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Experimental Determination of Performance Characteristics and Emissions of CI Engine using mixture of Vegetable oils blended with Diesel

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ABSTRACT

The rapid depletion of petroleum fuels and their ever increasing costs have led to an intensive search for alternative fuels. The most promising substitutes for petroleum fuels are the alcohols-mainly methanol and ethanol. Vegetables oils blended with diesel also is a alternative to petroleum. It has been known since the invention of the internal combustion engine that alcohol blended with diesel could be used as a motor fuel. In similar vegetables oil having cetane number more than 30 can be used as alternative of fuel which has good thermal efficiency and combustion properties. The objective of this report is to analyze fuel consumption and emission characteristics of four stroke diesel engine along with typical parameters of engine like indicated power, break power, mechanical efficiency etc. While S.I. engine can use alcohol fuel with minimum modification to their fuel delivery system, C.I. engine can't use alone alcohol. It should be used with proportion of diesel. Diesel blended with transesterified vegetable oil can be good alternative because vegetable oils have better ignition qualities for diesel engines than light alcohols and their cetane number being over 30. A four stroke diesel engine is adopted to study IP, BP, specific fuel consumption and exhaust emission when diesel and vegetable oil are blended together in various proportions. The performance of the engine using bio fuel is compared with engine using diesel alone by using variable compression ratio engine.

Keywords— Alternative fuels,blending, cetane number,Petroleum fuels, transesterification, vegetable oils,

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I. INTRODUCTION

At present vegetable oil is the best alternative to diesel oil since they are renewable and have similar properties. Also Vegetable oils have better ignition qualities for diesel engines than light alcohols, there cetane number being over 30 There are many vegetable oils which can be used in diesel engines like peanut oil, linseed oil, rapeseed oil but the most important in sunflower oil on which maximum work has been done. Many researchers have studied the use of Vegetable oils in diesel engines. Vegetable oils offer almost the same power output with slightly lower thermal efficiency when used in diesel engine. The difference in properties of vegetable oil and diesel oil leads to the following problem in the use of vegetable oil The viscosity of vegetable oil is much higher than that of diesel Vegetables oils are slower burning so that it can give rise to smoke, fuel consumption etc. Apart from this vegetable oils have some merit as follows, they are renewable energy as the vegetables that produce oil are renewable, heat release rate is similar to diesel, its emissions rate is relatively low, they do not contain almost sulfur element, and they can be used with simple or without modifications in the diesel engine. In order to solve these problems caused by the very high viscosity of neat vegetable oils, the following usual methods are adopted: blending in small blend ratios with normal diesel fuel, pre-heating, esterification. The main purposes of this study are to investigate the vegetable oil – diesel fuel blend as a fuel in a direct injection diesel engine and to determine engine performance and exhaust emissions characteristics.

II. BIODIESEL PRODUCTION

Many standardized procedures are available for the production of bio-diesel fuel oil . The commonly used methods for bio-fuel production are elaborated below.

a)Blending

Vegetable oil can be directly mixed with diesel fuel and may be used for running an engine. The blending of vegetable oil with diesel fuel in different proportion were experimented successfully by various researchers. Blend of20% oil and 80% diesel have shown same results as diesel and also properties of the blend is almost close to diesel. The blend with more than 40% has shown appreciable reduction in flash point due to increase in viscosity. Some researchers suggested for heating of the fuel lines to reduce the viscosity. Although short term tests using neat vegetable oil showed promising results, longer tests led to injector coking, more engine deposits, ring sticking and thickening of the engine lubricant. Micro-emulsification, pyrolysis and transesterification are the remedies used to solve the problems encountered due to high fuel viscosity. Although there are many ways and procedures to convert vegetable oil into a Diesel like fuel, the transesterification process was found to be the most viable oil modification process.

b)Transesterification

Transesterification is the process of using an alcohol (e.g.methanol, ethanol or butanol), in the presence of a catalyst, such as sodium hydroxide or potassium hydroxide, to break the molecule of the raw renewable oil chemically into methyl or ethyl esters of the renewable oil, with glycerol as a byproduct. Biodiesel, defined as the mono-alkyl esters of fatty acids derived from vegetable oil or animal fat, in application as an extender for combustion in diesel engines, has demonstrated a number of promising characteristics, including reduction of exhaust emissions. Transesterified, renewable oils have proven to be a viable alternative Diesel engine fuel with characteristics similar to those of Diesel fuel. The transesterification reaction proceeds with catalyst or without catalyst by using primary or secondary monohydric aliphatic alcohols having 1–8 carbon atoms as follows:

Triglycerides + Monohydric alcohol = Glycerine + Mono-alkyl esters

c) Micro –emulsification

To solve the problem of high viscosity of vegetable oil, micro emulsions with solvents such as methanol, ethanol and butanol have been used. A micro emulsion is defined as the colloidal equilibrium dispersion of optically isotropic fluid microstructures with dimensions generally in the range of 1–150 nm formed spontaneously from two normally immiscible liquids and one or more ionic or non-ionic amphiphiles. These can improve spray characteristics by explosive vaporization of the low boiling constituents in the micelles. All micro emulsions with butanol, hexanol and octanol will meet the maximum viscosity limitation for diesel engines

d) Cracking

Cracking is the process of conversion of one substance into another by means of heat or with the aid of catalyst. It involves sheating in the absence of air or oxygen and cleavage of chemical bonds to yield small molecules. The pyrolyzed material can be vegetable oils, animal fats, natural fatty acids and methyl esters of fatty acids. The pyrolysis of fats has been investigated for more than 100 years, especially in those areas of the world that lack deposits of petroleum. Since World War I, many investigators have studied the pyrolysis of vegetable oil to obtain products suitable for engine fuel application. Tung oil was saponified with lime and then thermally cracked to yield crude oil, which was refined to produce diesel fuel and small amounts of gasoline and kerosene.

III. PROPERTIES OF BIODIESEL

The term biodiesel commonly refers to fatty acid methylesters made from vegetable oils or animal fats, whose properties are good enough to be used in diesel engines. Since vegetables have cetane numbers close to that of diesel fuel, they can be used in existing compression ignition engines with little or no modifications. The fuel properties of vegetable oils indicate that the kinematics viscosity of vegetable oils varies in the range of 30–40 cSt at38°C. The high viscosity of these oils is due to their large molecular mass in the range of 600–900, which is about 20 times higher than that of diesel fuel. The flash point of vegetable oils is very high (above 200 8C). The volumetric heating values are in the range of 39–40 MJ/kg, as compared to diesel fuels(about 45 MJ/kg). The presence of chemically bound oxygen in vegetable oils lowers their heating values by about 10%. The cetane numbers are in the range of 32–40.The Biodiesel esters including density, viscosity, iodine value (IV), acid value, cloud point, pour point, gross heat of combustion and volatility. Methyl and ethyl esters prepared from a particular vegetable oil had similar viscosities, cloud points and pour points, whereas methyl, ethyl, 2-propyl and butyl esters derived from a particular vegetable oil had similar gross heating values. However, their densities, which were 2–7% higher than those of Diesel fuels, statistically decreased in the order of methyl similar to 2-propyl >ethyl > butyl esters . The HVs of the Biodiesel fuels, on amass basis, are 9–13% lower than diesel. The viscosities of Biodiesel fuels are twice that of diesel. The cloud and pour points of diesel are significantly lower than those of the Biodiesel fuels. The Biodiesel fuels produced slightly lower power and torque and higher fuel consumption than diesel. Biodiesel is clean, efficient, natural energy alternative to petroleum fuels. Among the many advantages of Biodiesel fuel are safe for use in all conventional Diesel engines, offers the same performance and engine durability as Diesel fuel, nonflammable and non-toxic, and reduces exhaust emissions, visible smoke and odors. Biodiesel is better than Diesel fuel in terms of sulphur content (SC), flash point, aromatic content and biodegradability.

Types of Vegetable Oils used in Compression Ignition Engines

1 Linseed Oil
2 Peanut Oil
3 Castor Oil
4 Sunflower Oil
5 Mustard Oil
6 Jatropha Oil
7 Mahua Oil
8 Soyabean Oil

And some other are used as biodiesel in Compression Ignition Engines.

TABLE-1 PROPERTIES OF VEGETABLE OIL

Property	Linseed	Castor	Palm stearin	Mustard oil	Neem	Diesel
Density (gm./cc) at 40 c	0.930	0.956	0.198	0.881	0.919	0.840
Viscosity (cst)	33.1	52	39.6	35	34	4.3
Flash point in degree Celsius	121	320	220	297	300	58
Calorific values (KJ/Kg)	38507	36000	37500	39000	35200	42800
Cetane number	34.6	42.3	42	45	38	47

A) Viscosity

The direct injection in open combustion chamber trough nozzle and pattern of fuel spray decides the case of combustion and thermal efficiency of the engine. Viscosity plays a vital role in the combustion. Low viscosity can lead to excessive internal pumping leakage where as high viscosity can increase system pressure to unacceptable levels and will effect injection during spray atomization. This effect is critical particularly at low speed or light load condition as pure vegetable oils have high viscosity. The derivatives of vegetable oils are called monsters and have low kinematics viscosity than that of oils. The monoesters are able to give stable solutions in wide range of proportions with diesel fuel, vegetable oils and with alcohol too. They can be solubilizers and can also make it possible to influence the viscosity of blended oils.

B) Self Ignition Response

It is expressed by the cetane number and for a good diesel fuel the value has to be not lower than 45. The cetane number of vegetable oils is less than the diesel. The cetane number of monoesters, on an average, is above that of vegetable oils. For example neem and karanji oils with diesel blends of 10% level have cetane number about 40-45 and at 20% level have cetane number about 35-40.

C) The Energy Content

The specific heating values of the different vegetable oils are nearly the same. They range from 30.5-40.5MJ/Kg and for fuels it are approximately 42.4MJ/Kg. if calorific or heating value of vegetable oils is more, it helps to reduce the quantity handled and to maximize equipment operating range. It is always desirable for vegetable fuels to have heating value nearer to diesel oil

D) Density

Density of the vegetable oils is 0.91-0.94gm/cc at 15oC. In comparison to the density of diesel fuel (0.81-0.86gm/cc)the density of vegetable oils 10% higher, and for ester about 5% higher. For example mahua oil-0.92, neem oil-0.921 & karanji oil-0.95 while the density of ethyl and methyl ester of rape oil is 0.87 and 0.88gm/cc respectively.

E) Pour point, Cloud point And Flash point

First two properties are important for cold weather operation. For satisfactory working, the values of both are well below freezing point of oil used. Flash point is important from safety point of view. The temperature should be practically as high as possible. Typical values of vegetable fuels range between 50 & 110 c addition of vegetable oil with diesel to form a blend should not decrease the flash point temperature.

F) Vegetable Oil Fuel Performance

The vegetable oil based fuels are renewable biomass derived fuels. Further these fuels can be readily mixed with standard diesel and can be used in blends at any proportion. As far as the impact engine is concerned, there has been no evidence of material compatibility, problems using vegetable oil fuel when it is used in the proportion of 20 to 30% blend with diesel. A test in this regard was carried out by national Soya diesel. According to NSDB(Development board USA) reports 100%esters of Soya bean oil indicated immersion incompatibility with certain rubbers and plastics, but not with metals. As far is durability is concerned most studies have shown no appreciable difference between vegetable oil based diesel and petrol. Vegetable oils based fuel can be substituted for diesel fuel with essential no engine modifications particularly at lower blending levels. Further, vegetable oil based fuel has a flash point of 64 c. vegetable oil fuel also has the advantage of not producing explosive fuel air mixtures.

IV. PROBLEMS ASSOCIATED WITH VEGETABLE OIL FUEL

1. Viscosity of vegetable oils is much higher than that of diesel. It can cause problems in fuel handling, pumping, atomization and fuel injection, incomplete combustion, poor cold startup, deposit formation and ring sticking.
2. Slower burning rate: vegetable oil gives rise to exhaust smoke, fuel impingements of oil on cylinder walls and lubricant oil contamination.
3. Volatility of vegetable oils is very less which preclude their use in spark ignition engine.

4. Flow Properties of the vegetable oils are poor which limit their utilization during cold weather in moderate temperature climates

A) Modifications

The problems associated with viscosity can be reduced by heating the oil before entering into the engine.

1. Further the fuel injection problem can be increasing the injection pressure.
2. The problems associated with late/slow burning can be avoided by advancing fuel injection and preheating the fuel.
3. All the above problems can be eliminated up to certain extent by blending vegetable oils with diesel.
4. Low problems can be eliminated by winterization (popular technique for reducing high melting point by freezing them over a prescribed time period and drawing the liquid portion off separately

B)Pollution Aspect Of Vegetable Oils

Vegetable oils have high carbon residue. Vegetable oil based fuel contribute less green house gases to the atmosphere and its use results in reduced air pollution to local levels. The parameters, which improve with vegetable oil based fuel, include smoke, polyrometric hydrocarbon, unburned hydrocarbon, sulphur dioxide, and acetaldehyde. One more important thing is that vegetable oil based fuels are biodegradable and non toxic. If spilled, it is at least 90% biodegradable within three weeks. Therefore, its spill and leaks in mines and other sensitive areas will have less impact on disturbed aquifers. These characteristics make it a valuable fuel particularly in environmentally sensitive areas. Vegetable oil has good ignition qualities than lighter alcohols for diesel engines, since their cetane number is above 30.

V. BLOCK DIAGRAM OF ENGINE TEST RIG

The experimental test rig consists of a variable compression ratio compression ignition engine, eddy current dynamometer as loading system, fuel supply system for both Diesel oil supply and biodiesel supply, water cooling system, lubrication system and various sensors and instruments integrated with computerized data acquisition system for online measurement of load, air and fuel flow rate, instantaneous cylinder pressure, injection pressure, position of crank angle, exhaust emissions and smoke opacity.

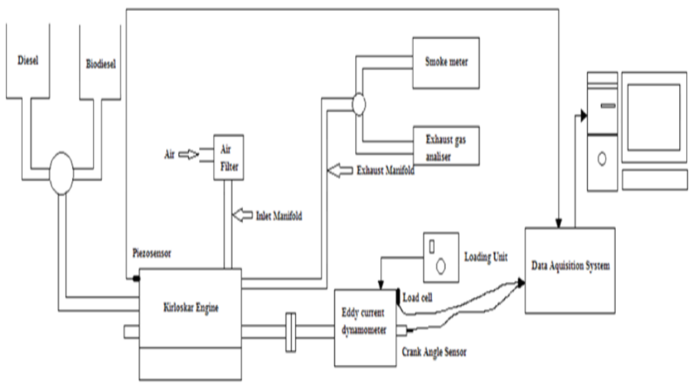


Fig-1. Block Diagram of Engine Test Rig

The setup enables the evaluation of thermal performance and emission constituents of the VCR engine. The thermal performance parameters include brakepower, brake mean effective pressure, brake thermal efficiency, volumetric efficiency, brake specific fuel consumption, exhaust gas temperature, heat equivalent of brake power and heat equivalent of exhaust gas. Commercially available lab view based Engine Performance Analysis software package ―EnginesoftLV‖ is used for on line performance evaluation. The exhaust emissions of the engine are analysed using an exhaust gas analyser.

VI. ENGINE SPECIFICATIONS

TABLE NO 2 ENGINE SPECIFICATIONS.

Make & Model	Kirloskar Oil Engine
Number of cylinder	One
Bore and Stroke	87.5 mm and 110 mm
Combustion principle	Compression ignition
Cubic capacity	0.661 litres
Compression ratio	17.5 :1 (modified to work at 12, 13, 14, 15, 16, 17.5 and 18 compression ratios
Peak cylinder pressure	77.5 kg/cm2
Direction of rotation	Clockwise
Maximum speed	2000 rpm
Minimum idle speed	750 rpm
Minimum operating speed	1200 rpm
Fuel injection timing for standard Engine	23^0 BTDC
Valve clearances at inlet and exhaust	0.18 mm and 0.20 mm
Lubricating system	Force feed system
Power rating 1. Continuous 2. Intermittent	7/1500 hp/rpm 7.7/1500 hp/rpm
Brake mean effective pressure at 1500	6.35 kg/cm
Lubricating oil pump	Gear type
Lubricating oil pump delivery	6.50 lit/min
Sump capacity	1.5% normally exceed of fuel
Connecting rod length	234 mm
Overall dimensions	617L × 504W × 877H
Piezo sensor	Range 5000 psi, with low noise cable
Dynamometer	Type eddy current, water cooled, with loading unit
Temperature sensor	Type RTD, PT100 and Thermocouple, Type K
Load indicator	Digital, Range 0-50 Kg, Supply 230VAC
Load sensor	Load cell, type strain gauge, range 0-50 Kg
Rotameter	Engine cooling 40-400 LPH; Calorimeter 25-250 LPH
Exhaust gas analyzer	Make – Indus Scientific, Five gas analyzer
Smoke meter	Make – Indus Scientific, Range – 0 to 100% HSU

Fig 2 Engine Setup

VII. TEST METHODOLOGY

The present set of experiments were conducted on a four stroke single cylinder vertical water cooled diesel engine equipped with a computer. First the maximum torque of the engine is calculated and the engine is started under no load condition by hand cranking using de-compression lever. The engine will run under no load condition for a few minutes so that the speed stabilizes at rated value. Now by increasing the load from zero to maximum and setting the compression ratio the respected values are automatically saved in a computer and also the exhaust emissions are noted down by using digital gas analyzer indicator. The two types of blends (B10, B20) were used in this experiment. The different parameters required for evaluation of fuel was noted.

VIII. RESULTS AND DISCUSSIONS

A) Engine Performance Test Analysis

Engine performance characteristics are the major criterion that governs the suitability of a fuel. The following engine performance parameters are evaluated.

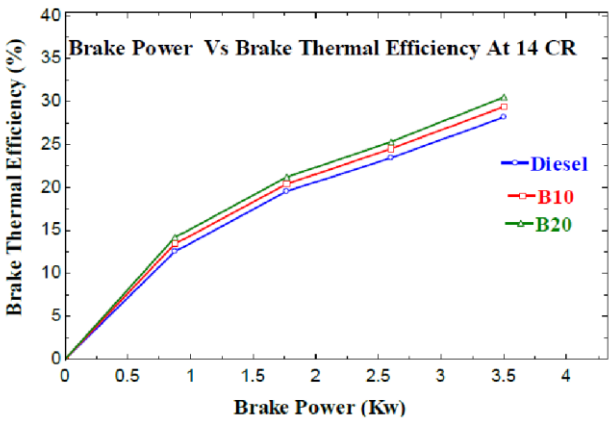


Fig 3 Variation of brake thermal efficiency for B10,B20its Blends and diesel at CR 14

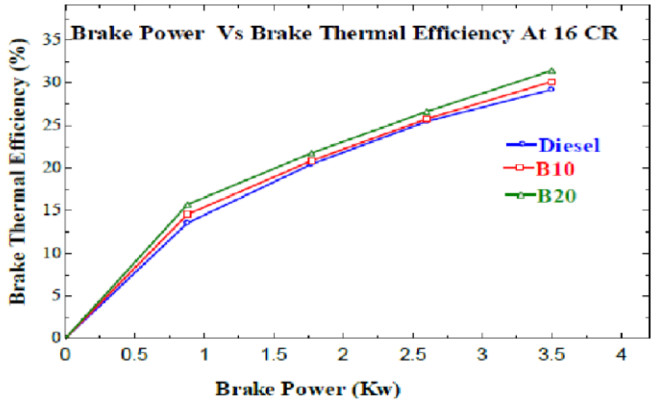
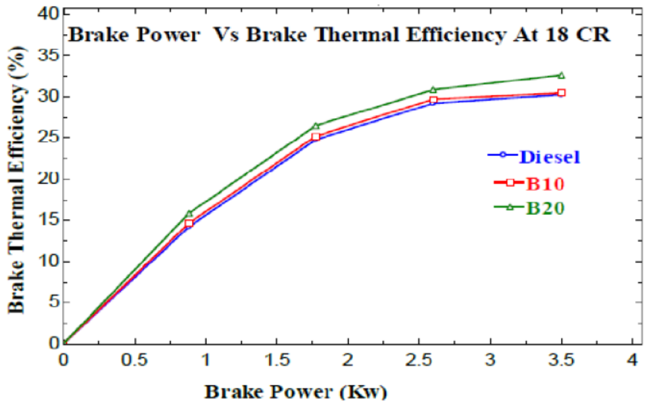


Fig 4 Variation of brake thermal efficiency for B10, B20 Blends and diesel at CR 16



.Fig 5 Variation of brake thermal efficiency forB10, B20 Blends and diesel at CR 18

The variation of brake thermal efficiency with respect to brake power for both fuels and its blends is as shown in Figs3,4,5 Brake thermal efficiency ofB10, B20 blends is slightly higher as compared to that of diesel. It has been observed that the brake thermal efficiency of the blends is increasing with increase in applied load. It was happened due to reduction in heat loss and increase in power developed with increaseinload.Themaximumbrakethermalefficiencyatfullloa dis32.63%forB20atCR18whichis78%higherthanthatofdiesel .Byincreasingtheloadoftheengine,the brakethermal efficiency also increases for Blends B10, B20 compare to the diesel fuel.

B) Brake Specific fuel Consumption

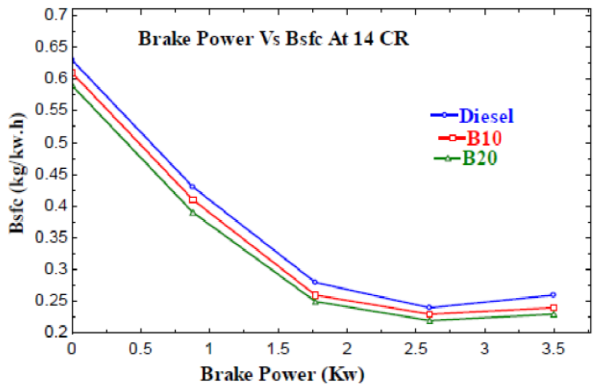


Fig 6 Variation of brake specific fuel consumption for B10, B20 blends and diesel for CR 14

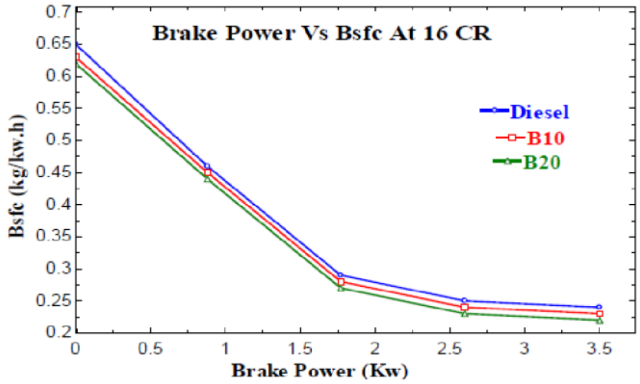


Fig 7 Variation of brake specific fuel consumption forB10, B20 blends and diesel for CR 16

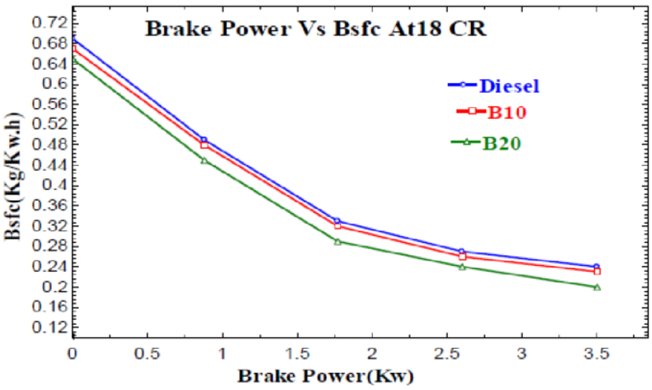


Fig 8 VariationofbrakespecificfuelconsumptionforB1 0, B20blendsanddieselforCR18

Variation of brake specific fuel consumption with show in figs.6,7,8 B10 has lower calorific value than that of diesel. Hence the specific fuel consumption is slightly higher than that of diesel for and its blends. At higher percentage of blends, the SFC increases. This may be due to fuel density, viscosity and heating value of thefuels.B20has higher energy content than other blends but lower than diesel.

C) Mechanical Efficiency

The variation of mechanical efficiency with respect to load for both fuel and its blends is as shown in fig

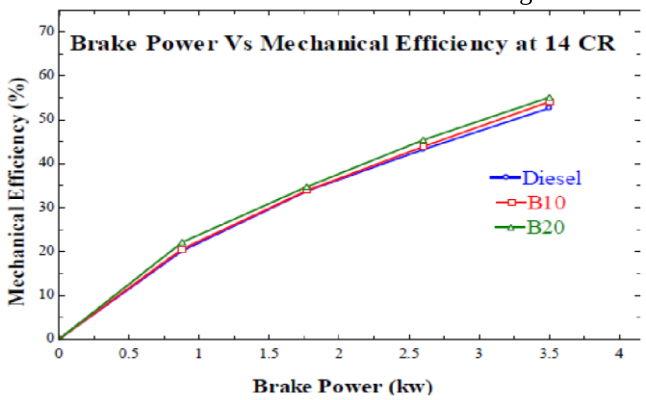


Fig 9 Variation of mechanical efficiency for MME ,its Blends and dieselforCR14

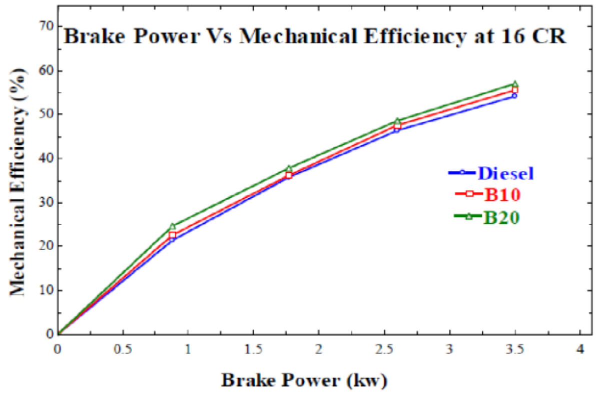


Fig 10 VariationofmechanicalefficiencyforB10, B20 Blends and diesel forCR16

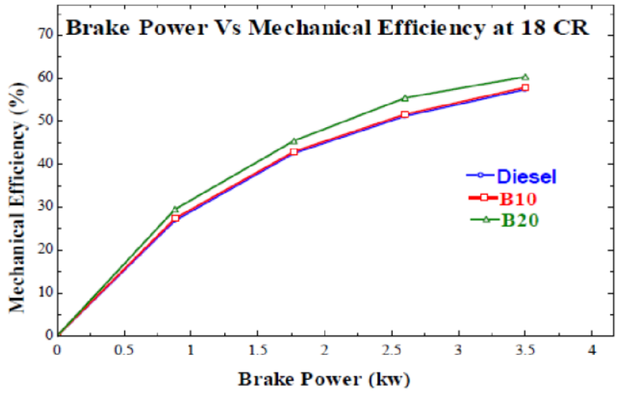


Fig 11 Variation of mechanical efficiency for B10,B20 Blends and diesel for CR18

In Figs: 9,10,11, the mechanical efficiency forB10,B20 blends are slightly increases compare to diesel for all compression ratios. The mechanical efficiency of the blend B20 increases with the increase in compression ratio, when compared to that of standard diesel. The maximum mechanical efficiency obtained from blend B20 for compressionratio18is 58.79%.Mechanicalefficiency increases with increasing compression ratio for all the blends

D)Exhaust Gas Temperature

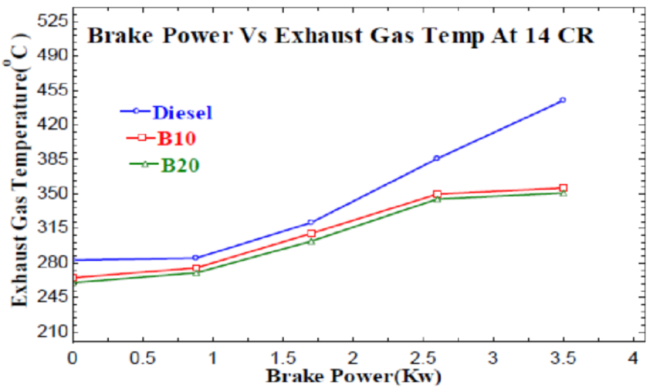


Fig 12 Variation of exhaust gas temperature for B10, B20 Blends and diesel for CR 14

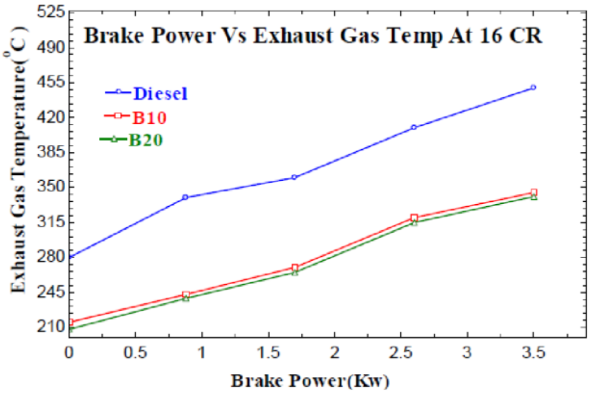


Fig 13 Variation of exhaust gas temperature for B10, B20 Blends and diesel for CR 16

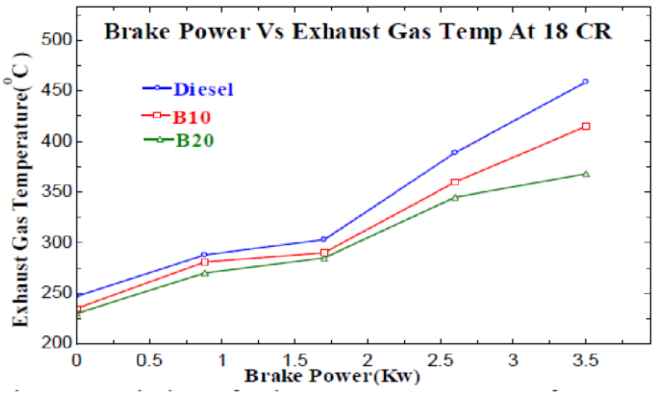


Fig 14 Variation of exhaust gas temperature for B10,B20 Blends and diesel for CR 18

The variations of exhaust gas temperature for different compression ratio and for different blends are shown in Fig.12,13,14. The result indicates that exhaust gas temperature decreases for different blends when compared to that of diesel. At medium compression ratio16:1theexhaustgastemperature of the blends are lower compared to that of standard diesel. As the compression ratio increases, the exhaust gas temperature of the various blends is lesser than that of diesel because we are adding (MTB) methyl tetra butyl ether to blends. The highest temperature obtained is 459 ^{o}C for standard diesel. For a compression ratio of16:1whereas the temperature isonly341 ^{o}C for the blend B20

E)Engine Emission Parameters

With problem like global warming, ozone layer depletion and photochemical smog in addition to widespread air pollution, automotive emission are placed under the microscope and every possible method is attempted to reduce emission. Following Engine Emission parameters are evaluatedforB10,B20blendswithdiesel

i)Carbon Monoxide;

The variation of carbon monoxide with respect to brake power for both blends and diesel is as shown in Fig. 17,18,19. Carbon monoxide emissions are decreases with increase in blend percentage at compression ratios 14,16cr.At all blinds CO is gradually decreased because CO is converted to CO2duetothepresenceof oxygen in biodiesel. Since mustard biodiesel is an oxygenated fuel, it leads to better combustion of fuel resulting in the decrease in CO emission.

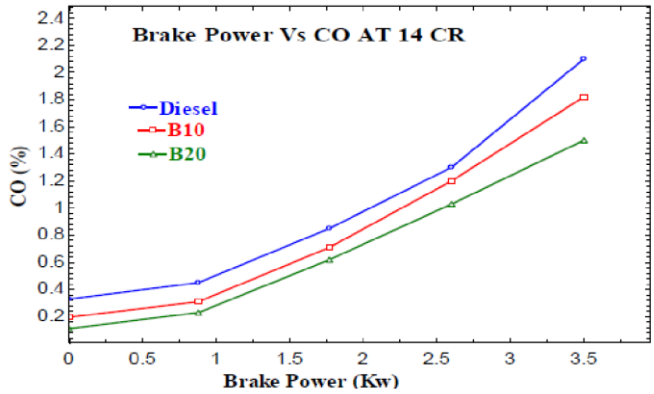


Fig 15 Variation of carbon monoxide forB10,B20Blends and diesel for CR14

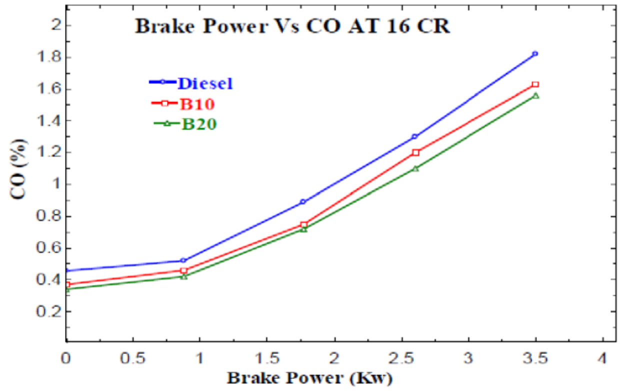


Fig 16 Variation of carbon monoxide for B 10, B20Blendsanddiesel forCR16

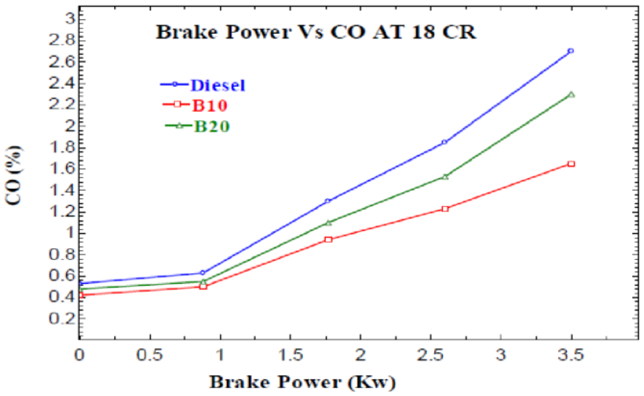


Fig 17 Variation of carbon monoxide for B10, B20Blendsanddiesel forCR18

The CO emission of the blend B10,B20 is less than the standard diesel. And it is found to be the blend B20 moderate compression ratio16 CO emission is1.5(%) is lesser for all compression ratios.

ii) Hydrocarbons ;

The variation of hydrocarbons with respect to load for both fuels and blends is as shown in Fig. 18,19,20. HC emissions reduced drastically at all blends at all compression ratios

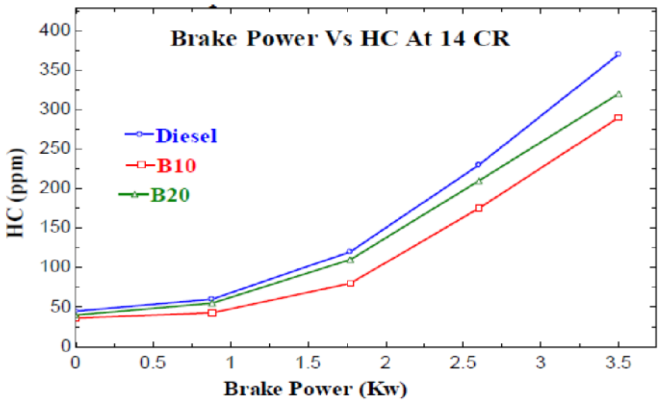


Fig 18 Variation of Hydrocarbons for blends and diesel for CR14

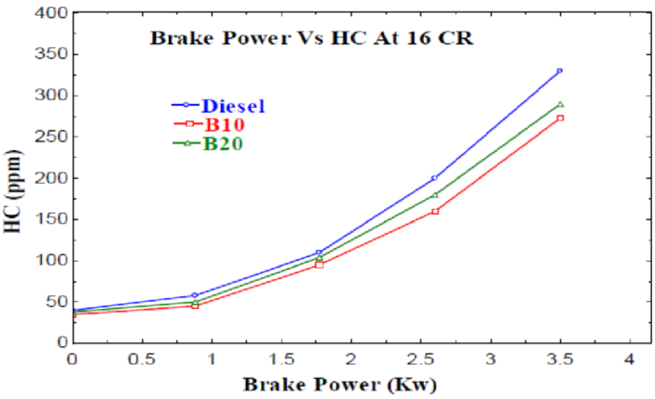


Fig 19 Variation of Hydrocarbons for blends and diesel for CR16

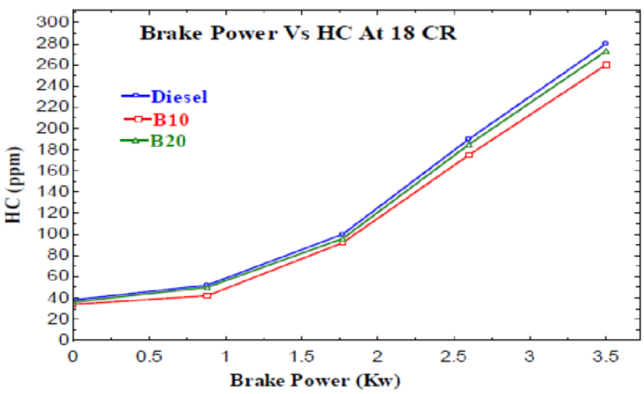


Fig 20 Variation of Hydrocarbons for blends and dies l for CR18

The blends produce lesser hydrocarbon emissions at all compression ratio than the standard diesel. Due to the shorter ignition delay, the complete combustion takes place in combustion chamber.

iii) Nitrogen Oxide;

The variation of nitrogen oxide with respect to load for both fuels and its blends is as shown in Figs: 21,22,23.NOx drastically decrease with the increase in percentage of blends in the fuel at 14,16 cr. The NOx decrease because we are MTB additive it having anti knocking charactreristics. The NOx emissions for all blends decreased compared to diesel because of the exhaust gas temperatures of all blends decrease compared diesel. Among these blend 10 at14cr is lower in NOx.

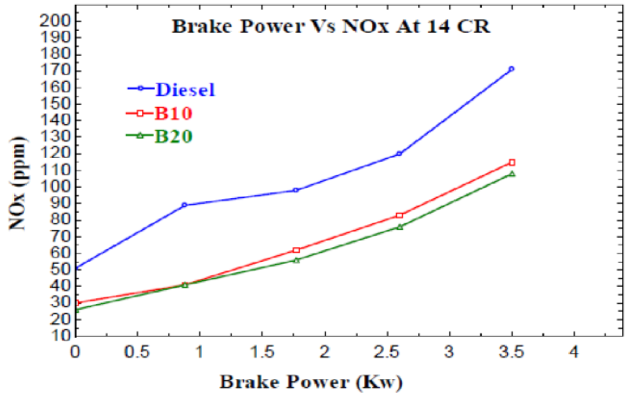


Fig 21 Variation of nitrogen oxide for blends and diesel for CR14

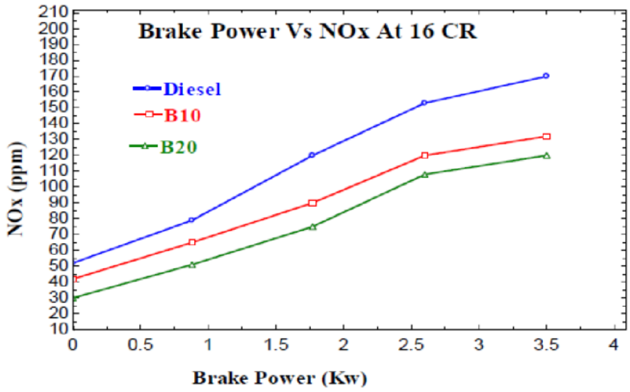


Fig 22 Variation of nitrogen oxide for blends and diesel for CR16

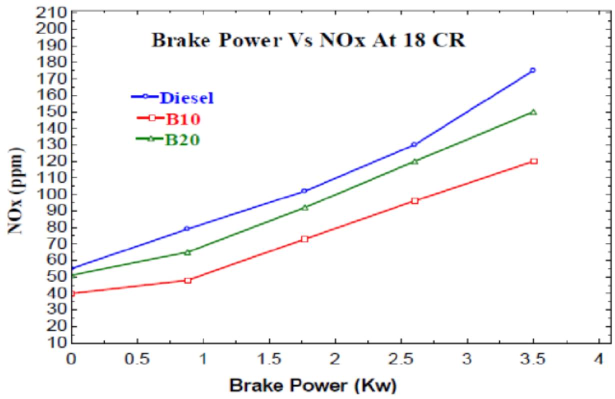


Fig 23 Variation of nitrogen oxide for blends and diesel for CR18

VI. CONCLUSION

The performance, emission and combustion characteristics of a variable compression ratio engine fuelled with mixture of biodiesel and diesel blends have been investigated and compared with that of standard diesel. The experimental results confirm that the BTE, SFC, exhaust gas temperature and mechanical efficiency Of variable compression ratio engine, are a function of biodiesel blend , load and compression ratio. For the similar operating conditions ,engine performance increase with increase in biodiesel percentage in the blend .However by increasing the compression ratio the engine performance varied and it becomes comparable with that of standard diesel. The performance and emission characteristics of a single cylinder direct injection CI engine fuelled withB10,B20 blends have been analysed and compared to the base line diesel fuel. The following conclusions are drawn from this investigation

The specific fuel consumption decrease with increase in percentage of the blends due to the addition of MTB additive to biodiesel.

• Methyl ester of mixture results in a slightly increased thermal efficiency as compared to that of diesel at higher compression ratio.

• The exhaust gas temperature decreases at higher compression ratio. The reason is the lower calorific value of blended fuel as compared to that of standard diesel and lower temperature at the end of compression. The exhaust gas temperature for the blend 20 is lower compared to that of standard diesel at lower compression ratios.

• The brake thermal efficiency of the blend B20 is slightly higher than that of standard diesel at higher compression ratios. The specific fuel-consumptionof blend B20 is lower than that of all other blends and diesel. This may be due to better combustion, and increase in the energy content of the blend.

• The hydrocarbon emission of various blends is higher at higher compression ratios. The increase in compression ratio increases the HC emission for blend B40. CO emission is low at higher loads for methyl ester of mustard oil when compared with diesel. NOx emission is decreased with methyl ester of mixture oil compared to diesel.

• Mixture biodiesel satisfies the important fuel properties as per ASTM specification of biodiesel and improves the performance, combustion and emission characteristics of engine significantly.

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