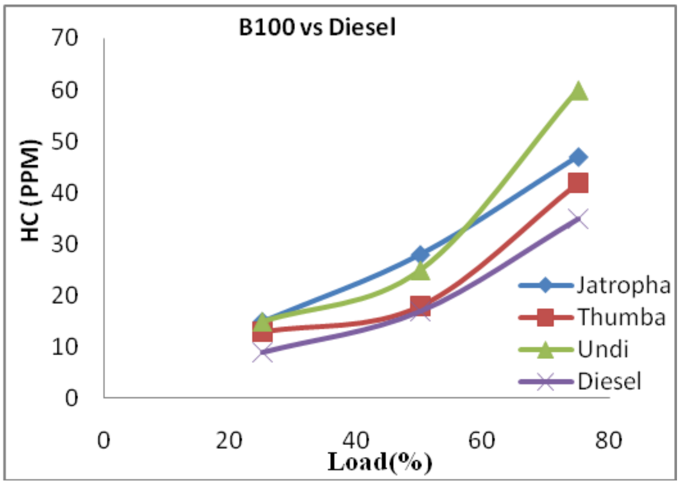

Fig. 5.6- Variation of Load vs HC of JB100, TB100, UB100 with diesel fuel

4) *CO_2 emissions:* The variation of CO_2 emissions were shown in Figure 6.1 to 6.6. The biodiesel and its blends emits lower percentage of CO_2 as compared to diesel. Biodiesel contains the high percentage of oxygen in it and lower percentage of the carbon compounds due to this CO_2 emissions would have been decreased compared to diesel [30].Incomplete combustion of high carbon content diesel fuel causes less CO_2 emissions as compared to biodiesel and its blends, but in the present work CO_2 emissions of all blend of biodiesel shown lower CO_2 emissions except jatropha B05 blend. Higher CO_2 emissions is the significance of the compete combustion. Because of higher oxygen content in the Undi biodiesel as compared to the jatropha and thumba oil biodiesel it showed lower CO_2 emissions [31], [32].

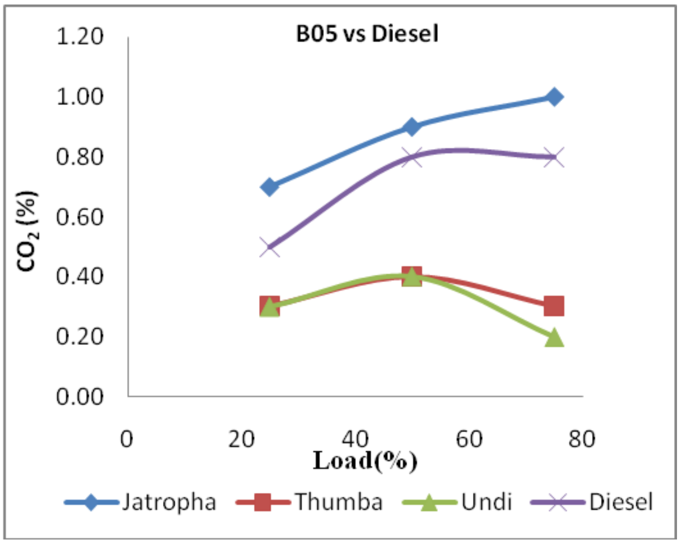

Fig. 6.1- Variation of Load vs CO2 of JB5, TB5, UB5 with diesel fuel

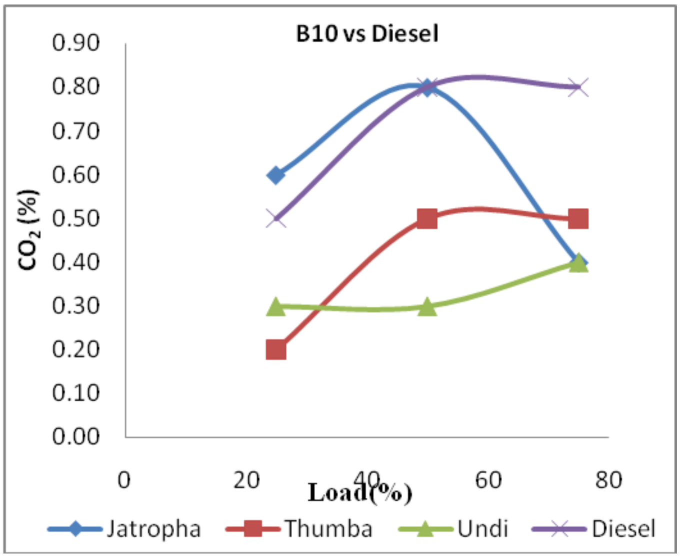

Fig. 6.2- Variation of Load vs CO2 of JB10, TB10, UB10 with diesel fuel

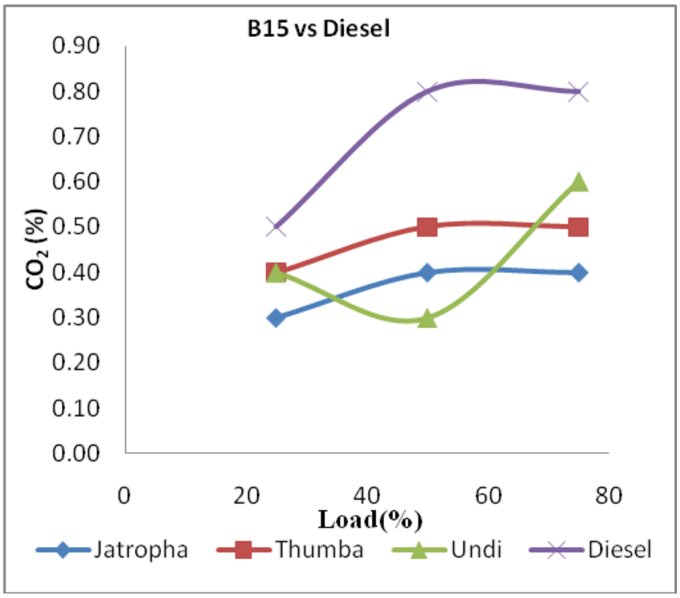

Fig. 6.3- Variation of Load vs CO2 of JB15, TB15, UB15 with diesel fuel

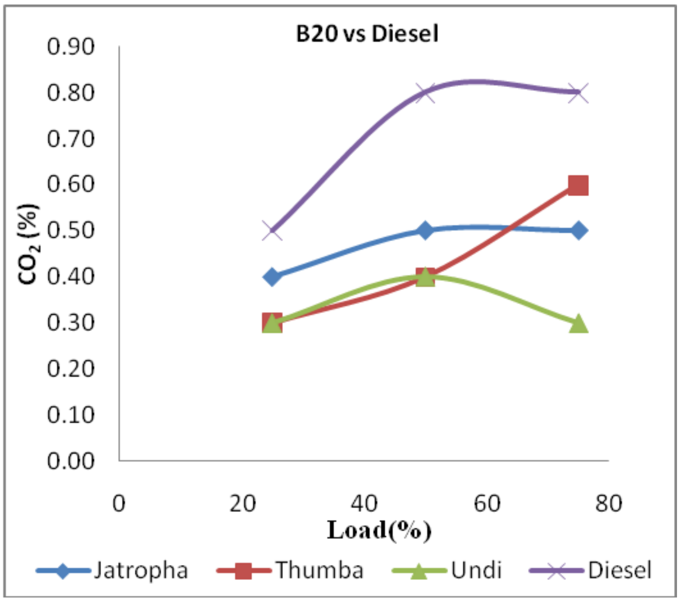

Fig. 6.4- Variation of Load vs CO2 of JB20, TB20, UB20 with diesel fuel

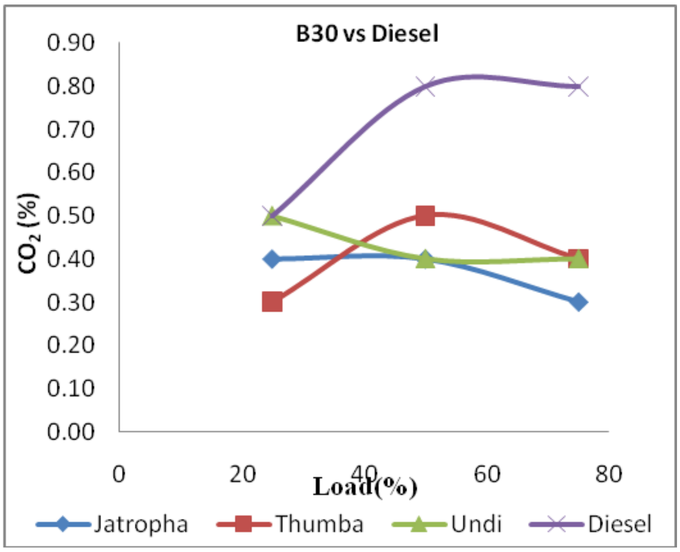

Fig. 6.5- Variation of Load vs CO2 of JB30, TB30, UB30 with diesel fuel

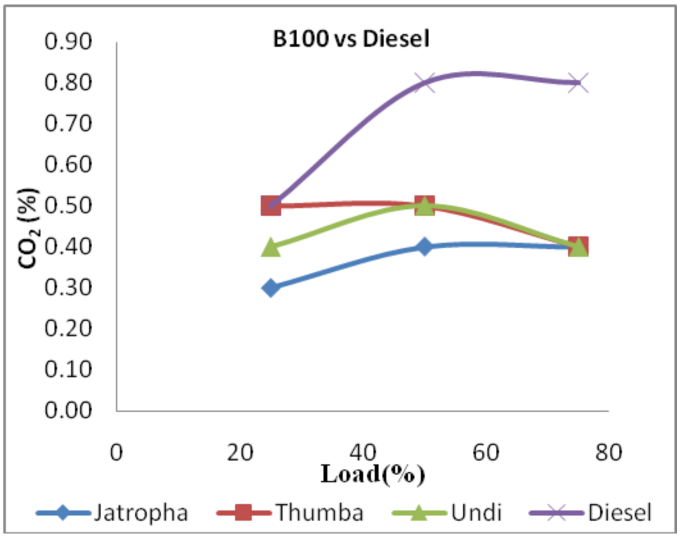

Fig. 6.6- Variation of Load vs CO2 of JB100, TB100, UB100 with diesel fuel

IV. CONCLUSION

1. Brake specific fuel consumption of biodiesel and its blends is higher as compare to diesel. Biodiesel blends B20 and B30 shows comparable brake specific fuel consumption to diesel.
2. Brake thermal efficiency of biodiesel blends is lower than diesel. It is because of lower calorific value of the biodiesel compare to diesel
3. In case of biodiesel blends, CO emissions were lower than that of diesel fuel, due to some extra oxygen contents, which convert CO to CO2 and resulted in complete combustion of the fuel.
4. Biodiesel shows high NOx emissions than the diesel fuel.This increase is mainly due to higher oxygen content in biodiesel.
5. Thumba oil biodiesel and its blends shows good performance and emission characteristics compared to jatropha and undi oil biodiesel and its blends.

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