Performance & Combustion Analysis of CI Engine using Optimum blend by mixing duel biodiesel & diesel

Lodha Abid Husain M[a] , Prof.Sajan Kumar Chourasia[b] , Prof.Nirav S Joshi[c]

[a]Research Scoholar, Mechanical Engineering Department, Gandhinagar Institute of Technology, Gandinagar, Gujarat - 382721, India.
[b]Assistant Professor, Mechanical Engineering Department, Gandhinagar Institute of Technology, Gandinagar, Gujarat - 382721, India.
[c]Head of Department, Mechanical Engineering Department, Gandhinagar Institute of Technology, Gandinagar, Gujarat - 382721, India.

Abstract

Environmental concern and availability of petroleum fuels have caused interest in the search for alternative fuels for internal combustion engine. Many alternate fuels are tried by various researches. Based on literature review it is found that for diesel engine Bio Diesel is most promising fuel. In this project works prospects and opportunities of increasing biodiesel-diesel blend ratio as fuel in diesel engine is going to be studied by varying compression ratio. Also based on experimentation an optimum blend and engine parameters are to be suggested for obtaining better performance and emission control. Biodiesel present a very promising scenario of functioning as alternative fuels to fossil diesel fuel. The properties of these can be compared favorably with the characteristics required for internal combustion engine fuels specially diesel engine. Preliminarily to compare performance of biodiesel-diesel blend with base cases i.e. performance of engine using diesel as a fuel, experiments were performed to study effect of variation of compression ratio on brake power, brake specific fuel consumption and brake thermal efficiency of diesel engine using diesel as a fuel at various loads ranging from 0.5% to 100%. Out of which that particular optimum perimeter has been selected for further engine performance analysis like brake thermal efficiency, brake specific fuel consumption and brake power, based on taguchi method optimization technique we have identified a best suitable blend of multiple biodiesel blend. As per the literature survey B20 (20%biodiesel and 80% diesel) is best in performance compare to other blends, so we have restrict our range within 20% of biodiesel.

Keywords: Biodiesel, Biodiesel-Diesel blend, Fatty acid.

Nomenclature

BTHE - Brake Thermal Efficiency
BP - Brake Power
BSFC - Brake Specific Fuel Consumption
EGT - Exhaust Gas Temperature
CO - Carbon Monoxide
HC - Hydrocarbons
NOx - Nitrogen Oxide
CO2 - Carbon Dioxide
B0 - Pure Diesel
B10 10% - Biodiesel mix with Diesel
B20 20% - Biodiesel mix with Diesel
B30 30% - Biodiesel mix with Diesel
B40 40% - Biodiesel mix with Diesel
B100 - Pure Biodiesel
CR - Compression Ratio
IT - Injection Timing
BTDC - Before Top Dead Centre
HSD - High Speed Diesel

Introduction

Energy Scenario and Importance of Diesel and Bio- diesel The world's budget rest on the burning of fossil fuel equivalent of approximate 185 million barrels of oil every day. The consumption speed is equal to an annual burning of what environment take around one million years to store as fossil deposits. The world at current is challenged with the duel crises of fossil fuel reduction and environmental degradation. Unselected extraction and excessive consumption of fossil fuels have lead to decrease in underground-based carbon capitals. The hunt for an alternative fuel, which assurances a pleasant correlation with sustainable growth, energy conservation, management, efficiency, and ecological protection, has become extremely marked in the present framework. More than 6.5 million diesel engines are existing in the Indian farming area for numerous activities. It is difficult to do absent with these current systems and hence alternative fuels are being expeditiously required. As far as the application in country agricultural areas of a emerging country like India is worried, such internal combustion engines must preferably utilize alternative fuels of bio-origin, which are nearby existing. With farming situations prevailing in India, the adaptation of the fuel to the current engines has been extra pronounced associated to developing a fresh engine for existing alternative fuel. This permits the replacement of diesel fuel by plant oils, and for a short-range fuel as a mixture. Alternative fuels are usually mentioned as cleaner fuels in contrast with petrol or else diesel fuels. While using a different fuel, it is very vital to strike a equilibrium among several conflicting constraints involving not only the performance and emission characteristics of the engine, but also the complete life of the system [1].

Keeping this in vision, engine conditions were examined by the freshly established biodiesel fuel. Trans esterification is possibly the maximum effective and extensively used method for expressing suitable fuel for CI engines from plant oils in order to escape these difficulties. Trans esterification existed recognized as early as 1864, after Rochleder described glycerol preparation from ethanolysis of castor oil. The process of trans esterification yields plant oil esters. Plant oil esters have improved fuel properties related to neat plant oils. Their viscosity decreases, volatility rises, and they drop their polyunsaturated character after trans esterification. The psychometric of the complete trans esterification reaction needs 1 mole of triglyceride for 3 moles of glycerol. This exists a reversible reaction, either acid or alkali catalyzed, and includes stepwise changes of triglycerides to diglycerides toward monoglycerides toward glycerol creating 3 moles of ester in this process.

Importance and Drawback of Usage of Bio diesel in Existing Engine

Amongst all the experiments done for the bio-diesel, it has been observed that bio-diesel, produced from renewable and often domestic sources, represents a more sustainable source of energy and will therefore play an increasingly significant role in providing the energy requirements for transportation. The majority of studies have shown that PM, CO2, unburned hydrocarbons and CO emissions for bio-diesel are significantly reduced, compared with diesel. Also, experiments show that the use of bio-diesel favours to reduce carbon deposit and wear of the key engine parts, compared with diesel [2]. The combustion-associated properties of plant oils are slightly like to diesel oil. Pure plant oils or their mixtures with diesel pose many long-standing problems in CI engines, e.g., Poor atomization characteristics, ring-sticking, injector-choking, injector deposits, injector pump disappointment, and lubricating oil thinning by crank-case polymerization. Such difficulties do not rise with short-range engine operations. Occasionally, the engine fails terribly, while operated on pure vegetable oils continuously for an extended period. The properties of plant oils such as great viscosity, low volatility, and polyunsaturated character are accountable for these difficulties.

Issues and compatibility problem with engine parts

The deposits on the piston top are black, dense and hard, and at the edge, they seal the clearance in the top dead center point so that they will polish the bore at every stroke. A main problem by using plant oil in engine operation is the deposits in the upper piston ring channel and on the piston ring. The piston ring becomes trapped in the channel thus weakening and lessening the engine performance, as the combustion becomes unpredictable. The deposits raise, and the efficiency decreases. Additional problem is that the plant oil and gases leakages through clearance into the engine crankcase as the stabbing ring fails to seal adequately. As an outcome, it contaminates the lubrication oil, which leads to harsh, rubber-like covering on the engine parts and the walls of the case, the fuel pump, camshaft and push rods. The coverings on these parts can origin for trouble or even failure. The accumulation of carbon deposits is usually attributed to the big molecular mass and resulting great viscosity of the medium-chain and long-chain triglycerides that constitute most marketable plant oils.

Several researchers have conducted experiments on single biodiesel blends in most cases, 15% to 25% blend of biodiesel with diesel showed relatively better engine performance than any other blend ratios. In this experiment, fuel properties have been improved by biodiesel-biodiesel blending and the effect of 20% blend of new biodiesels as well as individual biodiesels on engine performance and emission characteristics have been studied and compared with those of diesel.

Compositional differences in diesel and biodiesel

Biodiesel is basically mono-alkyl ester based oxygenated (11% oxygen by weight) fuel mostly produced from triglycerides (vegetable oils/animal fats) by transesterification reactions. To enhance the reaction rates and achieve better yields, different types of catalysts such as homogeneous alkaline catalysts (e.g. NaOH, KOH, CH3ONa, CH3OK, etc.) and acid catalysts (e.g. sulfuric acid, hydrochloric acid, phosphoric acid, etc.) are predominantly used in producing biodiesel from different feedstocks. As per standard EN 14214 , the minimum amount of esters in biodiesel should be around 96.5%. The rest could be unused catalysts, free fatty acid, moisture, mono-, di-, triglyceride, etc. which are mostly considered as impurities in biodiesel. Presence of these impurities may affect the compatibility of biodiesel exposed automotive materials. Especially residue of acid catalysts such as sulfuric acid, hydrochloric acid, phosphoric acid, etc. could be very aggressive for the corrosion of different metals. In addition, it is clear that in producing biodiesel alkaline catalysts are comparatively more effective than acid catalysts. Based on the used feedstock, the produced biodiesel could vary on the level of unsaturated components available. For instance, palm biodiesel normally has around 45% unsaturated esters. On the other hand, conventional diesel is a mixture of different hydrocarbons having no oxygen. It has around 75% aliphatic hydrocarbon and 25% aromatic hydrocarbon.

Although many fuel properties of diesel and biodiesel are close to each other, the level of compositional differences is an alarming issue to understand the tribology in biodiesel. It is very important to investigate the effect of different saturated and unsaturated components of biodiesel, molecular chain length, oxygenated moieties and different fuel properties including stability, density, viscosity, total acid number (TAN), etc. on the tribo-corrosion of automotive materials. It is noted that biodiesel as compared to petroleum diesel is more acidic in nature and may cause enhanced degradation of exposed metal surfaces. Therefore, use of alkaline catalysts such as NaOH, KOH, CH3ONa, CH3OK, etc. in producing biodiesel could be more logical. This is because the presence of the residue of alkaline catalyst may help to neutralize/reduce the acidic nature of biodiesel and thereby can reduce its affinity for metal surface. However, it is seen that choice of catalyst can also be influence on the types of feedstocks used for biodiesel production. For example, catalyst NaOH is good for the production of biodiesel from waste oil and sunflower oil but not from coconut oil as the yielding point does not meet standard EN 14214 which is 96.5% or above. Therefore this can be concluded that composition of biodiesel mainly depends on production process, types of used catalyst and feedstock.

Corrosive nature of biodiesel

At present, biodiesel is being used in automobiles as B5 blend (diesel containing 5 vol.% biodiesel) in different parts of the world including Australia, Europe and America. Higher percentages of biodiesel have not been used so far due to some concerns which include incompatibility of materials of the automotive fuel system in biodiesel. Corrosion is one of the topics very relevant to the biodiesel compatibility issue. Biodiesel becomes more corrosive if free water and free fatty acid are present. Free fatty acid may exist as a consequence of incomplete trans esterification reaction. Beside this, auto-oxidation of biodiesel can also enhance its corrosive characteristics.

In automobile engine, fuel comes into contact with a wide variety of engine parts including fuel pump, gaskets, fuel injector, filters, fuel liners, bearing, piston, piston rings, etc. Among them, copper alloy based parts like fuel pump, bearing, bushing, etc. are mostly affected by the fuel [1]. It has been suggested that copper, aluminum, zinc, brass and bronze are not compatible with biodiesel [2]. Geller et al. [3] observed that copper alloys are more prone to corrosion by biodiesel as compared with ferrous alloys. Pitting corrosion was found on sintered bronze filters in oil nozzle after 10 h of operation with biodiesel at 70 °C [4]. Corrosion attack was also reported even for lower biodiesel (2%) blend levels [5]. Concerns arise from the fact that biodiesel degrades through oxidation, moisture absorption, attack by microorganisms, etc. during storage or use and thereby becoming more corrosive. According to Tsuchiya et al. [5], oxidation of biodiesel reconverts esters into different mono-carboxylic acids like formic acid, acetic acid, propionic acid, caproic acid, etc which are responsible for enhanced corrosion. This process also increases the free water content. Free water is undesirable because it may promote microbial growth and corrode fuel system components [6,7]. According to Maleque et al. [8] and Kalam and Masjuki [9], wear rate in biodiesel was relatively higher due to its oxidative and corrosive behaviors. Corrosiveness of biodiesel also depends on its feedstock [10,11]. Diaz-Ballote et al. [12] found that the corrosiveness of biodiesel is decreased with decreasing the impurities remaining after processing. Under the circumstances of aeration, dissolved oxygen in biodiesel seems to accelerate its corrosive nature [5]. The situation becomes complex due to the interplay between different features such as changes in TAN value, increased water content, oxidation product, presence of metals species, unsaturated molecules, etc. The aim of the present study is to investigate the corrosion behavior of copper and bronze in palm biodiesel. Immersion tests have been carried out at room temperature (25–30 °C) and 60 °C. Results obtained are expected to help in understanding the corrosion behavior of fuel system at where the operating temperature is changed between 44 and 86 °C [13].

Multiple biodiesel blending

In today's scenario, the most appropriate method to use the vegetable oils in CI engines is through its conversion into fatty acid methyl ester by the process of transesterification [3]. The engine power output and the fuel consumption of the vegetable oil and its blends are almost the same when the engine is fueled with die-sel [4]. Jatropha oil can also be used as a substitute for diesel in a diesel engine [5]. Due to lower calorific values and higher viscosity as compared to diesel, vegetable oils are converted to biodiesel [1]. Lower blends of palm biodiesel increased the brake thermal efficiency and reduced the fuel consumption with reduction in engine emissions [6]. Increased brake thermal efficiency of palm blends is attributed to increase in oxygen content of the fuel, resulting in improved combustion. Efficient fuel combustion of low viscosity and low density fuel leads to lower fuel consumption. Previous research works also found out that high kinematic viscos-ity and density fuels with lower calorific value tend to increase the brake specific fuel consumption and lower the brake power as it results in poor atomization of fuel during spraying of fuels inside the combustion cylinder [7]. The presence of high amount of oxy-gen molecules in biodiesel results in complete combustion of fuel. This condition leads to lower hydrocarbons and carbon monoxide emissions. The in-cylinder temperature is an important factor for nitrogen oxides (NOx) formations. The NOx emissions substantially increase with temperatures. In many experiments, there has been decrease in nitrogen oxides emissions with biodiesel perhaps because in-cylinder temperature is lower which can be due to lower calorific value of the fuel [7]. In single cylinder engine running with palm [8,9] and jatropha biodiesel [10,11], the reported results indicate lower brake powers and higher brake specific fuel consumptions (BSFC) [12]. In six cylinder engine fueled with palm biodiesel, the brake power decreased about 2.5% and BSFC increased by 7.5%. The literature shows lower smoke, hydrocarbons and CO emissions. The NOx emissions, on the other hand, increases compared to those fuelled with conventional diesel [13]. There have been studies on oxidation stability of biodiesel from tree borne oil seeds like jatropha, pongamia, etc. Oxidation stabil-ity of jatropha biodiesel is poor when compared to palm biodiesel. For market acceptability and for longer storage of jatropha biodie-sel, antioxidant doping is required. To cut the doping cost, studies of palm biodiesel with jatropha has been carried out. The blend of palm and jatropha biodiesel leads to a composition with improved and efficient low temperature property and good oxidation stabil-ity [14]. Research works published regarding palm, jatropha and other biodiesels are mainly based on single biodiesel blending i.e. mixing only one kind of biodiesel with diesel. Very few works have been done with the combination of two different biodiesel blends with diesel [15]. The brake thermal efficiency of the blend with 90% die-sel, 5% Pongamia pinnata ethyl ester and 5% mustard ethyl ester composition was found to be greater than those from diesel. The emissions of hydrocarbons, nitrogen oxides and smoke were higher than diesel but the exhaust gas temperature was lower for the Pongamia pinnata and mustard ethyl ester blends [1]. The objective of this experiment is to investigate the performance of a dual biodiesel, a mixture of two different kinds of bio-diesel. The final product will have the beneficial attributes of both biodiesels. The aim is to understand the properties of newly formed biodiesel mixture and the changes in properties when mixed with diesel in different proportions, and to determine the variations in emissions and performance characteristics of a DI CI engine while operating on these dual biodiesel blends.

Experimental Setup

The experiments are carried out on a computerize test bench coupled with single Cylinder, Kirlosker 4 Stroke, Water cooled, direct injection diesel engine. The test rig is equipped with eddy current dynamo-meter (to measure load on engine), crank angle encoder (crank angle measurement), rota-meter (flow measurement) and fuel tank with digital piezo sensor, temperature and pressure sensors etc. The setup enables study of VCR engine performance parameters like brake power, frictional power, BMEP, brake thermal efficiency, indicated thermal efficiency, specific fuel consumption, mechanical efficiency, volumetric efficiency, A/F ratio, heat balance and combustion analysis at different values of compression ratio, injection timing and injection pressure. The schematic arrangement is shown in the Fig.1.Technical specifications of the engine are given in table 1, Here T1 − inlet (engine) water temperature (0C), T2 − outlet (engine) water temperature (0C), T3 − inlet (calorimeter) water temperature (0C), T4 − outlet (calorimeter) water temperature (0C), T5 − exhaust gas temperature before calorimeter (0C), T6 − exhaust gas temperature after calorimeter (0C), F1 − fuel consumption measurement unit, F2 – air flow measurement, PT− pressure transducer, EGA − exhaust gas analyzer and N − engine speed measurement.

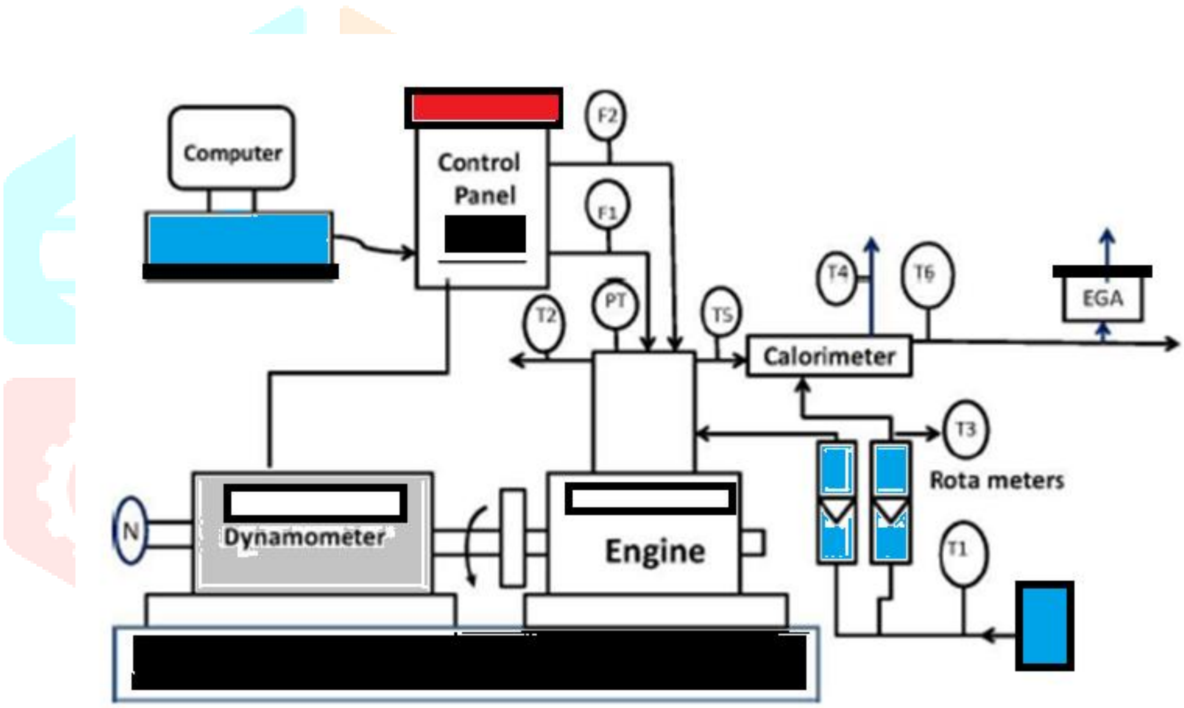

Fig 1: Line diagram of the experimental setup used in the present study.

Table 1: Engine test rig set up specifications provided by manufacturer including hardware and software data.

Components	Specification
Engine	Research Engine test setup 1 cylinder, 4 stroke, Multi fuel (Computerized), Water cooled, STROKE 110mm, BORE 87.5mm
Diesel mode	Power 3.5 kW C.R. range 12.1-18.1 Speed 1500 rpm Injection Variation 0-250 BTDC
Compression ratio	18:1
Inlet valve open BTDC	15 Degree
Injection start BTDC	20 Degree
Inlet valve close ABDC	30 Degree
Exhaust Valve Open BBDC	30 Degree
Exhaust Valve close ATDC	15 Degree
Fuel injection Pressure	180 Bar
Dynamometer	Eddy current type, water cooled, with loading unit
Fuel tank	Capacity 15 lit, Type: Duel compartment, with fuel metering pipe of glass
Air box	M S fabricated with orifice meter and manometer
Calorimeter	Type Pipe in Pipe
Rotameter	Engine cooling 40-400 LPH , Calorimeter 25-250 LPH
Piezo sensor	Combustion: Range 5000 PSI, with low noise cable Diesel line: Range 5000 PSI, with low noise cable
Crank Angle Sensor	Resolution 1 deg, speed 5500 rpm with TDC pulse

Performance Analysis

Engine performance plays a vital role in performance analysis of the engine. For this experiment the performance analysis were carried on both the engine fueled with diesel, all the performance parameters (like: mass of fuel, BSFC, BSEC and thermal efficiency), were calculated by the Test setup provided by APEX Innovations which is equipped with online fuel measuring meters and lab view software which calculate all the performance data and give accurate results.

Emission Analysis

The emission from the engine exhaust plays a vital role in the environmental degradation by emitting harmful gases (like: NO_X , HC, CO, CO_2). So to protect the environment monitoring on the engine emission is essential. Since 1970, more and more stringent engine emission norms and regulation have been implemented, but the practice for reducing emission up to desirable lowest level goes on practice. So for this in this experiment the emission level with respect to engine life has been measured for comparing the emission in between the various blends and Diesel. This analysis was done on ″five gas analyzer supplied by NEXTEK equipment and is capable to analyze ″five gases (like : NO_X , HC, CO, CO_2, O_2) images of ″five gas analyzer were shown in Fig. 2

Table 2: Five gas analyzer measurements data provided by manufacturer shows the CO, HC, CO2, NOx, O_2 measurement range, measurement of HC and NOx are in ppm and CO,CO_2, O_2 are in volume percentage.

Emission parameters	**Measurements**
Unburned Hydrocarbons (HC)	0-20000 PPM
Carbon Dioxide (CO2)	0-20%
Nitrogen Oxide (NOx)	0-5000 PPM
Oxygen (O2)	0-25%
Carbon Monoxide (CO)	0-15%

Result and Discussion:

Performance characteristics

Brake power (BP)

The output power of an engine is known as brake power. The variation in brake power of the tested biodiesel samples with varying loads. Jatropha (10%)-Rapeseed (10%) sample showed slight increase in brake power of average 4.65% than diesel. Apart from that pure diesel dominated the output brake power at various loads. The viscosity and density plays major roles in atomization process of fuels and can slow down the fuel–air mixing rate, which can result in poor combustion of fuels leading to a lower brake power. One research reported that due to higher kinematic viscosity and density jatropha biodiesel blends have about 5.3% lower break power than palm biodiesel. In this test, it was observed that there was not any higher reduction in brake power for lower blends of biodiesel than diesel. Jatropha (10%)-Palm (10%), Palm (10%)-Rapeseed (10%) showed 3.98% and 7.04% reduction in brake power respectively. This may be due to higher viscosity, density and lower calorific values [7].

Brake specific fuel consumption (BSFC)

BSFC is the measurement of fuel mass consumption in kilogram per unit of work done by the engine. Abedin et al. stated that palm blends have 14.4% lower BSFC due to lower viscosity and density, although their calorific value is lower than that of jatropha blends [7]. As shown in Fig. 2, sample Jatropha (10%)-Rapeseed (10%) slightly higher and lower BSFC at various load condition as compared to diesel by 0.91% in average. The average reduction for Palm blend is observed at 2.55%. In contrast, other samples showed an increase in BSFC at values around 2.36%, 16.52% and 10.56% for Jatropha (10%)-Palm (10%), Palm (10%)-Rapeseed (10%) and Rapeseed blend respectively. The higher density of biodiesel compared to conventional diesel indicates that the fuel injection pump is delivering more fuel mass to the engine for the same output power. Higher viscosity resulting in poor mixing of biodiesel blend with air increases BSFC due to weak atomization of fuel. Lower calorific value of higher biodiesel blends also plays its part in increased value of BSFC.

Brake thermal efficiency

Thermal efficiency indicates how well an energy conversion or transfer process is accomplished. It was found to be nearly same as diesel for the lower blends of biodiesel. Initially it was observed that with increase in biodiesel percentage in the fuel, thermal efficiency decreases. However, as the blending percentage of biodiesel was increased beyond 20% by volume, the thermal efficiency continues to increase. This may be due to high oxygen content of biodiesel resulting in good combustion of fuel. Samples Jatropha (10%)-Rapeseed (10%), Palm (10%)-Rapeseed (10%), Jatropha (10%)-Palm (10%), Jetropha blend and Palm blend showed 3.2%, 2.1%, 1.2%, 1.5% and 0.9% increase in thermal efficiency than diesel respectively.

Combustion analysis:

Increase in in-cylinder temperature also contributes in improved thermal efficiency. Sample Jatropha (10%)-Rapeseed (10%) showed an average decrease of 27.83% compare to diesel, a substantial reduction in pressure. Brake thermal efficiency for biodiesel samples is shown in Fig. 2. Lower calorific value and higher viscosity might have been the dominating factor for lower brake thermal efficiency but due to high oxygen content in the fuel the efficiency was found to be higher among all in Jatropha (10%)-Rapeseed (10%) blend, also it was found that the reduction in peak pressure will leads to reduction in NOx formation..

Sequential arrangement of various diesel biodiesel and duel biodiesel blends:

1- Diesel
2- Palm (20%)
3- Jatropha (20%)
4- Rapeseed (20%)
5- Palm (10%)-Jatropha (10%)
6- Palm (10%)-Rapeseed (10%)
7- Jatropha (10%)-Rapeseed (10%)

Fig. 2 shows the sequential arrangement of performance analysis (a) BSEC (kj/kWh) vs Load (%), (b) BSFC (kg/kWh) , (c) BTE (η_{bth}) , (d) m_f (g/hr) and along with this the combustion analysis including (a) P VS θ (Diesel, Diesel-biodiesel blends), (b) Close view of P VS θ (Diesel, Diesel-biodiesel, Diesel-biodiesel blends), (c) Close view of P VS θ (Palm-Jetropha, Palm-Rapeseed & Rapeseed-Jetropha blend) has been detailed analysed.

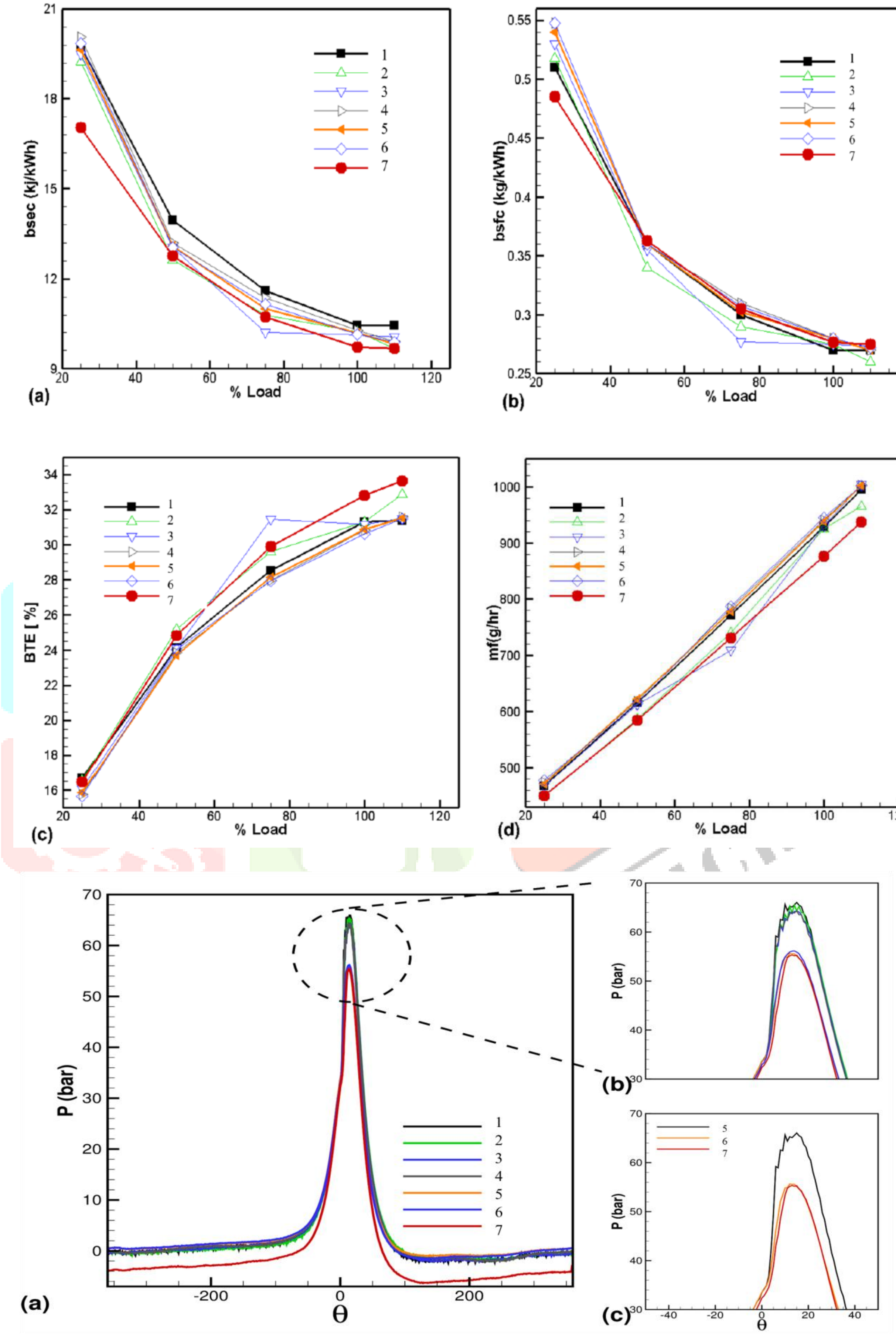

Fig 2: Performance and combustion analysis of CI engine using optimum multi fuel blend.

Conclusion:

From the results of Performance and combustion analysis following things has been concluded:

- BSEC of Jetropha-Rapeseed blend is found to be lowest among all blends.
- BSFC of palm blend is found to be lowest among all blends.
- Highest ηBTE is found to be 33.7% with jetropha- rapeseed blend and with diesel is found to be 31.4% only.
- The mf was found to be lowest among all blends is jetropha- rapeseed blend which is 9.21% lower then diesel.
- Pmax of diesel was found to be 67 bar which was 8.7% higher than jetropha- rapeseed blend.

References

[1] A. K. Agarwal, J. Bijwe, L. M. Das. Effect of Bio-diesel utilization of wear of vital parts in Compression Ignititon Engine, Transaaction of ASME vol 125, April 2003 603-611.

[2] Agrawal AK. Bio fuels (alcohols and bio diesel) applications as fuels for internal combustion engines. Progress in Energy and Combustion Science. 2007; 33: 233-271

[3] A.A Rodrigo Munoz, M. David Fernandes, Q. Douglas Santos, G.G Tatielli Barbosa and M. Raquel Sousa. "Biodiesel: Production, Characterization, Metallic Corrosion and Analytical Methods for Contaminants". INTECH, 2013.

[4] Md. Arbab Iqbal, Mahendra Varman, Masjuki Hj. Hassan, Md. Abul Kalam, Sajjad Hossain. "Tailoring fuel properties using jatropha, palm and coconut biodiesel to improve CI engine performance and emission characteristics", Journal of Cleaner Production, 2015.

[5] A Nalgundwar , B Paul, S Sharma,"Comparison of performance and emissions characteristics of DI CI engine fueled with dual biodiesel blends of palm and jatropha". Fuel, 2016.

[6] M.A. Fazal, A.S.M.A. Haseeb, H.H. Masjuki. "Comparative corrosive characteristics of petroleum diesel and palm biodiesel for automotive materials". Fuel Processing Technology, 2010.

[7] A.S.M.A. Haseeb, H.H. Masjuki, L.J., M.A. Fazal. "Corrosion characteristics of steel and bronze in palm biodiesel". Fuel Processing Technology, 2010.

[8] M. Arbab Iqbal, M Varman, H Masjuki, M Hassan, A Kalam. "Tailoring fuel properties using jatropha, palm and coconut biodiesel to improve CI engine performance and emission characteristics". Renewable and Sustainable Energy Reviews, 2013.

[9] A.S.M.A. Haseeb, H.H. Masjuki, L.J. Ann, M.A. Fazal. "Corrosion characteristics of copper and leaded bronze in palm biodiesel". Fuel Processing Technology, 2010.

[10] M.I. Arbab, H.H Masjuki, M. Varman, M.A. Kalam, S. Imtenan, H. Sajjad. "Fuel properties, engine performance and emission characteristic of common biodiesels as a renewable and sustainable source of fuel". Renewable and Sustainable Energy Reviews, 2013.

[11] K. Bozbas. "Biodiesel as an alternative motor fuel: Production and policies in the European Union". Renewable and Sustainable Energy Reviews, 2008.

[12] AK Agarwal, A. Dhar. "Experimental investigations of performance, emissions and combustion characteristics of Karanja oil blends fuelled DICI engine". Renew Energy , 2013.

[13] R Sarin, M Sharma ,S Sinharay, RK Malhotra. "Jatropha–palm biodiesel blends an optimum mix for Asia". Fuel, 2007.

[14] S Jain, MP Sharma. "Thermal stability of biodiesel and its blends: a review". Renewable and Sustainable Energy Review, 2011.

[15] Kumar Chourasia, Sajan., 2015,Life cycle analysis of CI engine using bio-diesel and Di ethyl ether (DEE) [M.Tech. thesis]. Ahmedabad, Gujarat, India: Mechanical Engineering Department, Institute of Technology, Nirma University.

[16] Patel, PD., Chourasia, Sajan., Lakdawala, AM., Patel, RN.,.2016,Bio Fuels for Compression Ignition Engine: A Review on Engine Performance, Emission and Life Cycle Analysis.Renewable & Sustainable energy Reviews.;65:24-43.

[17] Patel, PD., Chourasia, Sajan., Lakdawala, AM., Patel, RN,.2015,Performance Emission and Combustion characteristic of CI engine using bio diesel and Diethyl Ether- DEE at 24rdNational Conference on I. C. Engine and Combustion(NCICEC 2013) UPES, Dehradoon.