International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 4 Issue 12, December-2015

Experimental Studies on Performance and Emission Characteristics of Ethanol-Cottonseed oil-Diesel blends in C.I Engine

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***Abstract* — Biodiesel represents an alternative to petroleum-based diesel fuel. Chemically speaking, biodiesel is a mixture of mono-alkyl esters of fatty acids, most often obtained from extracted plant oils and/or collected animal fats. With increasing demand on the use of petroleum products, a stronger threat to clean environment is being poised as the burning of these fuels in associated with emissions like CO_2, CO and particulate matter, which is currently the dominant global source of emissions. Cottonseed oil methyl ester was prepared by transesterification using sodium hydroxide (NaOH) as catalyst, and used as additive which blends the mixture of ethanol-diesel. An unmodified single cylinder, constant speed of 1500 rev/min, four stroke, direct injection, and naturally aspirated vertical compression ignition, typical to engines used in the agricultural sector (pumps, tractors) was fueled with ethanol, diesel and cottonseed oil biodiesel at different ratios in the current performance and emission studies.Fuel characteristics (density, calorific value, viscosity and flash point), engine performance and emission characteristics have been investigated and significant improvements were observed. Blends E15CSO50D35, E20CSO50D30, E25CSO50D25 experience a better higher brake thermal efficiency compared to the conventional diesel fuel at different Injection pressures. Even there is a 2.51% higher brake thermal efficiency improvement with blend E25CSO50D25 at 190 bar compared to diesel. For E25CSO50D25 at 170 bar injection pressure, Exhaust gas temperature is lower compared to all other blends at full load condition. Unburnt hydrocarbons emission is found to be 72 ppm for E25CSO50D25 at 170 bar is less compared to 89 ppm for Neat diesel at 210 bar at full load condition.**

Key words – Bio-diesel, Cottonseed Oil, Transesterification, Brake Thermal Efficiency, Brake Specific Fuel Consumption.

I. INTRODUCTION

With the increased emphasis on the need for clean, renewable fuels, it is imperative to fully understand the operational characteristics of biodiesel. Liquid fuels from renewable sources are biodegradable and inexhaustible. In this regard tree based oils or vegetable oils having their physical and combustible characteristics closed to diesel fuels may stand as immediate candidate alternative fuel for diesel fuel and the seeds can be grown and processed in rural areas. It has been observed that the crude vegetable oils, when used for long hours, choke the fuel filter because of high viscosity and insoluble's in crude oil. Viscosity of vegetable oils exerts a strong influence on the shape of the fuel spray jet penetration. With high viscosities, the jet tends to be a solid stream instead of spray of small droplets. As a result, the fuel is not distributed in or mixed properly with the air required for burning. This results in poor combustion, accomplished by loss of power and economy. In small engines, the fuel spray may impinge upon the cylinder walls, washing away the lubricant oil film and causing dilution of the crankcase oil. Such a condition contributes to excessive wear and tear. Most of the vegetable oil has kinematic viscosity at 40°C in the range of 35-50 cst., where as for diesel oil is 4-6 cst. Simple esters of the fatty acids in vegetable oils have greatly reduced viscosities in the range of 2.4 - 8 cst. at 40 °C.

Additionally, ethanol has also been considered as oxygenated alternative fuel for diesel engines as the blended fuel for a long time. However, using ethanol as fuel or fuel additive in diesel engines is limited by their miscibility problems with diesel fuel. Other problems are low cetane number, low lubricity and reduced heating value. A mixture of biodiesel-diesel-ethanol can be utilized to improve the poor cold-flow properties of biodiesel besides to low cetane number and lubricity of ethanol-diesel blends. Also, biodiesel is known to improve the phase stability of blends.

The major problem of using ethanol in diesel engine is phase separation. It posses a major barrier for using a fuel in C.I Engine. Bio ethanol is not fully miscible with diesel fuel and its stability depends strongly on temperature and water content. It required some additive to produce a stable blend. The following two techniques used for prevention of separation such as emulsification and co-solvent (additives). The co-solvent act as a bridging agent through molecular compatibility and bonding to produce a homogeneous blend, such as n-butanol, isobutanol, diethyl ether and vegetable oil esters. Among those above co-solvents locally available, easily produceable and economically suitable co-solvent is known as vegetable oil esters. It is commonly known as bio diesel. The properties of methyl and ethyl alcohol are compared with octane (high quality gasoline) and hexadecane (high quality diesel fuel). Octane and hexadecane (petroleum fuels) have higher boiling points, lower latent heats and are insoluble in water. The alcohols become more like petroleum fuels as their chemical weights increase. Ethyl alcohol is also known as ethanol or grain alcohol. Like petroleum driven fuels, ethanol contains hydrogen and carbon, but ethanol also contains oxygen in its chemical structure. The oxygen makes ethanol a cleaner burning fuel than fossil origin fuels. It can be produced chemically from ethylene or biologically from grains, agricultural wastes, or any material containing starch or sugar. Ethanol can also be produced from spilled beer, and dated soda. Because ethanol can be produced from crops, it is classified as a renewable fuel.

A. Biodiesel (cottonseed oil) as an additive

Ethanol and diesel fuel are inherently immiscible because of their difference in chemical structures and characteristics. The addition of ethanol to diesel affects properties such as viscosity, lubricity, Cetane number, energy content and mainly, volatility and stability. Phase separation occurs at relatively low temperatures, which are still used in the blending of anhydrous ethanol. The phase separation can be prevented in two ways. First is the addition of an emulsifier, which acts by lowering the surface tension of two or more substances and the second is the addition of a co-solvent, which acts by modifying the power of solvency for the pure solvent. Diesel and ethanol fuels can be efficiently emulsified into a heterogeneous mixture of one micro-particle liquid phase dispersed into another liquid phase by mechanical with suitable emulsifiers. The emulsifier would reduce the interfacial tension force and increase the affinity between the two liquid phases, leading to emulsion stability. A suitable emulsifier for ethanol and diesel fuel is suggested to contain both lipophilic part and hydrophilic part, in order to obtain an emulsion of diesel and alcohol. Such chemical structures can be found in biodiesel.

Biodiesels are used because of their similarity to diesel oil, which allows the use of biodiesel-diesel blends in any proportion. The biodiesel allows the addition of more ethanol-blended fuel, keeps the mixture stable and improves the tolerance of the blend to water, so that it can be stored for a long period. The large Cetane number of the biodiesel offsets the reduction of Cetane number from addition of ethanol to diesel, thus improving the engine ignition. The addition of biodiesel increases the oxygen level in the blend. Also biodiesel have lubricating properties that benefit the engine, and are obtained from renewable energy sources such as vegetable oils and animal fats. Similar to ethanol, biodiesel have a great potential for reducing emissions, especially particulate materials.

II. TRANSESTERIFICATION

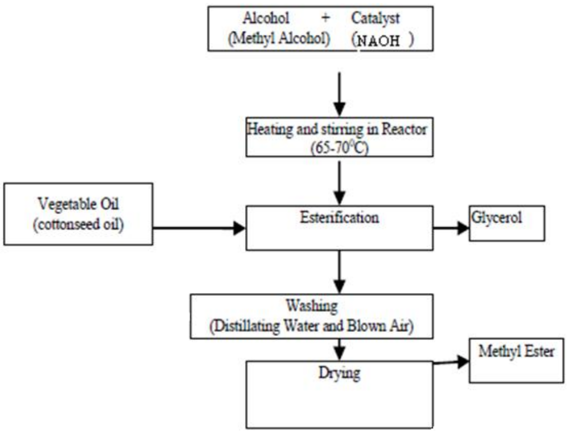

Fig.1 The flowchart of the Cottonseed oil methyl ester (CSOME) production processes.

The Process of Transesterification was carried out in laboratory, Bio-fuel Park, Agricultural research station, Madenur, Hassan. The Transesterification Process steps are discussed in detail:

Filtering: Oil is filtered to remove solid particles. The oil is required to be warm up to have a free flow, 30-40°C which is enough. The filter is used for trapping the solid particles from the oil.

FFA Test: 1 ml of CSO is added to the conical flask using pipette and 0.1 gm of NaOH is added further.

3 to 5 drops of P-H indicator is added to the conical flask and Isopropyl alcohol of 100ml is taken in burette. Titration process is carried, initial reading is noted and when color changes to pink final reading is noted 5.5 ml.

Here FFA value is within 10, No acidic Esterification is required. Hence the oil is ready for carrying out Transesterification process.

Removing of water: The cottonseed oil is heated to 100°C in order to remove water content, otherwise this can slow down the reaction and can cause soap formation. When the water content is removed then it is allowed to cool to 50-60°C.

Preparation of sodium methaoxide: About 6 grams of NaOH (catalyst) pellets is dissolved in 160 ml of methanol in a conical flask to prepare methaoxide solution, which activates the alcohol. Then stirring is done vigorously until the NaOH is dissolved completely.

Heating and mixing: 1 liter of Cottonseed oil is preheated to 65°C in 3-valve flask (reactor). Slowly sodium methaoxide solution is added to oil while stirring is done by using a magnetic rotor. The reaction is often completed in 50 minutes, but longer is better conversion. This separates the methyl esters from glycerin.

The Recovery of methanol can be obtained from the middle valve opening to which condenser is attached and methanol vapour is maintained back.

The equipment is air tightened and heated at constant temperature of 65-70°C for 2½ hr.

Settling and separation: The mixture is allowed to settle by gravity in a separating funnel overnight. It is observed that there are two distinct layers formed. The dense semi-liquid glycerin has a dark brown colour which settles at bottom and bio-diesel has pale yellow colour found at top. Without disturbing the funnel the bottom layer is separated out, which is glycerin and methyl ester of cottonseed oil is retained in funnel.

Washing and drying: Bio-diesel is rinsed with water to remove alcoholic content and then it is further heated to 100-120°C to make the ester free from moisture. After heating, the mixture is once again transferred to the separating funnel where water with any emulsion formed settled at bottom. The pure methyl ester of cottonseed oil is found at upper layer. It is estimated that 65% of methyl ester is obtained in final step.

B. Stability test for ethanol–biodiesel–diesel blends:

Miscibility with ethanol-diesel: Cottonseed methyl ester is mixed with ethanol-diesel blends at various proportions and kept untouched for 24 hours. It was observed that they did not separate. It showed that these blends are completely miscible.

This test is used to identify the phase separation phenomena and to determine the quantity of ethanol, bio diesel, diesel required for long term stability of the blend. A set of five sample blends were prepared, E5CSO50D45, E10CSO50D40, E15CSO50D35, E20CSO50D30, and E25CSO50D25. The commercial available diesel, ethanol and bio diesel prepared from cotton seed oil through transesterification process are used in this stability test. It is observed from samples stability test, the ethanol percentage increases from E05 to E25, the blends are stable for more than ten days.

Table.1 Phase separation time of ethanol–biodiesel–diesel blends.

Fuel blend	E5CSO 50D45	E10CSO5 0D40	E15CSO5 0D35	E20CSO5 0D30	E25CSO5 0D25
Time of separation	Stable	Stable	Stable	Stable	17 days

C. *Properties of biodiesel and its blends:*

Vegetable oils typically have large molecules, with carbon, hydrogen and oxygen. Prior to the conduct of performance tests on the engine, the following important properties of methyl esters of cottonseed oil and its blends with ethanol, diesel fuel for different proportions are determined. The Properties like viscosity, flash point, fire point were tested in laboratory, Madenur, Hassan. and due to lack of facility the remaining properties of blends were tested in Bangalore test house, Marenahalli, Bangalore.

Table.2 Properties of biodiesel, ethanol and diesel

Sl. No	Property	Unit	CSOME	Ethanol	Diesel
1	Calorific value	MJ/Kg	44.934	26.400	43.300
2	Cetane number		76	9	55
3	Carbon residue	%	Nil	0.01	0.12
4	Density at 40°C	kg/m³	867	788	825
5	Specific gravity at 40°C		0.867	0.788	0.825
6	Kinematic Viscosity at 40°C	cst	7.37	1.2	3.98
7	Flash point	°C	170	13	72
8	Fire point	°C	178	15	83
9	Formula		C54H101 O6	C2H5OH	C12H23
10	Colour		Pale yellow	Resembles like Water	Light yellow bluish

Table.3 Properties of Different proportion of Cottonseed oil methyl ester-ethanol-diesel blends.

Sl. No	Property	Unit	E5CSO50D45	E10CSO50D40	E15CSO50D35	E20CSO5030	E25CSO50D25
1	Calorific value	MJ/Kg	42.824	40.865	39.346	38.463	37.785
2	Density at 40°C	kg/m³	859	846	841	838	832
3	Specific gravity at 40°C		0.859	0.846	0.841	0.838	0.832
4	Kinematic Viscosity at 40°C	cst	6.29	5.92	5.17	4.78	4.38
5	Flash point	°C	145	120	85	60	53
6	Fire point	°C	149	125	88	65	57
7	Cetane number		63	58	56	50	47
8	Carbon residue	%	Nil	Nil	Nil	Nil	Nil

III. EXPERIMENTAL SETUP

The line diagram of the experimental setup used for this investigation work is shown below:

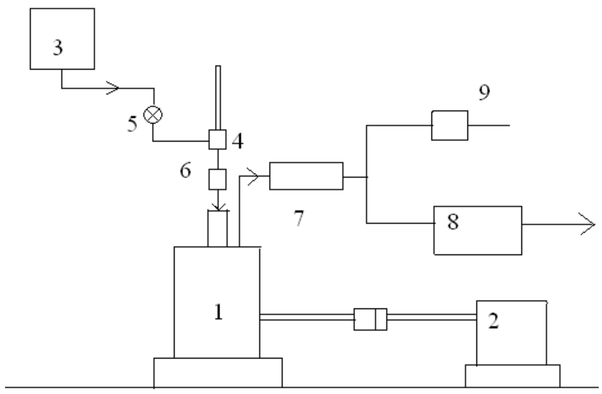

Fig. 2 Schematic diagram of experimental setup

1. Engine 2. Dynamometer 3. fuel tank 4.Burette 5.Fuel filter 6. Air filter 7. Silencer 8. CO/HC exhausts gas analyzer 9. EGT indicator with K-type thermocouple wire.

IV. DESCRIPTIONS

In most of the heavy transport vehicles (HTV) and heavy duty applications of I.C engines used direct injections (DI) diesel engine. A typical kirloskar make - single cylinder - naturally aspirated - direct injection - vertical - constant speed - water cooled - four stroke diesel engine was used in present work. The technical specifications of the engine are listed in appendix.

The engine is connected with fuel tank, for neat diesel and blends of cottonseed oil methyl ester-ethanol -diesel for various proportions at different injection pressure.

The engine is provided with electrical lamp loading arrangement and the burette for volumetric measurement of fuel consumption in c.c. with time. A Japan Fuji electric automobile exhaust gas analyzer (photo.10) was used to measure the emission such as CO and HC. This analyzer has a measuring range of CO: 0 to 10% and HC: 0 to l000 ppm. The sampling lube directly inserted in tailpipe of exhaust while measuring HC and CO. The Exhaust gas temperature is measured using a temperature indicator with K-type thermocouple wire measuring range of 1500°C.

V. RESULTS AND DISCUSSIONS

A Series of experiments were conducted on a direct injection, single cylinder-four stroke diesel engine at constant speed with varying blends of ethanol-methyl ester of cottonseed oil- diesel at different injection pressures of 170 bar, 190 bar, 210 bar. The effects of various blends on the performance and emission characteristics were studied at optimum injection pressure. The Experimental data generated were discussed and presented through appropriate graphs.

Results obtained with diesel fuel at 210 bar IP were taken as baseline data for comparison with different blends for three injection pressures.The Tabulated observations have been plotted in the form of various graphs for analysis.

<u>FOR 170 BAR</u>:

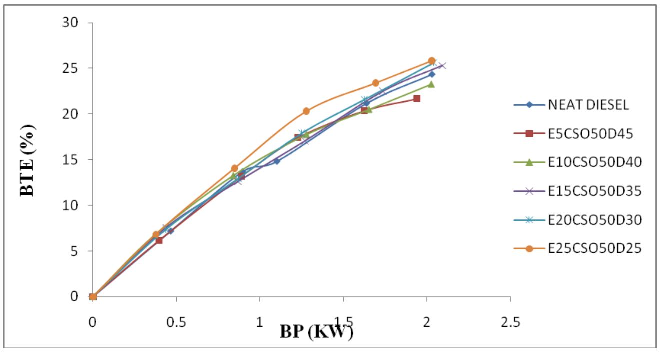

Fig.4 BTE v/s BP for Different Blends.

Fig.4 shows variation of Break thermal efficiency v/s Brake power for different blends at 170 bar. It is noticed that for all the blends efficiency increases with increase in brake power and comparing with neat diesel, it is found to be 1.5 % increase in BTE of E25CSO50D25 blend.

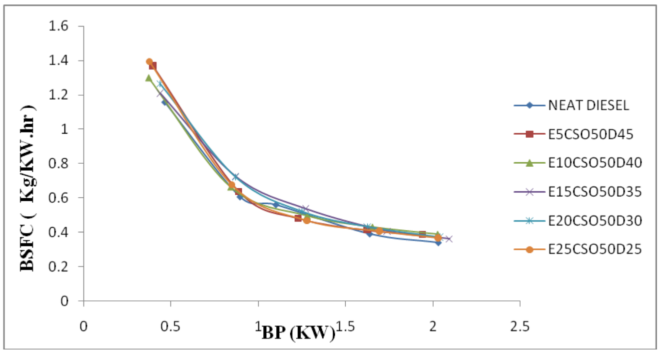

Fig.5 BSFC v/s BP for Different Blends

Fig.5 shows variation of Break specific fuel consumption v/s Brake power for different blends at 170 bar. It is noticed that for all the blends fuel consumption decreases with increase in brake power, for blend E25CSO50D25, fuel consumption is 0.368 kg/kW.hr at full load.

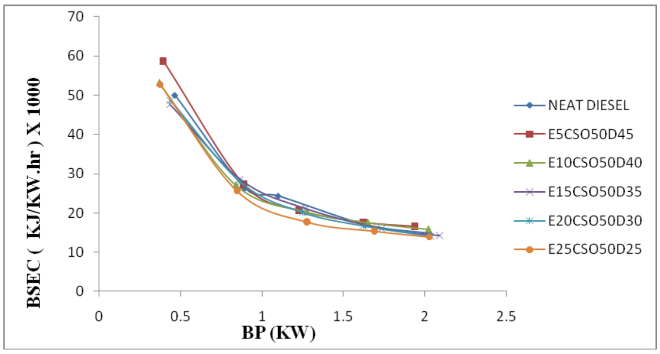

Fig.6 BSEC v/s BP for Different Blends.

Fig.6 shows variation of Break specific energy consumption v/s Brake power for different blends at 170 bar. It is noticed that for blend E25CSO50D25, Break specific energy consumption is 13.928 x10³ kJ/kW.hr at full load condition, which is found nearer to diesel.

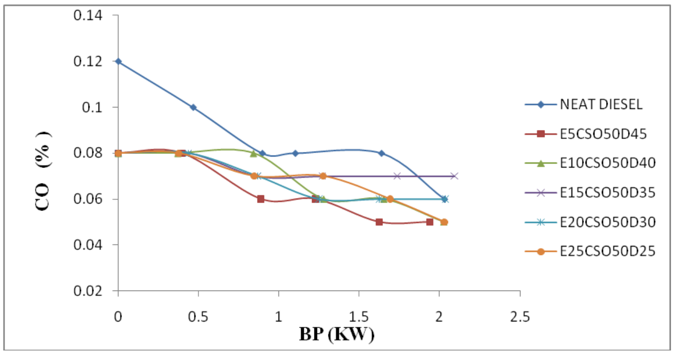

Fig.7 CO (%) v/s BP for Different Blends.

Fig.7 shows variation of Carbon monoxide v/s Brake power for different blends at 170 bar. It can be noticed that for all the blends Carbon monoxide (%) is decreases as increase in B.P, and found better as compared with diesel.

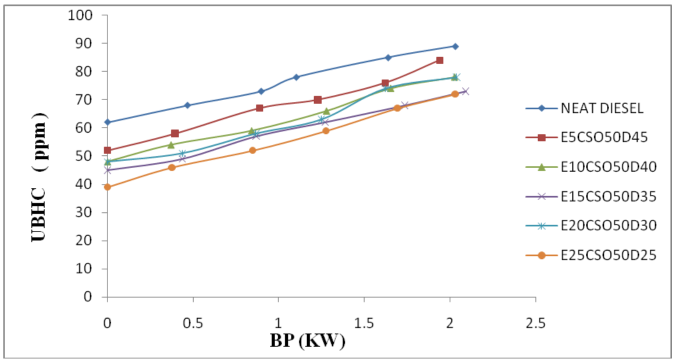

Fig.8 UBHC v/s BP for Different Blends.

Fig.8 shows variation of Unburnt hydrocarbons v/s Brake power for different blends at 170 bar. It is found that Unburnt hydrocarbons increases with increase in load.

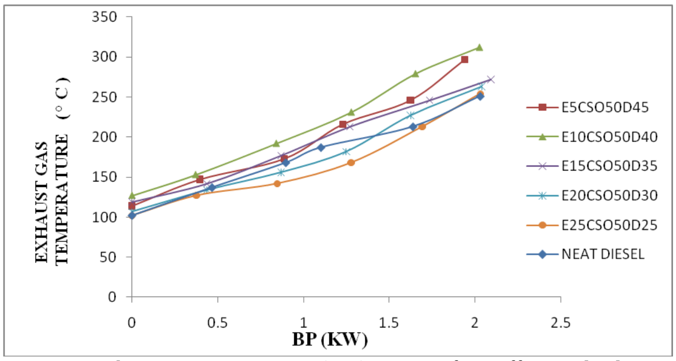

Fig.9 Exhaust Gas Temperature (°C) v/s BP for Different Blends.

Fig.9 shows variation of Exhaust gas temperature v/s Brake power for different blends at 170 bar. It is found that from figure, Exhaust gas temperature for all blends is close to Exhaust gas temperature of diesel.

<u>FOR 190 BAR</u>:

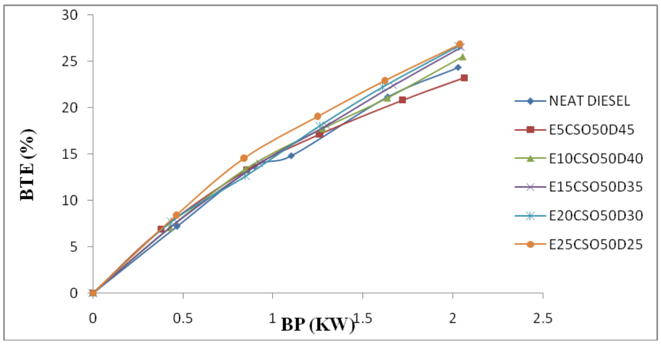

Fig.10 BTE v/s BP for Different Blends.

Fig.10 shows variation of Break thermal efficiency v/s Brake power for different blends at 190 bar. It is noticed that for all the blends efficiency increases with increase in brake power and it is found to be 2.51 % increase in Break thermal efficiency of E25CSO50D25 blend.

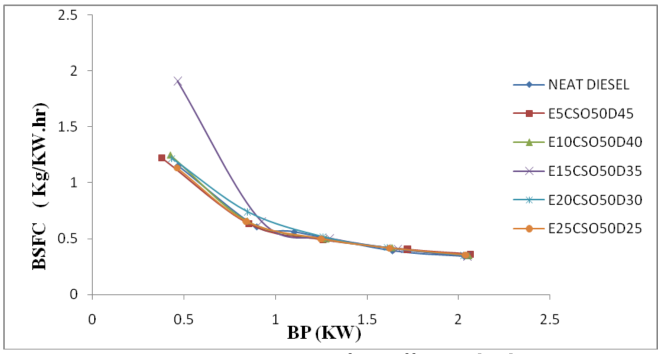

Fig.11 BSFC v/s BP for Different Blends.

Fig.11 shows variation of Break specific fuel consumption v/s Brake power for different blends at 190 bar.It is found that for all blends, fuel consumption decreases with increase in brake power and fuel consumption of all blends are comparable with diesel.

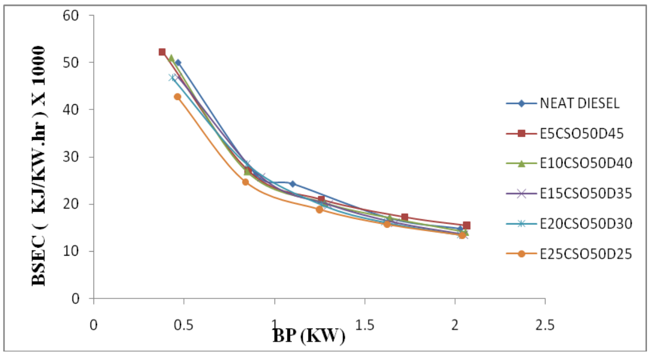

Fig.12 BSEC v/s BP for Different Blends.

Fig.12 shows variation of Break specific energy consumption v/s Brake power for different blends at 190 bar. It is found that BSEC of all blends decreases with increase in B.P at full load condition and blend E25CSO50D25 has less energy consumption compared to all other blends.

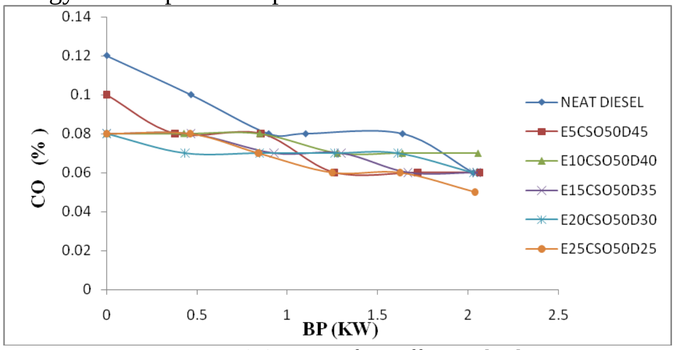

Fig.13 CO (%) v/s BP for Different Blends.

Fig.13 shows variation of Carbon monoxide (%) v/s Brake power for different blends at 190 bar. it is found that CO(%) decreases with increase in load for all blends,this due biodiesel blending which reduces emission.

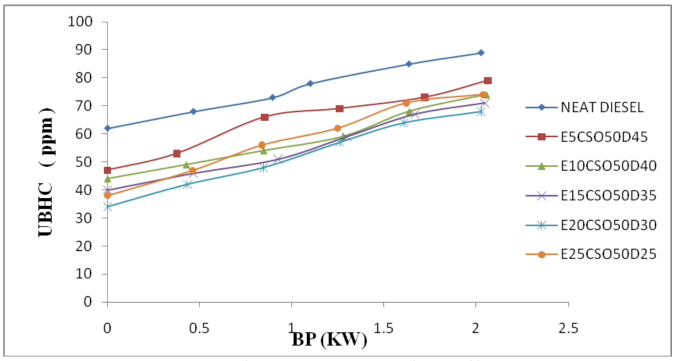

Fig.14 Variation of UBHC with BP for Different Blends.

Fig.14 shows variation of Unburnt hydrocarbons v/s Brake power for different blends at 190 bar.It is noticed that E20CSO50D20 and E25CSO50D25 blends have low Unburnt hydrocarbons compared to other blends.

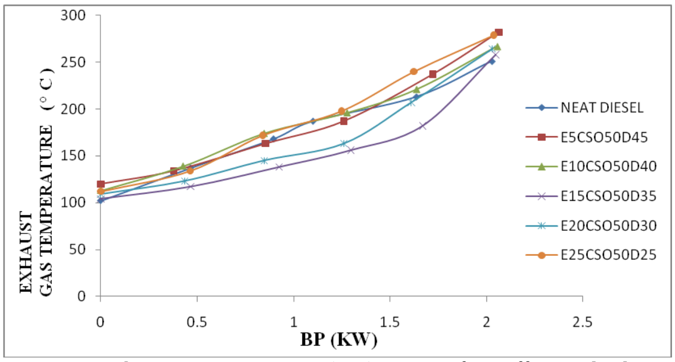

Fig.15 Exhaust Gas Temperature (°C) v/s BP for Different Blends.

Fig.15 shows variation of Exhaust gas temperature (°C) v/s Brake power for different blends at 190 bar. Exhaust gas temperature of different blends increases with increase in B.P.It is noticed that all blends Exhaust gas temperature is found to be maximum compared to diesel.

FOR 210 BAR:

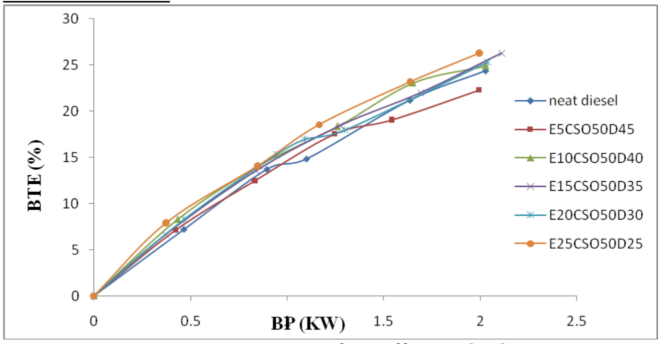

Fig.16 BTE v/s BP for Different Blends.

Fig.16 shows variation of Break thermal efficiency v/s Brake power for different blends at 210 bar. It is noticed that for all blends, efficiency increases with increase in brake power and it is found that 1.95 % increase in Break thermal efficiency of E20CSO50D30 blend.

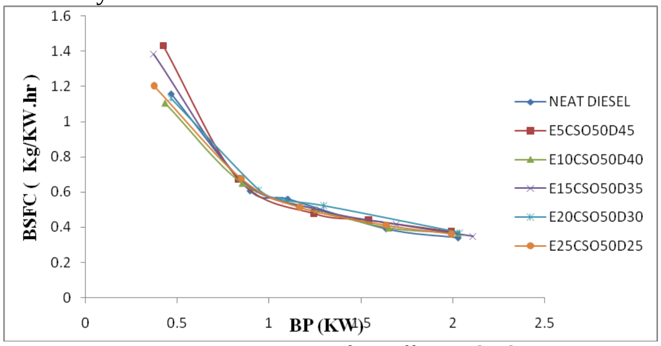

Fig.17 BSFC v/s BP for Different Blends.

Fig.17 shows variation of Break specific fuel consumption v/s Brake power for different blends at 210 bar. It is noticed that for all blends fuel consumption decreases with increase in brake power, for blend E25CSO50D25, fuel consumption at full load is comparable to neat diesel.

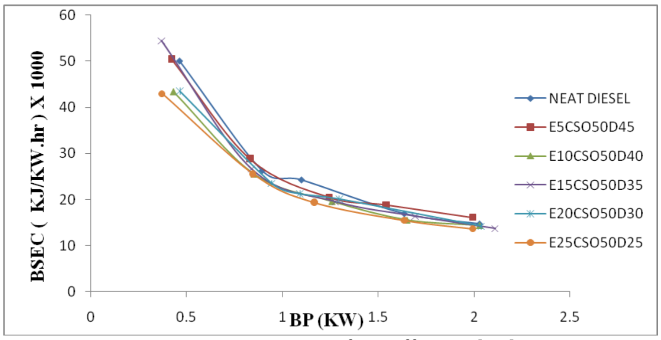

Fig.18 BSEC v/s BP for Different Blends.

Fig.18 shows variation of Break specific energy consumption v/s Brake power for different blends at 210 bar. it is noticed that BSEC of all blends decreases with increase in B.P and blend E25CSO50D25 has less energy consumption compared to other blends.

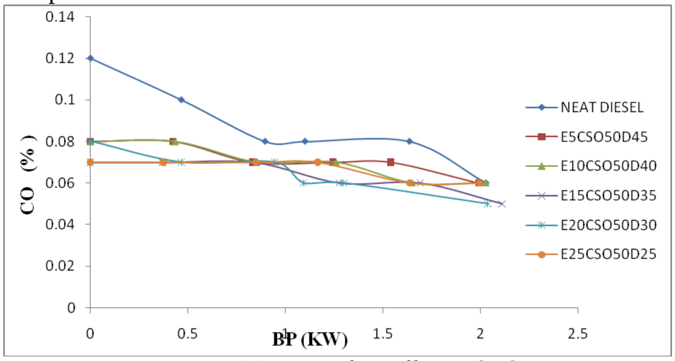

Fig.19CO (%) v/s BP for Different Blends.

Fig.19 shows variation of Carbon monoxide v/s Brake power for different blends at 210 bar. it is noticed that Carbon monoxide (%) of all blends decreases with increase in Brake power.

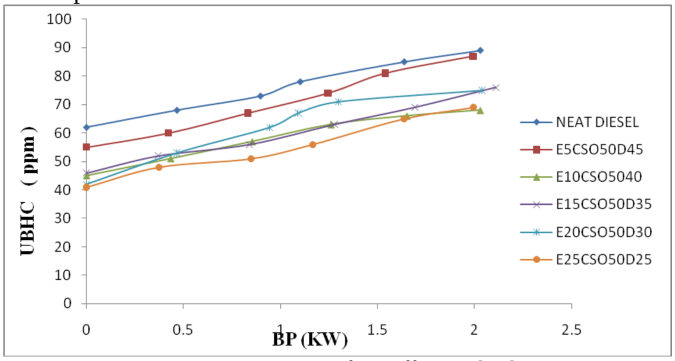

Fig.20 UBHC v/s BP for Different Blends.

Fig.20 shows variation of Unburnt hydrocarbons v/s Brake power for different blends at 210 bar. it is noticed that Unburnt hydrocarbons of all blends increases with increase in B.P and blends E25CSO50D25 has low hydrocarbons compared to all other blends.

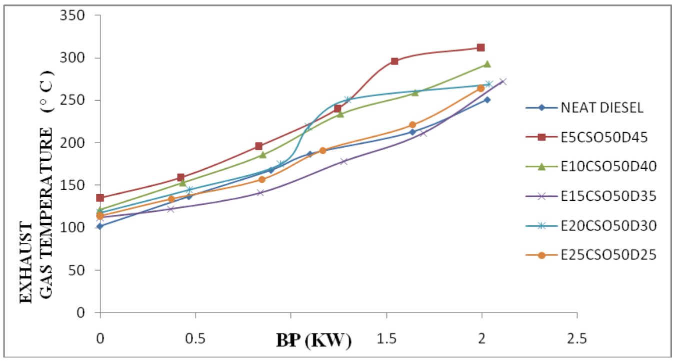

Fig.21 Exhaust Gas Temperature (°C) v/s BP for Different Blends.

Fig.21 shows variation of Exhaust gas temperature (°C) v/s Brake power for different blends at 210 bar. it is noticed that Exhaust gas temperature of all blends increases with increase in Brake power.

5. CONCLUSIONS

All blends have a specific gravity almost near to the specific gravity of conventional diesel fuel. Pure cottonseed oil methyl ester exhibits the largest specific gravity of all the blends, which is clear evidence that this project is necessary that by emulsification of biodiesel and other blends, we can bring biodiesel to a better engine friendly fuel.

The calorific value of all the blends are lower than the diesel. Because of lower calorific value, increase in brake specific fuel consumption of biodiesel. Specific gravities of blends are higher as compared with diesel.

The presence of oxygen in the molecular structure of ethanol and biodiesel derived from cottonseed oil intensifies the complete combustion phenomenon with the emulsified blends.

Cottonseed oil biodiesel exhibits the large flash point of all blends and the blends which contains more percentage of ethanol in the composition has low flash point.

Blends E20CSO50D30, E25CSO50D25 experience a higher brake thermal efficiency compared to the conventional diesel at different Injection Pressures. It is found that 1.5%, 2.51% increase in brake thermal efficiency of E25CSO50D25 blend at 170 bar and 190 bar respectively, compared to diesel and 1.95% increase in break thermal efficiency of E20CSO50D30 blend at 210 bar.

Brake specific fuel consumption for blend E25CSO50D25 is 0.368 kg/kW.hr, 0.362 kg/kW.hr at 170 bar, 210 bar respectively and 0.344 kg/kW.hr for blend E15CSO50D35 at 190 bar.

Break specific energy consumption for blend E25CSO50D25, is 13.928 x10^3 kJ/kW.hr , 13.403x10^3 kJ/kW.hr, 13.70 x10^3 kJ/kW.hr at 170 bar, 190 bar, 210 bar respectively which is low compared with diesel.

Emissions of carbon monoxide mainly depend upon the physical and chemical properties of the blends. Since all blends contains ethanol which oxygenate the fuel and acts as a combustion promoter inside the cylinder which results in better combustion than diesel fuel. Hence carbon monoxide, which is present in the exhaust gas, is lower than diesel.

It is found that for all blends Carbon monoxide (%) is low at different injection pressures.It is conclude that, CO (%) emission is low compared to diesel where Cetane number for E25CSO50D25 blend is 47 nearer to diesel, as shorter delay period occurs.

It is found that for blend E25CSO50D25 has low Unburnt hydrocarbons of 72 ppm, 69 ppm at 170 bar and 210 bar respectively and blend E20CSO50D30 has 68 ppm hydrocarbons at 190 bar compared to all other blends.

Exhaust gas temperature of all blends obtained is maximum as compared with the diesel at different injection pressures. Exhaust gas temperature of E25CSO50D25 is 254˚C at 170 bar is least temperature measured.

6. REFERENCES

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