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Performance and Emissions Study in Diesel Engines Using Cotton Seed Biodiesel

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Abstract:

The use of biodiesel is rapidly expanding around the world, making it imperative to fully understand the impacts of biodiesel on the diesel engine combustion process and pollutant formation. Biodiesel is known as the mono-alkyl-esters of long chain fatty acids derived from renewable feedstock, such as, vegetable oils or animal fats, for use in compression ignition engines. Different parameters for the optimization of biodiesel production were investigated in the first phase of this study, while in the next phase of the study performance test of a diesel engine with neat diesel fuel and biodiesel mixtures were carried out. Biodiesel was made by the well known transesterification process. Cottonseed oil (CSO) was selected for biodiesel production. Cottonseed is non-edible oil, thus food versus fuel conflict will not arise if this is used for biodiesel production. The transesterification results showed that with the variation of catalyst, methanol or ethanol, variation of biodiesel production was realized. However, the optimum conditions for biodiesel production are suggested in this paper.

A maximum of 77% biodiesel was produced with 20% methanol in presence of 0.5% sodium hydroxide. The engine experimental results showed that exhaust emissions including carbon monoxide (CO) particulate matter (PM) and smoke emissions were reduced for all biodiesel mixtures. However, a slight increase in oxides of nitrogen (NOx) emission was experienced for biodiesel mixtures.

***Key Words:* Diesel engine, Alternative fuel, Cottonseed oil, Bio diesel, Engine Performance and Emissions. transesterification.**

I.INTRODUCTION

The worldwide worry about the protection of environment and the conservation of non-renewable natural resources, has given rise to alternate development of sources of energy as substitute for traditional fossil fuels. The major part of all energy consumed worldwide comes from fossil sources (petroleum, coal and natural gas). However, these sources are limited and will be exhausted in the near future. Thus, looking for alternative sources of new and renewable energy such as hydro, biomass (better sources of energy), wind, solar, geothermal, hydrogen and nuclear is of vital importance. Alternative new and renewable fuels have the potential to solve many of the current social problems and concerns, from air pollution and global warming to other environmental improvements and sustainability issues.

II.Preparation and Characterization BIO DIESEL

Production of biodiesel

Vegetable oils are chemically complex esters of fatty acids. These are the fats naturally present in oil seeds, and known as tri-glycerides of fatty acids. The molecular weight of these tri-glycerides would be of order of 800 kg/m3or more. Because of their high molecular weights these fats have high viscosity causing major problems in their use as fuels in CI engines. These molecules have to be split into simpler molecules so that they have viscosity and other

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properties comparable to standard diesel oils. Modifying the vegetable oils (to make them lighter) can be achieved in many ways, including; Pyrolysis, Micro emulsification, Dilution and Transesterification. Among these, transesterification is the most commonly used commercial process to produce clean and environmentally friendly light vegetable oil fuel i.e. biodiesel

Transesterification

Biodiesel, an alternative diesel fuel is derived from a chemical reaction called transesterifcation of plant-derived oil. It is the chemical conversion of oil to its corresponding fatty ester in the presence of a catalyst. The reaction converts esters from long chain fatty acids into mono alkyl esters. Chemically, biodiesel is a fatty acid methyl ester. Transesterification process helps reduce the viscosity of the oil. The process proceeds well in the presence of homogenous catalysts such as sodium hydroxide (NaOH), potassium hydroxide (KOH), sulphuric acid The formation of fatty acid methyl esters (FAME) through transesterification of seed oils requires raw oil, 15% of methanol & 5% of sodium hydroxide on mass basis. However, transesterification is an equilibrium reaction in which excess alcohol is required to drive the reaction very close to completion Transesterification transform the large branched molecule structure of the oils into smaller, straight chained molecules similar to the standard diesel hydrocarbons. Transesterification is the process of exchanging the organic group R" of an ester with the organic group R’ of an alcohol. These reactions are often catalyzed by the addition of an acid or base. Transesterification is common and well-established chemical reaction in which alcohol reacts with triglycerides of fatty acids (non-edible oil) in the presence of catalyst. The transesterification reaction scheme is shown below

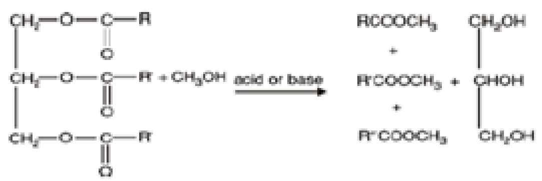

Fig:2.1 Transesterification Reaction Scheme

Methanol and ethanol are used most frequently; especially methanol is preferred because of its low cost and its physical and chemical advantages (polar and shortest chain alcohol). It can quickly react with triglycerides and NaOH gets easily dissolved in it. Ethyl ester and methyl ester almost has same heat content .The two methods preferred for the industrial production of biodiesel from non-edible oils are base catalyzed and acid catalyzed transesterification.

Transesterification

Acid stage

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Base stage

III. Experimentation

3.1 Experimental Design

The experimental tests were conducted on a single-cylinder, four-stroke, and water cooled diesel engine with eddy current dynamometer having a rated output of 3.5 kW at a constant speed 1500 rpm. It was fuelled with CSOME and PD fuel separately and was operated at different engine speed conditions. The technical specifications of the engine are given in table 8. The Eddy current dynamometer for loading was coupled to the engine for different loading (0-12 Kg) conditions. The engine and dynamometer were interfaced to a control panel which is connected to a computer. The exhaust gas emissions from the engine was measured using AVL multi exhaust gas analyzer (NOx, HC, CO, CO2, O2) and the smoke opacity was measured using AVL smoke meter. AVL angle encoder provided at the extended shaft of the dynamometer was used to measure the pressure and crank angle of the engine. Piezoelectric transducer fitted on the cylinder head to measure pressure in the combustion chamber was connected to a console which in turn was connected to the computer.

This computerized test rig was used for calculating the engine combustion and performances characteristics like brake thermal efficiency and specify fuel consumption and for recoding the test parameters like fuel flow rate temperature , air flow rate , load etc., IC engine soft vesuion.9.0 software was used to generate supports of values related to combustion and performance and analysis at different loads.

Table: Technical Specification of Engine test Rig

Model	Kirloskar TV 1 ENGINE
Engine Type	4 stroke diesel engine
Nof of cylinders	1
Cooling system	WATER
RATED POWER (kW)	3.50
BORE X STROKE (MM)	87.50X110.0
CONNECTING ROD LENGHT (mm)	234.0
Compression ratio (variable)	17.50 :1
Fuel injection system	Inline, direct injection
Fuel injection timing(deg)	23^0 BTDC
IVO	4.5 ^{0} BTDC
IVC	35.5^0 ABDC
EVO	35.5^0 BBDC
EVC	4.5^0 ATDC
NOZZELE OPENING PRESSURE (kgf/cm^2)	215
Rated speed (constant speed) (rpm)	1500
Swept volume (cc)	661.45
Loading device	Eddy current dynamometer (water cooled)
Dynamometer arm length(mm)	185

Instrumentations

The emissions and smoke opacity analysis was carried out by using smoke meter and exhaust gas analyser

Exhaust Gas analyser

An exhaust gas analyser particularly for testing motor vehicle engine emissions has a sampling tube into which a mixture of exhaust gas and ambient air is fed through gas lines a gas feed pump is disposed down steam of the sampling tube with a flow meter inserted in the air line feeding electrical signals at a computing unit. The unit computes instantaneous standard total floe rate allowing for gas pressure and temperature.

Table: List of exhaust emissions measured by gas analyser with its measuring range, resolution and accuracy

IV.Result and Discussions

A four stroke water cooled single cylinder direct injection diesel engine was run successfully using cotton seed biodiesel in diesel fuel. The combustion, performance and emission characteristics of the engine were analysed and compared to baseline fuel.

Performance parameters of Petodiesel and Cotton Seed Biodiesel (CSOME) Diesel Exhaust Gas Emissions

Load (Kg)	BP (kW)	MECH EFFICIENCY(ME)		Brake thermal Efficiency (BTE)		IMEP (bar)		BSFC(kg/kWh)	
		D	CSBD	D	CSBD	D	CSBD	D	CSBD
2.4	0.72	23.6	20.8	12.2	11.07	3.7	4.1	0.37	1.08
4.4	1.3	1.3	32.5	20.2	17.11	4.4	4.8	0.63	0.81
6.4	1.86	1.86	43.5	24.7	21.4	4.8	5.2	0.55	0.71
8.6	2.42	2.42	54.98	28	24.79	5	5.6	0.51	0.65
10.4	3.0	3.0	63.78	30.4	26.77	5.5	5.8	0.48	0.63
11.4	3.3	3.3	67.32	31.2	27.6	5.7	5.9	0.47	0.613
12.4	3.6	3.6	68.2	32.2	27.7	5.9	6.2	0.47	0.611

Load (Kg)	BP (kW)	Speed (rpm)	CO (%vol)	HC (PPM)	CO_2 (%vol)	O_2 (%vol)	NO_X (PPM)	SMOKE OPACITY %
2.4	0.72	1530	0.065	20	2.5	14.49	215	1.02
4.4	1.3	1525	0.055	20	3.1	16.74	359	1.4
6.4	1.86	1520	0.045	21	3.7	16.01	545	1.8
8.6	2.42	1515	0.035	23	4.3	15.11	738	2.3
10.4	3.0	1510	0.025	28	5	14.5	955	2.9
11.4	3.3	1505	0.028	32	5.3	14.2	1045	3.6
12.4	3.6	1500	0.032	37	5.6	14.1	1090	4.5

Biodiesel Exhaust Gas Emissions

Load (Kg)	BP (kW)	Speed (rpm)	CO (%vol)	HC (PPM)	CO_2 (%vol)	O_2 (%vol)	NO_X (PPM)	SMOKE OPACITY %
2.4	0.72	1530	0.05	15	2.45	17.5	217	0.39
4.4	1.3	1525	0.045	14	2.8	16.6	368	0.59
6.4	1.86	1520	0.04	14	3.4	15.7	555	0.89
8.6	2.42	1515	0.033	15	4	14.7	753	1.2
10.4	3.0	1510	0.035	17	4.7	14.1	995	1.7
11.4	3.3	1505	0,036	19	5	13.9	1095	2.1
12.4	3.6	1500	0.041	22	5.3	13.85	1155	2.8

Performance Analysis

In this analysis, performance properties will be illustrated through graphs that show the behavior in both cases of biodiesel and diesel. Performance properties include:

1. Mechanical efficiency (ME)
2. Brake thermal efficiency (BTE)
3. Exhaust gas temperature (EGT)
4. Indicated mean effective pressure (IMEP)
5. Brake specific fuel consumption (BSFC)

Mechanical efficiency (ME)

Figure 34 shows an increase in ME values for diesel and biodiesel with increase of brake power. For biodiesel, ME is lower than that of diesel at each brake power corresponding value due to low volatility and high density of ester which affects the atomization of the fuel and thus leads to poor combustion [74]. The percentage of decrement in ME of biodiesel relative to diesel is -8.21%.

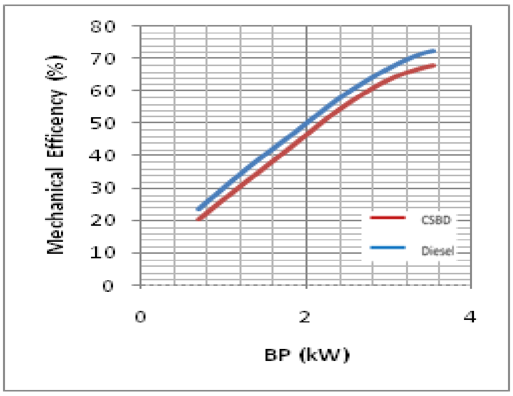

Figure 5.6 Variation in mechanical efficiency with change in brake power

Brake thermal efficiency (BTE)

Thermal efficiency is the ratio between the power output and the energy introduced through fuel injection which equals the product of the injected fuel mass flow rate and the lower heating value, thus the inverse of thermal efficiency is often referred to as BSFC (Brake specific fuel consumption). The obtained efficiency in experiments is the brake thermal efficiency since it is usual to use the brake power for determining it [75].

Figure 35 shows that brake thermal efficiency increases for biodiesel and diesel both with an increase in brake power at different load conditions. It is noticed that BTE is less in case of using biodiesel instead of diesel at each brake power corresponding value due to lower calorific value as it has higher oxygen content and due to higher viscous nature of biodiesel which result in slow combustion, hence reducing the brake thermal efficiency. The percentage of decrement in BTE of biodiesel relative to diesel is -11.58%.

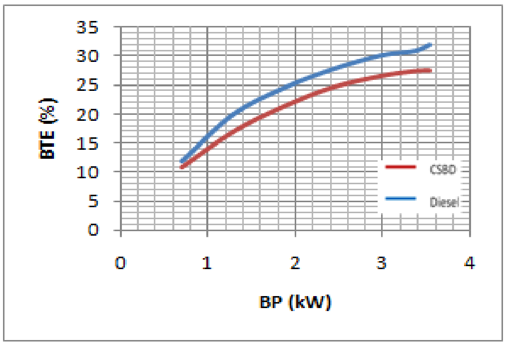

Figure 5.7 Variation in brake thermal efficiency with change in brake power

Indicated mean effective pressure (IMEP)

Indicated mean effective pressure is measured for diesel and biodiesel at different brake power values and they are compared to each other. A gradual increase in IMEP for both biodiesel and diesel with the increase in brake power is observed. For biodiesel, IMEP is little higher than that of diesel value due to higher peak pressure of biodiesel since it burns earlier because of its higher CN which leads to early injection. The increase percentage in IMEP of biodiesel relative to diesel is +10.21%.

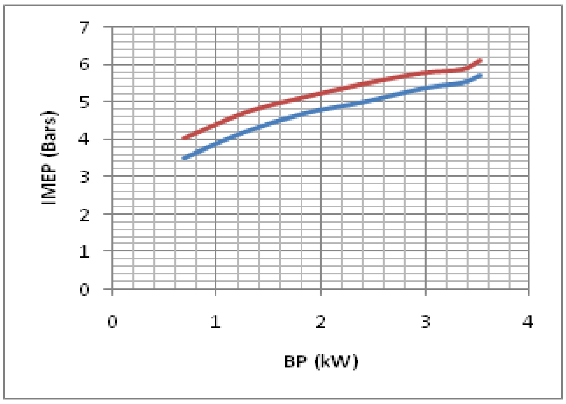

Figure 5.8 Variation in indicated mean effective pressure with change in brake power

Brake specific fuel consumption (BSFC)

Figure 38 shows a decrease in brake specific fuel consumption with the increase in brake power for both biodiesel and diesel. It is well known that brake specific fuel consumption is inversely proportional to the brake thermal efficiency. Therefore, diesel has higher brake specific fuel consumption. It is noticed that BSFC increases in case of using biodiesel instead of diesel at each brake power corresponding value because of lower calorific value of biodiesel. The percentage value of increase in BSFC of biodiesel relative to diesel is 14.18% because the energy content of these fuels differs which would made a great difference in fuel consumption. At higher loads, the diesel fuel operation returned the lower fuel consumption due to the combined effect of lower calorific value and high density of biodiesel.

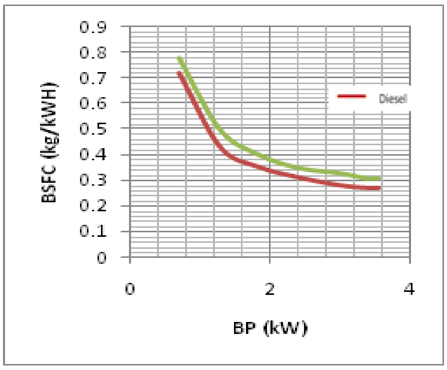

Figure 5.9 Variation in Brake specific fuel consumption with change in brake power

Gas Emissions analysis

This analysis shows the percentage average of(CO,O_2,CO_2,HC and NO_x) emission gases in exhaust.

Carbon monoxide emissions (CO)

Carbon monoxide emission concentrations in the exhaust are a measure of the combustion efficiency of the system. At low loads, combustion is more complete and CO emissions are much lower. The biodiesel showed decrease in CO emissions at low load level. However, the increasing trends of carbon monoxide emissions levels are observed with power output at high loads for both fuels due to higher peak pressure(and also higher rate of pressure rise with is more than 6) which leads to higher knock levels and less smooth combustion leading to increase of CO at high levels.

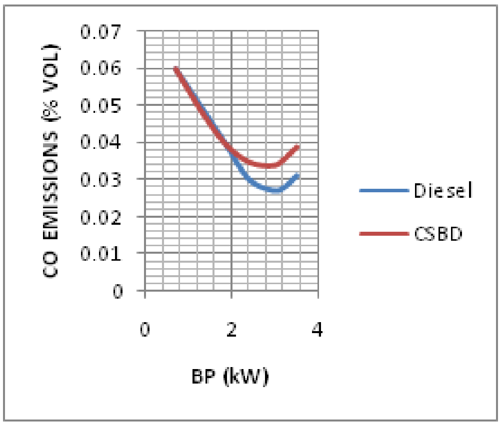

Figure 5.10 Variation in co emissions with change in brake power

Hydrocarbon emissions (HC)

Figure 40 shows an increase of HC emissions with load increasing for both biodiesel and diesel. Biodiesel results in better combustion rate as it contains 11% oxygen content and has higher cetane number which leads to completely burn the fuel during combustion thereby formation of HC emission become lower. As diesel fuel viscosity decreases, the spray cone angle increases and the penetration length decreases, hence HC emissions are noted to increase. The lower vapor pressure of biodiesel means fewer evaporative losses and lower unburned hydrocarbon emissions[76]. The percentage decrease is -37.9%.

Figure 40 shows decreasing trend first and then increasing trend with power output. The reason for higher level of HC at 0 kW power output is attributed to the flame quenching and cooled layer of the charge near the cylinder walls during the cold start. It is less than diesel due to inherent presence of oxygen in the molecular structure of biodiesel.

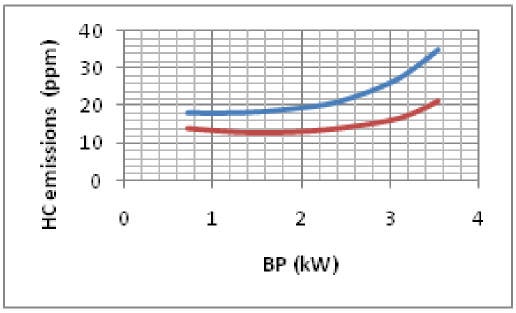

Figure 5.12 Variation in CO_2 Emissions with change in brake power

Carbon dioxide emissions (CO_2)

Figure 41 shows a decrease in co_2 emission of biodiesel. As the viscosity increases, the cone angle decreases and penetration length increases which results in reduction of amount of air entertainment in the spray hence the emissions of co_2 were noted to decrease. It affects combustion characteristics of fuel. Its percentage decrease is -3.7%.

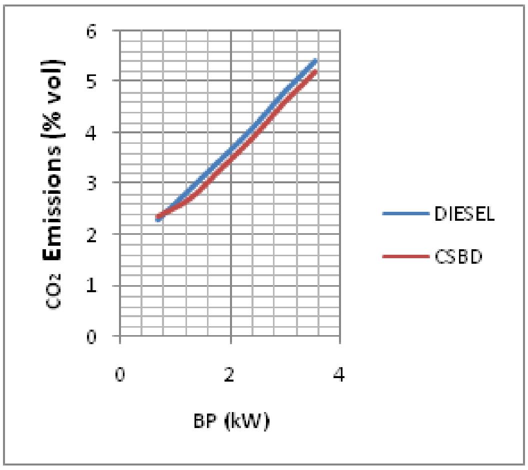

Figure 5.12 Variation in CO_2 Emissions with change in brake power

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Oxygen emissions (O_2)

Oxygen gas (O_2) volume percentage value is measured for diesel and biodiesel at different values of break power and the values are compared to each other. From chart we notice that O_2 emission values decreases. The results conclusively showed that biodiesel fuel operation had the highest O_2 utilization. Its percentage decrease is +2.5%.

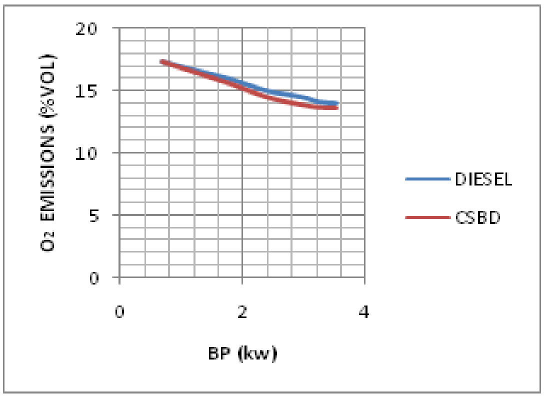

Figure 5.13 Variation in CO_2 Emissions with change in brake power

Oxides of nitrogen emissions (NO_x)

At small loads, very little fuel is injected resulting in very low NO_x levels, thus NO_x emissions are roughly proportional to the mass of fuel injected. NO_x emissions tend to be higher at higher loads with higher peak pressures and higher temperatures because of higher duration of combustion attributed to high cetane number associated with the availability of oxygen which drastically cause higher NO_x levels. Biodiesel and diesel have similar NO_x emission trends but biodiesel seems to have slightly higher NO_x emissions than diesel. Its percentage increase is +5.02%.

The increased engine loads promote NO_x emissions. Since the formation of NO_x is very sensitive to temperature which is responsible for thermal (Zeldovich)NO_x formation. Also long chain biodiesel produces more NO_x than diesel Also the higher bulk modulus (density) leads to early injection which contributes toward large premixed combustion which is responsible for thermal NO_x production. Higher levels of oxygen lead to improvement in oxidation of the nitrogen available during combustion which will raise the combustion bulk temperature responsible for thermal NO_x formation. It is also observed that the higher the peak pressure of premixed combustion, the larger will be the NO_x formation.

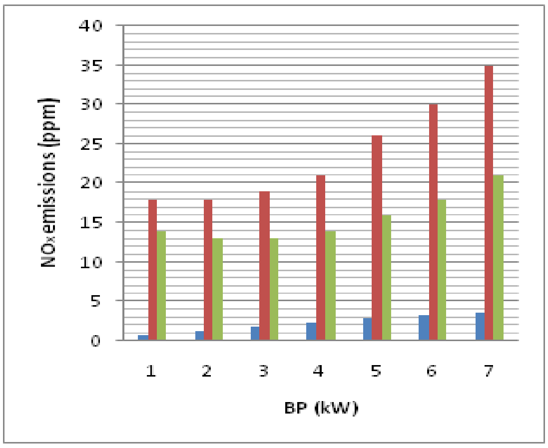

Figure 5.14 Variation in NO_X Emissions with change in brake power

Smoke opacity

Figure 44 shows that the smoke opacity increases for biodiesel and diesel. During the first part, smoke level is almost constant due to excess air. However, in the higher load range, there is an abrupt rise in smoke levels due to more fuel to air ratio, hence incomplete combustion and more soot density marginal decrease of smoke levels at all loads of biodiesel is observed when compared with diesel due to inherent oxygen presence which improves the combustion and due to less amount of fuel accumulation on the hot combustion chamber walls at different operating conditions of the biodiesel in addition to the biodiesel early initiation of combustion since the oxygen in biodiesel provides an effective way to enhance the combustion Process and inhibit soot formation in diesel engines [77].cetane number is an indicator for the fuel in terms of quality, hence the higher the cetane number, the better the ignition property of the fuel by producing less black smoke[78]. It is observed that as the ratio of carbon to hydrogen increases, the fuel tendency of smoke emission producing increase. The smoke reduction for biodiesel is -32.56%

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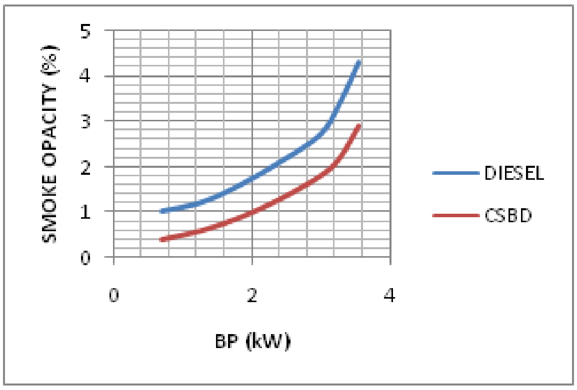

Figure 5.15 Variation In smoke opacity Emissions with change in brake power

V.CONCLUSIONS

1.Due to the higher density of Biodiesel, an early injection occur and higher cylinder pressure result which is about (3.19%) at maximum output power. same reasons lead to higher premixed combustion for biodiesel for about (9.6), but for diffusive combustion is less due to higher viscosity and lower volatility of biodiesel .

2.Biodiesel has higher mass fraction burnt comparing to diesel (0.01%) at maximum output power due to its more effective combustion as it has extra amount of oxygen.

3. On the whole, the methyl esters of cottonseed oil can be used as an alternative fuel for (CIDI) diesel engines without any engine modification. It gives lower un-burnt hydrocarbon, carbon dioxide and smoke emissions when comparing to diesel fuel at the expense of nitrogen oxides and carbon monoxide emissions.

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