

**Performance and Emissions Study on Variable Compression
Ratio Engine fuelled with Babassu and Sal Oil Methyl Ester and
its Blends with Diesel Fuel**

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in

Thermal Engineering

by

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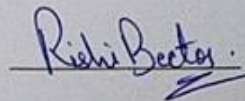
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JUNE, 2018

CERTIFICATE

I hereby declare that this thesis report entitled "**Performance and Emissions study on Variable Compression Ratio Engine fuelled with babassu and sal oil methyl ester and its blends with diesel fuel.**" is an authentic record of my work carried out as requirements for the award of the degree of **Master of Engineering in Thermal Engineering at Thapar University, Patiala** under the supervision of **Dr. S. S. Ragit** (Assistant Professor, MED). No part of the matter embodied in this report has been submitted to any other university or institute for the award of any degree.



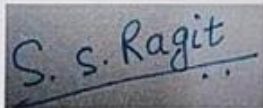
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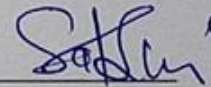
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*Dedicated to
My Parents*

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Abstract

Due to rapid industrialisation and urbanisation, demand for energy has sky rocketed. Amongst all the primary sources of energy, fossil fuels still tops the list. Around 88.6% of global energy demand is met by fossil fuels. In current investigation, transesterification of babassu and sal oil is employed using KOH as catalyst and CH₃OH as alcohol and optimised it with mathematical model like Taguchi method. Optimum parameters for babassu biodiesel were found to be 6:1 molar ratio, 0.5g KOH amount, 75 minutes and reaction temp of 60 °C and the yield obtained at optimised parameters was 98.18%. Similarly, for sal biodiesel optimisation, optimised parameters were found to be 8:1 molar ratio, 1g KOH, 75 minutes and the yield obtained at optimised parameters was 96.39%. Fuel properties of optimised biodiesel were calculated and observed to be with standard methods. In the present study, mixes of 10%, 20% and 30% of streamlined BOME and SOME each are set up as test energizes and test examination is improved the situation the assessment of execution parameters and discharge attributes of a four stroke variable pressure proportion motor having single barrel at steady rpm of 1500 at 0kg, 2kg, 4kg, 6kg, 8kg and 10kg loads and the tests were carried out using test fuels and diesel separately at compression ratios of 18, 16 and 14. BP was more or less same. Higher Exhaust Gas Temperature and mechanical efficiency for blended fuels were observed with SB30 showing maximum in comparison to other blends. Emissions of blended test fuels were observed to be lesser as compared to petro diesel. BB10 showed least rise in NO_x emissions as compared to other blends. Experimentations also revealed that HC emissions increased for BB10 and BB20 and SB30 but reduces for SB10, SB20 and BB30. CO emissions for SB30 were found to be the least and BB20 the largest. It can be inferred from the experimentations that biodiesel blends lower down emission levels. It is found from the research that overall performance of SOME blended fuel was greater as compared to BOME blended fuel.

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Nomenclature

BO	Babassu Oil
SO	Sal Oil
SOME	Sal Oil Methyl Ester
BOME	Babassu Oil Methyl Ester
FFA	Free Fatty Acid
BP	Brake Power
sfc	Specific fuel consumption
MEff	Mechanical Efficiency
EGT	Exhaust Gas Temperature
BTHE	Brake Thermal Efficiency
cSt	centistokes
VCR	Variable Compression Ratio
BB10	10% BOME + 90% Diesel
BB20	20% BOME + 80% Diesel
BB30	30% BOME + 70% Diesel
SB10	10% SOME + 90% Diesel
SB20	20% SOME + 80% Diesel
SB30	30% SOME + 70% Diesel
HC	Hydrocarbons
CO	Carbon Monoxide
NO _x	Oxides of Nitrogen

Chapter 1

Introduction

1.1 Biodiesel : A promising source of energy

Due to rapid industrialisation and urbanisation demand for energy has sky rocketed. Amongst all the primary sources of energy, fossil fuels still tops the list. Rapid usage of fossil fuels and increasing global fuel prices has become a serious problem that needs urgent addressal. According to the latest report, it is believed that that global energy consumption will increase by 30%. China and India will both account for increase in energy demand up to 45% by 2020 and oil consumption will soar up in future. Report also showed increase in coal consumption up to 30% by 2020. According to BP Energy Outlook 2017, world energy demand increases by 30%. It is reported that energy consumption will rise to around 12 billion tonnes (BP EO 2017). Thus meeting energy demands along with complying CO₂ emissions will pose a serious challenge towards us. Another fact that report has predicted is CO₂ emissions. It has been predicted that by 2020, CO₂ emissions would spurred up to 30% mainly in Asia. Deterioration in AQI (air quality index) has made Delhi Govt. prepone the deadline set to run vehicles complying BS VI norms to 2018 instead of 2020. In order to comply with Kyoto protocol for reduction of greenhouse gases emissions, particularly CO₂, alternative methods of fuel has to be developed. As indicated by Indian Nitrogen Assessment report, there has been increment in NO_x outflows of around 69% from 2001 to 2011. Biodiesel is one such novel method which can cater the needs of energy requirement for future generations along with keeping the emission levels in check. Biodiesel is termed under second gen biofuels that can replace conventional fuel i.e. petrol and diesel. It has gained popularity because of easier method of production as well as because of its eco-friendly nature. Primary wellspring of biodiesel generation are vegetable oils however as the populace blasts, so is the interest for sustenance. At present, 95% of biodiesel is gotten from eatable oils. Thus research for new methods of renewable fuel production has to be developed in order to reduce pressure on edible sources along with ensuring food security. Non-edible vegetable oils proves one such excellent source of biodiesel production. Recently, India has proposed new bio ethanol policy in an effort for cutting down huge energy import dependence and to boost ethanol blending of 22% and biodiesel 15%. Raw vegetable oil would pose a challenge as they are highly viscous that could damage the engine. Therefore, transesterification is the convenient and shabby process for biodiesel generation. The procedure is likewise named as alcoholysis as the vegetable oil is

changed over into esters within the sight of liquor and impetus. Significant elements influencing biodiesel yield are molar proportion, catalyst amount, time of response and the temperature at which response is completed. Non-edible oils contain some toxic components in their feedstock rendering them unfit for human consumption. Biodiesel obtained from babassu (*Attalea speciosa*) and sal (*Shorea robusta*) are excellent non-edible source of biodiesel production. Babassu is palm native to the Amazon forests and can be found in South American region and some parts of south India. Babassu nut contains around 62% of oil. Moreover, babassu palm is resistant to drought having extraordinary oil rate of production. (1541 kg oil ha⁻¹). The oil is light pale yellow coloured has low FFA value. Sal seed production is excellent (1.5 million tonnes per year). Its contribution is significant as sal tree accounts for about 5% of total forest area. Different employments of sal incorporates tanning material, solidifying milder waxes and salves for skin sicknesses.

1.2 Methods of biodiesel production

1.2.1 Pyrolysis

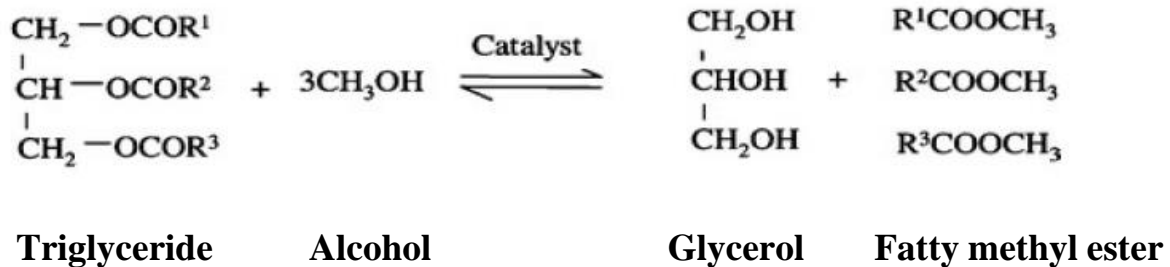
The process of formation of a substance to a different one by heating it in the air's absence with the help of catalyst like palladium. In this method, triacylglycerols are decomposed into soluble and unsaturated fatty acids. Fuel's chemical composition found out by this method remains more or less same as that of standard diesel fuel. This method is further categorised into three parts conventional, flash and fast pyrolysis. Biodiesel obtained by this method shows improved pseudo cold plugging point.

1.2.2 Micro emulsification

It is the process of reduction of vegetable oil's viscosity. These are stable isotropic fluids having three different phases – oil phase, aqueous phase and surfactant. Cosurfactants like Butan 2 ol can be used as it possess good physical stability. Mono and di glycerides and FFAs acts as surfactants for micro emulsion formation. This is one of the easiest and effective biodiesel production method.

1.2.3 Transesterification (alcoholysis)

It is the process of conversion of triglycerides into ester using alcohol. It is also called alcoholysis process in which catalyst is used so as to accelerate the reaction.



It is one of the cost effective method to produce biodiesel. Transesterification process maybe single staged or double staged depending upon the FFA value of oil [1, 2, 40]. Normally, base catalysed reactions results in lower yield but it is more preferable as compared to acid one as acids are highly corrosive. Moreover, alkali catalysed reactions are faster than acid catalysed process [3]. Various alcohols used in the reaction includes methanol, ethanol, propanol etc., methanol is most commonly used because of its cheapness and ready availability. Moreover methanol requires shorter response time and smaller catalyst amount [4, 5]. NaOH, KOH are commonly used base catalysts that are employed in the alcoholysis process. Generally, molar ratio as high as 4:1 are employed in order to shift the equilibrium reaction.

1.3 Pros of Biodiesel

- It is environment friendly, less toxic and has low sulphur content.
- Emits lower emissions as compared to conventional petro-diesel.
- Can be obtained from waste sources and using cheaper chemical process.
- It can be blended with other sources of energy and oil.
- Biodiesel possess another important feature of having low to zero sulphur content which extends the life of catalytic converters.
- It reduces foreign oil dependence and have positive impact on the economy of a country.

1.4 Cons of Biodiesel

- Higher NO_x emissions relatively to standard petro-diesel.
- Higher viscous as compared to petro- diesel which could cause engine clogging.
- Different biodiesels responds differently at various temperatures.

1.5 Objectives of current work

- To optimise the biodiesel obtained from babassu oil and sal oil via methanolysis process.
- To determine physico chemical properties of the same.
- To assess and look at changed discharge attributes of BOME and SOME mixes with diesel fuel.
- To assess and look at motor execution qualities like BP, sfc, BTE, ME of BOME and SOME mixes with diesel fuel.

Chapter 2

Literature Review

Bouaid A [6] et al used Babassu oil in their work and investigated production and its optimisation under various operating parameters. Two methods namely DOE and RSM were followed. The author did the experimentation using KOCH_3 as catalyst and methanol as an alcohol. Yield obtained at optimised parameters was as high as 99.85% under the optimum conditions of 45 °C, 0.95% catalyst concentration. The reaction time was kept at 60 minutes at optimised molar ratio of 6:1 and the biodiesel so obtained exhibited high oxidation stability.

Eduardo J.M. Paiva [7] et al observed transesterification of babassu oil using ethyl alcohol as the feasible method for alternate fuel production. The effect of using ethanol was studied in this paper. In this study, two methods of transesterification were employed, one general and the other by using ultrasound. During experimentation, author employed taguchi design with orthogonal arrays and effect of variation of parameters were studied for both conventional and ultrasound procedure. Author also reviewed the effect of FFA value on biodiesel preparation. This paper employed statistical methodology for optimizing the alcoholysis process and nuclear magnetic spectroscopy to quantify the obtained conversion. The author studied the influence of various variables like temperature, catalyst type, time of reaction, molar ratio on the ester production and the optimum yield was attained as high as 97% at 1% KOH concentration at 30 °C for 60 minutes under constant mechanical agitation of 400 rpm.

Adriano A.Mendes [8] et al elucidated biocatalyst's effect on the activity on the reaction using Babassu oil and ethanol. This paper envisaged the potential use of microbial lipases in catalytic reactions in biodiesel synthesis. Author prepared microbial lipase by hydrophobic adsorption and observed full formation of ethyl esters at 72 hours using *pseudozyma antarctica* as biocatalyst. Author did experimentation using 9:1 alcohol to oil ratio for 4 days at 45 °C under constant stirring of 180 rpm and yield was accounted up to 85% using lipase. Kinematic viscosity of the obtained ethyl ester was then found out using Brookfield viscometer. The paper envisages that Lipase preparation from BTL2 did not show any transesterification reaction.

Bayindir [9] et al examined the utilization of biodiesel blends with lamp fuel and diesel fuel in diesel control generator fuelled motor. Two type of blends B80K20 (80% of which was biodiesel and 20% kerosene) and B80K10D10 were used in this experimental work. The experimental work was performed on diesel engine that had four cylinders, at constant revolutions of 1500 rpm and tests were conducted for 3.6kW, 7.2kW and 10.9kW for each of the test fuels. Authors reported quite similar results of mass fuel consumption and bsfc for B80&K20 and B80&K10&D10. It was investigated that the nitrogen oxide (NO_x) emission lowered down followed by increase in hydrocarbon (HC) as per effect of kerosene blending with biodiesel fuel. At higher engine loads, higher EGT for B80&K20 and B80&K10&D10 were noticed.

Awad [10] et al. prepared ethyl ester from jojoba and evaluated the properties of ethanol blends. Transesterification process is employed for production of (JEE) by using ethanol (CH₃CH₂OH), catalyst sodium hydroxide (NaOH) and reaction time, temperature, stir speed are 60 minutes, 60°C, 600 rpm respectively. In this paper, it was observed that maximum yield of JEE is obtained by using 7% ethanol in alcoholysis process and low calorific value, density are decreased with elevated ethanol amount in the fusion. Properties of optimised ester and its blends with ethanol in distinct proportion such as E5, E10 (10% ethanol and 90% JEE), E15% (15% ethanol and 85% JEE), E20 (20% ethanol and 80% JEE), E0% (100% JEE) were observed. It is concluded in this paper that flash point of 100% JEE i.e. 105°C which is higher compared to diesel fuel is dropped to 61°C by mixing ethanol at different concentration with JEE.

Jerry L.Solis [11] et al showed the synthesis of catalysts like calcium and stannic oxide and transesterification process using the synthesized catalysts. Experimentations were done using transesterification process and optimum parameters were tuned up to obtain the maximum yield and those were 54 °C, 10:1 molar ratio, 250 rpm, 6 wt. % of CaO/SnO₂ (7:3 mass ratio of the binary catalyst) tin chloride 98% (SnCl₂) calcium hydroxide 95% (Ca (OH)₂) 2-propanol 99.9% (C₃H₇OH) and deionized water were used as a raw material for catalyst production. Authors also employed full factorial design for selection of optimised variables and they suggested low significance between the response variable and independent variables.

Silva [12] et al used Cu (II) and Co (II) ions as catalysts in their experiments and studied their effects on transesterification of Babassu oil. In this study, production of heterogeneous catalyst from Cu and Co was done and were then used up in methanolysis of Babassu oil. The experimentation was done by first preparing the catalyst and the prepared catalyst was used in transesterification process using methanol as alcohol in the presence of NaOH. The yield percentage for Babassu oil using Co and Cu as catalyst were found to be 86.65% and 71.89% respectively. In this study, thermo gravimetric analysis was carried out to find out the boiling point of the obtained biodiesel as well as to confirm the transesterification process.

Da Ros [13] et al analysed the formation of ester from Babassu oil via transesterification process by employing enzymatic action accompanied by microwave radiation. In this paper, author did the experimentation work employing RSM and the other method was rotational central composite design method. While carrying out the experimentation work, reaction temperature and oil/alcohol ratio were kept as variable parameters. Optimisation of parameters were done using response surface methodology by employing molar ratio of 12:1 at reaction temperature of 50 °C under constant magnetic stirring. The influence of enzyme activity is greatly enhanced by irradiation of microwave radiation and higher absorption of energy at high alcohol to oil ratio is observed owing to polar nature of C₂H₅OH. In this paper it is observed that yield obtained by conventional method and by using microwave radiation was almost same but reaction time was drastically reduced from 48 hours to 10 hours and enhanced productivity was observed for the latter.

N.Vedaraman [14] et al studied the diesel engine performance that was kirloskar made using biodiesel obtained from Sal oil. In this paper, author carried out the experimentation work in order to optimize biodiesel obtained from Sal oil methyl ester [SOME] and the produced biodiesel is then run on kirloskar make diesel engine single cylinder 4 stroke at 15000 rpm. It is observed that there is decrease in exhaust emissions. High *sfc* was obtained for SOME as compared to diesel. For all range of brake power, *sec* for SOME and diesel was more or less same. At higher brake power, SOME's BTHE was found to be lower than diesel. Optimum yield of SOME was obtained at 65°C, catalyst being NaOH alcohol being methanol 150% in excess, reaction time being 90 minutes and catalyst amount 0.25% wt.

Pali [15] et al optimised Sal oil methyl ester and employed SOME in the diesel engine having single cylinder that was water cooled for evaluation of performance parameters and emission

characteristics. In their study, Sal oil was employed for biodiesel production via transesterification process. Author did the experimental work by setting the operating conditions of 0.5% KOH as catalyst, 60 minutes reaction time on 65 °C at 450 rpm. At higher blend percentages, some of the physico chemical properties enhanced except calorific value which was reduced marginally. These trends were more or less similar to cotton seed oil. In this experimental study, four different blends specifically SME10, SME20, SME30 and SME40 were taken. At higher load conditions, CO, UHC and smoke outflows were discovered lower for all SME mixes. Higher NO_x emissions were observed during the exhaust emissions calculations. The study revealed slight drop in BTE with higher SME volume fraction in the test fuel at max load in comparison to petro diesel. BSEC spurred with the expanding mix rate in the test fuel. The full load BSEC esteem got for SME10 was 13.6 MJ/kW h took after by 14.3 MJ/kW h for SME20, 14.7 MJ/kW h for SME30 and 14.8 MJ/kW h for SME40.

Pradeep T. Kale [16] et al investigated the potential of Babassu oil and prepared methyl esters from it via transesterification process. Various process parameters like reaction temperature, oil/alcohol ratio, reaction temperature, catalyst concentration were investigated. Optimisation of parameters were investigated using Taguchi method. Operating parameters were investigated and were reported as 50 °C, 1% catalyst amount and methanol/oil ratio of 6:1 was employed under operating time of 60 minutes resulting in the yield as high as 99.42%. In this study, author also calculated other physical properties which were in compliance with ASTM and EN standards.

K. Murlidharan [17] et al examined the capability of methyl ester got from squander cooking oil on the execution of VCR motor having four stroke. Comparison of engine performance was done using blends of WCO20, WCO40, WCO60 and WCO80 and engine was kept running at 1500 rpm but different engine loads. It was found that engine showed improved BTHE and maximum BTHE was obtained at 40% blended fuel. Exhaust gas temperature showed reduction at higher engine loads. Mechanical Efficiency was found to be increasing for all blended fuel. B20 showed maximum efficiency among all the test fuels. Among emission characteristics, HC was found increasing for every blended fuel except B20. B40 testing fuel showed maximum combustion temperature.

Haldar [18] et al took three non-edible oil sources namely Putranjiva, Karanja and Jatropa

and compared the performance of engine and its emission characteristics. They employed different blends that were four in number namely 10%, 20%, 30%, 40% were taken. For their experimentation, they used Ricardo variable compression engine. It was found that 20% blended fuel showed better performance as compared to all other blends for all non-edible oil sources. From all the sources, Jatropha showed better performance. Higher emissions of CO₂ were observed for karanja blends as compared to other non-edible oil blends. Putranjiva blend showed higher HC emissions as compared to other two. Authors also reported higher NO_x emissions for Jatropha blended fuel.

Singh [19] et al took coconut oil blended fuel and elucidated the performance and emissions characteristics of the same. In their work, they used diesel engine that was direct injection type and prepared hybrid blend fuels using CCO and VCO .After experimentation, they found out that sfc for hybrid blended fuels was more than diesel. No significant change in efficiency was observed. As far as emissions were concerned, low NO_x emissions were observed in case of blended fuel. For 87CCO 10E 3B, 70CCO 17E 13B NO_x emissions values were respectively 459ppm and 454ppm. For 85VCO 10E 5B, 67VCO 17E 16B NO_x emissions values were respectively 323ppm and 402 ppm.

Yadav [20] et al reported engine performance and emission characteristics using KOME, OOME and BGOME. Engine was run at various speeds during the experimentation. Authors reported lower BTHE for blended fuel in comparison to diesel. KOME exhibited least efficiency (19.7%) and OOME exhibited max efficiency (20.7%). Amongst all blended fuels, OOME showed minimum bsfc as compared to BGOME and KOME blend showed maximum bsfc. At all engine speeds, reduced CO emissions for all the methyl esters was noted down by the authors. OOME exhibited higher CO emissions than BGOME and KOME at 0.19%, 0.14% and 0.15% respectively. Lower HC emissions as compared to diesel were observed while BGOME exhibited the least among all blended fuel at 55 ppm. NO_x emissions for biofuels were found to be enlarged in contrast to diesel and BGOME exhibited the largest among the three.

Chauhan [21] et al used jatropha as non-edible oil and its blends and checked the performance and engine emissions of the blends. In their experimentation, they used 75, J10, J20, J30 and J100. For their experimentation, they used single cylinder diesel engine which was direct injection type. Lower peak pressure for blended fuel was observed by the authors. From their experimental investigation, higher bsfc for jatropha blended fuel was reported. J100 showed maximum rise as compared to other blends. It was also found out that higher EGT was exhibited by jatropha blended test fuels. Lower CO and Higher NO_x trend was observed. J100 exhibited least increase in CO but higher increase in NO_x emissions. Authors also reported reduced HC emissions for jatropha blended fuels.

Lin [22] et al reported the performance of different types of VOME that were eight in number on a four stroke diesel engine .that had single cylinder. For the preparation of methyl esters, they used sodium methoxide as catalyst. Engine was made to run and engine speeds and loads were kept as variables. It was investigated that among all the fuel samples that were tested, palm kernel oil methyl ester showed higher bsfc. No significant change in power was observed. Higher rate of NO_x emissions for all the blended fuels were observed when compared to petro diesel. Around 50% smoke reduction was also investigated. From their experimental work it was noted that EGT, there was reduction in HC emissions when compared to petro diesel.

Devan [23] et al used poon oil and its mixes and the performance and emission characteristics of a four stroke diesel engine having single cylinder was calculated. They took four blends in their experimental work 20%, 40%, 60% and neat poon biodiesel. Engine was made to run at different loads. It was found that bsec was significantly on higher side as compared to diesel. BTHE was observed on the lower side as compared to diesel fuel with B100 showing maximum drop as compared to other three blends. Higher EGT for blended fuel was reported. Max EGT was exhibited by B100. Lower NO_x emissions in comparison to petro diesel were also reported by the authors. With increasing load NO_x emissions decreased. Around 32% reduction was studied in NO_x emissions of diesel and B100. From the experiments, except B20, CO emissions were observed to be at elevated levels as compared to diesel. For B20 it was reduction around 20%. B20 was found to be better as compared to other blends and diesel.

Srinivas [24] et al detailed the execution of VCR CI motor utilizing mixes of palm bit oil and eucalyptus oil. They did their experimentation at three compression ratios namely 14:1, 16.5:1 and 19:1. They used three different blends B5, B10 and B15. They used palm kernel fuel as

primary fuel and eucalyptus oil as secondary oil. It was found from the experiments that increasing blended fuel showed higher mechanical efficiency. Higher BTHE was observed for B15 than all other blends. B15 showed higher EGT as compared to other blends. It was also found that HC and CO CO₂ emissions rose significantly.

Nayak [25] et al elucidated the performance of a diesel engine having single cylinder water and is water cooled using mahua oil methyl esters along with additives. In their experimentation, they used four different blended fuels namely B85, B90, B95 and B100 as test fuels and the engine was run on different loads. From their experiments, increase in BTHE and BP with addition of additives in methyl ester was observed. BSFC, EGT and emissions were found to be decreased. Authors also reported drop in EGT when additives were used. Reduction in CO and HC with additive addition had also been observed with B100 exhibiting lowest HC emission (31.093 ppm)

Rathod [26] et al studied the comparison of kusum oil and its mixes powered in a diesel engine which is direct injection type. In this paper, 20%, 40%, 60%, 80% and neat kusum methyl ester were taken as testing fuel. Paper also discussed physico chemical properties and kinematic viscosity of KOMe and density were observed to be 14.2 cSt and 850 kg/m³ respectively. Another aspect that was studied in this paper was reduction of emissions using kusum blended fuel except NO_x

Solis [27] et al produced babassu biodiesel via transesterification route using oxides of calcium and tin and studied its optimisation. In this paper, authors used tin chloride, calcium hydroxide and used methanol as alcohol and they followed the three way process namely screening, characterisation and production. In the experimentation, authors had used factorial design for optimisation. It was found in the paper that optimised conditions for babassu biodiesel were 6% by wt. amount of 7:3 (CaO/SnO₂) catalyst ratio, 54.1 °C reaction temperature, and 10:1 molar ratio and 250 rpm rotational speed.

Ayeter [28] et al elucidated the effect of variables affecting transesterification process. In this paper, author utilised three feedstock namely jatropha, palm kernel and coconut oil. In this paper, author utilised alkaline transesterification process at four different molar ratios namely 4:1, 5:1, 6:1 and 8:1 and catalyst concentration variation were taken as 0.6g, 0.8g 1g and 1.2g and physico chemical properties were observed. It was found in this paper that operating parameters for optimisation of all the samples were 1g NaOH and molar ratio for jatropha and other remaining samples were 6:1 and 8:1 respectively.

Musa [29] et al reported the effects of molar ratio and alcohol type on production of biodiesel. In their study, authors studied various alcohols such as methanol, ethanol butanol etc. They also observed that for alkali and acid catalysed transesterification optimum molar ratios were 6:1 and 3:1 respectively. Their study revealed methanol to be most commonly used alcohol.

Ragit [30] et al investigated the optimisation of neem oil via tranesterification route. In this paper, author used filtered neem oil as a raw material and used KOH and methanol as catalyst and alcohol respectively. Authors carried out the experimentation using 4:1, 6:1 and 8:1 molar ratio and catalyst concentration was taken as 1%, 2% and 3%. Authors then studied the effects of various parameters like alcohol to oil ratio, time of activity, temperature at which reaction was carried out and catalyst amount and optimised conditions were found to be 6:1 alcohol to oil ratio, 60 °C temperature of reaction, 60 minutes time of reaction and 2% KOH catalyst concentration .Viscosity and ester yield of optimised neem oil methyl ester were found to be 2.7 cSt and 83.36% respectively.

Palash [31] et al elucidated the performance of engine and emission characteristics using oil derived from pithraj tree. In this paper, authors prepared biodiesel via two stage transesterification process using HCl, methanol and KOH as reagents and two different blends 5% and 10% were used as test fuels along with diesel fuel. 4 stroke IDI engine was made to run at different speeds and the authors reported maximum and minimum value of BP for 5% blends at 4000 and 1000 rpm respectively. Higher bsfc for blended fuel, reduction of CO emissions for 10% blended fuel around 4.7% as compared to diesel was reported. Authors also

reported the increase in NO_x and CO₂ emissions and comparative decrease in HC emissions for blended fuel around 9.86% and 22.32% for 5% blend and 10% blend respectively.

Ahmed [32] et al evaluated the engine's performance and emission characteristics using blends of mustard oil. While carrying out the experimental work, authors made use of four cylinder inline Mitsubishi Pajero engine and prepared 10% and 20% blends as test fuel and run the engine at full loads using engine speed as variable. From their experiments, authors found no significant change in the density of blended fuel, reduced brake power for blended fuel, higher NO_x emissions, lower HC emissions with 20% blend showing almost 42% reduction as compared to diesel. Authors also investigated significant amount of reduction in CO (around 40%).

Chandra Shekhar [33] et al did the optimisation of Pithecellobium dulce seed oil and then evaluated the performance of engine and emission characteristics of the same. In this paper, authors used three neck 1L round bottom flask, magnetic stirrer and reflux condenser and they found that optimised biodiesel was prepared at following parameters: 8:1 methanol to oil ratio, 0.8% KOH catalyst amount, 90 minutes time of activity and 60 °C reaction temperature using RSM method. Four different blends namely 20%, 40%, 60% and 80% blends were prepared and engine employed for experimentation was a single cylinder constant speed DI engine which was water cooled and the engine was run at different engine loads. Authors after experimentation found increase in bsfc with increasing blends with maximum increase of around 18.8% of 80% blended fuel. They also observed decrease in BTE with biodiesel blends with maximum reduction of 13.37% for 80% blended fuel. CO emissions were found to be decreasing with B80 showing reduction around 42.85% for B80 blend. Reduction in EGT was also reported by authors in this paper.

Can [34] et al did experimentation on evaluation of performance of engine and emission characteristics using canola oil. In this paper, authors prepared canola biodiesel using 6:1 as molar ratio, 60 °C reaction temperature and 0.4g of NaOH as catalyst. Authors did experimentation on single cylinder DI diesel engine at 2200 rpm at 4 loads and four different blends B5, B10, B15 and B20 were used as testing fuel samples. Authors reported increase in

bsfc and reduction of BTE at 6.52% and 4.2% at full load. Increase in NO_x emissions and reduction in THC and CO emissions at higher loads to around 30.3% and 32% respectively was also reported by authors.

Attia [35] et al used waste cooking oil and elucidated engine performance using biodiesel prepared from it. In this paper, authors prepared biodiesel from waste cooking oil at 6:1 molar ratio, 1g KOH catalyst and prepared five different namely B5, B10, B20, B30 and B50 and these test fuels were poured in a diesel engine running at constant rpm of 1500. Authors observed increase in brake thermal efficiency with max attained at B20. Low CO emissions for blended fuel was reported. B30 and B50 showed reduction of about 50% CO emissions. Authors also reported reductions of UHC at B50 and for lower blends, UHC appeared to be lower at higher loads. Lower NO_x emissions were also observed. Authors also made significance observation that best blended fuel for optimum performance were in between 30% and 50%.

Emiroglu [36] et al utilized turkey rendering fat and explored the diesel motor's execution and discharge qualities utilizing mixes of the same. In this research paper, authors applied double stage transesterification process and used sulphuric acid as dehydrating agent, methanol as alcohol and KOH as catalyst. Optimised biodiesel was prepared at 2:1 molar ratio, 60 minutes reaction time and 63 °C reaction temperature. Authors then prepared three different blends namely TRFB10, TRFB20 and TRFB50 as test fuels. Experimentation was employed on a diesel engine that was single cylinder running at unchanged rpm of 2000 at different loading conditions and lower value of bte for TRFB blends was obtained at all loading conditions. NO_x emissions using blended fuel were reported to be more than that with the use of diesel with maximum increase was by using TRFB50.

Yatish [37] et al used B. variegata seed oil as a starting material for production of methyl ester and investigated the effect of mixes on performance of engine and evaluated the emission characteristics of a diesel engine. Authors used methanol and sodium phosphate as reactants and optimised the biodiesel using CCRD (RSM design) and optimised parameters were found to be 11:1 molar ratio, 45 minutes time of activity, 2.96% catalyst amount and 74 °C reaction

temperature and prepared five different blends namely 10%, 20%, 30%, 40% and neat biodiesel as test fuels. Experimentation was employed on a diesel engine having four stroke and direct injection that run at 1500 rpm at five different types of loads (0%, 25%, 50%, 75% and 100%). For all blended fuel samples BTE was observed as compared to diesel in the order of B30>B20>B10>B40>B100. Slight increase in bsfc for blended fuel was observed that decreased with increasing load with B100 exhibiting around 26.6% higher than diesel. Higher NO_x (around 20%) and lower THC and CO emissions (30.23% and 47.06% respectively) were also reported by authors in this paper.

Chapter 3

Experimental strategy and approach

3.1 Materials

Babassu oil was procured from Paras Perfumers, New Delhi. It is a pale yellow coloured oil with lauric acid as its main constituent around 44% rendering babassu biodiesel with great physical and chemical properties. It has an average molecular mass of 710 gmol^{-1} . Sal oil was acquired from Moksha Lifestyle Products, New Delhi. It is also yellowish coloured oil having average molecular mass of 886 gmol^{-1} . The FFA value of babassu and sal oil were found to be 1.2 and 0.18 respectively meaning that only single stage transesterification process for ester production. KOH pallets were obtained from local merchant in Patiala. Methanol was also obtained from a local vendor.

3.2 Preparation of methyl ester procedure

3.2.1 Babassu oil methyl ester production

- 100 g babassu oil was put in a 250 ml conical flask and was preheated at a temperature so as to remove any moisture present in it.
- Now catalyst is prepared after taking the methanol in the ratio (alcohol to oil ratio) of 4:1, 6:1 and 8:1. In it, catalyst KOH is mixed in the proportions of 0.5g, 1g, 1.5g and the mixture is stirred mechanically. Stirring is done till KOH is completely mixed in methanol.
- Now, catalyst mixture is poured in the preheated oil sample. Care must be taken while setting the mixture in the preheated oil.
- Different samples are prepared in the same way and then are installed in the water bath shaker for time period being 60minutes, 75 minutes and 90 minutes at constant reaction temperature of 60° C under constant mechanical stirring. In order to prevent any loss, the mouth of the beakers were covered with the foil paper.
- After the reaction time is lapsed, the beakers were taken out of the bath shaker and the samples obtained were poured in different separating funnels. The mixture is then allowed to stand undisturbed for around 10 to 12 hours. In the funnel, product

separation takes place. Glycerol, the by product, settles at the bottom (dark colour) and the upper part is termed as methyl ester.

- Now glycerol is removed from the sample and the remaining methyl ester is subjected to hot water wash. This is done so as to remove any methanol or catalyst or any impurity remaining in the ester part.
- Then the sample is heated till all the water and soap present in sample is completely eliminated. Now, final result is neat methyl ester.

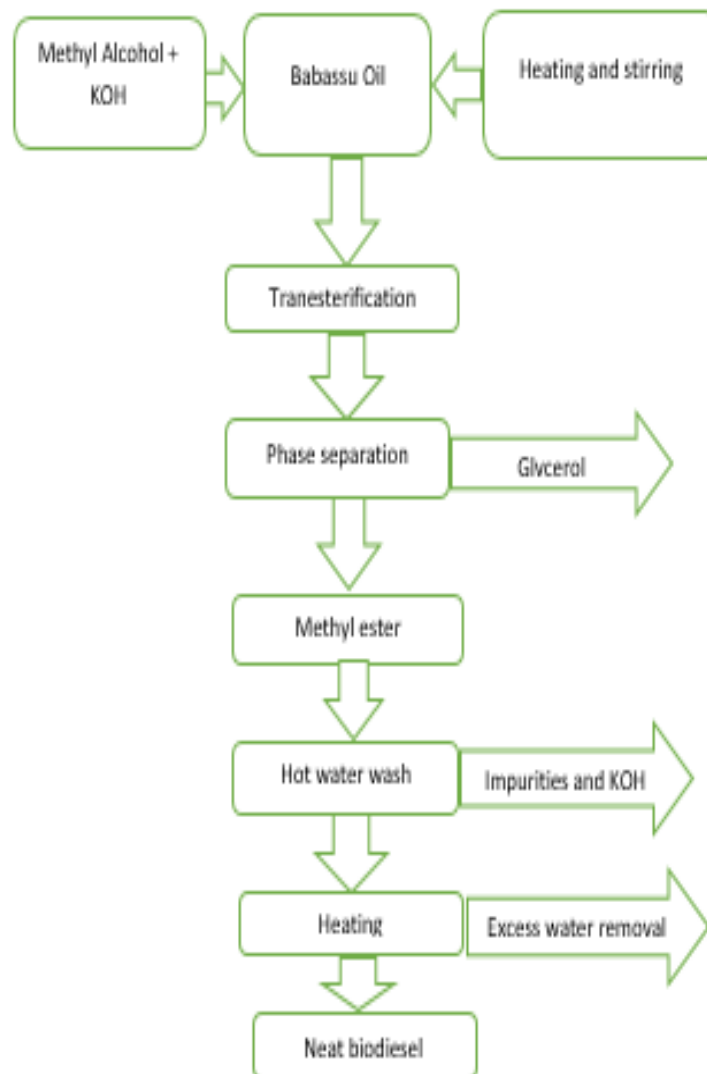


Fig 3.1 Process flow diagram for transesterification of babassu oil



Fig 3.2 Phase separation

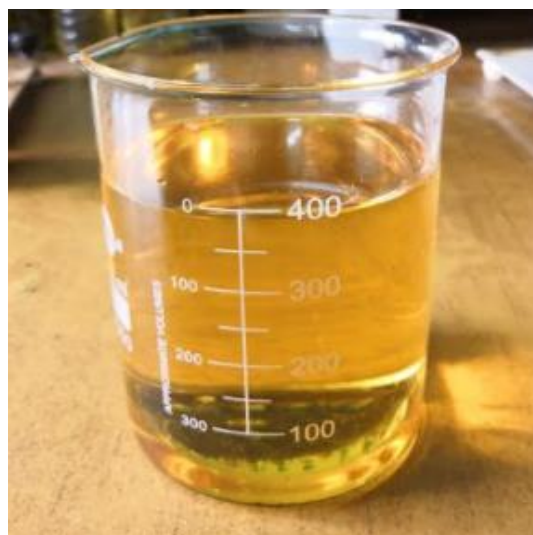


Fig 3.3 Neat babassu biodiesel

3.2.2 Sal oil methyl ester (SOME) production

- 100 g of refined sal oil is put in the 250 ml conical flask. Since the FFA value of the oil is as 0.269, single stage base transesterification was enough to carry out the process.
- Catalyst is prepared using methyl alcohol in the 250 ml conical flask in the alcohol to oil ratio of 4:1, 6:1 and 8:1 and KOH in the proportions of 0.5g, 1.0g and 1.5g was put in the flask and constant stirring is provided for the complete dissolution of KOH in CH₃OH.
- Samples are then preheated at the desired temperature and catalyst is then carefully poured in the samples.
- Samples are then subjected to constant mechanical agitation in the water bath shaker temperature of which is set at 60⁰ C. Reaction time was kept at 60 minutes, 75 minutes and 90 minutes.
- After the reaction time is lapsed, the samples are taken out of water bath shaker and poured into the separating funnel. Samples are then allowed to stand undisturbed for around 10-12 hours.
- Phase separation takes place as the dark thick liquid settles at the bottom. This dark liquid is the glycerol which is formed as a by-product. The upper layer is lighter which is actually methyl ester. Glycerol is then removed from the sample.
- Now hot water wash of the samples were done in order to remove any unreacted methyl alcohol or impurity present in the methyl ester. Water washing is generally done from

about 4 to 5 times in order to make sure that there is no impurity or unreacted methyl alcohol present in it.

- Samples were then heated above boiling point of water to eliminate any impurity or water present in the sample. After that we obtain neat biodiesel.

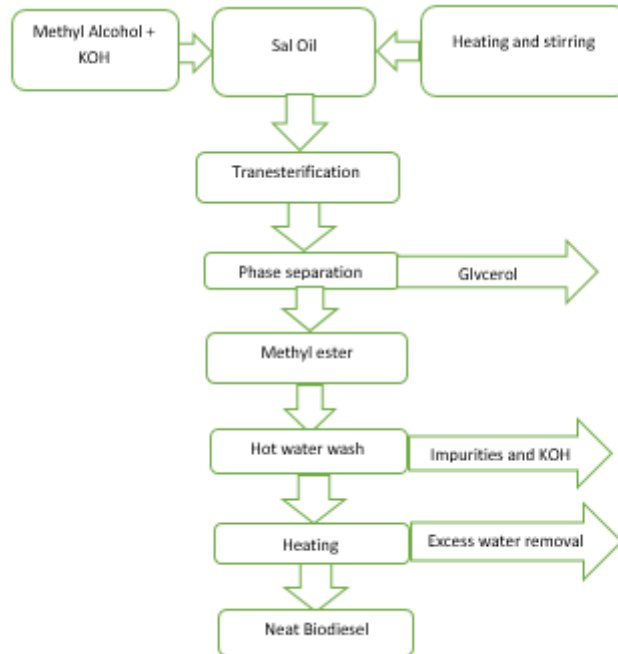


Fig 3.4 Process flow diagram for transesterification of sal oil



Fig 3.5 Phase Separation



Fig 3.6 Hot water wash



Fig 3.7 Heating



Fig 3.8 Neat sal biodiesel

3.3 Calculation of properties of biodiesel

Various physicochemical properties of biodiesel were determined during the experimentation. Some of them are listed below.

- Kinematic viscosity (cSt)
- Flash point ($^{\circ}\text{C}$)
- Cloud point ($^{\circ}\text{C}$)
- Pour point ($^{\circ}\text{C}$)
- FFA
- High calorific value (MJ/kg)
- Fire point ($^{\circ}\text{C}$)

3.4 Apparatus used for biodiesel production and calculation of properties for the same

3.4.1 Water bath shaker



Fig 3.9 Water bath shaker

The figure above shown is the water bath shaker. This device is used for complete mixing of catalyst in the sample for the transesterification to take place. Induction motor is connected with the tray. As the motor runs, tray has reciprocatory motion. Inside the tray, four slots are provided where the samples are kept. Now the apparatus is set at a predetermined temperature of 60⁰ C. When the temperature is reached, motor is switched on for the requisite time period.

3.4.2 Redwood viscometer

This device is used for the measurement of one of the key property of biodiesel i.e. kinematic viscosity. Device gives measurement in terms of seconds which is termed as Redwood seconds. Care must be taken to ensure that orifice through which oil comes out is not blocked. Procedure for calculating the viscosity is listed below:

- Take oil sample and pour it in the device up to the brim. Make sure that orifice is closed at the time of pouring in the sample.
- Place a 50 ml measuring cylinder below the device.
- Preheat the sample until the sample temperature reaches 40 ⁰C. Measure the temperature using thermometer.
- Pull out the stopper and start the stopwatch. At the point when the oil in the estimating barrel achieves the 50 ml check, stop the clock and set back the plug. This time taken by the oil to achieve the 50 ml check is called redwood seconds.

Equations used for calculating the kinematic viscosity of oil (cSt) are:

$$\text{If } t > 100 \text{ s, } V_k = 0.24t - 50/t \quad (1)$$

$$\text{If } t < 100 \text{ s, } V_k = 0.24t - 179/t \quad (2)$$

Where t = time in seconds, V_k = kinematic viscosity (cSt)

3.4.3 Bomb Calorimeter



Fig 3.10 Bomb Calorimeter

The above figure represents digital bomb calorimeter. This device is used to quantify calorific value of biodiesel. Following is the procedure to find calorific value:

Take sample of oil (approx. 5 gm.) in a crucible around which a metallic wire is wound. Crucible is then hung in a container. Pressure of the container is maintained by inserting O_2 gas at desired pressure. O_2 gas is used because it supports combustion. Around the crucible is thread is wound. Container is then inserted into another container that contains water. Electric circuit is then completed after inserting the probe in cathode and anode. Now the stirrer is switched on and initial reading is noted down. When current starts to flow, sample starts to burn and temperature of the surrounding water starts to rise up. When the steady stage is reached, temperature difference is noted down. Basic principle to find the calorific value is energy conservation i.e. heat lost by fuel is equal to heat carried by surrounding water. Equation used for calculating calorific value is:

$$\text{HCV (kJ/kg)} = (m_1 + m_2) \times (T_c + \Delta T) \times C_w / m_f \quad (3)$$

Where m_1 denotes mass of water in calorimeter, m_2 = water equivalent, m_f = fuel sample's mass

ΔT = temperature difference recorded by digital meter

C_w = specific heat of water, T_c = Temperature correction

3.4.4 Pensky Martens Apparatus



Fig 3.11 Pensky Martens apparatus

This device is employed for calculation of flash and fire point of the oil. Fuel sample is tipped in the cup. Continuous heating of the apparatus is done till the temperature rises 4 to 5 °C. Temperature is measured using thermometer. Test flame is brought towards oil vapour by moving the shutter for every 1°C rise in temperature. Temperature at which vapour shows bluish colour flame for about 5 to 6 secs when test flame was brought close to oil vapour is called flash point and the temperature at which oil catches fire is called fire point. Flash point generally appears around 5 to 12 °C earlier than fire point.

3.4.5 FFA value

Procedure for calculating FFA value is as follows:

Take 10g of biodiesel in a 250 ml conical flask. Now prepare 0.1 N solution of KOH by dissolving 0.56g of KOH in 100g of distilled water. Put this prepared solution in a burette. Flask containing biodiesel was then warmed up and 50 ml of ethanol was poured in it and the mixture was thoroughly mixed. Now 4 to 5 drops of phenolphthalein were emptied in the flask. Now slowly pour the prepared solution of KOH in the flask. It was observed after sometime pink coloured appeared for some time. Now difference in the level of KOH solution was noted down and the FFA value was calculated using formula [38, 43]:

$$\%FFA = (V-b) \times N \times 28.2/M \quad (4)$$

Where %FF is free fatty acid percentage of oil; V is value of titrant; volume of blank (ml); N is the normality; M is the weight of sample in grams.

3.4.6 Apparatus used for cloud point and pour point measurement

The apparatus consists of glass tube and cork and cooling jacket. Sample biodiesel was poured in a glass tube up to the mark and cork was applied on the tube. Ice cubes were then poured into the chamber and some salt was sprinkled over the ice cubes. Then the glass tube containing oil sample was inserted between the ice cubes and the adjacent areas were covered to prevent any heat entering the chamber. Over the inserted cork mounted on the glass tube there lies a hole into which thermometer was inserted. The apparatus is then allowed to stand undisturbed for some time. After few minutes glass tube was taken out of the chamber. A cloudy semi solid type substance appeared in the glass tube. This point is called cloud point. And after sometime semi solid substance is formed. This point of appearance of semi-solid wax is called pour point and the temperature corresponding to it is termed as pour point temperature.



Fig 3.12 Cloud point apparatus

3.5 Apparatus for determination of engine performance characteristics and engine emissions

3.5.1 Variable compression ratio engine (VCRS)

Engine performance parameters were calculated on a variable compression ratio engine that was Kirloskar made. Various switches were connected to engine including water temperature indicator, pressure gauge, fuel supply meter and load changing nob. Various engine performance parameters were calculated using VCR engine like BP, sfc,



Fig.3.13 VCR Engine

Table 3.1 Specifications of the engine

Engine type	4 stroke VCR engine
No. of cylinders	Single cylinder
Capacity	661 cm ³
Bore	87.5 mm
Stroke	110 mm
Compression ratio	14:1 to 20:1
Power	3.5 kW at 1500 RPM
Dynamometer	Eddy current type water cooled
Software	“EnginesoftLV” engine performance analysis

3.5.2 Eddy current dynamometer



Fig 3.14 Eddy current dynamometer

Eddy current dynamometer was coupled with output for power and torque measurement. It is of water cooled type. Dynamometer is coupled with load sensors for variation in the loads applied on the engine. Characteristics of the dynamometer are listed below.

Table 3.2 Eddy current dynamometer specifications

Model	AG10
Make	Saj Test Plant Pvt. Ltd
Water inlet	1.6 bar
Torque (Nm)	11.5 Nm
Speed maximum	10000 rpm
Load	1.5 kg

3.5.3 Exhaust Gas Analyser

Main function of the device is used to quantify the type and amount of the exhaust components emitting from engine. Components of emissions includes CO, NO_x, CO₂, SO_x, HC and exhaust gas temperature (EGT).



Fig 3.15 Exhaust analyser



Fig 3.16 Sensor probe

3.6 Experimental Procedure

- Three different blends namely B10, B20 and B30 of BOME and SOME were taken up for the experimentation.
- Firstly, diesel was used and engine was kept running and the compression ratios were adjusted accordingly.
- Now water pump was switched on and make sure that fuel position at “tank” was maintained.
- Loading is now increased in the increments of 0,2,4,6,8,10 kg at different compression ratios using DLU knob. Care must be taken that loading is increased steadily and not abruptly.
- Now using the software click on the LOG ON icon and set the fuel knob from “tank” to “measuring”. Now after 60 seconds, turn the knob again to “tank” position and save the readings in the software. The procedure is now repeated at different compression ratios. Now instead of petro diesel, use the blended fuel in the engine and repeat the above procedure for different loading conditions at different compression ratios.
- For measurement of emissions, first of all connect all the connections of exhaust analyser.
- Now insert the sensing probe into the exhaust and switch on the analyser.

- Readings corresponding to different components of emissions were obtained on the digital screen of the analyser. After noting down the readings, sensing probe was removed.
- Now this procedure is followed for different loading conditions at different compression ratios.

Table 3.3 Specifications of exhaust gas analyser

Parameters	Range	Resolution	Accuracy
O ₂	0 to 21%	0.1%	± 2% of reading
CO	0 to 5000 ppm	1 ppm	± 5% of reading
CO ₂	0 to 21%	0.1% of reading	± 0.3% of reading
HC	0 to 2000 ppm	0.01%	± 10% of reading
NO _x	0 to 5000 ppm	1 ppm	± 5% of reading

Chapter 4

Results and discussions

4.1 Biodiesel optimisation

In this experimentation, optimisation of oil via methanolysis route using KOH as catalyst was done considering three controlling parameters namely molar ratio, time of activity, catalyst amount and reaction temperature. In this experimentation of optimisation of both BOME and SOME, reaction temperature was invariably kept constant at 60 °C. Methanol to oil ratio were varied in the ratio of 4:1, 6:1 and 8:1. Catalyst concentration was varied as 0.5g, 1.0g and 1.5g. Reaction time was chosen for 60 minutes, 75 minutes and 90 minutes. This optimisation was done STB (smaller the better) in accordance with viscosity and LTB (larger the better) in case of biodiesel yield. Following results were noted down.

Table 4.1 Results of babassu biodiesel

S No	Babassu oil (gm.)	Molar Ratio	Catalyst KOH (gm.)	Reaction time (min)	Reaction Temperature (° C)	Yield (%)	Viscosity at 40 ° C (cSt)
1	100	4:1	0.5	60	60	95.3	4.187
2	100	4:1	0.5	75	60	83.7	4.55
3	100	4:1	0.5	90	60	87.27	4.369
4	100	4:1	1	60	60	75.95	5.625
5	100	4:1	1	75	60	85.5	15.58
6	100	4:1	1	90	60	83.12	3.89
7	100	4:1	1.5	60	60	84.05	10.89
8	100	4:1	1.5	75	60	74.33	10.78
9	100	4:1	1.5	90	60	78.48	7.37
10	100	6:1	0.5	60	60	91.15	3.28
11	100	6:1	0.5	75	60	98.18	1.98
12	100	6:1	0.5	90	60	92.09	9.12
13	100	6:1	1	60	60	93.52	2.098

14	100	6:1	1	75	60	80.24	9.174
15	100	6:1	1	90	60	82.28	10.82
16	100	6:1	1.5	60	60	73.8	12.67
17	100	6:1	1.5	75	60	88.07	12.46
18	100	6:1	1.5	90	60	85.1	3.67
19	100	8:1	0.5	60	60	90.6	6.22
20	100	8:1	0.5	75	60	91.5	5.05
21	100	8:1	0.5	90	60	86.25	3.091
22	100	8:1	1	60	60	92.26	2.42
23	100	8:1	1	75	60	85.62	4.927
24	100	8:1	1	90	60	87.75	7.37
25	100	8:1	1.5	60	60	82.6	4.88
26	100	8:1	1.5	75	60	81.43	8.82
27	100	8:1	1.5	90	60	67.4	3.91

From the above table, it is concluded that for minimum viscosity and maximum yield best operating conditions were molar ratio of 6:1, catalyst concentration 0.5g KOH, time of activity 75 minutes at reaction temperature of 60 °C and the obtained value of yield and viscosity at the optimised conditions were 98.18% and 1.92cSt respectively.

Table 4.2 Optimised parameters for BOME production

Molar ratio	6:1
Reaction time (minutes)	75 minutes
Reaction temperature (°C)	60 °C
Catalyst concentration (g)	0.5g

Table 4.3 Properties of BOME

Fuel Property	Diesel	BOME	ASTM D6751	EN14214
Density (g/cm ³)	820-835	874	-	860-900

Kinematic viscosity 40 ⁰ C (cSt)	3.7	1.98	1.9-6	3.5-5
Flash Point(⁰ C)	60	122	>130	>101
Fire point (⁰ C)	65	128	-	Min 120
Cloud point (⁰ C)	-12	5.5	10	-1
Pour Point (⁰ C)	-16	0.5	-15	-
Cetane No	47.48	61	48-67	Min 51
Calorific Value (MJ/kg)	43	36.29	36-41	-
Acid value(mg KOH/g)	0.2	0.18	0.5 max	0.5 max

Table 4.4 Results of sal biodiesel

S No	Sal oil (gm.)	Molar Ratio	Catalyst KOH (gm.)	Reaction time (min)	Reaction Temperature (⁰ C)	Yield (%)	Viscosity at 40 ⁰ C (cSt)
1	100	4:1	0.5	60	60	84.435	8.9125
2	100	4:1	0.5	75	60	85.035	7.9872
3	100	4:1	0.5	90	60	83.514	9.1045
4	100	4:1	1	60	60	91.12	5.554
5	100	4:1	1	75	60	90.829	9.2604
6	100	4:1	1	90	60	90.079	7.8142
7	100	4:1	1.5	60	60	84.051	6.469
8	100	4:1	1.5	75	60	79.809	7.4920
9	100	4:1	1.5	90	60	84.687	6.545
10	100	6:1	0.5	60	60	89.714	4.296
11	100	6:1	0.5	75	60	90.145	5.7383
12	100	6:1	0.5	90	60	88.635	5.36826

13	100	6:1	1	60	60	94.56	4.6410
14	100	6:1	1	75	60	93.710	5.3416
15	100	6:1	1	90	60	93.422	6.1065
16	100	6:1	1.5	60	60	88.048	8.151
17	100	6:1	1.5	75	60	86.351	9.637
18	100	6:1	1.5	90	60	84.703	9.846
19	100	8:1	0.5	60	60	96.247	4.184
20	100	8:1	0.5	75	60	93.727	4.304
21	100	8:1	0.5	90	60	96.289	10.7870
22	100	8:1	1	60	60	92.261	6.193
23	100	8:1	1	75	60	96.39	2.7792
24	100	8:1	1	90	60	92.147	7.141
25	100	8:1	1.5	60	60	80.798	6.4548
26	100	8:1	1.5	75	60	85.06	5.8917
27	100	8:1	1.5	90	60	84.679	8.645

Table 4.5 Optimised parameters for SOME production

Reaction temperature ($^{\circ}\text{C}$)	60 $^{\circ}\text{C}$
Reaction time (minutes)	75
Catalyst concentration (KOH in gms)	1
Molar ratio	8:1

Table 4.6 Properties of SOME

Fuel Property	Diesel	SOME	ASTM D6751	EN14214
Density (g/cm^3)	820-835	877.2	-	860-900
Kinematic viscosity 40 $^{\circ}\text{C}$ (cSt)	3.7	2.7792	1.9-6	3.5-5
Flash Point($^{\circ}\text{C}$)	60	137	>130	>101
Fire point ($^{\circ}\text{C}$)	65	146.4	-	Min 120
Cloud point ($^{\circ}\text{C}$)	-12	22	10	-1
Pour Point ($^{\circ}\text{C}$)	-16	18	-15	-

Cetane No	47.48	51	48-67	Min 51
Calorific Value (MJ/kg)	43	39.4	36-41	-
Acid value(mg KOH/g)	0.2	0.13	0.5 max	0.5 max

4.2 Effects of various operating variables on BOME production

4.2.1 Effect of catalyst concentration on BOME production

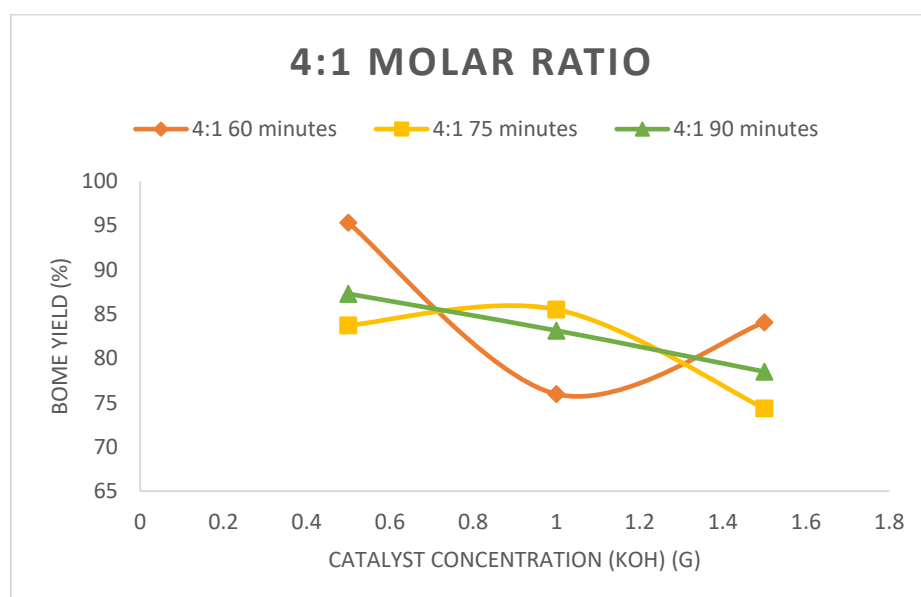


Fig 4.1 Yield versus catalyst conc at 4:1 molar ratio for BOME

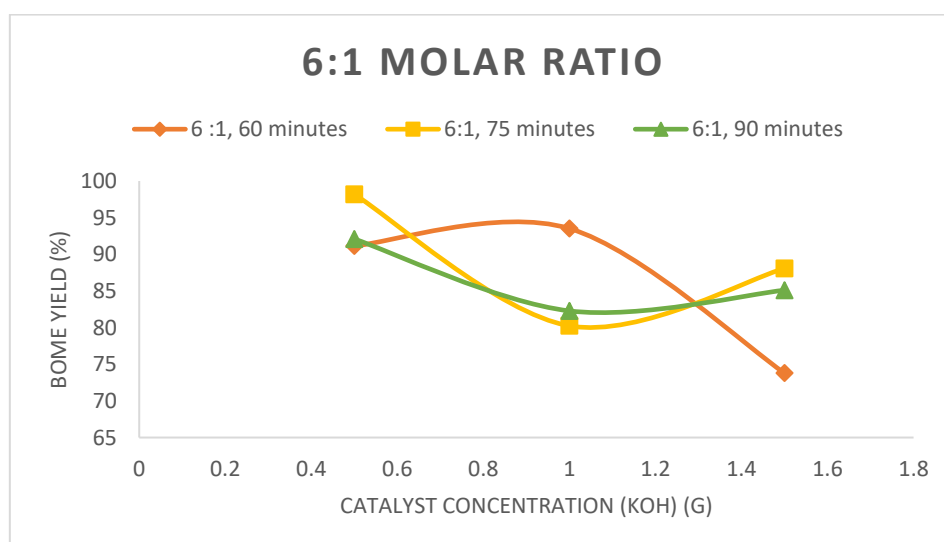


Fig 4.2 Yield versus catalyst conc at 6:1 molar ratio for BOME

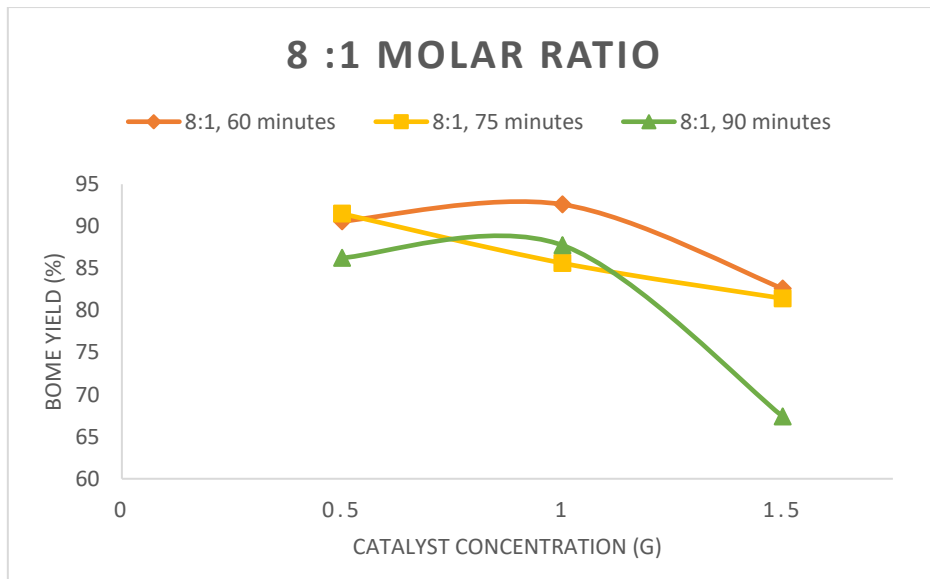


Fig 4.3 Yield versus catalyst concentration at 8:1 molar ratio for BOME

One key factor affects biodiesel yield is catalyst concentration. KOH is generally used because it is easily dissolved in methanol at lower temperature. It has been observed in Fig 4.1 and Fig 4.2 that for same molar ratio and time being same, BOME yield increases as catalyst concentration is increased from 0.5gm to 1gm and then reduces if further increased to 1.5gm. This is because at higher concentration, unreacted catalyst would hamper the methyl ester production due to soap formation [41]. Excess catalyst present in the sample would enhance viscosity of methyl ester thereby reducing the yield [42]. Highest yield was obtained at 6:1 molar ratio, 60 °C reaction temperature, 0.5gm KOH concentration and reaction time 75 minutes.

4.2.2 Effect of molar ratio on BOME

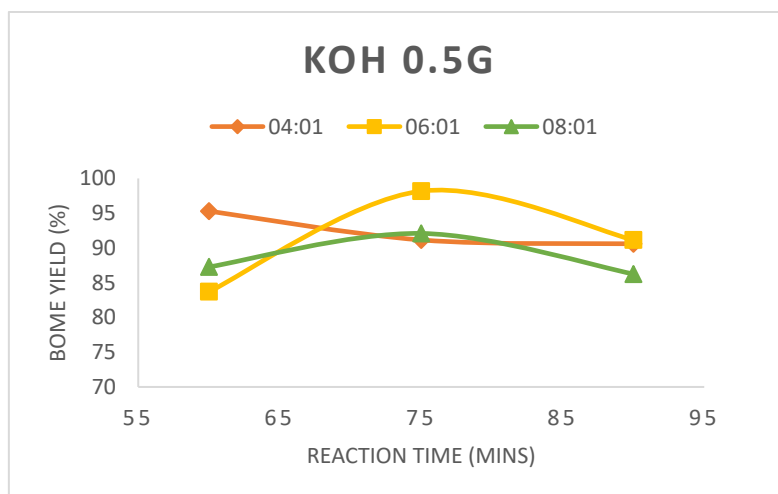


Fig 4.4 KOH 0.5 g, Reaction temp 60°C BOME



Fig 4.5 KOH 1g, Reaction temp 60 °C BOME

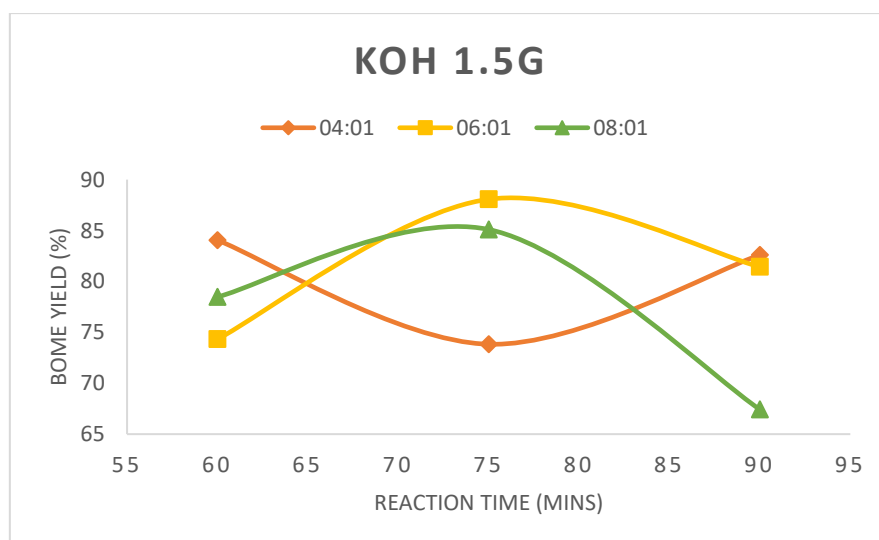


Fig 4.6 KOH 1.5g, Reaction temp 60 °C BOME

From the given graphs, it can be concluded that as the time of activity increases to 75 minutes, yield first increases and then decreases as the molar ratio is changed to different times. This is attributed to polar nature of methanol that would increase glycerol solubility in ester thereby decreasing the yield as one progress to higher molar ratio [44]. Moreover, excess methanol present would result in shifting of reaction in backward direction [45] Maximum yield is obtained at 6:1 0.5g KOH and 75 minutes. From Fig 4.5 it is cleared observed that at the same conditions, as the molar ratio is made higher towards 8:1, yield has decrease. Hence, justifying the above said reasoning.

4.2.3 Effect of time of activity on viscosity

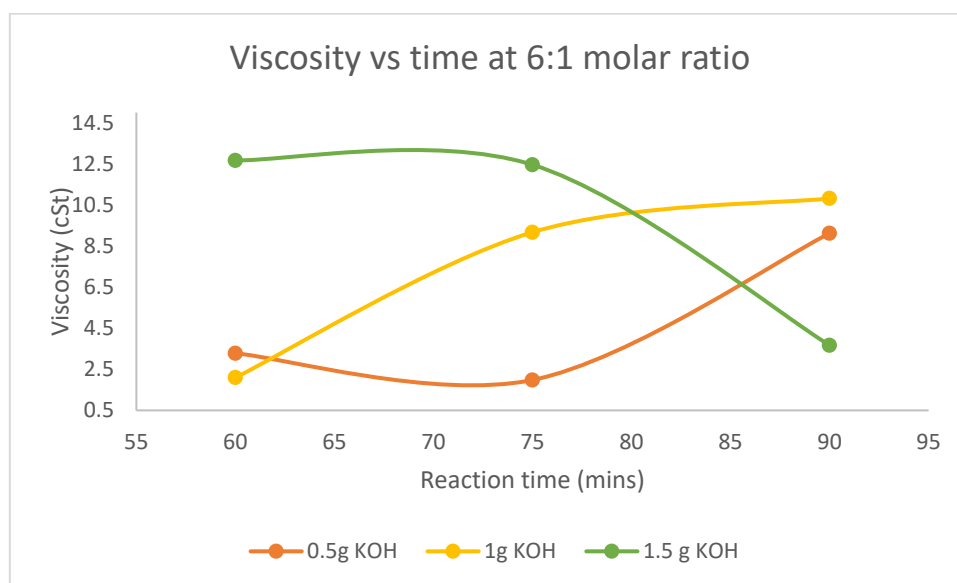


Fig 4.7 Viscosity vs. reaction time for 6:1 molar ratio BOME

It is observed for a given catalyst concentration as the reaction time progresses towards 75 minutes, there has been decrease in viscosity trend which then increases as the reaction time reaches 90 minutes (Fig 4.7). This is because at 75 minutes, maximum yield of BOME has been observed which has a direct relation to viscosity trend. After 75 minutes, there has been decrease in BOME yield due to side reactions occurred during transesterification reaction along with some unreacted catalyst present in it. Hence decrease in yield would cause an increase viscosity trend.

4.3 Outcome of various operating parameters on SOME production

4.3.1 Effect of molar ratio on SOME yield

It has been observed that for 0.5g KOH as there is a rise in the methanol to oil ratio, SOME yield spurs significantly. This is because of proper mixing of alcohol at higher levels which increases the SOME yield (Fig 4.8 and Fig 4.9). At lower levels of molar ratio, proper mixing does not take place for transesterification reaction to take place thereby decrease in yield was reported.



Fig 4.8 Yield versus time at 0.5g KOH, SOME



Fig 4.9 Yield versus time at 1g KOH, SOME



Fig 4.10 Yield versus time at 1.5g KOH, SOME

4.3.2 Effect of catalyst amount on SOME yield

It is reported that as the molar ratio is kept unchanged at 8:1, increasing catalyst concentration results in decrease in the SOME yield. This is because higher concentration of catalyst would result in lowering of catalyst activity which results in soap formation. Hence at higher catalyst concentration and at higher times decreasing trend was followed. Extra catalyst present in it would result in gel formation which leads to drop in ester yield. Maximum yield was attained at 8:1 molar ratio, for 60 minutes at 0.5g KOH catalyst amount. (Fig 4.11, Fig 4.12 and Fig 4.13)

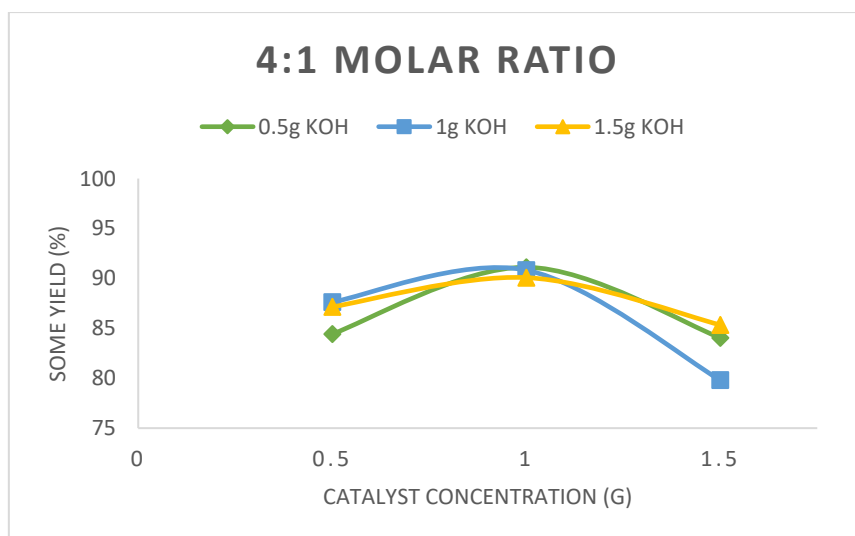


Fig 4.11 Yield versus catalyst concentration at 4:1 molar ratio, SOME

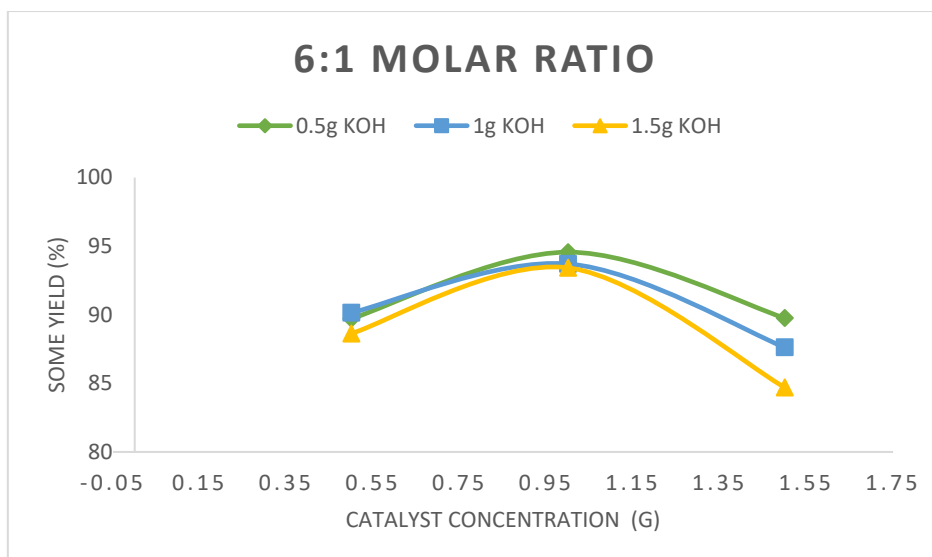


Fig4.12 Yield versus catalyst concentration at 6:1 molar ratio, SOME

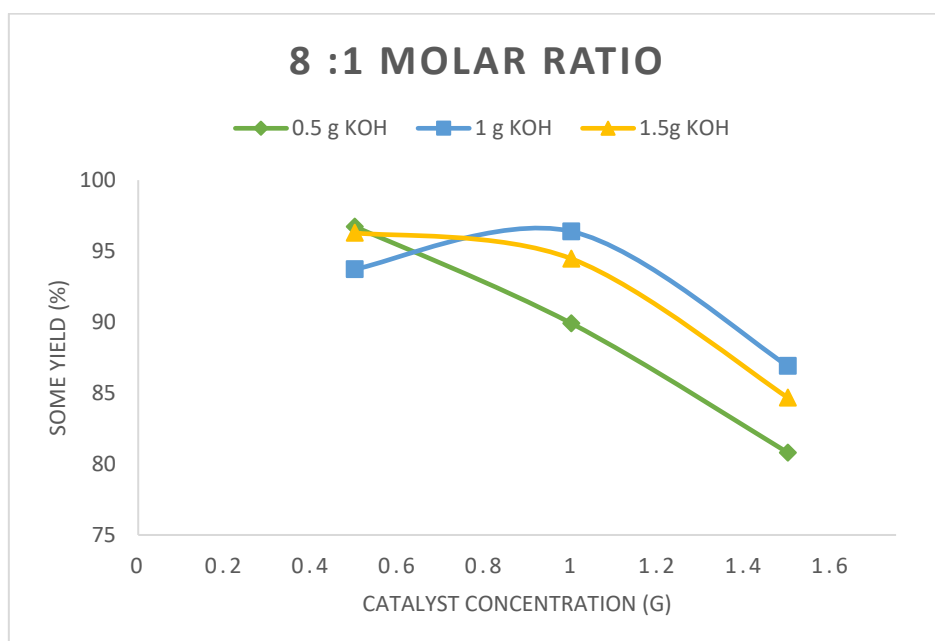


Fig 4.13 Yield versus catalyst concentration at 8:1 molar ratio, SOME

4.3.3 Effect of time of activity on SOME yield

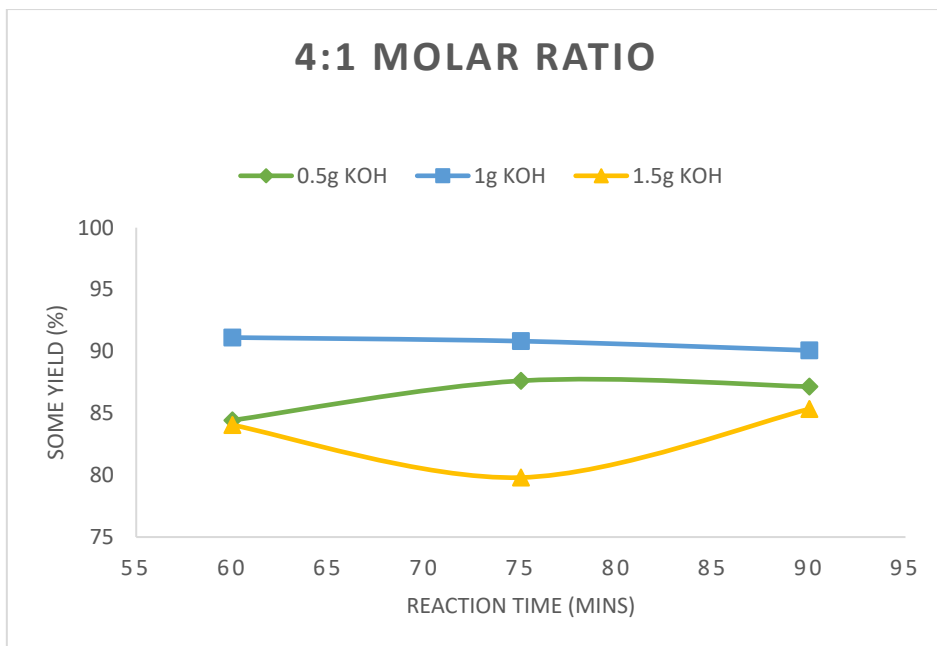


Fig 4.14 Yield versus time at 4:1 molar ratio, SOME

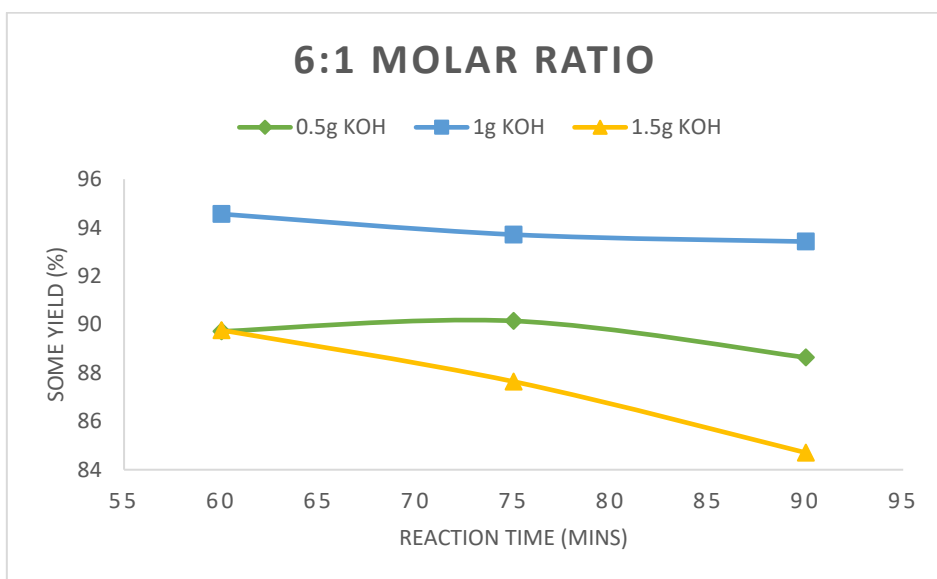


Fig4.15 Yield versus time at 6:1 molar ratio, SOME

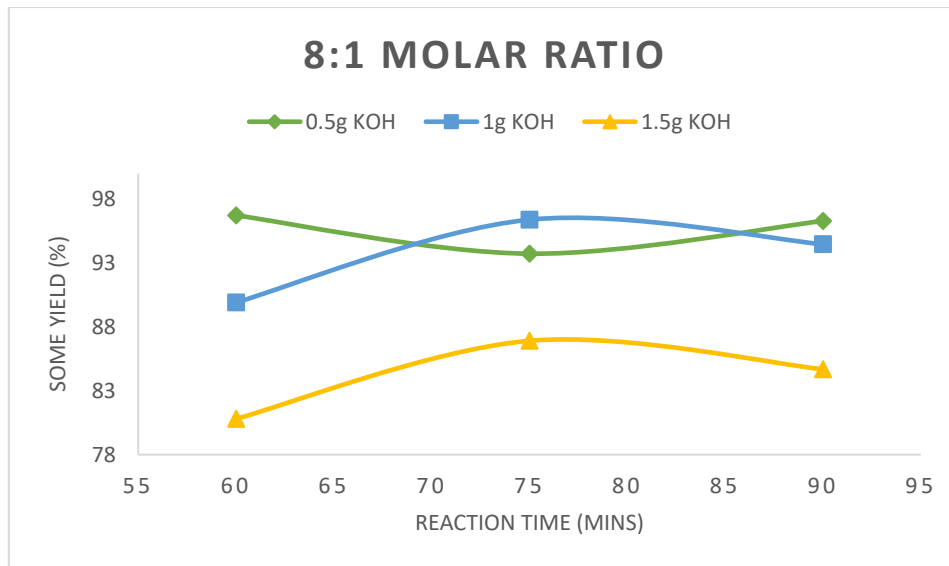


Fig 4.16 Yield versus time at 8:1 molar ratio, SOME

Reaction time is one of the key factors that affect ester yield. It is observed that for 8:1 molar ratio, at constant catalyst amount, yield first decreases when 75 minutes is lapsed then increases for 90 minutes reaction time (Fig 4.16). This is because of presence of different proportion of catalyst and methanol to oil ratio combination. Decrease in yield is observed at 75 minutes for 0.5g KOH at 75 minutes because of absence of sufficient amount of catalyst required for transesterification reaction to take place.

4.4 Engine performance parameters and experimental procedure

In experimentation carried out on VCR engine, three different blends were prepared as test fuels namely BL 10, BL 20, and BL 30 for both BOME and SOME. Experimentation was done using three compression ratios namely 14:1, 16:1, 18:1 at constant engine speed and load was varied in increment of 2kg with maximum load being 10kg. Different parameters such as BP, mechanical efficiency, BTE, sfc, were calculated using engine software. Emissions were noted down using exhaust analyser by inserting sensing probe into the exhaust of engine and noting down values on digital screen of the instrument.

4.4.1 Engine and emission characteristics of BOME

4.4.1.1 Brake thermal efficiency (BTE)

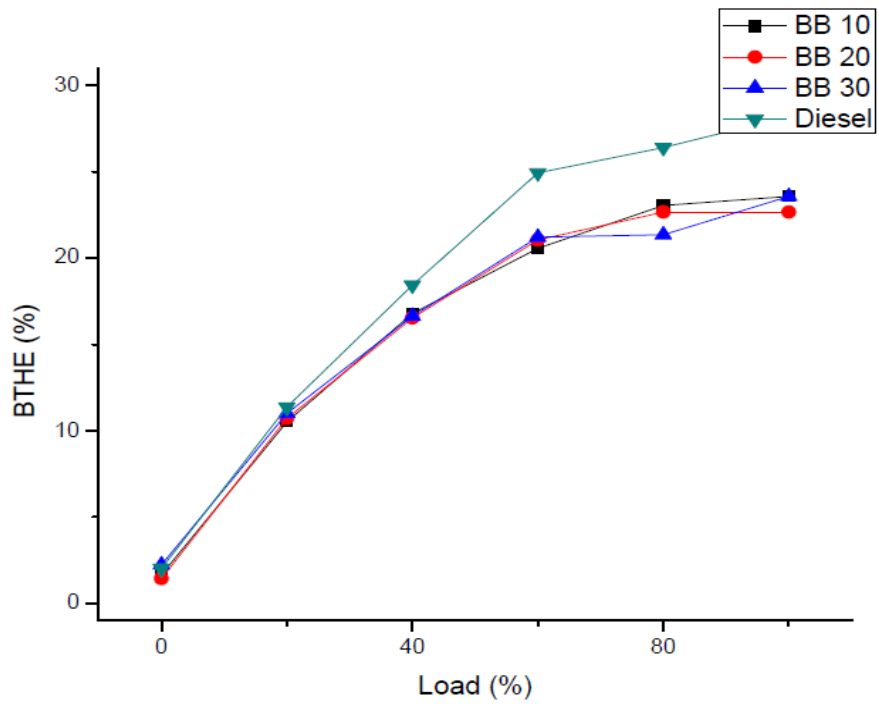


Fig 4.17 BTHE versus load for BOME at CR 14

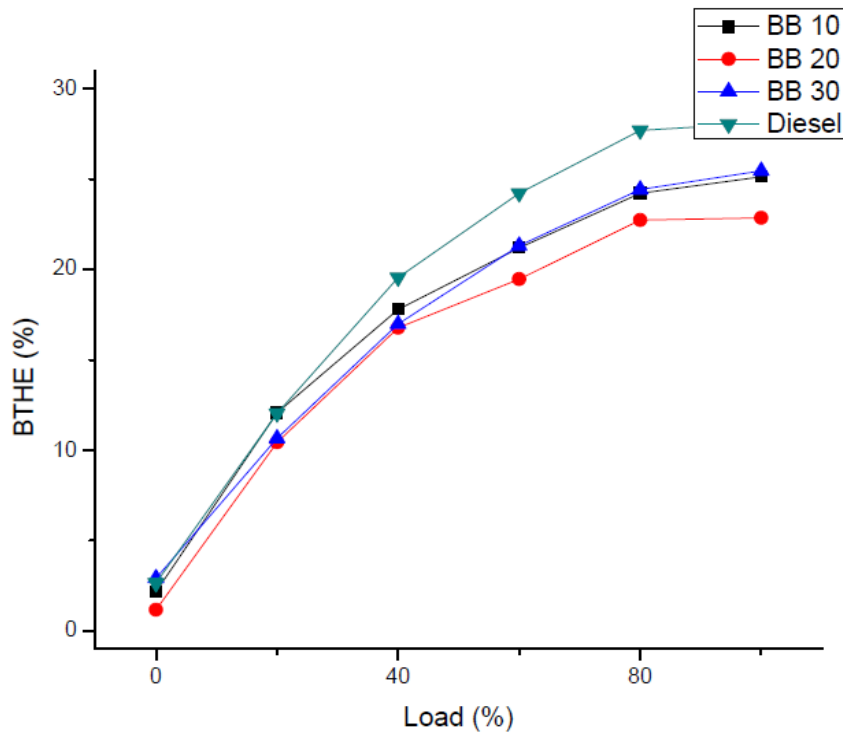


Fig 4.18 BTHE versus load for BOME at CR 16

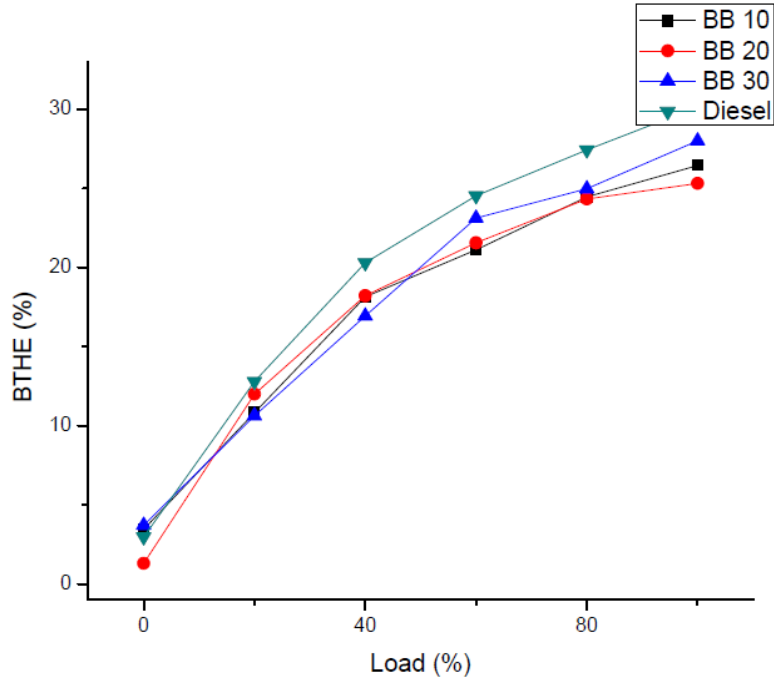


Fig 4.19 BTHE versus load for BOME at CR 18

From Fig 4.17, 4.18 and 4.19, it is envisaged that brake thermal efficiency showed linear trend with loads. This is because of less loss of heat and high power obtained at increasing loads. Following graphs were obtained by performing experiments at different compression ratios. Amongst all the blends that have been taken for experimentation, BB30 has higher BTHE in all the experiments. Relatively lower value of BTHE than diesel fuel is attributed because of higher viscosity and poor spray characteristics of blended fuel [46]. For compression ratio 14, highest BTHE obtained at full load (100%) was 23.57% for BB30. For compression ratio 16, highest BTHE obtained was 25.46% for BB 30 and for compression ratio 18, highest BTHE obtained was 28% at full load (100%). At CR 18, BTHE is improved as compared to CR16 and CR14 due to better combustion of blended fuel.

4.4.1.2 Brake Power (BP)

From the following graphs (Fig 4.20, 4.21 and 4.22), it was concluded that BP followed linear trend with increasing engine load. There is not much significant difference in the power obtained using biodiesel blended fuel [47]. This is because of greater density and viscosity of biodiesel which compensates for lower calorific value of biodiesel thereby increasing air- fuel mixing which leads to proper combustion process. Another reason for almost near BP trends for biodiesel and diesel is high bsfc for the biodiesel. At CR18, BB30 showed higher BP at full

load. This might be because of better combustion and higher cylinder temperature which supports combustion.

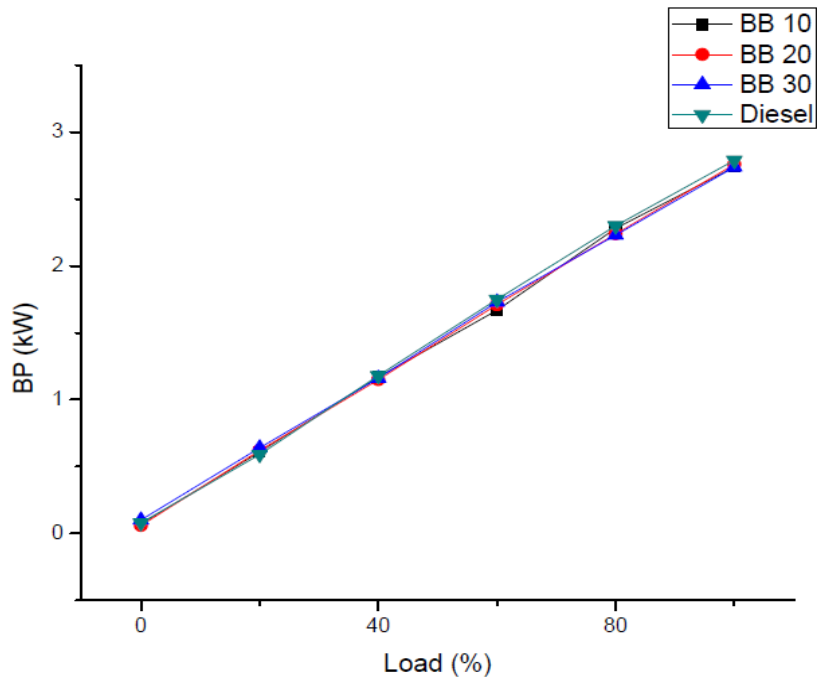


Fig 4.20 BP versus load for BOME at CR 14

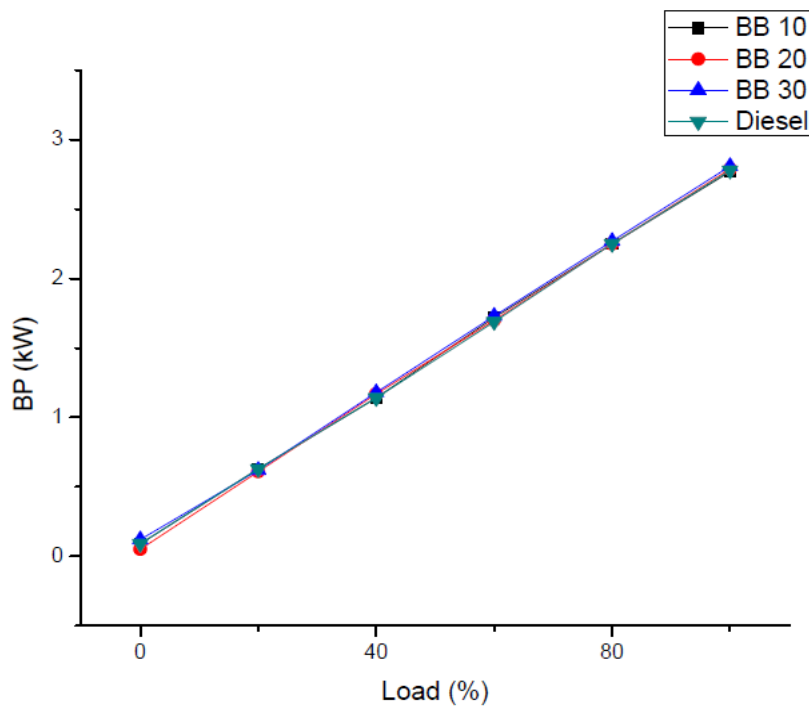


Fig 4.21 BP versus load for BOME at CR 16

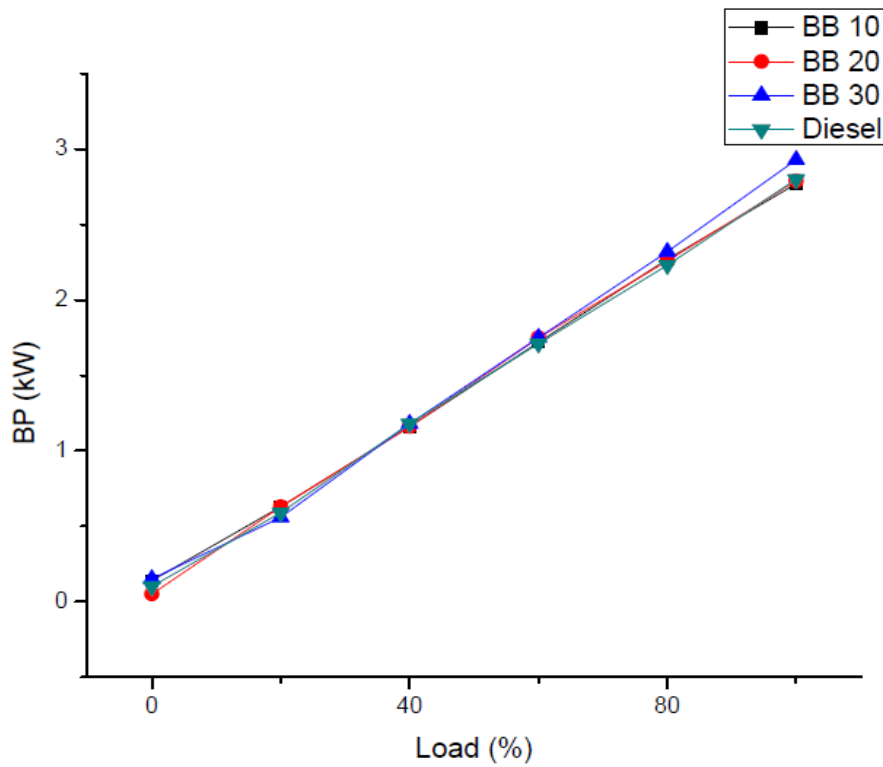


Fig 4.22 BP versus load for BOME at CR 18

4.4.1.3 Mechanical efficiency

From the following graphs (Fig 4.23, 4.24 and 4.25), it is found that mechanical efficiency increases with higher blended fuel at different loads. Maximum efficiency was obtained for BB 30 blend at maximum load (100%). At CR 14, maximum efficiency attained is 46.45 % at full load (100%). At compression ratio 16, maximum efficiency attained for BB 30 is 45.16% at maximum load. At compression ratio 18, maximum efficiency for BB 30 obtained is 47.12% at full load. This rise in mechanical efficiency is attributed to the improved spray quality and lower flame temperature contrasted to diesel fuel [48].

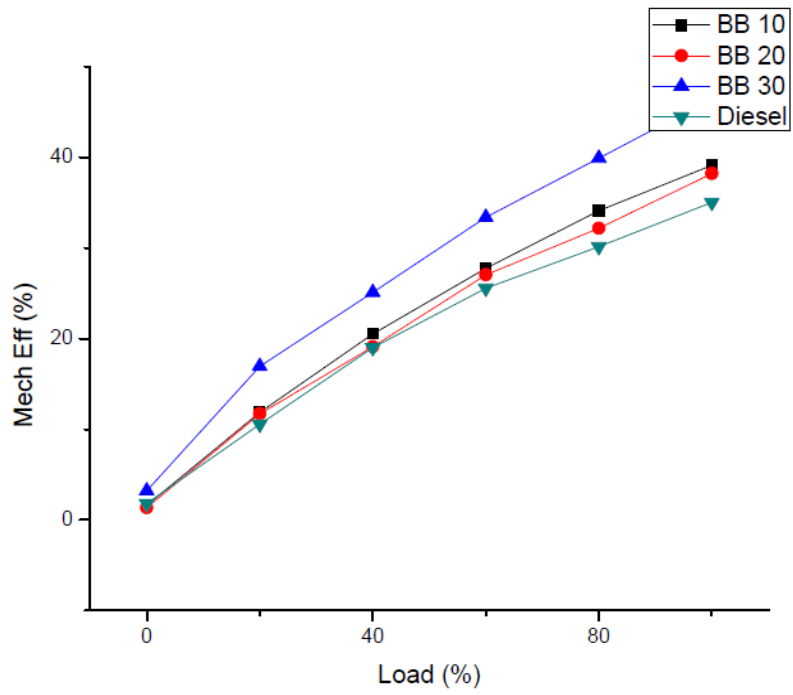


Fig 4.23 Mechanical efficiency versus load for BOME at CR 14

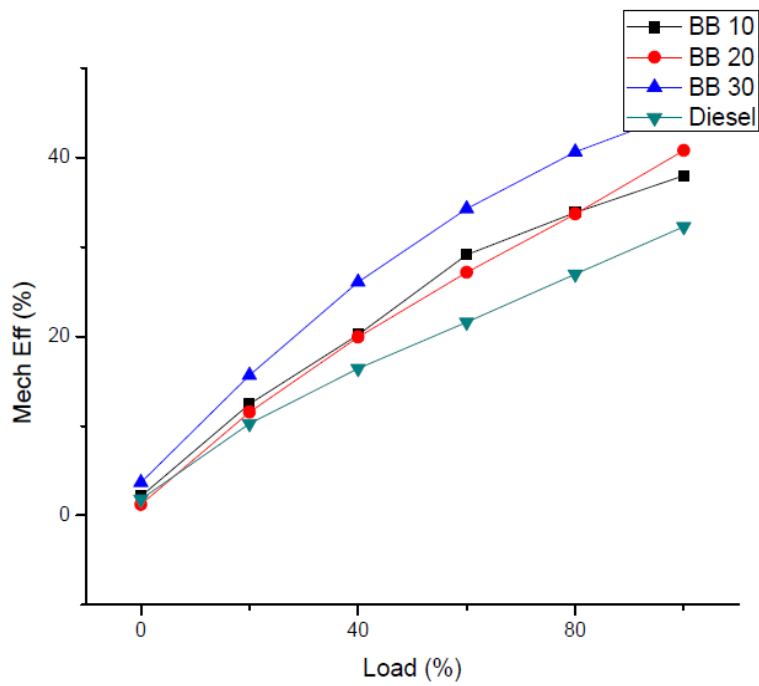


Fig 4.24 Mechanical efficiency versus load for BOME at CR 16

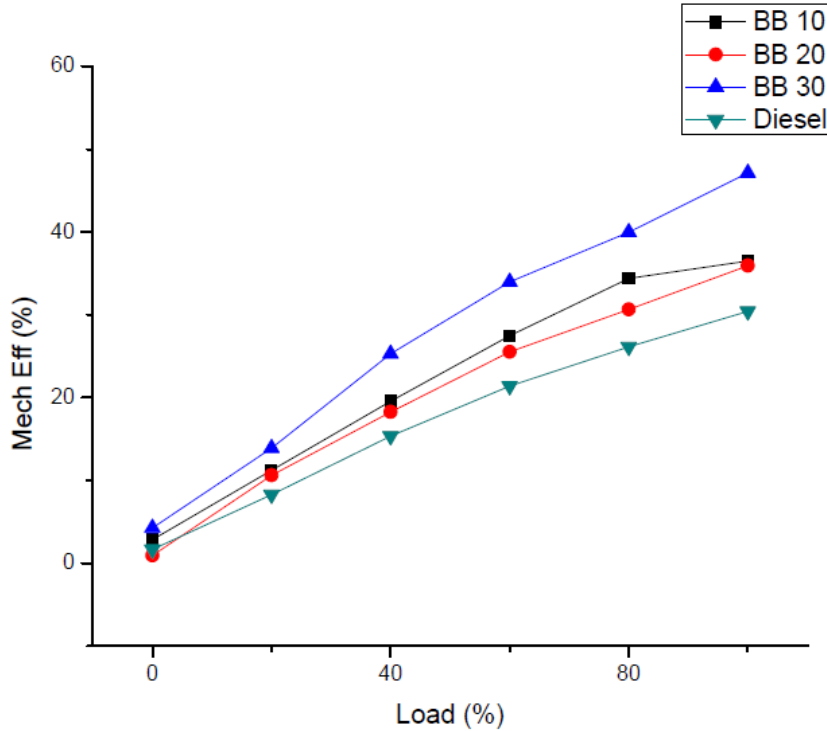


Fig 4.25 Mechanical efficiency versus load for BOME at CR 18

4.4.1.4 Specific fuel consumption (sfc)

From the following graphs (Fig 4.26, 4.27 and 4.28), it has been found that as the engine load increases, sfc decreases. This is because of increase in break power with fuel consumption. Another reason is improved combustion process due to high in-cylinder temperature which occurs on increasing engine load which further improves mixing and enhances atomisation process for better combustion. For BB 10 and BB 20 there is increase in sfc at lower loads. Such trend is attributed due to relatively high density of BOME than diesel fuel. Thus resulting in high discharge of fuel. Moreover, for same amount of power delivery, lower heating value of BOME calls for higher fuel delivery by fuel pump. At no load condition, sfc for B10 and B20 are 3.95 kg/kWh and 7.31 kg/kWh respectively for compression ratio of 16. For compression ratio 14, sfc for BB10 and BB20 were found to be 5.2kg/kWh and 5.98 kg/kWh respectively. For BB 30 decreasing trend was obtained. This is because of better combustion and more oxygen available at high blends.

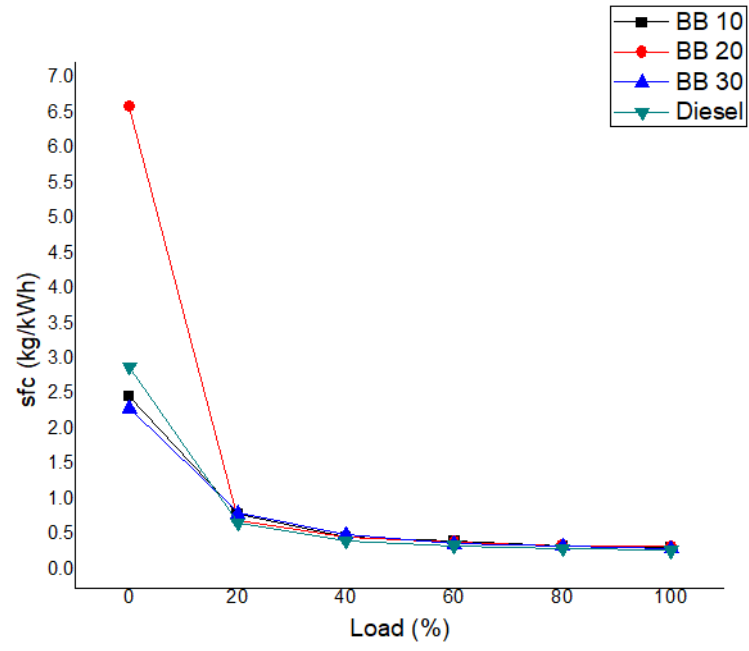


Fig 4.26 Sfc versus load for BOME at CR 18

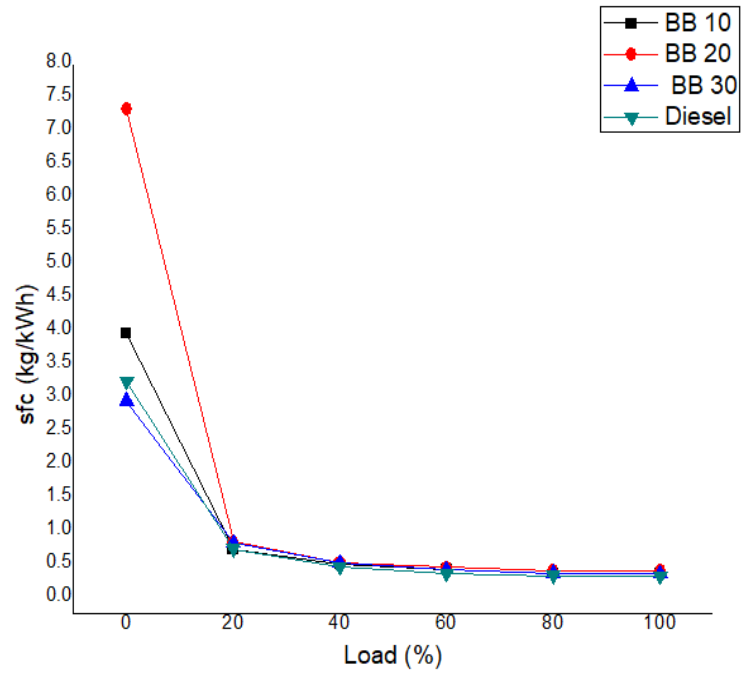


Fig 4.27 Sfc versus load for BOME at CR 16

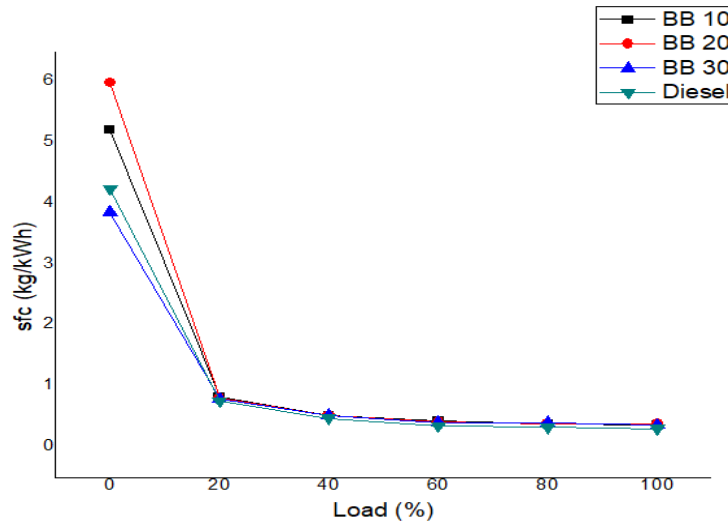


Fig 4.28 Sfc versus load for BOME at CR 14

4.4.1.5 Exhaust Gas Temperature (EGT)

From the acquired graphs (Fig 4.29, 4.30 and 4.31), it is elucidated that fumes gas temperature ascends at higher loads at all pressure proportions. Exhaust gas temperature of blended fuel BB10, BB20 and BB30 is more than petro diesel. Maximum EGT is for BB30. This trend is followed because of the extra oxygen content available in the blended fuel and presence of high boiling point components which supports combustion [49]. Maximum EGT for BB10, BB20 and BB30 at compression ratio 16 is 322.16 °C, 353.89 °C and 303.91 °C respectively. At compression ratio 18 and 14 same trend was noticed. Blended fuel exhibits highest EGT as compared to diesel fuel with BB 30 showing maximum EGT for each of the compression ratio at full load condition.

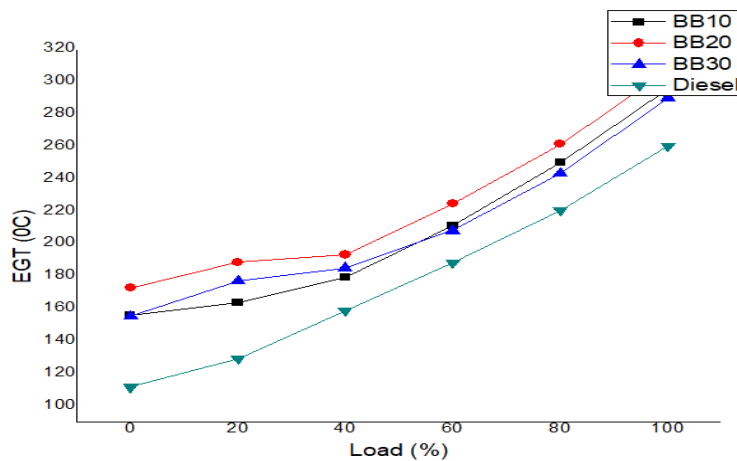


Fig 4.29 EGT versus load for BOME at CR 18

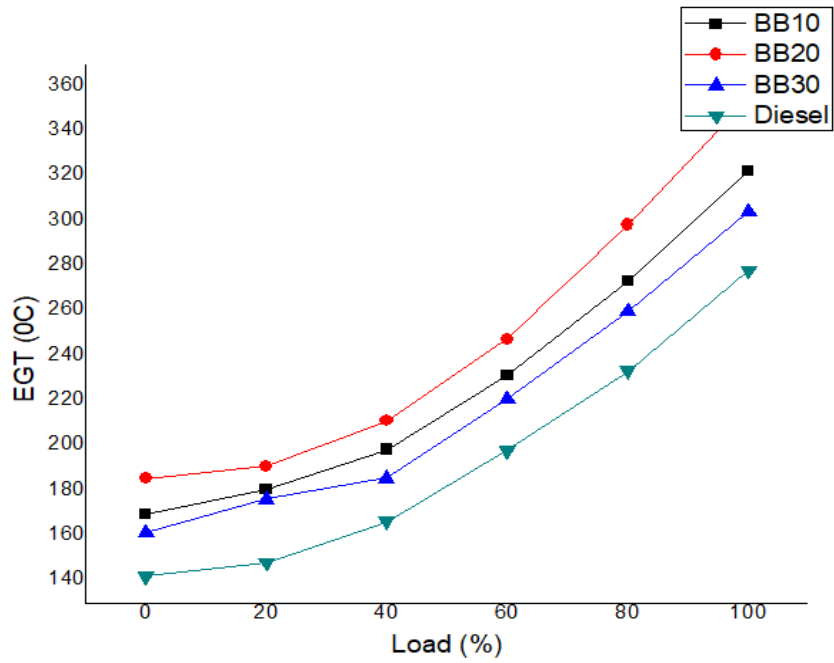


Fig 4.30 EGT versus load for BOME at CR 16

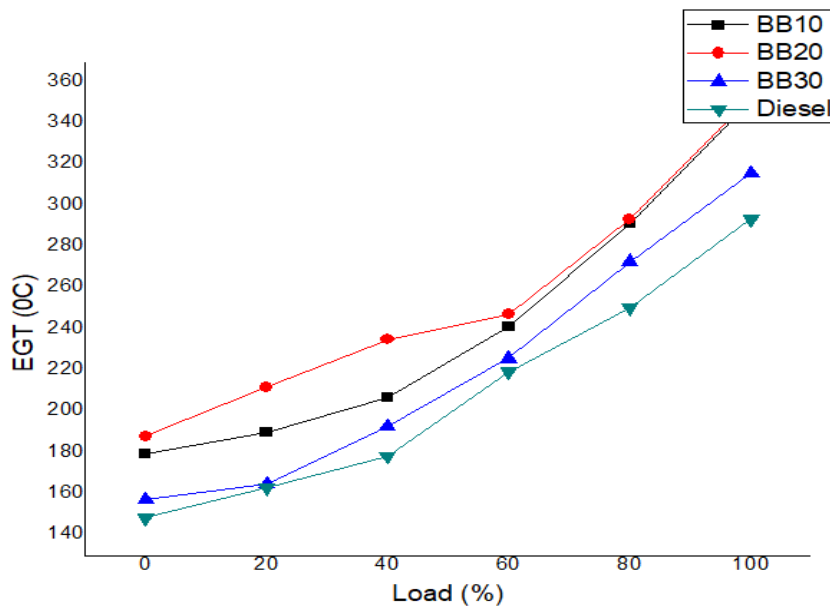


Fig 4.31 EGT versus load for BOME at CR 14

4.4.1.6 Carbon Monoxide emissions (CO)

At higher mixes of biodiesel there is reduction in CO emission for a particular engine load. Possible reasoning for this behaviour is proper oxidation of biodiesel blend as compared to

diesel fuel. As the load is increased engine cylinder temperature rises up causing a reduction in CO emissions. At full load, CO emissions tends to rise (Fig4.32, 4.33, 4.34). This is because of production of smoke on excess fuel delivery preventing oxidation of CO to CO₂ [50, 51]. For all the compression ratios, it has been investigated that blended fuel trims down the level of CO emissions when compared to petro diesel.

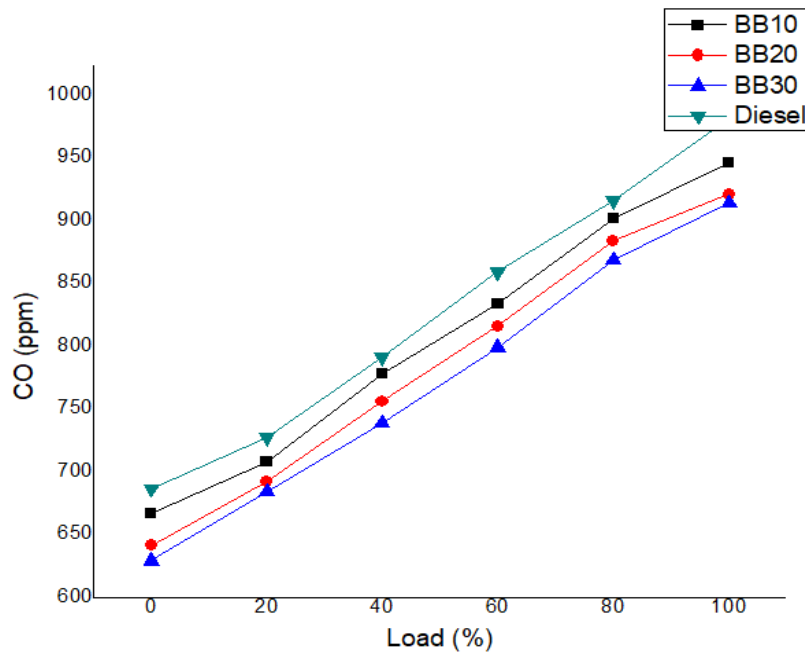


Fig 4.32 CO versus load for BOME at CR 14

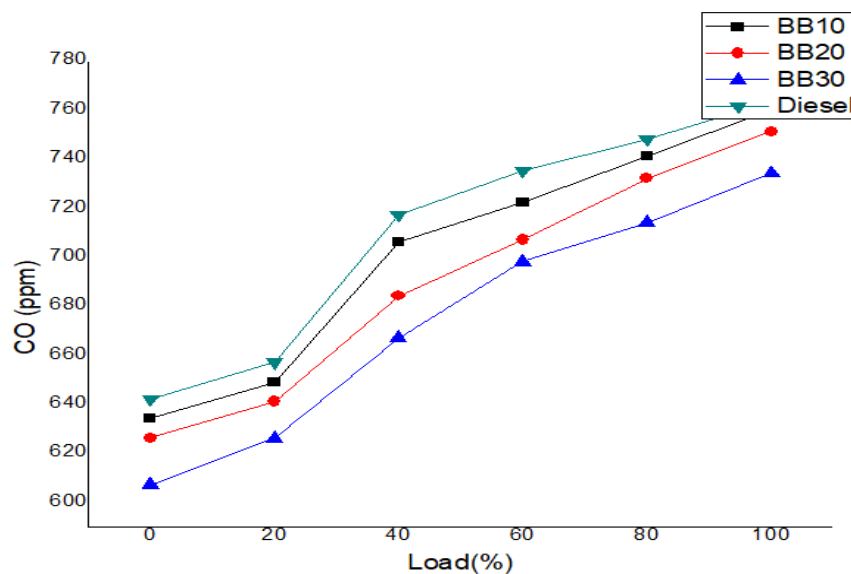


Fig 4.33 CO versus load for BOME at CR 16

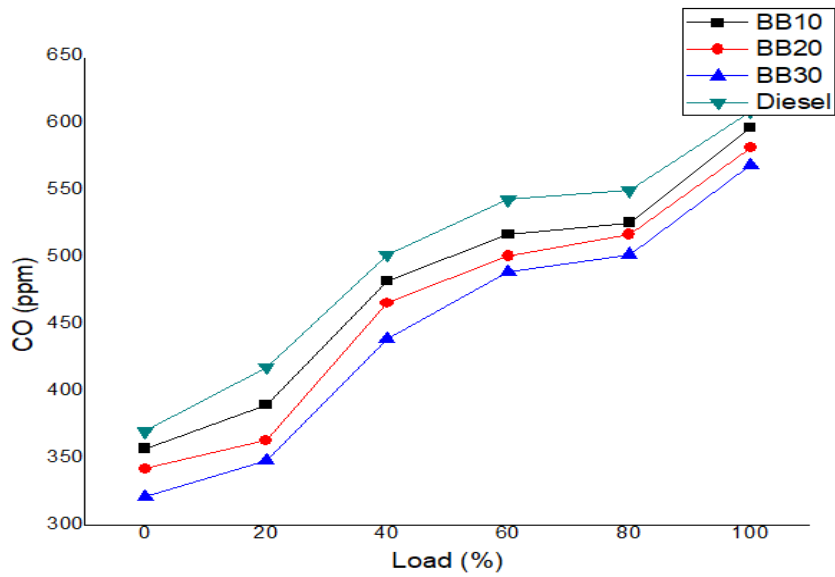


Fig 4.34 CO versus load for BOME at. CR 18

4.4.1.7 Nitrogen oxides (NO_x)

In all the three graphs two things can be inferred. Firstly, NO_x emissions are directly proportional to load varied. With increasing loading, NO_x emissions increases (Fig 4.35, 4.36 and 4.37). This is because at higher engine loads, combustion chamber temperature shoots up and NO_x emissions are directly temperature dependent. Another perception that has been made is that NO_x discharges are lower when contrasted with HSD (fast diesel). This is a result of high cetane number which causes a decrease in start defer resulting in downfall of NO_x emissions. Another explanation for reduced NO_x emissions is saturation in fatty compounds [52].

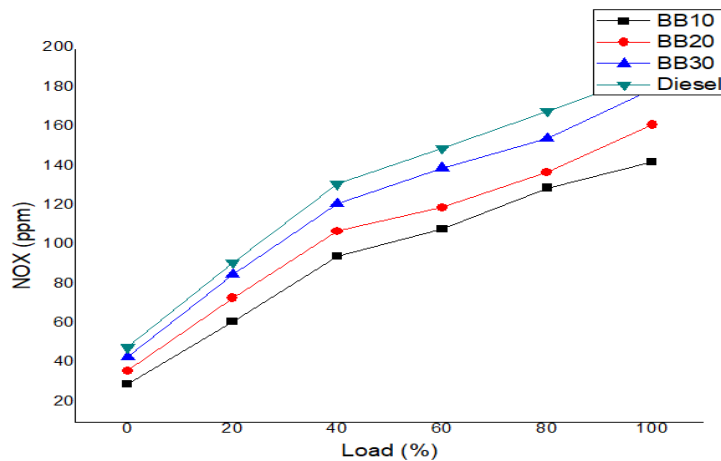


Fig 4.35 NO_x versus load for BOME at CR 14

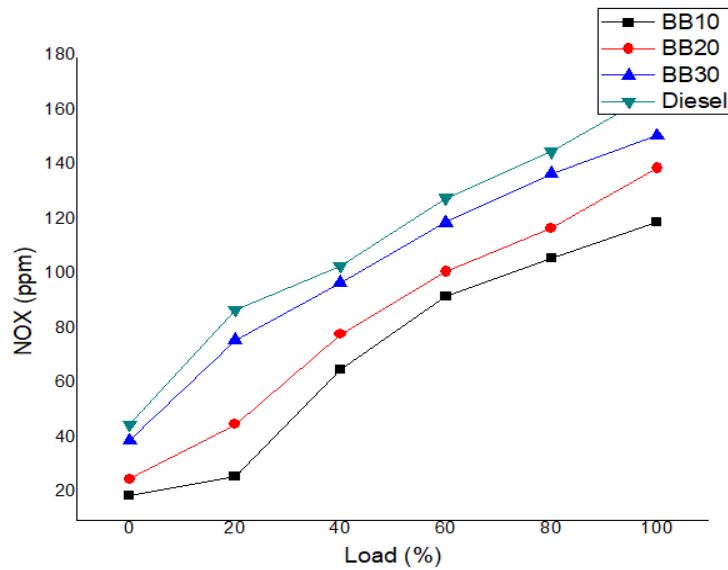


Fig 4.36 NO_x versus load for BOME at CR 16

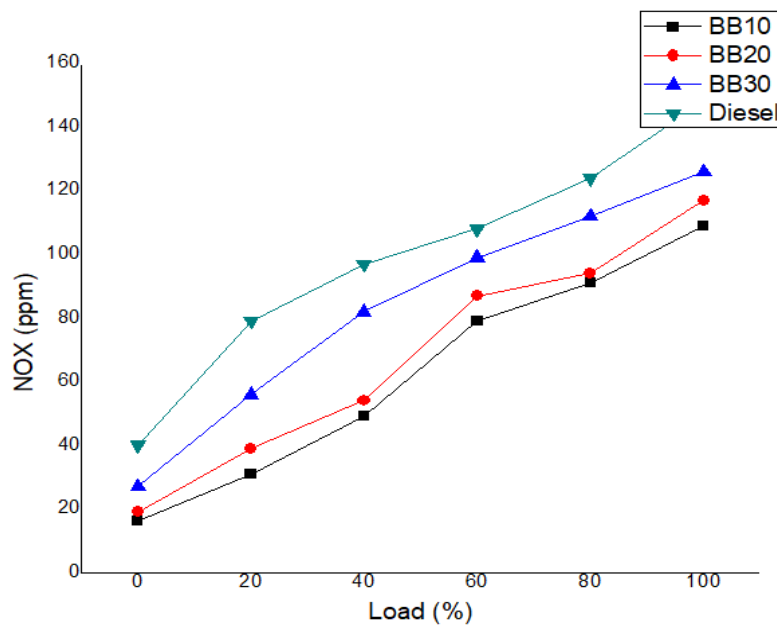


Fig 4.37 NO_x versus load for BOME at CR 18

4.3.1.8 Hydrocarbons (HC)

From Fig 4.39 and 4.40, it is observed that HC emissions are lowered in comparison to high speed diesel fuel. Reasons suggested is saturation in the compounds present in blended fuel and stable combustion and faster rate of evaporation. Another explanation behind this pattern is propelled infusion timing combined with high cetane number. But with load, it is reported

that at higher loads, HC emission levelled up. This is because of high rate of fumigation and oxygen is less available to support combustion at higher engine loads. Hence increasing trend for HC with respect to load was observed.

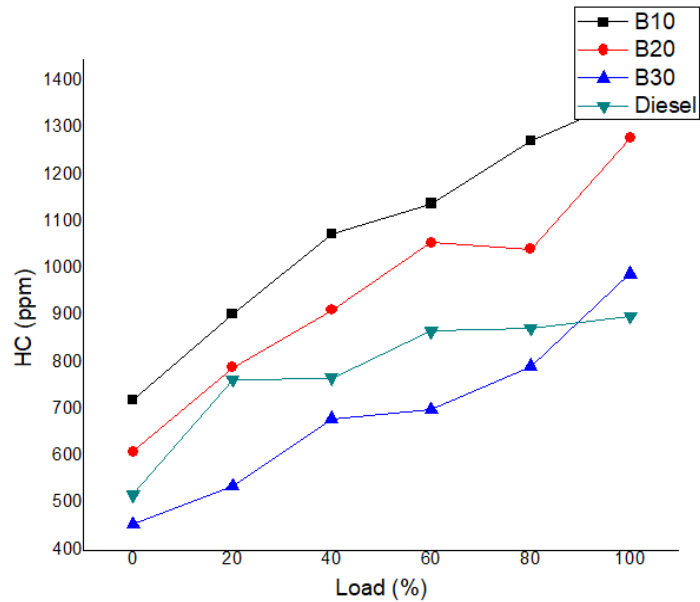


Fig 4.38 HC versus load for BOME at CR 18

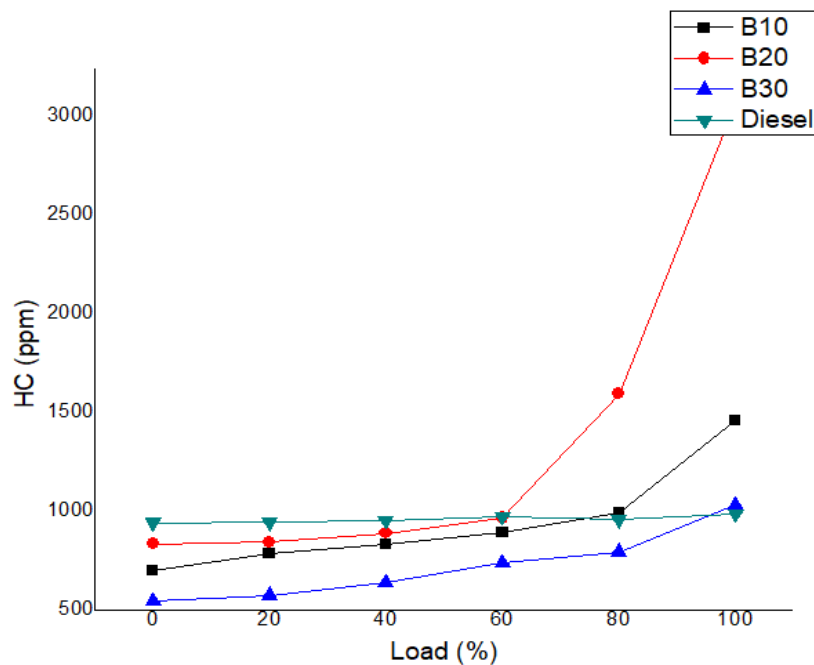


Fig 4.39 HC versus load for BOME at CR 16

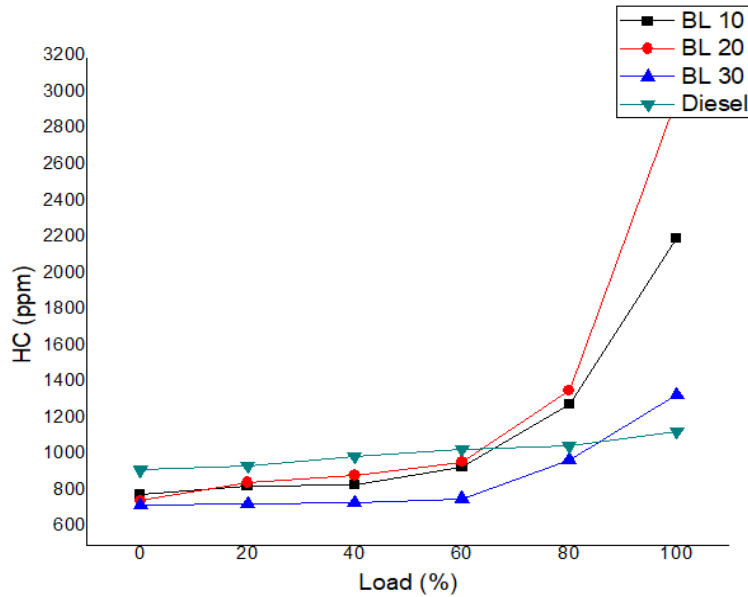


Fig 4.40 HC versus load for BOME at CR 14

4.5 Performance and emission characteristics for SOME biodiesel and its mixes

4.5.1 Brake power (BP)

From the graphs plotted, it was inferred that with increase in engine loading, brake power increases and showed promising results. It was also observed that there was no remarkable difference found in the BP obtained by SB10, SB20, SB30 and diesel fuel [53]. Diesel and SB30 contributed most extreme brake control at no heap (0%) and full load (100%) individually. This is because of proper combustion of blended fuel compensating for lower CV of fuel. For compression ratio 18, BP at full load was 2.78kW, 2.77kW and 2.80 for SB10, SB20 and SB30 respectively. For compression ratio 16, brake power obtained at full load for SB10, SB20, and SB30 were 2.75kW, 2.76kW and 2.75kW respectively (fig 4.42) and for compression ratio 14, brake power obtained at full load for SB10, SB20, SB30 was 2.77kW, 2.75kW and 2.79 kW respectively (fig 4.43).

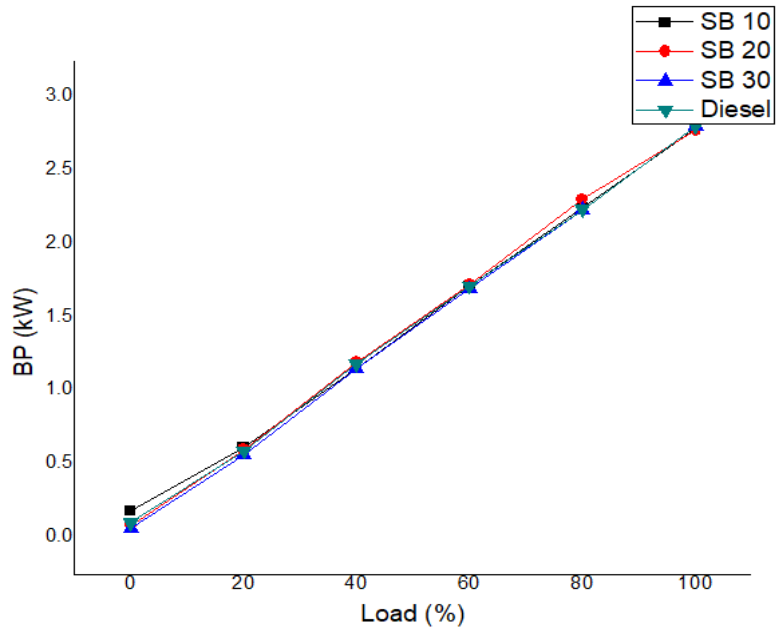


Fig 4.41 BP versus load for SOME at CR 18

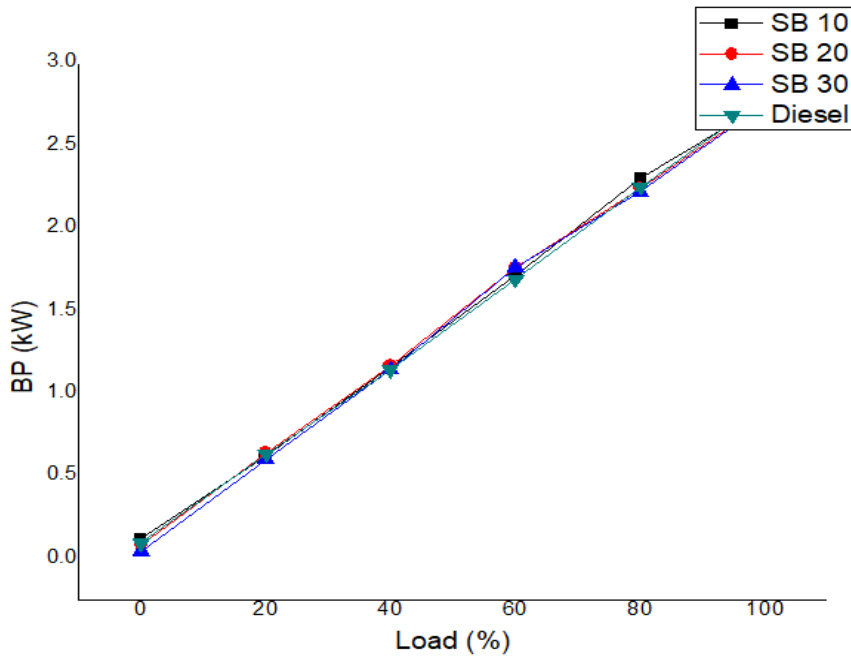


Fig 4.42 BP versus load for SOME at CR 16

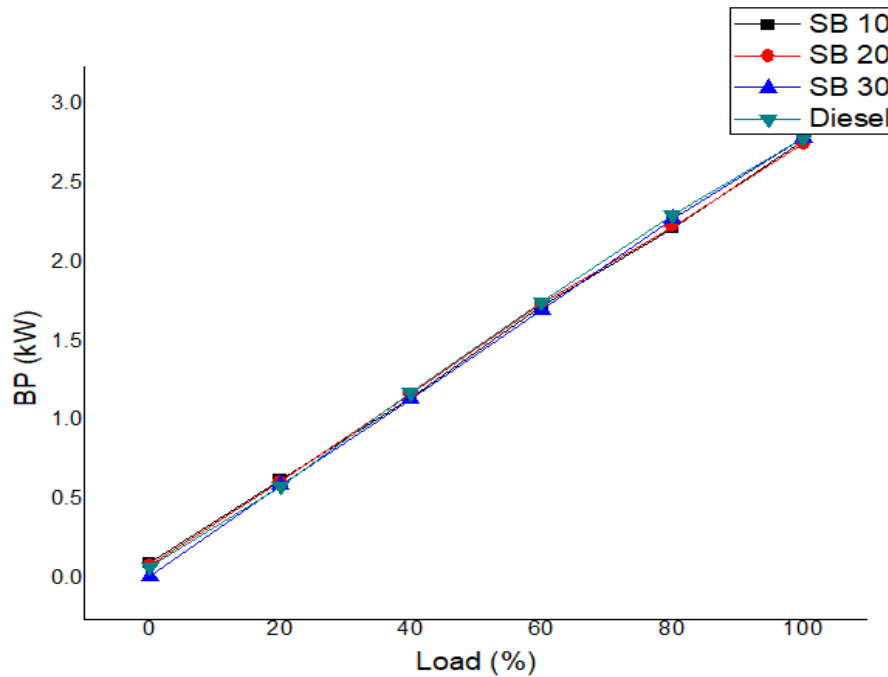


Fig 4.43 BP versus load for SOME at CR 14

4.5.2 Brake thermal efficiency (BTHE)

From experimental analysis, it is noteworthy that brake thermal efficiency exhibits linear trend load. This is because of less heat loss and more power obtained with increasing loads. Following graphs were obtained by performing experiments at different compression ratios. Amongst all the blends that have been taken for experimentation, BB30 has higher BTHE in all the experiments (fig 4.44 and 4.45). Lower value of BTHE than petro diesel is attributed to elevated sfc. This variety in BTE is likewise because of quality of oxygen in the SOME which catalyse the ignition procedure. This elevation observed in BTE with increasing load is because of reduction of cylinder wall heat loss at higher loads.

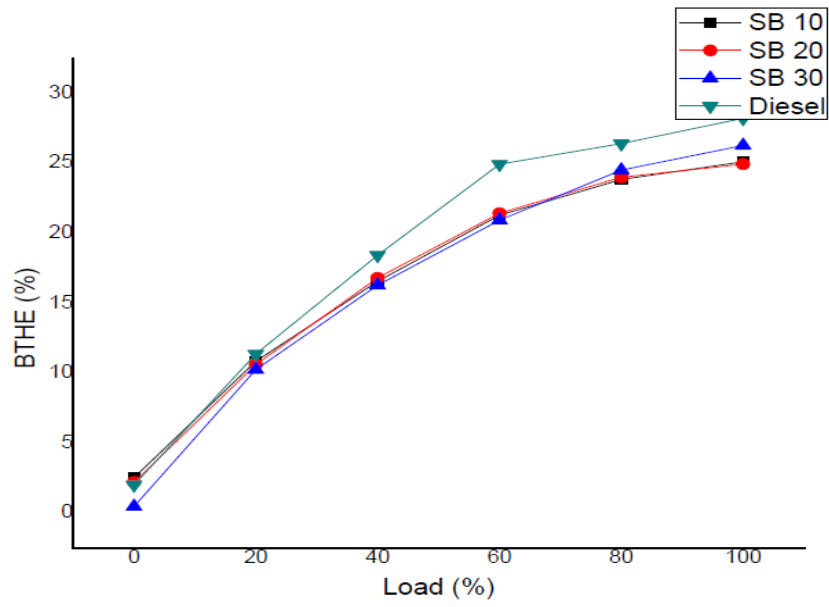


Fig 4.44 BTHE versus load for SOME at CR 14

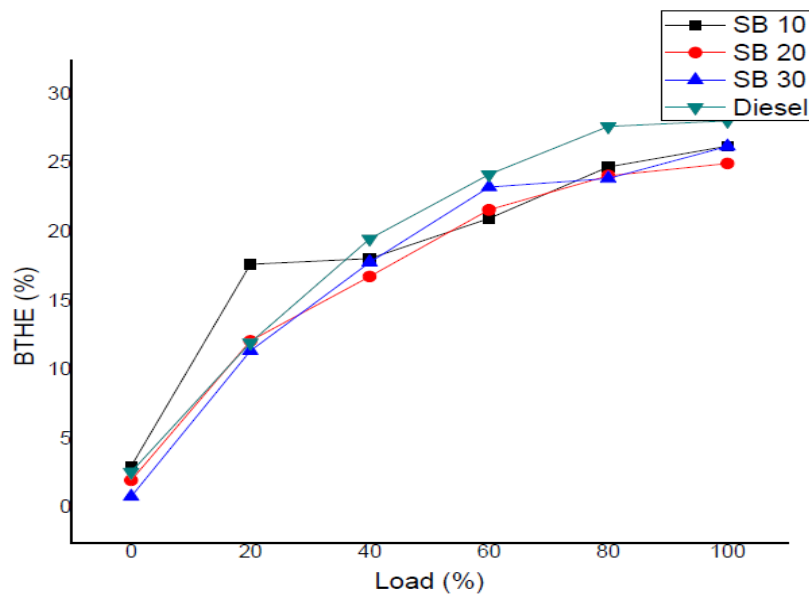


Fig 4.45 BTHE versus load for SOME at CR 16

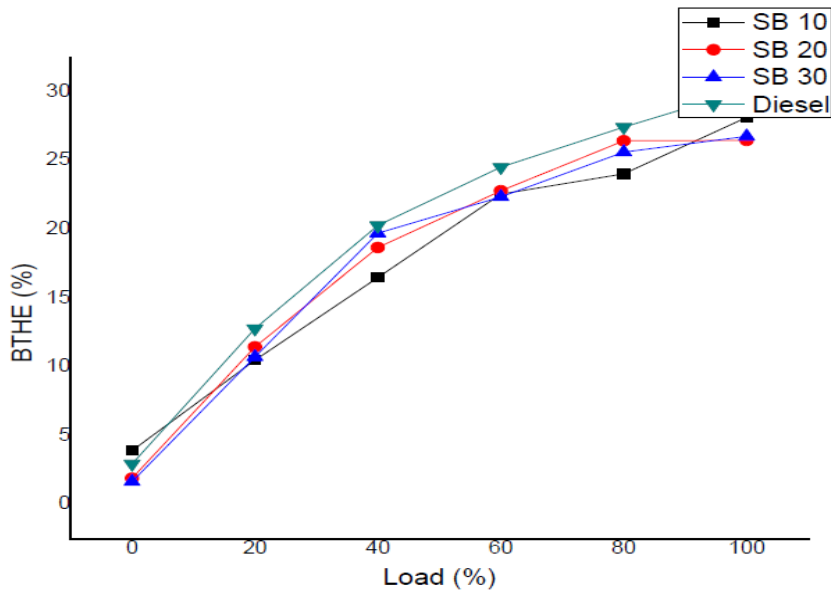


Fig 4.46 BTHE versus load for SOME at CR 18

4.5.3 Specific fuel consumption (sfc)

From the following graphs, it has been found that as the engine load increases, sfc decreases. This is because of increase in break power with fuel consumption. Another reason is improved combustion process due to high in-cylinder temperature which occurs on increasing engine load which further improves mixing and enhances atomisation process for better combustion. From the graphs it is clearly visible that at no load condition, sfc for SB30 was at a higher side than petro diesel (fig 4.48 and 4.49). Reason suggested is high density of SOME resulting in higher discharge of fuel. But at higher engine load, there is not much significant difference in sfc .

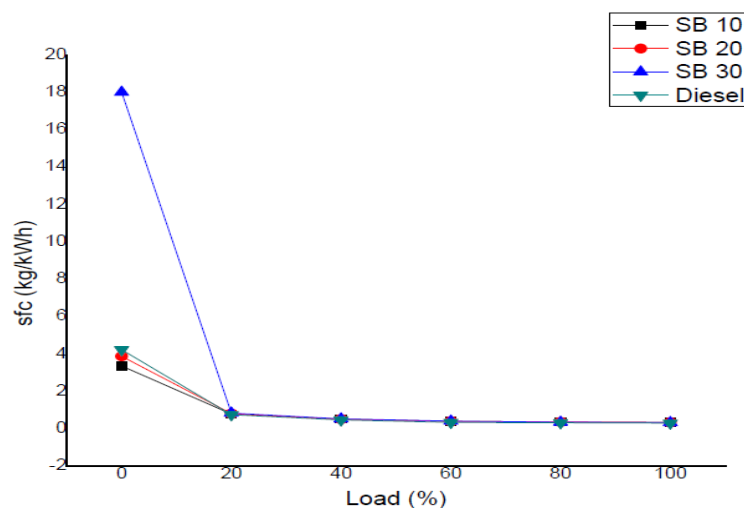


Fig 4.47 Sfc versus load for SOME at CR 14

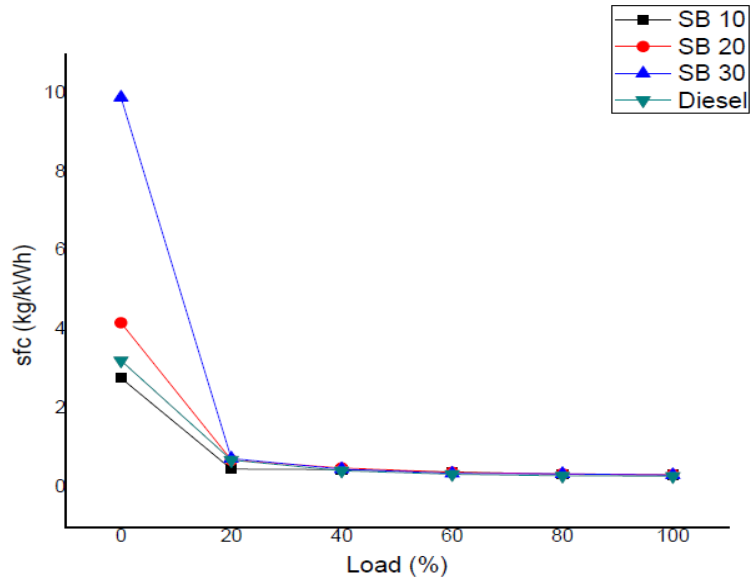


Fig 4.48 Sfc versus load for SOME at CR 16

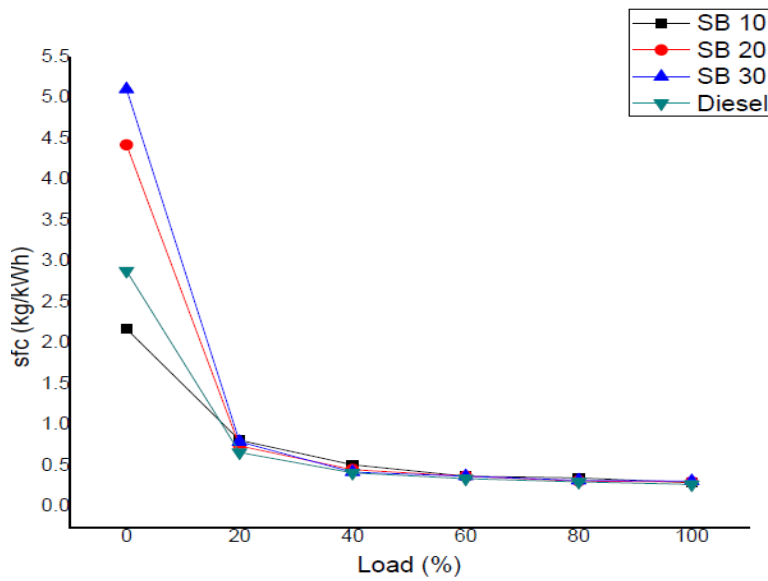


Fig 4.49 Sfc versus load for SOME at CR 18

4.5.4 Mechanical efficiency

From the following graphs, it is found that mechanical efficiency spurs up with higher amounts of blends at different loads. Maximum efficiency was obtained for BB 30 blend at full load (100%). For compression ratio 14, maximum efficiency obtained is 46.45 % at maximum load (100%) (Fig 4.50). At compression ratio 16, maximum efficiency obtained for BB 30 is 45.16%

at full load condition (fig 4.51). At compression ratio 18 maximum efficiency for BB 30 obtained is 47.12% at full load (fig 4.52). This increase in mechanical efficiency is attributed to improved spray quality and low flame temperature than petro diesel.

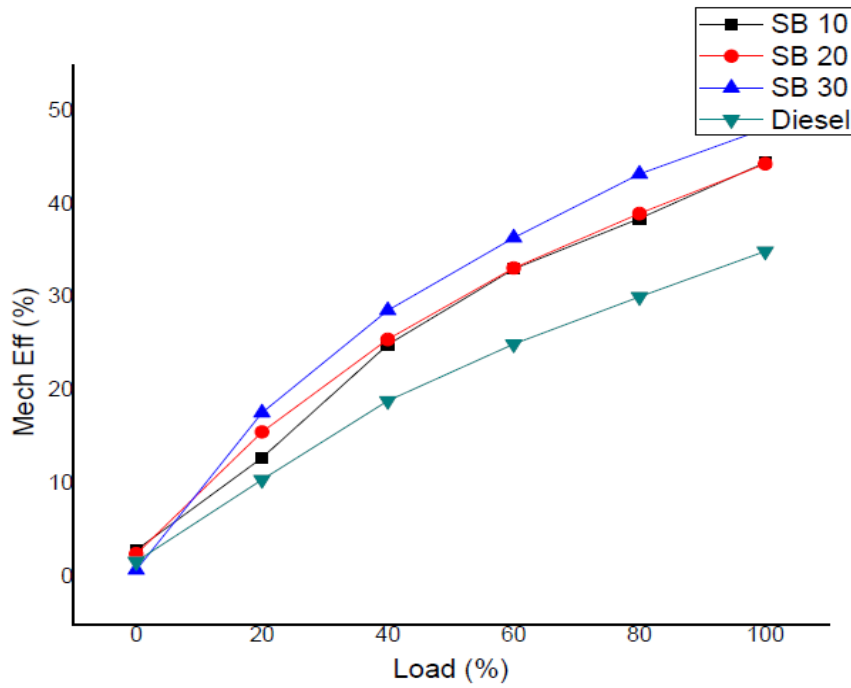


Fig 4.50 Mechanical efficiency versus load for SOME at CR 14

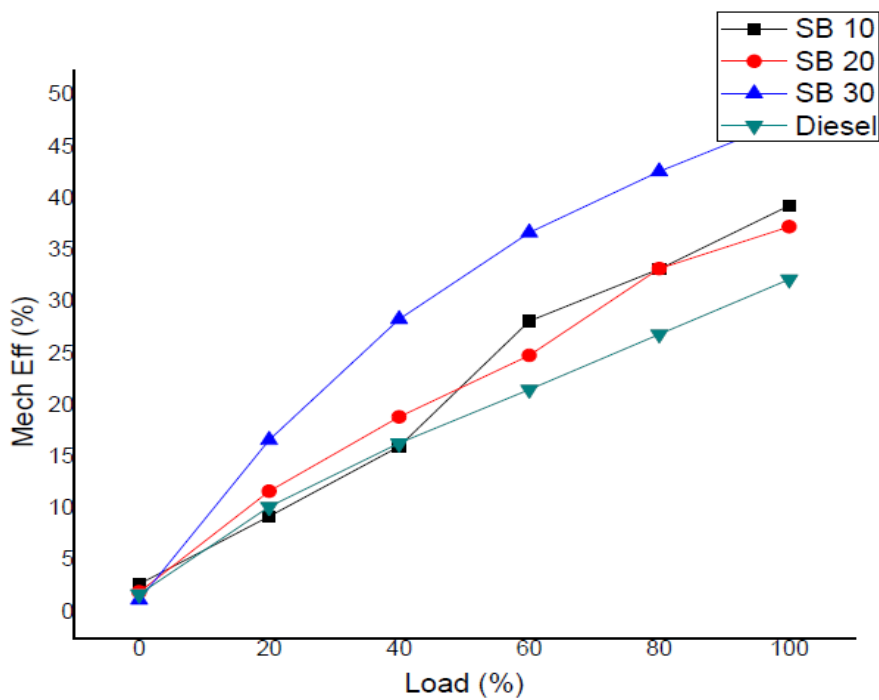


Fig 4.51 Mechanical efficiency versus load for SOME at CR 16

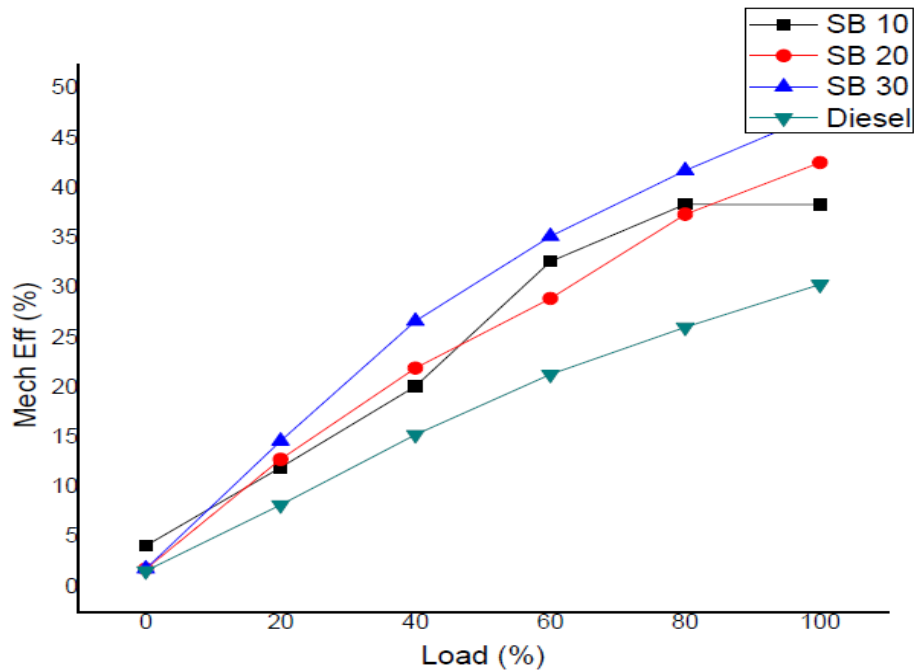


Fig 4.52 Mechanical efficiency versus load for SOME at CR 18

4.5.5 Exhaust gas temperature (EGT)

From the obtained graphs it is observed that blended fuel exhibits higher EGT. Reason being suggested is better combustion process by employing blended fuel in comparison to diesel. Better oxygen content available in blended fuel results in better combustion process. Another conceivable clarification for this pattern could be more fuel taken up by motor as motor load is expanded. Also, presence of high boiling point constituents in the blends results in combustion at higher temperature leading to higher EGT (fig 4.54 and 4.55).

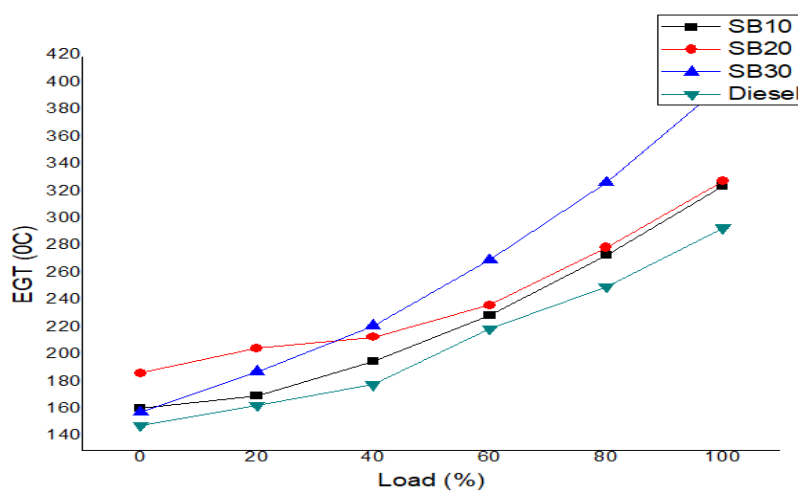


Fig 4.53 EGT versus load for SOME at CR 14

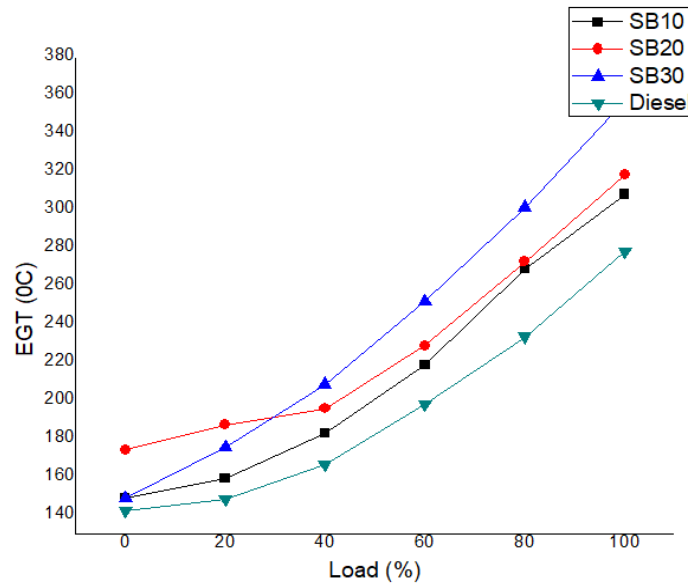


Fig 4.54 EGT versus load for SOME at CR 16

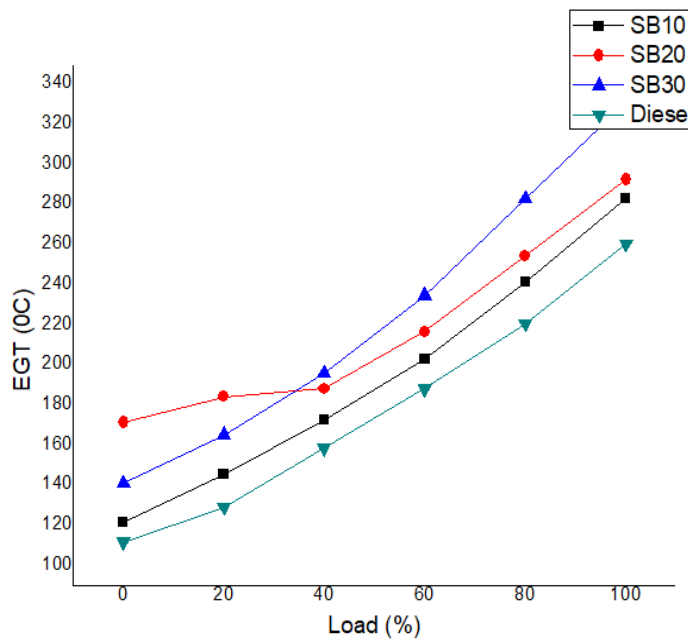


Fig 4.55 EGT versus load for SOME at CR 18

4.5.6 Carbon monoxides (CO)

From the following graphs, it is concluded that in relation to diesel, biodiesel blended fuel emits lower CO emissions (fig 4.57 and 4.58). Reason suggested is complete oxidation of CO to CO₂ due to availability of extra oxygen content present in the blended fuel. SB30 indicated

most elevated lessening in CO outflows took after by SB20 and SB10. For increasing load, CO emissions tends to increase but when the load reaches its zenith (100%) CO emissions decreases due to more complete combustion and presence of lower C/H ratio in biodiesel [54, 55]

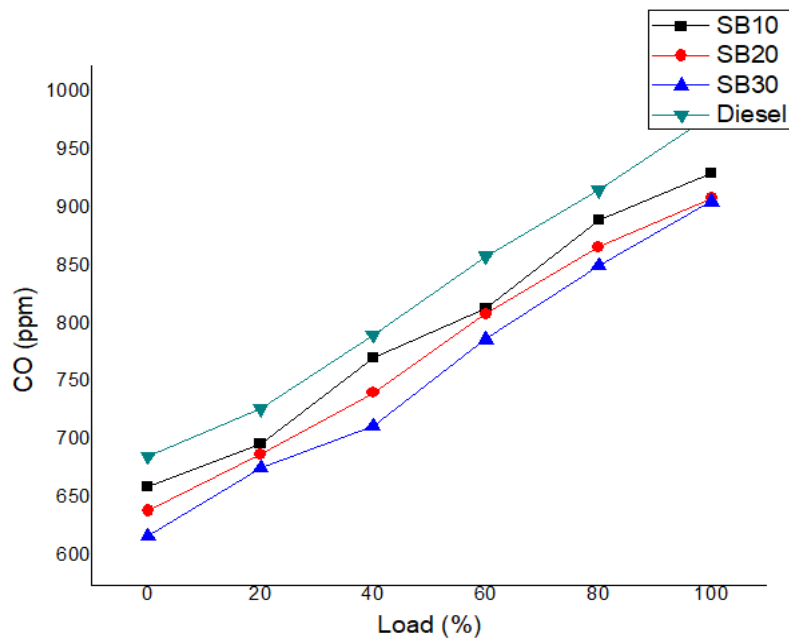


Fig 4.56 CO versus load for SOME at CR 14

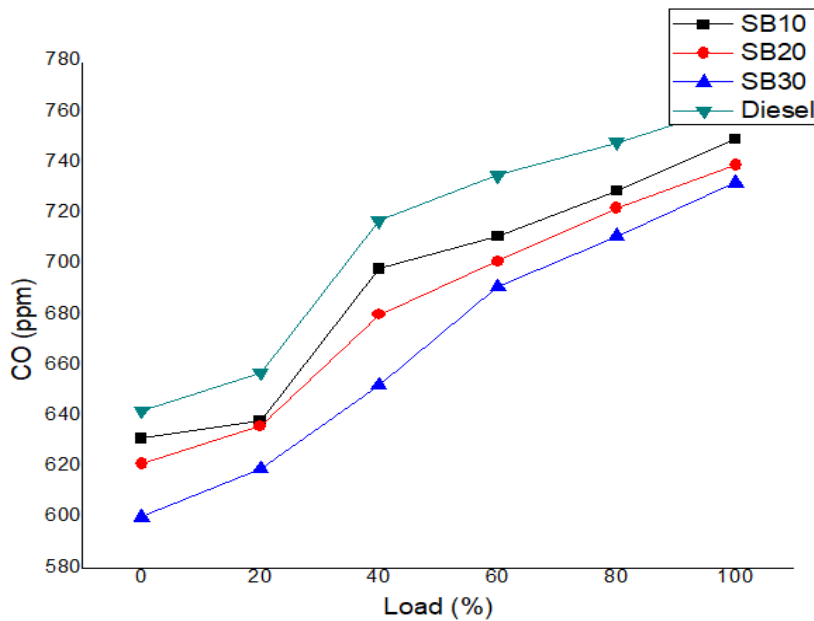


Fig 4.57 CO versus load for SOME at CR 16

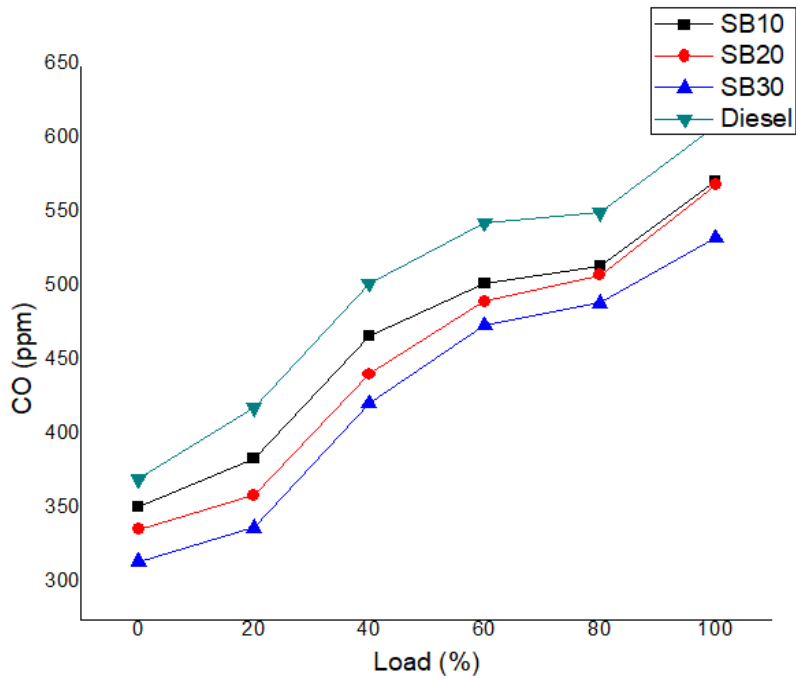


Fig 4.58 CO versus load for SOME at CR 18

4.5.7 Nitrogen oxides (NO_x)

From the graphs obtained it is observed that NO_x emissions of SOME with respect to diesel fuel decreases significantly (fig 4.59 and 4.60). This decrease is because of low heating value of sal oil resulting in reduction of peak combustion temperature. As the load increases, NO_x emissions rises because NO_x are temperature dependent. With increasing load, combustion temperature rises (fig 4.61). Hence, increasing trend was observed. Among all the blend test fuels, SB30 showed maximum NO_x emissions due to presence of more availability of oxygen content that supports combustion.

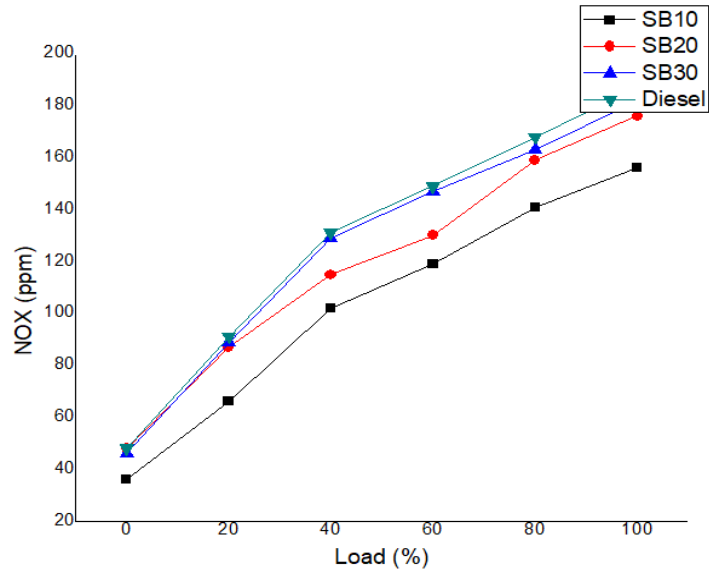


Fig 4.59 NO_x versus load for SOME at CR 14

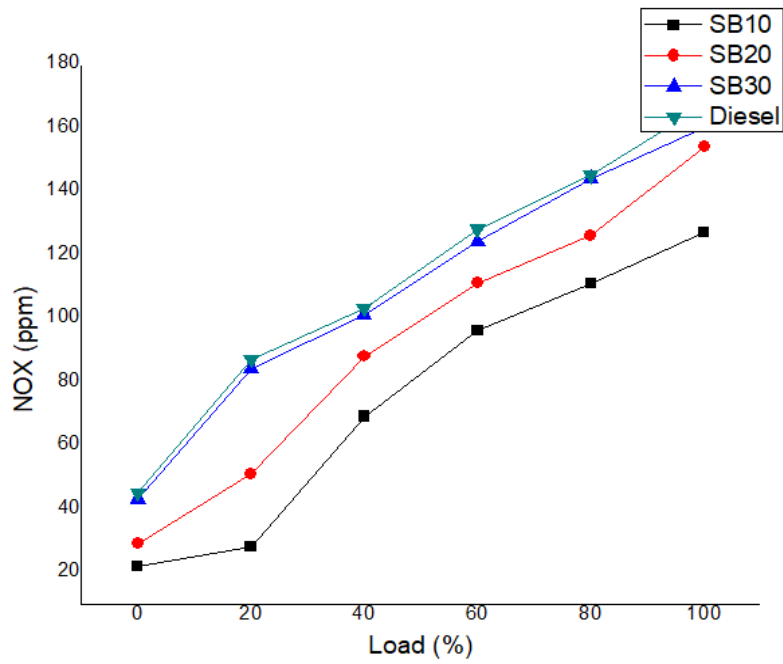


Fig 4.60 NO_x versus load for SOME at CR 16

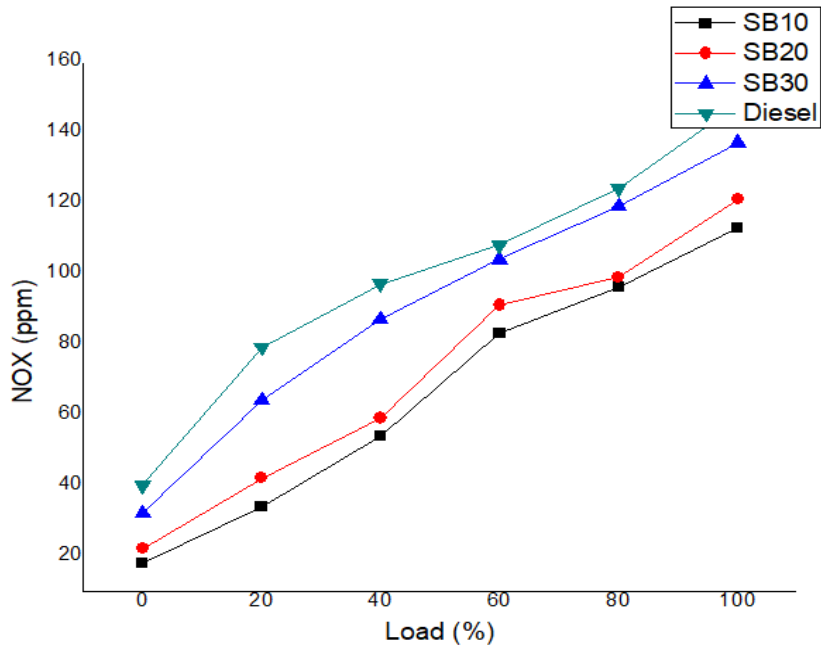


Fig 4.61 NO_x versus load for SOME at CR 18

4.5.8 Hydrocarbons (HC)

From the graphs obtained, it is found that in comparison to petro diesel, HC emissions for blended fuel reduced. This is mainly because of net oxygen content and property like cetane number of the SOME [56, 57]. Higher cetane number of biodiesel brings about shorter start defer period causing appropriate burning procedure. At higher blends, HC tends to rise because of more injection of fuel per hour injected in the engine and lesser availability to support combustion process resulting in higher HC emissions (fig 4.63 and 4.64). At full load condition, SB20 exhibited highest HC emission among all the test fuels.

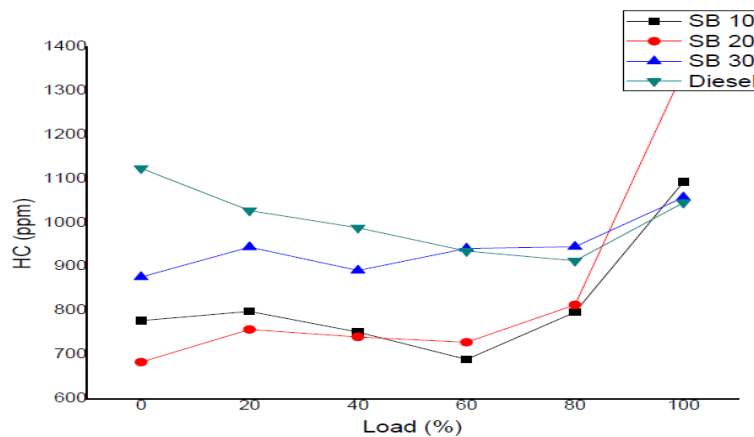


Fig 4.62 HC versus load for SOME at CR 14

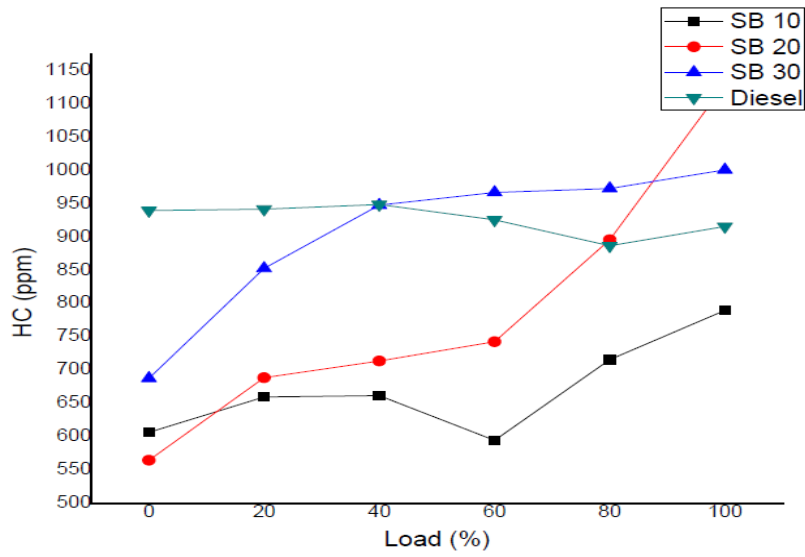


Fig 4.63 HC versus load for SOME at CR 16

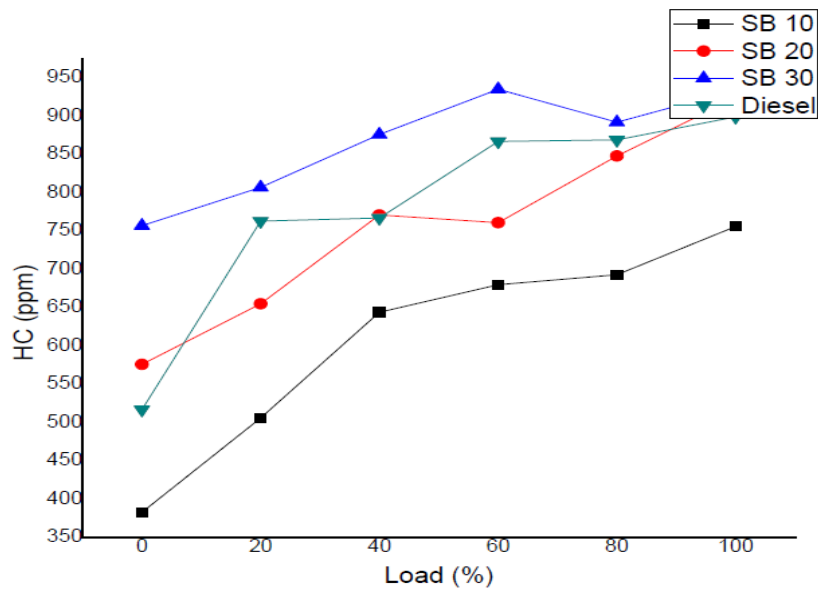


Fig 4.64 HC versus load for SOME at CR 18

4.6 Comparison of performance and emission characteristics of babassu and sal mixed fuel comparative to petro diesel

4.6.1 Engine performance

VCR engine is made to run at three different compression ratios. Three different blended test fuels are prepared for each of the biodiesel and then engine was again run at constant rpm at zero kg load which goes maximum to 10kg load. Following observations are made from this.

4.6.1.1 Brake power

From the experimentations, no significant change was observed in the blended test fuels of both oil samples meaning test fuel showed almost similar trend when diesel was employed as testing fuel. At full load condition operated at compression ratio 18, BB30 exhibited improved BP in relation to all other blended fuels. This is due to presence of high oxygen content contained in the blend that supports combustions resulting in enhanced power delivery. When operated at compression ratio 16, no significant variation was observed in the BP for all test fuels. (Fig 4.65 and Fig 4.66)

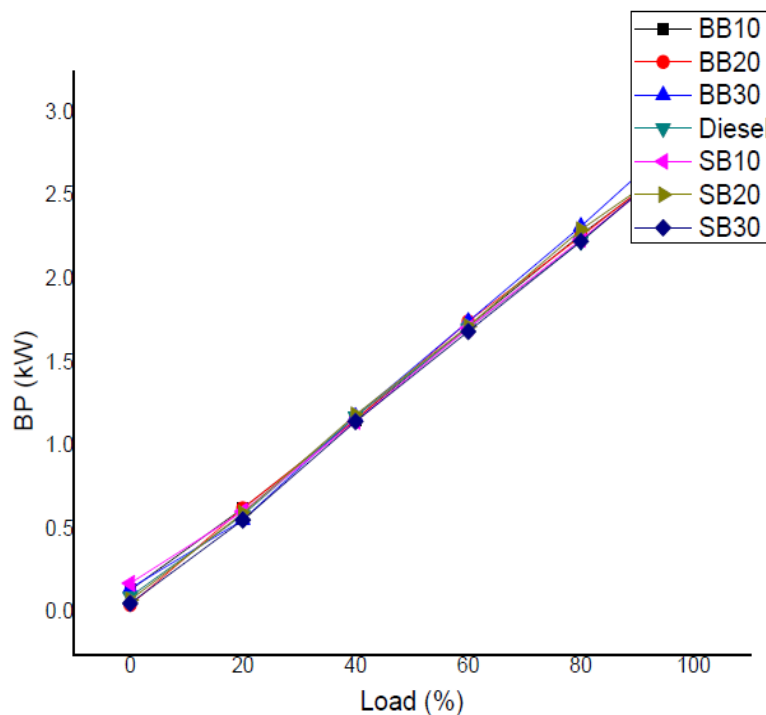


Fig 4.65 Variation of BP with load at CR 18

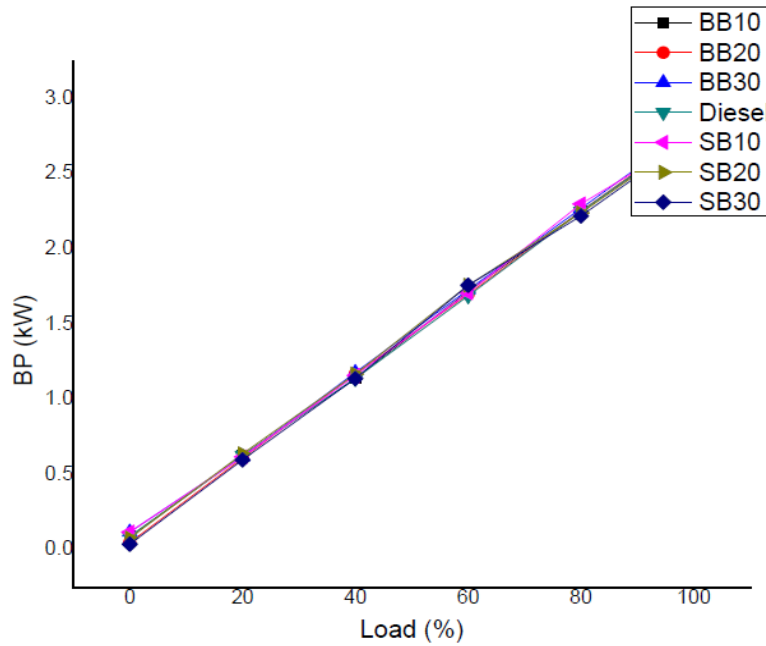


Fig 4.66 Variation of BP with load at CR 16

4.6.1.2 Brake thermal efficiency

From the experimentations, it has been investigated that for all test fuels, brake thermal increases at higher engine load. Reason suggested is lower amount of heat loss incurred at higher loads and higher output is obtained. It was also elucidated that relative to diesel fuel, brake thermal efficiency decreases for all other test fuels. This is possibly because of lower calorific value of SOME and BOME, poor spray characteristics and increased fuel consumption. It was also reported that SOME blended test fuels exhibits higher brake power as compared to BOME blended fuel. (Fig 4.67 and fig 4.68)

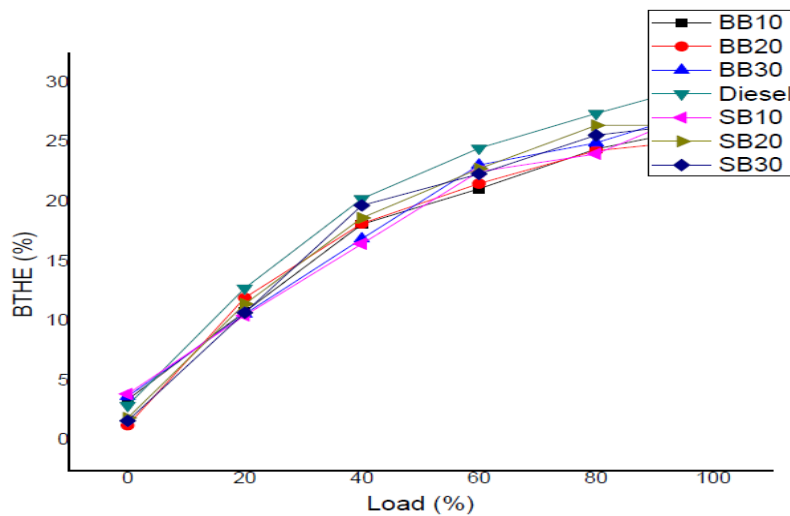


Fig 4.67 Variation of BTHE with load (CR18)

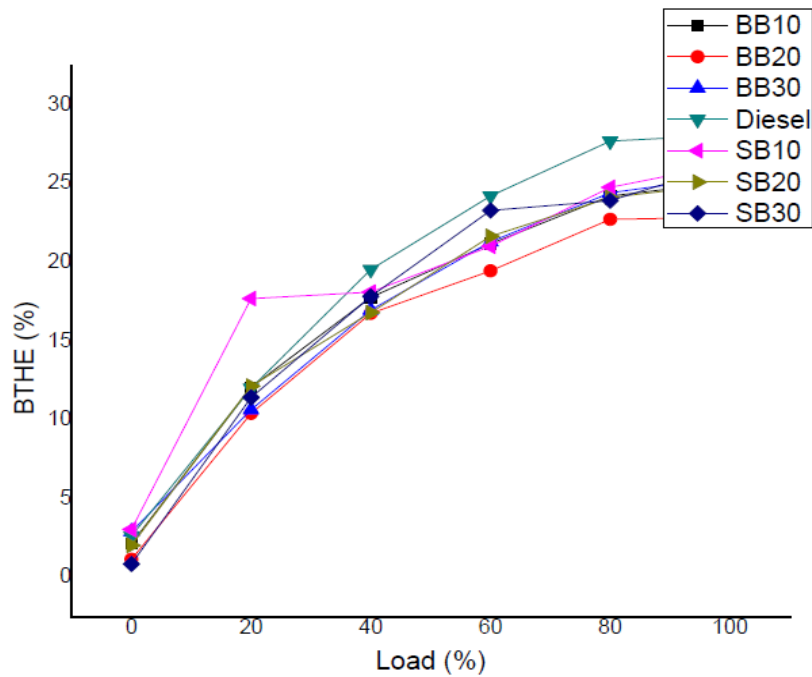


Fig 4.68 Variation of BTHE with load (CR16)

4.6.1.3 Mechanical Efficiency

From the experiments it was found that mechanical efficiency increases at higher engine loads, Fig 8. But there was not much difference in the efficiency obtained by blended fuels as compared to diesel. Chemical properties of biodiesel are the chief causes of it. It has also been envisaged that among all the samples, SB30 showed greatest variation with respect to diesel Fig. This is because of sal oil biodiesel has more calorific value as compared to babassu oil biodiesel and also because of low flame temperature as compared to diesel. Moreover, at SB30, there is high oxygen content leading to more efficient combustion process. (Fig 4.69 and Fig 4.70)

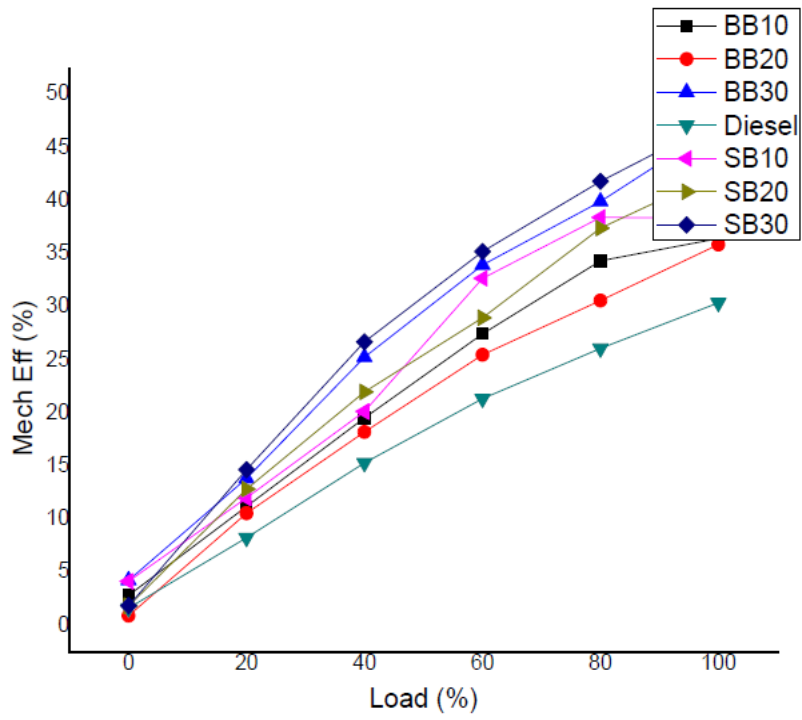


Fig 4.69 Mech Eff versus load at CR 18

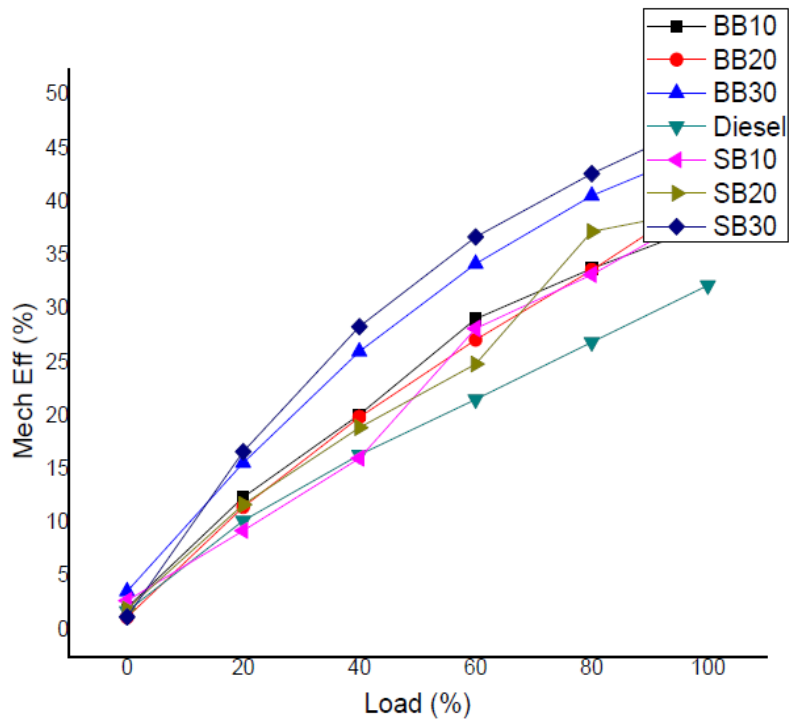


Fig 4.70 Mech Eff versus load at CR 16

4.6.1.4 Specific fuel consumption

From the experiments conducted it has been noted down that power yield has circuitous connection to particular fuel utilization. There is an exchange off amongst sfc and power output. But from the Fig 4.71 and Fig 4.72 it can be inferred that specific fuel consumption for blended fuel is on higher side as compared diesel. It is observed that at BB20 has higher sfc owing to its lower GCV as compared to diesel fuel. Insignificant rise in sfc for blended fuel was observed as compared to petro diesel.

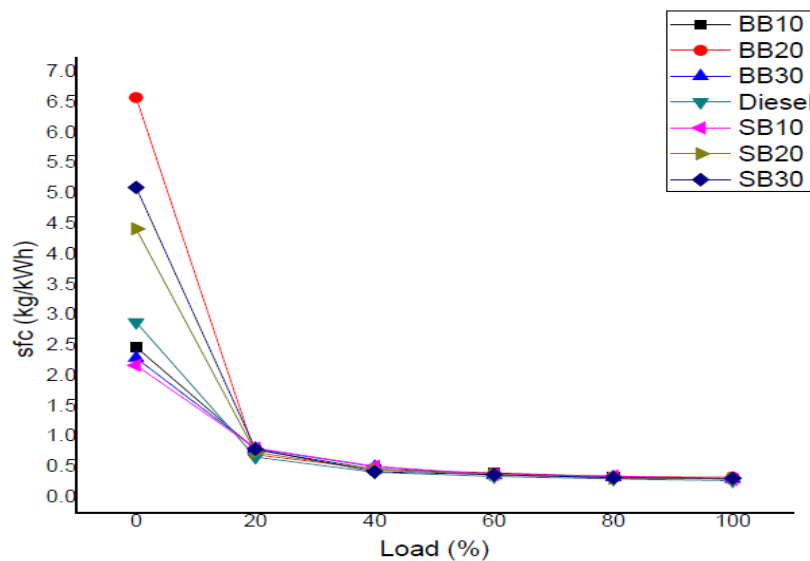


Fig 4.71 Sfc versus load at CR 18

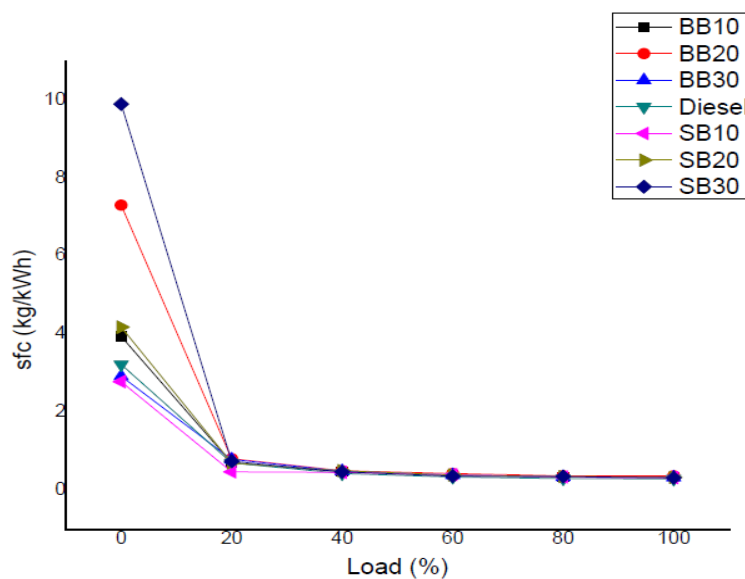


Fig 4.72 Sfc versus load at CR 16

4.6.1.5 Exhaust Gas Temperature

From the experimental analysis, it was found that for blended fuels, EGT was relatively higher than diesel fuel. At higher loads, EGT showed increasing trend. Reason being suggested is more complete combustion taking place which results in elevated temperatures at higher loads. From the fig 4.73 and fig4.74 it is observed that at no load condition, BB20 has higher EGT in relation to other tested fuels. At greatest load condition, SB30 exhibited higher EGT when contrasted with other tested fuels. This is because of higher calorific value of sal biodiesel than babassu biodiesel and at higher blends there is more oxygen availability in blended fuel which supports combustion process.

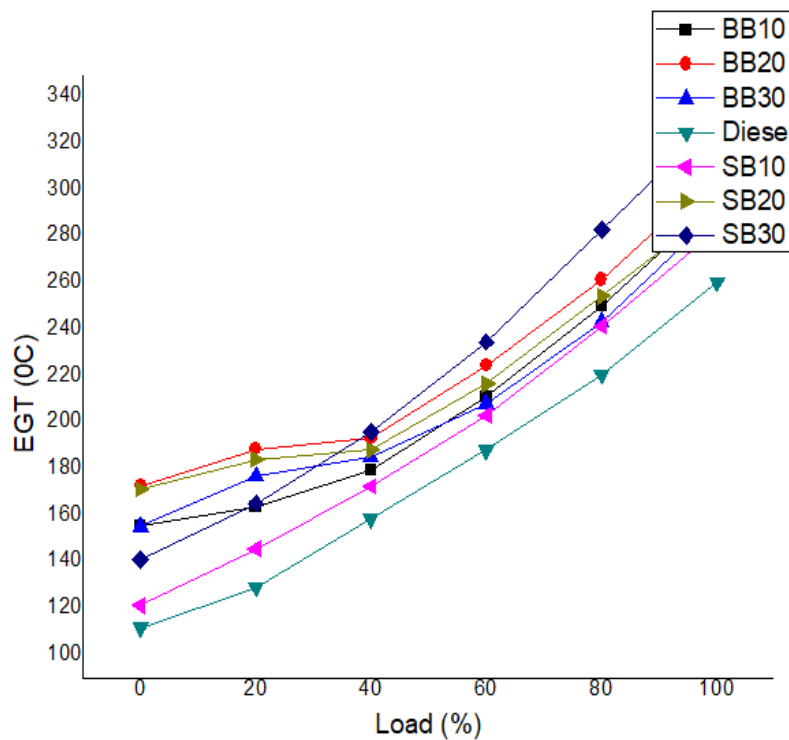


Fig 4.73 EGT versus load at CR 18

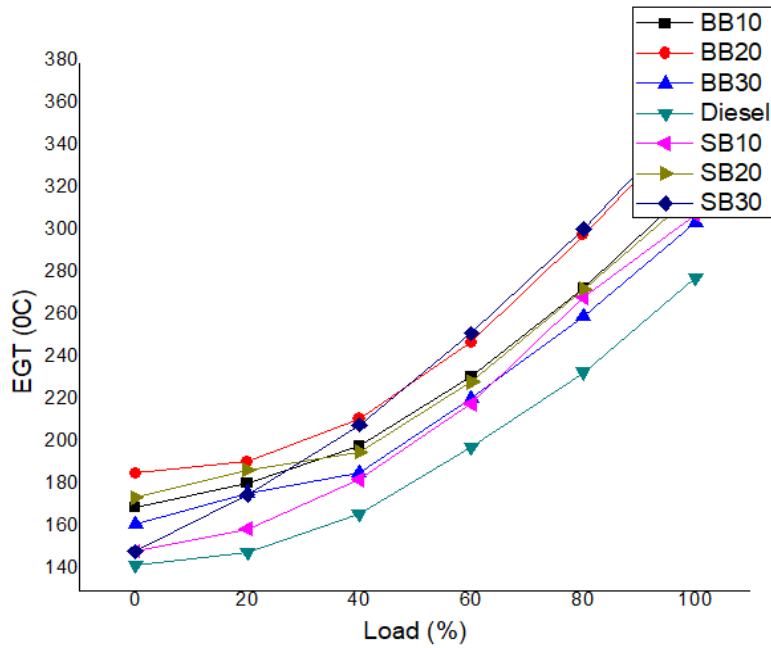


Fig 4.74 EGT versus load at CR 16

4.6.1.6 Carbon Monoxide

It was found after the experimentations that CO emissions trimmed down at all compression ratios. Reason being suggested is proper oxidation. Some of the CO might have taken up oxygen present in biodiesel chain thus converting some CO to CO₂. At higher load, CO emissions rises up. This is due to incomplete combustion of fuel, less combustion process period, lack of oxygen content at higher loads. Another possible explanation for such trend is biodiesel viscosity that results in elevated CO emissions. From the experiments, another observation was among all the biodiesel blends, SB30 showed lower emissions as compared to other tested fuels. This is because of higher CV of sal biodiesel as compared to babassu biodiesel. Fig 4.75 and Fig 4.76

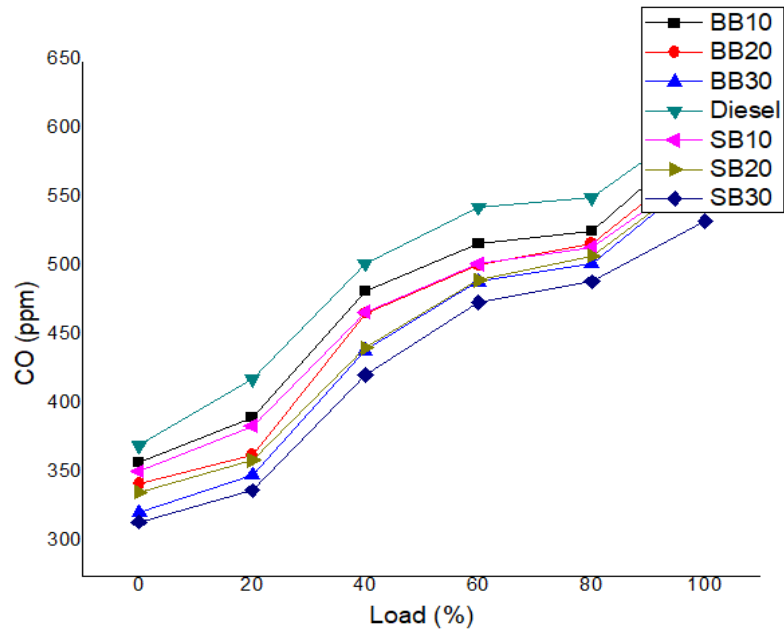


Fig 4.75 CO versus load at CR 18

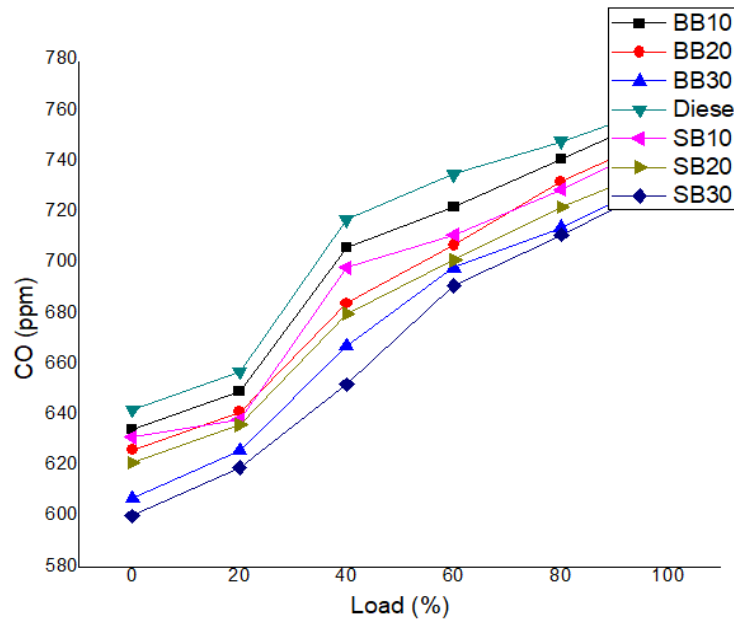


Fig 4.76 CO versus load at CR 16

4.6.1.7 Hydrocarbons

It was found that HC shot up at higher engine loads because of availability of relatively lower amount of oxygen for carrying out combustion process. Moreover due high value of Cetane

Number there is shorter ignition delay causing reduction of HC emissions. Another aspect that was noted down was that among all the test fuels, SB20 demonstrated fewer HC emissions as compared to babassu blends. This is due to the fact that sal blends have higher CV as compared to babassu blends resulting in proper combustion process thereby reducing HC emissions. Fig 4.77 and Fig 4.78.

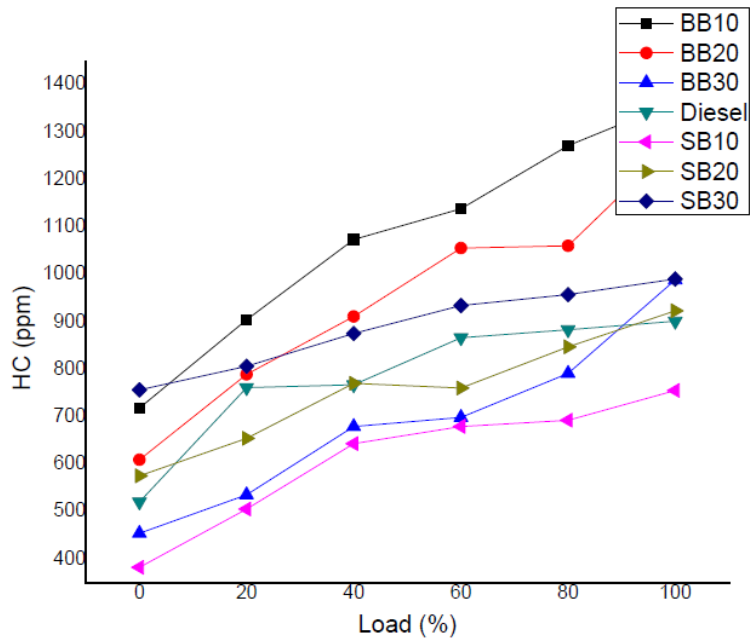


Fig 4.77 HC versus load at CR 18

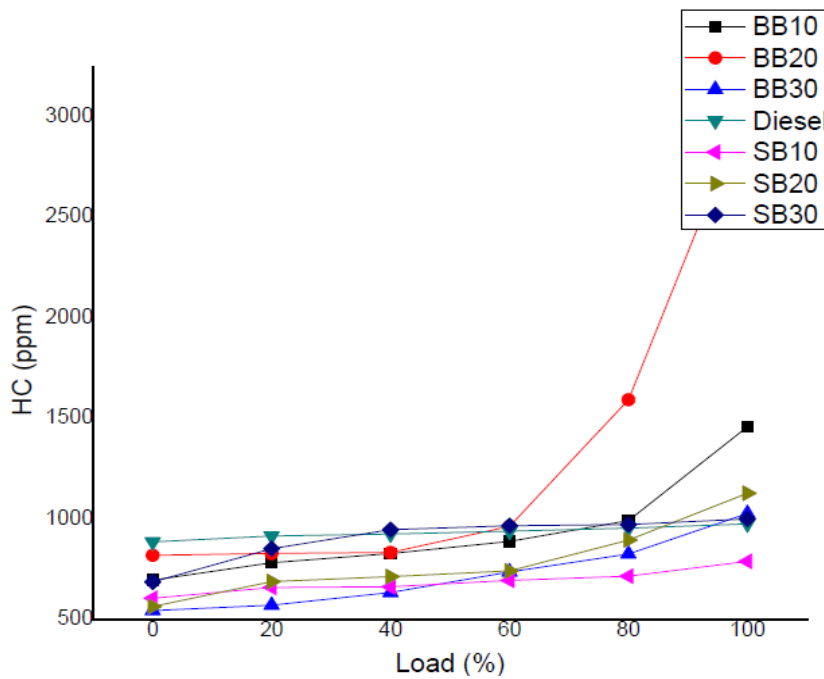


Fig 4.78 HC versus load at CR 16

4.6.1.8 Oxides of Nitrogen

It is found that relative to diesel, NO_x emissions for all the blends reduced. This is because of high cetane number and small value of flash point of blended fuel which results in lower localised gas temperatures. Hence reduction in NO_x was observed. But as the load increases, cylinder wall temperature rises up resulting in better combustion process. NO_x are highly dependent upon temperature. So, when combustion takes place, EGT rises, and NO_x also increases. From all the blended fuels taken up for experimentation, it was found that for SB30 has higher NO_x emissions as compared to other blended fuels and BB10 has lower emissions. This is because of higher CV of sal blends which results in better localised gas temperatures due to better combustion rate as compared to babassu blends which has comparatively lower CV. Fig 4.79 and Fig 4.80.

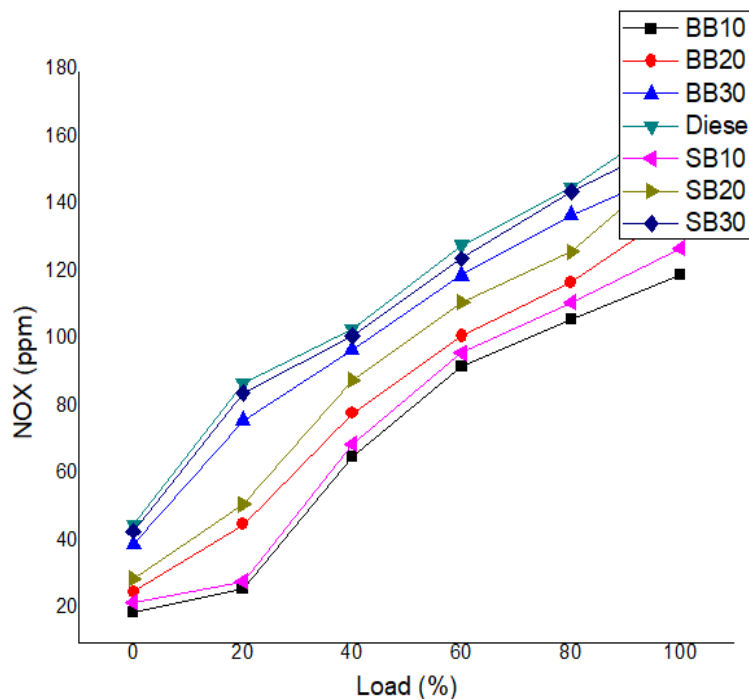


Fig 4.79 NO_x versus load at CR 16

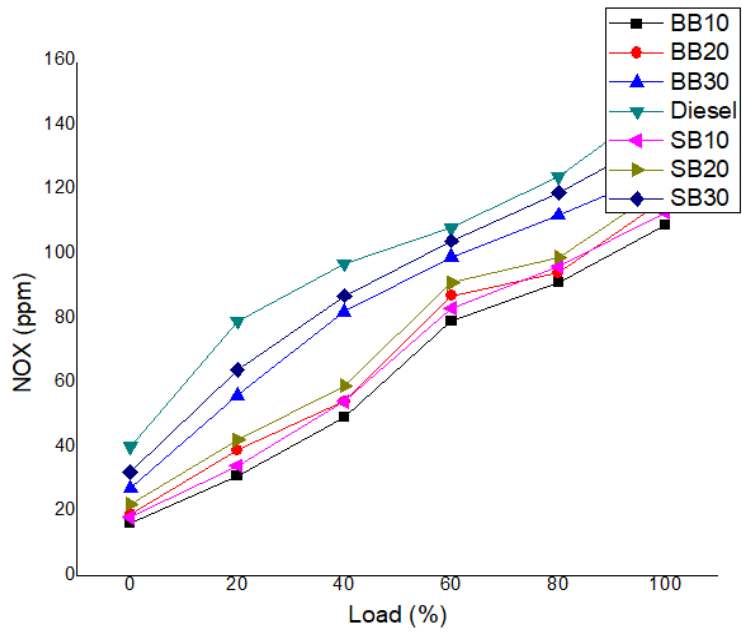


Fig 4.80 NO_x versus load at CR 18

Chapter 5

Conclusions and future scope

5.1 Conclusions

Optimisation of methyl ester obtained from babassu and sal oil was done on the basis of viscosity and yield of methyl esters. Soluble base catalysed transesterification responses has ideal molar proportion shifting from 6:1 to 8:1. Three distinct mixes to be specific 10%, 20% and 30% for each oil were readied and execution and outflow attributes of a VCR engine was noted down. Following things can be concluded from experiments.

- Optimised parameters for BOME production are 6:1 molar ratio, 0.5g KOH catalyst amount, 75 minutes activity time and 60 °C reaction temperature and the yield and viscosity at optimised parameters are 98.18% and 1.98 cSt respectively.
- Optimised parameters for SOME production are 8:1 methanol to oil ratio, 1g KOH catalyst, 75 minutes reaction time at 60 °C reaction temperature. Yield and viscosity at optimised parameters are 96.39% and 2.779 cSt respectively.
- BP for both blends were more or less same.
- BB30 exhibits higher mechanical efficiency as compared to diesel, BB20 and BB10.
- For all biodiesel blends, there was significant increase in EGT with B30 and SB30 showing maximum increase with respect to diesel fuel.
- As far as emission parts are concerned, there was significant lowering down in CO and NO_x emissions when either babassu or sal oil blends were used.
- On comparison between babassu blends and sal blends (BOME and SOME), SB30 showed higher BTHE as compared to babassu blends.
- SB30 exhibits higher mechanical efficiency as compared to other blends.
- Among all the test samples, BB10 showed least amount of NO_x emissions.
- Overall performance of engine was better when fuelled with SOME blended fuel.

5.2 Future scope

Biodiesel is a promising source to lessen reliance on the exhausting vitality sources yet cost of generation of biodiesel relies on the accessibility of feedstock. In spite of jatropha and karanja that is already suggested by Planning Commission, some other non-edible sources can also be

used to harness their ability for biodiesel production. Some other noteworthy points are mentioned below:

- Quality seeding for non-edible oilseeds needs to be promoted to reduce dependence on edible sources.
- Sources that results in lower NO_x emissions like babassu and sal that are non-edible, needs to be developed. Such sources would help in dependence on EGR that would provide cost effective solutions.
- More work can be done on catalyst (renewable in nature) that would enhance the biodiesel yield. Bio ethanol produced from the sources can also be an alternative to reduce diesel dependence.
- Govt of India has set an indicative target of 20% blend for both biodiesel and biofuel. Research needs to be done for complete shift of diesel to biodiesel.
- Long hour tests of biodiesel blended fuels can be done on single or multi cylindered engine to check if they are compatible with the engine.

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