Experimental Investigation on Effect of Kusum and Safflower Oil Methyl Ester in a VCR Engine

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Submitted By

NITIN KUMAR
Registration No.: 801583017

Under The Guidance of

Dr. S. K. MOHAPATRA	**Dr. S. S. RAGIT**
(Senior Professor & Head)	(Assistant Professor)

DEPARTMENT OF MECHANICAL ENGINEERING

THAPAR UNIVERSITY, PATIALA

JUNE, 2017

CERTIFICATE

I, **Nitin Kumar**, declare that this thesis report entitled, "**Experimental Investigation on Effect of Kusum and Safflower Oil Methyl Ester in a VCR Engine**" submitted towards fulfillment of the requirements for the award of Master's Degree in Thermal Engineering, in Mechanical Engineering Department of Thapar University, Patiala, is entirely my own work. This document has not been submitted for any degree in any other institution.

Nitin kumar

Date: **9th June, 2017**
Place: **Patiala**

Nitin Kumar
801583017
TU, Patiala

This is to certify that the above statement made by the candidate is correct and true to the best of my knowledge.

12/6/17

Dr. S. K. Mohapatra
Senior Professor & Head, MED
TU, Patiala-147004

S.S. Ragit

Dr. S. S. Ragit
Assistant Professor, MED
TU, Patiala-147004

Dedicated to

My parents

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Nitin Kumar

Nitin Kumar
801583017
TU, Patiala

Abstract

Due to continuous increase in the dependency on fossil fuels and hiking its price because of fast depletion of petroleum resource have promoted to the shift toward green energy sources such as alternative renewable and sustainable fuel. Biodiesel has been recognized as clean and potential renewable fuel which is obtained from biomass resources and animal fats. The aim of this experimental investigation is to optimize biodiesel production from safflower and kusum seed oil followed by transesterification process. As per consideration of maximum biodiesel yield, the optimum parameters were 4:1 molar ratio, 1.5% KOH catalyst concentration, 75 minutes reaction time and 6:1 molar ratio, 1% KOH catalyst concentration, 60 minutes reaction time followed by safflower and kusum oil methyl ester production respectively. The yield of safflower and kusum oil methyl ester corresponding to optimized process parameters were 97.07% and 90.34% respectively. Three types of blended fuels B10, B20 and B30 of each biodiesel have been studied and all tests were carried out in variable compression ratio (VCR) engine at constant speed 1500 rpm, compression ratio 17:1 under different load conditions. The various performance, emission and combustion characteristics like brake power (BP), brake thermal efficiency (BThE), brake specific fuel consumption (BSFC), mechanical efficiency (MEff), carbon monoxide (CO), hydrocarbon (HC), nitrogen oxide (NOx), exhaust gas temperature (EGT), peak cylinder pressure and heat release rate (HRR) were evaluated. It was observed that the performance of all blended fuels of safflower oil biodiesel almost same to the diesel fuel and B20 blend fuel of kusum oil biodiesel showed better performance among the all tested fuels KB10, KB30 and standard diesel. The emissions of CO, HC decreased by increasing percentage proportion of biodiesel in blend fuel and apart from that NOx, EGT were increased. It was concluded that by comparing the SOME and KOME blend fuels, the overall performance of KOME blend fuels have been noticed better than that of SOME blend fuels.

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Nomenclature

SO	Safflower oil
KO	Kusum oil
SOME	Safflower oil methyl ester
KOME	Kusum oil methyl ester
BP	Brake power
BSFC	Brake specific fuel consumption
BTE	Brake thermal efficiency
MEff	Mechanical efficiency
CO	Carbon monoxide
HC	Hydrocarbon
NOx	Nitrogen oxide
EGT	Exhaust gas temperature
VCR	Variable compression ratio
FFA	Free fatty acid
cSt	Centistokes
SB10	Blend of 10% SOME & 90% diesel fuel
SB20	Blend of 20% SOME & 80% diesel fuel
SB30	Blend of 30% SOME & 70% diesel fuel
KB10	Blend of 10% KOME & 90% diesel fuel
KB20	Blend of 20% KOME & 80% diesel fuel
KB30	Blend of 30% KOME & 70% diesel fuel
HRR	Heat release rate
HBP	Heat Eq. to BP
HJW	Heat Eq. to cooling jw
HGas	Heat Eq. to exhaust gases
HRad	Unaccounted losses

Chapter 1

Introduction

1.1 Biodiesel as alternative fuel

As the vast and rapid industrialization is taking place and more sophisticated instruments are available nowadays, the requirement of energy is increasing very fast and fossil fuels are the primary source for fulfilling the energy demand till date. Continuous depletion of fossil fuels and hiking of its price have become a serious global issue [1, 2]. Some new kind of energy resources including renewable energy has been taken into account of the researcher to resolve this problem [3]. Biodiesel is the second generation fuel which can replace one of the primary fossil fuels i.e. petro diesel [4, 5]. It has become an enchanting fuel due to its eco-friendly nature. It is obtained from biomass resources [6]. Vegetable oils are used as the main resource of biodiesel. Many studies on these crops are taking place to develop new species of productive plants with the high yield of oil and faster growth. Some breeds of plants which produce non-edible vegetable oils are becoming the targets these days for biodiesel production. Biofuel project has been launched in 200 districts of 18 states in India as per planning commission of India [7, 8, 9]. Nowadays, fossil fuels like gasoline, natural gas and petroleum-based diesel are mainly used for fulfilling the energy demand of the world. Such resources of fossil fuels are gradually getting deficient to meet the future energy requirements and challenges of rapid development of technologies as well as the growth of population [10]. The continuous reduction of supply of fossil fuels has promoted the efforts to motivate the implementation of renewable energy sources such as bio-based fuel resources. As replacements for fossil fuels, various types of bio-based fuel have been searched such as vegetable oils (raw, processed or used), methyl esters from oil and liquid fuels from biomass etc. [11]. In this century, various researchers have accelerated the study on alternative energy and renewable fuel. Biodiesel produced from vegetable oils and its derivatives have been identified to be major substitutes for petro diesel fuel. Direct application of vegetable oils in engine arises some problems because of its high viscosity and low volatility. It has been proposed that transesterification process is one of the promising methods to convert vegetable oil to fatty acid alkyl ester which can be used in existing diesel fuel based engines [12, 13]. The factors which affect the transesterification process are methanol to oil molar ratio, catalyst concentration, reaction time, reaction temperature and free fatty acid contents [14, 15]. Apart from transesterification pyrolysis of bio oil of safflower to produce biodiesel has been reported [16]. It was observed that biofuels derived from vegetables are eco-friendly [51]. Although the largest safflower producing country is India, only little amounts safflower oil is exported from here. USA and Mexico are the biggest producers of safflower in term of world trade which are followed by Australia and Argentina [17]. Biodiesel derive from kusum (*Schleichera oleosa* sp.) oil can be one of the potential ones which is available abundantly in India. Kusum oil is non-edible and bitter in taste due to the presence of toxic cyanogenic compounds [55, 19] and is used for various applications like hairdressing, medicines and soap manufacturing [20]. In India, almost 66,000 tons of kusum oil is produced per year but only 4000 to 5000 tons of it is used [21, 22].

1.2 Different methods of production of biodiesel

1.2.1 Pyrolysis (Thermal cracking)

The method in which one form of substance converts into another form by heating with the help of a catalyst in the absence of oxygen or air is known as pyrolysis or thermal cracking [23]. The fuel which produced by thermal cracking has approximately same chemical composition to standard diesel fuel [24]. This process can be categorized into three parts such as conventional, fast and flash pyrolysis by mean of operating conditions. Many studies have been done on thermal cracking of vegetable oils and its cakes to developed suitable renewable fuel for diesel engine.

1.2.2 Micro-emulsification

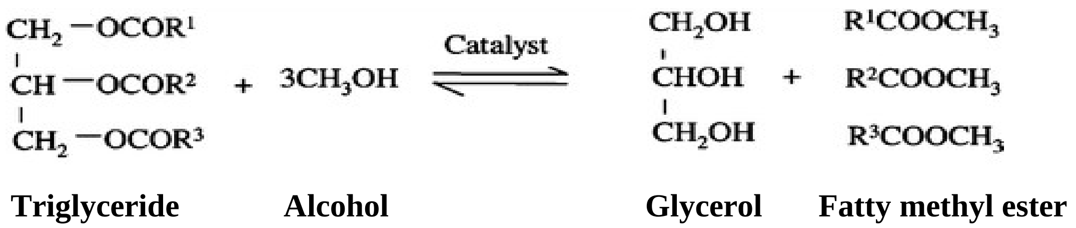
Micro-emulsification is the different approach to minimize the vegetable oil viscosity. Micro-emulsions are type of stable isotropic fluids with three distinct sections: an oil phase, an aqueous phase and a surfactant. The salts or other ingredients may be available in aqueous phase and the oil may contain different hydrocarbons and olefins mixture. This ternary phase can improve the characteristics of spray via explosive vaporization of the low-boiling-point constituents in the micelles. All micro-emulsions with butanol, hexanol and octanol reach the extreme viscosity constraint for diesel engines [25, 26].

1.2.3 Dilution

Direct application of vegetable oils has not been considered to be acceptable and suitable fuel for diesel engines. The high acid composition, high free fatty acid content, high viscosity as well as gum formation due to oxidation and polymerization during storage and combustion, carbon deposits and lubricating oil thickening are some problems which are encountered by the use of its blends in the DI engines.

1.2.4 Transesterification

Transesterification is a process used for minimize the viscosity of vegetable oils or animal fats and ester production. In transesterification process, the vegetable oil or animal fat is reaction with alcohol in the presence of catalyst to form esters and byproduct glycerol. The function of catalyst is to accelerated the reaction rate and improve ester yield. Due to high reversible rate of transesterification reaction, extra alcohol has been used to shift the equilibrium to higher ester yield side. The below Eq. (1.1) showed the triglyceride reaction with alcohol.



(1.1)

Different types of alcohol could have been used in this process such as methanol, ethanol, propanol, butanol and amyl alcohol. Among all types of alcohol, methanol is most widely used due to its physical, chemical advantage and low cost. Due to its chemical advantage, it is easy to react with triglycerides and catalysts such as NaOH, KOH are easily diffused in it. Generally minimum 3:1 methanol to oil molar ratio (alcohol to triglyceride) is needed for completion of transesterification process. In practice, higher molar ratio requires to be shift the equilibrium toward maximum product side. Types of catalysts like alkalis (NaOH, KOH, $NaOCH_3$, $KOCH_3$), acids (Sulfuric acid, sulfonic acids and hydrochloric acid), or enzymes have been used in transesterification reaction [59]. Commercially, the alkaline transesterification process is most widely used than that of acid-catalyzed transesterification depends on free fatty acid content of oil. Higher cloud point, pour point and cetane number have been obtained by using this process. The only limitation of this process, it is applied with oils which have less free fatty acid content. This process is generally preferred in comparison of above all discussed process for biodiesel production.

1.3 Advantages and disadvantages of biodiesel

Advantages

- Biodiesel is biodegradable, non-toxic, no sulfur content and aromatic content.
- Use of biodiesel reported less emissions generation in comparison to petro-diesel.
- Lubricating properties of biodiesel is better compared to standard petro-diesel which can improve engine’s life.
- It has shorter ignition delay compared to standard diesel.

Disadvantages

- It is expensive in comparison to standard petro-diesel.
- Biodiesel has significantly higher viscosity and low energy content compared to standard petro-diesel.
- Biodiesel is responsible for higher NOx emission compared to petro-diesel.

1.4 Objectives of present work

The proposed work has been conducted with biodiesel obtained from safflower oil and kusum oil with the following objectives.

1. Optimization of biodiesel production derived from safflower oil and kusum oil by transesterification process.
2. Determination of physicochemical properties of optimized biodiesel.
3. Evaluation of performance parameters such brake power, brake thermal efficiency, brake specific fuel consumption, mechanical efficiency of safflower biodiesel and kusum biodiesel blend fuels and comparison with petro diesel.
4. Evaluation and comparison of various emission characteristics of safflower biodiesel and kusum biodiesel blend fuels with petro diesel.
5. Comparative study of SOME and KOME blend fuels with diesel fuel.

Chapter 2

Literature Review

2.1 Literature review of previous work

Various studies on biofuel have been carried out by many researchers in the past. In this chapter previous published written works were surveyed, which establishes framework and reason for further work in this investigation. This gives a better comprehension about the topic. The focus of investigations has mostly been on biofuel and its application in CI engine.

Alptekin [28] et al. examined the injection, combustion and emission characteristics of oxygenated and biodiesel blend fuel. In this investigation different fuel blends have been tested in an engine such as canola-safflower biodiesel, oxygenated fuel solketal, ethanol as an additive. The experiment was done on common rail diesel engine under different speeds consideration i.e. 1500 rpm, 2000 rpm, 2500 rpm and medium load condition (100 Nm). Higher brake specific fuel consumption (BSFC) was observed for biodiesel and its blends with oxygenated fuel solketal, ethanol than that of standard diesel fuel and no significant difference was obtained in cylinder pressure for all test of fuel. It is reported that the emission CO, CO_2, HC decreased and amount of NOx increase of blended fuel in comparison of pure biodiesel test fuel.

Bayindir [29] et al. evaluated the effect of biodiesel blend with kerosene and diesel fuel in diesel power generator fueled engine. Two type of blends B80K20 (80% of biodiesel with 20% kerosene) and B80K10D10 (80% of biodiesel with 10% kerosene and 10% diesel) were used in this experimental work. The test was carried out on four cylinder diesel engine at constant speed 1500 rpm. It is found that the nitrogen oxide (NOx) emission decreased followed by hydrocarbon (HC) increases as per effect of kerosene blending with biodiesel fuel.

Can [30] et al. investigated the performance of single cylinder direct injection diesel engine with canola biodiesel blends. Different proportion of biodiesel blends (5%, 10%, 15%, 20%) with diesel fuel have been studied in single cylinder DI engine under varied load conditions (4.8, 3.6, 2.4 and 1.2 bar BMEP). At full load condition, the results showed that increase in brake specific fuel consumption (BSFC) and reduction in brake thermal efficiency i.e. 6.56% and 4.2% respectively for 20% blend fuel of canola as well as all emission parameter decreased except NOx for all blends fuel.

Patel [31] et al. investigated the combustion, vibration, noise and spray characterization of jatropha oil biodiesel fuel in genset engine. A single cylinder genset engine has been used in this experimental work and three different fuels standard diesel, jatropha biodiesel (JB100) and blend JB20 (20% biodiesel and 80% standard diesel) were tested in it. It was observed that the spray characterization parameters such as penetration length and cone angle of spray for all testing fuels are greatly affected by ambient pressure. It is concluded that higher levels of combustion noise followed by higher heat release rate (HRR).

Aydin [32] et al. studied the performance of diesel engine with biodiesel-kerosene fuel blends and evaluated its emission characteristics. In this study, safflower oil was taken for biodiesel production by transesterification method. In this investigation, safflower biodiesel was blended with kerosene in distinct proportion of S90K10 (90% safflower biodiesel-10% kerosene), S75K25 (75% safflower biodiesel-25% kerosene) and S50K50 (50% safflower biodiesel-50% kerosene). The experimentation work was conducted on 4 cylinders, water cooled diesel engine and tests were taken out at 3.6 kW, 7.2 kW and 10.2 kW loads operation with constant engine speed 1500 rpm and constant compression ratio 17:1. It is observed that average mass fuel consumption and brake specific fuel consumption (bsfc) lowest for blending S50K50 and diesel fuel, because of its higher calorific value, in comparison of S90K10, S75K25 blending fuel. Brake thermal efficiency (BTE) increased by 3% for S50K50 fuel than that of diesel fuel. The amount of NOx emissions were reduced with percentages of 68%, 56.9% and 55.1% with increase in kerosene percentages of 50%, 25% and 10% in blending respectively.

Eryilmaz [33] et al. evaluated the influence of blending ratio on the physicochemical properties of safflower oil methyl ester-safflower oil (SOME-SO), safflower oil methyl ester-euro diesel (SOME-ED), safflower oil-euro diesel (SO-ED). The blending of SOME-SO, SOME-ED and SO-ED were prepared in the ratio of 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 % by volume. They studied the preparation of safflower oil methyl ester (SOME) by transesterification method at temperature 60°C with 6:1 methanol to oil ratio and NaOH as catalyst. In this, they conducted the experimental investigation on physicochemical properties (density, kinematic viscosity, flash point, pour point etc.) of SO, SOME, ED and blending. They developed the mathematical relation between properties and additive content like SO, SOME which showed linear regression.

Gangli [34] et al. studied the impact of karanja biodiesel on the engine performance. In this investigation, karanja oil has used as a feedstock for biodiesel production. Different blends (B20, B40, B60, B80 and B100) of the karanja biodiesel have been used in this experimental work for evaluating the performance and emission characteristics of diesel engine. This experimental investigation was carried out using single cylinder, four stroke water cooled internal combustion engine with 16.5 compression ratio, 1500 rpm and 3.7 kW rated power. The author observed that lower concentration of karanja biodiesel in the blend improves the thermal efficiency and blending of biodiesel with the commercial diesel has reduced the gaseous emission (HC and CO) except NOx.

Acharya [35] et al. investigated the effect of preheated karanja and kusum oil on its emission characteristics. In this studied, the shell and tube type heat exchanger was used for preheating of karanja and kusum oil at before inlet of the engine and evaluated emission characteristics. This study was carried out at single cylinder, four strokes, water cooled engine with constant compression ratio (16.5:1) and 1500 rpm. It is reported that by using preheated karanja and kusum oil, the emission component such as carbon monoxide (CO), hydrocarbon (HC), carbon dioxide (CO_2) were increased with increase the engine load and oxide of nitrogen (NO_x) was discussed by Fig. 2.1 and Fig. 2.2.

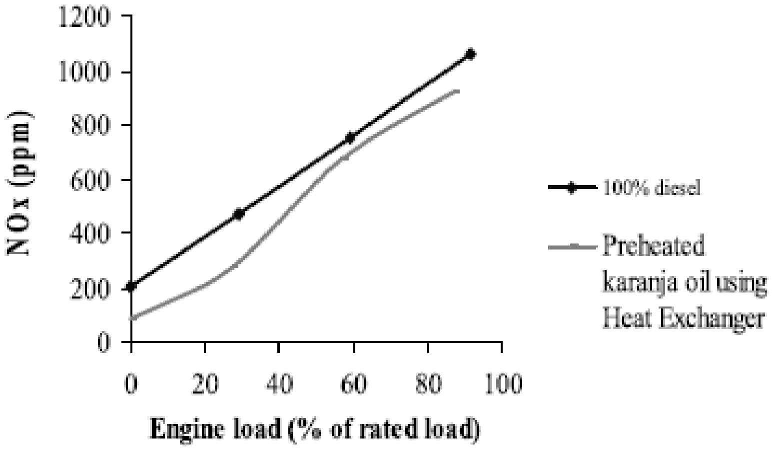


Figure 2.1: Variation of NO_x emission with engine load of preheated karanja oil [35]

Figure 2.1 showed the linear relationship of NO_x formation and engine load when diesel fuel used and concentration of NO_x formation decreased 10-15% with using preheated karanja oil.

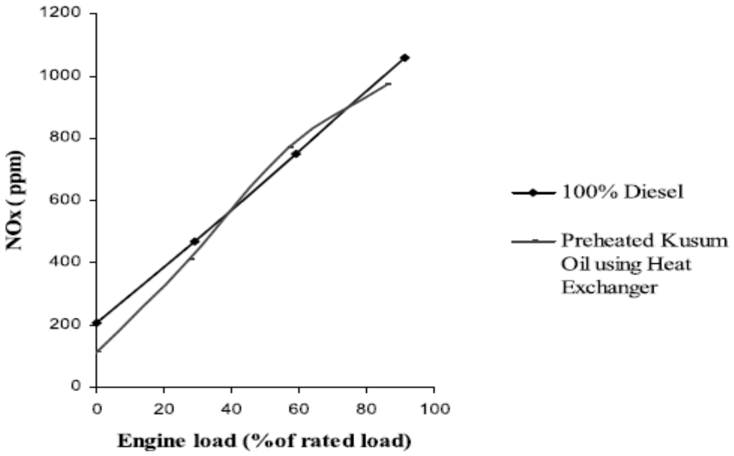


Figure 2.2: Variation of NO_x emission with engine load of preheated kusum oil [35]

Figure 2.2 showed that first concentration of NO_x formation less for preheated kusum oil and increase after 45% rated load and further decrease after 80% rated load in comparison of diesel fuel. The overall percentage decrease in NO_x concentration 5-7% compared to diesel fuel.

It is concluded that kusum oil have slightly higher emission compare to karanja oil due to its high viscosity.

Kumar [36] et al. examined the pinnai oil biodiesel fuel performance and emission characteristics in variable compression ratio (VCR) engine. Two steps such as acid esterification, transesterification process were used for pinnai biodiesel production. This study was carried out on variable compression ratio engine (VCR) with varied compression ratio 15:1 to 18:1 and different blends B10, B20 have been studied in this experimental investigation. The brake power for all compression ratios was observed higher at part load condition for blends other than that of diesel fuel and no significant difference obtained in specific fuel consumption (BSFC). It was reported that the emission also reduced except nitrogen oxide (NOx).

Mofijur [37] et al. investigated the emission characteristics of biofuels use on IC engines. In this study the author focused on the worldwide development of alternative fuel i.e. biofuels as well as discussed its importance in an internal combustion engines. It is reported that the engine emission was reduced with biofuels and apart from that 80% reduction have been noticed in greenhouse gas (GHG) emission.

Jawre [38] et al. reported the experimental analysis of performance of diesel engine using kusum oil methyl ester (KOME) with di ethyl ether (DEE) as additive. Screw type expeller is used for extraction of oil from kusum seed and viscosity of raw kusum oil is much higher. Transesterification process is introduced to reduce viscosity and conversion of kusum oil into kusum oil methyl ester (KOME) with molar ratio 6:1 (alcohol to oil), 0.5% potassium hydroxide (KOH) catalyst. In this studied, di ethyl ether (DEE) is used as additive and its blending with kusum oil methyl ester (KOME) in the ratio of B100 (100% KOME), BD-1 (95% KOME and 5% DEE), BD-2 (90% KOME and 10% DEE), BD-3 (85% KOME and 15% DEE) respectively. This experimental work carried out single cylinder, four stroke D.I. engine with injection pressure 170 bar and 190 bar, compression ratio 16:1 and rated rpm 1500. It is examined that brake thermal efficiency (BTE) of BD-2 increased by 2.05% compared to BD-3 at 170 bar injection pressure and at 190 bar pressure, BTE of BD-3 higher by 6.7% in comparison of 170 bar. Lower brake specific fuel consumption (bsfc) was observed of BD-2 and BD-3 compared to B100 at 170 bar and 190 bar pressure respectively and smoke reduced to 21% and 28% respectively. It is observed that use of additive (DEE) with KOME gave improved performance and emission results.

Awad [39] et al. examined the jojoba ethyl ester production and properties of ethanol blends. Transesterification process is used to produce jojoba ethyl ester (JEE) by using ethanol (CH_3CH_2OH), catalyst sodium hydroxide (NaOH) and reaction time, temperature, stir speed are 60 min, 60°C, 600 rpm respectively. In this paper, it is reported that the properties of jojoba ethyl ester and its blends with ethanol in distinct ratio of such as E5 (5% ethanol and 95% JEE), E10 (10% ethanol and 90% JEE), E15% (15% ethanol and 85% JEE), E20 (20% ethanol and 80% JEE), E0% (100% JEE). The results of kinematic viscosity and flash point were described by Fig. 2.3 and Fig. 2.4.

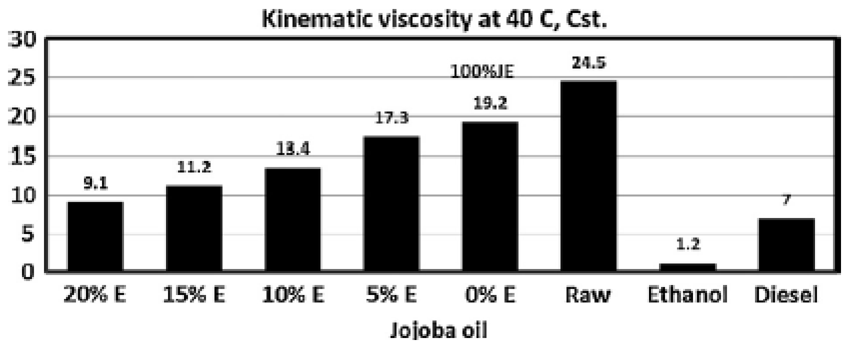


Figure 2.3: Kinematic viscosity for the Jojoba ethyl ester as compared to diesel and blends with ethanol [39]

Figure 2.3 showed that kinematic viscosity of ethanol i.e. 1.2 mm^2/sec which is very low compared to diesel and blending of ethanol and JEE. The trend of graph represents that by increased the percentage of ethanol in mixer of JEE and ethanol, decrease the kinematic viscosity of blends.

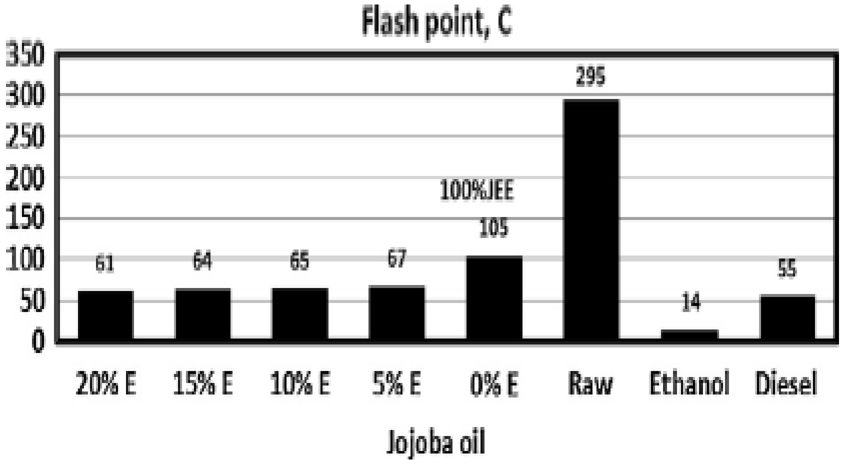


Figure 2.4: Flash point for the Jojoba ethyl ester as compared to diesel and blends with ethanol [39]

Figure 2.4 showed that flash point of 100% JEE i.e. 105°C which is higher compared to diesel fuel and it is drop to 61°C by mixing ethanol at different concentration with JEE.

It is concluded that maximum yield of JEE is obtained by using 7% ethanol in transesterification process and low calorific value, density are decreased with increase proportion of ethanol in the mixture.

Jena [40] et al. reported the effect of inherent oxygen of biodiesel fuel on efficiency of compression ignition engine. In present study the author was used palm, karanja biodiesel and diesel fuel separately and evaluate the impact of fuel oxygen on energy and exergy of engines. It is observed the best performance results for respective fuel at 85% loading condition. Finally it is concluded that oxygen played the important role in combustion and reduced formation of byproducts in an engine.

Abedin [41] et al. studied the palm and jatropha biodiesel fuel blends in diesel engine. The present investigation was based on the performance, emission and heat loss evaluation of blends B10, B20 of palm and jatropha biodiesel fuel. This experimental work was conducted on four cylinder diesel engine. It is found that the brake power of palm and jatropha biodiesel blends B10, B20 was decreased and 26.4% brake specific fuel consumption (BSFC) increment was noticed for B20 blend fuel of palm and jatropha biodiesel. The reduction in emission parameters such as carbon monoxide (CO), hydrocarbon (HC), nitrogen oxide (NOx) were observed for PB20 palm biodiesel blend fuel and apart from that the NOx emission increased by 3% for jatropha biodiesel blends JB10, JB20.

Nayak [42] et al. studied the transesterification of neat mahua oil and used its methyl ester with additive in an engine for evaluating the performance and emissions. The proposed experiment was carried out with single cylinder water cooled diesel engine under different loads. It is reported that the brake power (BP) and brake thermal efficiency (BTE) have been increased with increased in additive percentage in mahua oil methyl ester. Apart from that brake specific fuel consumption (BSFC), exhaust gas temperature (EGT) and all emission parameters (CO, HC, NOx and Smoke) were decreased.

Debnath [43] et al. investigated the effect of palm oil methyl ester on exergy and energy of variable compression ratio (VCR) diesel engine. This experimental work was performed on single cylinder water cooled VCR engine with varied compression ratio like 16, 17, 17.5, 18 and three different injection timing 20°, 23° and 28° before top dead centre (BTDC) and at constant speed 1500 rpm. In this studied the author was discussed the parameters such as shaft power, heat losses, energy input, heat release rate and peak pressure etc. The results showed that the higher shaft power, exergy efficiency and lower heat losses due to the injection advancement.

Rathod [44] et al. investigated the comparative review study on vegetables oils and its blends in direct injection C.I. engine. In this paper, it discussed thermodynamic property of vegetable oils such as density, calorific value, cetane number, viscosity, oil content, flash point and pour point. The focus of this study based on kusum oil and its methyl ester (KOME) properties and performance. The blending of methyl ester with diesel in the ratio of B20, B40, B60, B80 and B100 which showed that percentage increase of kusum oil methyl ester (KOME) in blending cause of increase viscosity of oil. The result showed that viscosity and density of kusum oil and kusum oil methyl ester (KOME) at 40°C were 40.36 cSt and 860 kg/m^3, 14.2 cSt and 850 kg/m^3 respectively. It is concluded that vegetables olis are good alternate fuel in order of performance of I.C. engine and emission of hydrocarbon (HC), carbon monoxide (CO), carbon dioxide (CO_2) are also reduced except oxide of nitrogen (NO_x).

Mihaela [45] et al. examined the comparative study of safflower oil with rapeseed and soybean oil. It reported that safflower corps are capable to utilize the land in southern part of Romania, characterized by difficult climate condition. In this paper, the author discussed distinct method of oil extraction, two stage transesterification methods, properties of oil and fatty acid composition of safflower, soybean and rapeseed oil. It is examined that safflower oil is suitable for very extreme weather conditions and detrimental land of Europe and South Romania and sulfur content of safflower, rapeseed, soybean were examined to be below 2 ppm.

Kumari [46] et al. investigated the diesel engine performance with safflower oil. This experiment was performed on single cylinder Kirloskar diesel engine at speed 1500 rpm and compression ratio 16.5:1. It is reported that performance of diesel engine was taken out in the consideration of varied load condition from 0-100% load and different blends (B20, B40, B60, B80 and B100) of safflower oil with diesel have been studied. It was found that minimum average fuel consumption and brake specific fuel consumption (bsfc) for blend B20 in comparison of B40, B60, B80, B100 and mineral diesel and brake thermal efficiency (BTE) increased from 21.9% to 27.1% (5.2%) for B20 at 80% full load when compare with mineral diesel.

Rathod [47] et al. reported the experimental investigation of kusum oil methyl ester and its blends used in C.I. engine. In this paper, the author discussed the performance parameters of I.C. engine such as specific fuel consumption (SFC), brake thermal efficiency (BTE), brake power (BP), exhaust gas temperature (EGT) and smoke density (SD). Biodiesel is prepared by alkaline transesterification process with molar ratio 6:1 (methanol to oil), 10gm catalyst potassium hydroxide (KOH) by weight, reaction temperature 60°C and reaction time 2h. This work was conducted on a single cylinder, four stroke, air cooled engine with 18.8:1 compression ratio and constant speed 1500 rpm. It studied that the performance of I.C. engine with diesel fuel (DF) and its blends with kusum oil methyl ester (KOME) in distinct ratio such as B20% (20% KOME and 80% DF), B40% (40% KOME and 60% DF), B60% (60% KOME and 40% DF), B80% (80% KOME and 20% DF) and B100% (100% KOME) with maximum load capacity of 5 kw. It is found that brake thermal efficiency (BTE) and exhaust gas temperature (EGT) were attained higher value for all blends of KOME then that of diesel fuel but B80% and B40% offered maximum BTE and EGT respectively, smoke density also reduced in comparison of diesel fuel.

Atabani [48] et al. studied the non-edible vegetable oils. In this, the author has discussed the various process of oil extraction from seeds, different methods of biodiesel production from oil, physicochemical properties of biodiesel and reviewed on engine performance and emission production. The oils are categorized into two types: edible oils and non-edible oils. The demand of edible oil is more, due to this, they are expensive. The non-edible vegetable oils have a toxic component, that’s why these are not suitable as human food. Non edible vegetable oils have given the alternative energy source in replacement of fossil fuel because they are used as a second generation feedstock for the production of biodiesel. Biodiesel belongs to renewable energy and is a promising resource of diesel engine. It is ecofriendly and easily available fuel. In this, different types of feedstock and its properties have been studied for the production of biodiesel including Jatropha, Curcas, Pangamia, Rubber seed, Neem etc. The author reviewed the performance and emission of diesel engine. Vegetable oil and biodiesel have blended with diesel at different concentration and examined the engine performance, emission characteristics. The overall performance of vegetable oil and biodiesel with diesel engine resulted in lower emission and best combustion characteristic depends on the feedstock. Most of the researchers concluded that 20% blend of biodiesel and vegetable oil with diesel have satisfactory work in the existing engine designs.

Kumar [49] et al. studied the kusum oil as a potential fuel for C.I. engine. In this investigation, the author discussed parameters of kusum oil, its physico-chemical properties and its application. Kusum oil is the type of non-edible oil and these oils are mostly preferred for preparation of biodiesel due its low cost in comparison of edible oil. Non-edible oils are called second generation feedstock. India secured second position in the world in percentage of world oil seed area. Kusum oil is also known as Macassar oil and every year 66 thousand tonnes of kusum oil is produced in india. It is concluded that kusum oil have great potential in preparation of biodiesel and it contain free fatty acid (FFA) 5-11% wt, iodine value 215-220 and total fatty acid 91.6%.

Jothithirumal [50] et al. studied the combined impact of biodiesel and exhaust gas recirculation on NO_X emission in D.I. diesel engine. Oxide of nitrogen (NO_X) formation is the function of higher temperature and exhaust gas recirculation (EGR) is used to reduce NO_X emission by I.C. engine. This experimental work carried out four strokes, two cylinders, water cooled I.C. engine at constant compression ratio i.e. 18.5:1 and the performance was evaluated at different load condition such as 20%, 40%, 60%, 80%, 100% with different percentage of EGR i.e. 25%, 50%, 75%, 100%. In this paper, the author discussed mechanism of NO_X formation, EGR techniques for NO_X reduction, classification of EGR systems and different biodiesel blends B25, B50, B75, B100. It is reported that NO_X was reduce at 25% EGR for all load operating condition and all fuel concentration whereas smoke and particulate increase.

Llkilic [51] et al. investigated the safflower oil methyl ester application in diesel engine and its production. The transesterification process was employed for preparation of biodiesel by safflower oil with pretreatment temperature of oil 50-55°C, 0.4% catalyst (NaOH), 20% methyl alcohol of prepare oil. It is reported that the performance of single cylinder, four stroke, air cool C.I. engine and its emission characteristics at various engine speeds. In this study, safflower oil methyl ester and diesel were blended in the ratio of 5% (B5), 10% (B10) and 50% (B50) and evaluating effect of these blends on the engine performance and emission. The results showed that power and torque of biodiesel decrease and brake specific fuel consumption (bsfc) increases for B50 fuel in comparison to B5, B20 fuel and showed reduction in smoke, particulate matter (PM) and CO emission in comparison to mineral diesel.

Duz [52] et al. conducted the experimental investigation of alkali catalyzed transesterification of safflower oil assisted by microwave irradiation. Safflower oil extracted by soxhlet extraction method and biodiesel was prepared by transesterification method, using 10:1 molar ratio (alcohol/oil) and 1% w/w NaOH as catalyst. In this investigation, they discussed the advantage of microwave irradiation heating over convectional heating of product during trans-esterification method. They reported that microwave irradiation increased the rate of chemical reaction and produced high quality product. Under microwave irradiation condition, chemical reaction time reduced from 120 min to 6 min and percentage conversion of oil to ester was obtained 98.4% which is higher than in comparison of conversion under convectional condition i.e. 93%.

Jagdish [53] et al. investigated the performance of a diesel engine with the effect of exhaust gas recirculation. In this paper, palm stearin methyl ester (PSME) and its blends with diesel (D) in the ratio of B10% (10 % PSME and 90% D), B20% (20% PSME and 80% D), B100% (100% PSME) were used for evaluation the performance and emission characteristic such as brake thermal efficiency (BTE), brake specific fuel consumption (BSFC), oxide of nitrogen (NO_x), unburnt hydrocarbon (UHC), carbon monoxide (CO) with or without of exhaust gas recirculation (EGR) effect. Palm stearin methyl ester is prepared by transesterification process. This study was carried out four stroke, single cylinder, water cooled C.I. engine which is operated at 1500 rpm, compression ratio 16.5:1 and studied 5%, 10%, 15%, 20% exhaust gas recirculation (EGR) effects at half and full load operating condition of the engine. It is reported that brake thermal efficiency (BTE) of blends B10, B20 was obtained higher than that of diesel fuel and percentage of NO_x emission reduced of biodiesel and its blends with EGR and specific fuel consumption (SFC), emission of UHC, CO were also increased. It is concluded that EGR rate is valuable for biodiesel operated engine from 10% to 15% with lower penalty of fuel economy.

Muralidharan [54] et al. studied the performance, emission and combustion characteristics of waste cooking oil methyl ester. In this investigation the author used four different biodiesel blend fuels (B20, B40, B60 and B80). This experimental work was carried out on four stroke, single cylinder variable compression ratio engine at constant speed 1500 rpm and compression ratio 21 under various load conditions. It has observed the reduction in carbon monoxide (CO), carbon dioxide (CO2), hydrocarbon (HC) and increment in oxide of nitrogen when blends were used as fuel. It is reported that the almost same combustion characteristics was observed for waste cooking oil methyl ester and its blends followed by standard diesel fuel.

Sharma [55] et al. reported the kusum (Schleichera triguga) seed oil an ideal feedstock for preparation of biodiesel. It belonged from non-edible oil category due to its toxic in nature. Different processes have been used for preparation of biodiesel such as pyrolysis, micro-emulsification and transesterification. Out of these processes, transesterification is commonly used process in development of biodiesel. In this paper, the author was used acid esterification and alkaline transesterification processes for biodiesel production and bring to down acid value of vegetables oils. In this experimental work, different molar ratio such as 6:1, 8:1, 10:1 and 12:1 were used in both acid esterification and alkaline transesterification process. Catalyst sulfuric acid (H_2SO_4) was used in different amounts 0.5%, 0.75%, 1.0% and 1.25% (volume/volume) in acid esterification process and distinct concentration of catalyst potassium hydroxide (KOH) such as 0.5%, 0.7%, 0.9%, 1.1% (weight/weight) used in alkaline transesterification process. Optimum reaction time and temperature of these both process were 1h and 55±0.5°C respectively. It is concluded that the optimum conditions for acid esterification and alkaline transesterification were found 10:1 molar ratio, 1% (v/v) catalyst H_2SO_4 and 8:1 molar ratio, 0.7 (w/w) catalyst KOH respectively for obtaining the optimum yield. The results obtained by acid esterification and alkaline tranesterification as shown in below Table 2.1.

Table 2.1: Change in values after transesterification reaction [55]

Parameters	Values			
	Initial	After acid esterification	After alkaline transesterification	ASTM Standards D 6751
Viscosity (cst) at 40°C	25.18	13.88	4.9	1.9-6.0
Acid value (mg KOH/g)	21.30	0.94	0.45	0.50 (max)
Specific gravity	0.897	-	0.874	-
Density (kg/m^3) at 30°C	893.4	-	870.6	-

Haldar [56] et al. investigated the performance of diesel engine and emission characteristics using three non-edible vegetable oils. He has used putranjiva, jatropha and karanja as non-edible vegetable oil. Degumming process was employed to remove impurities (gummy material) from the vegetable oils. It is a chemical process and the chemical used in this process is phosphoric acid. It is economical process because the cost for production of biodiesel by degumming process less than the trans-esterification. By degumming process, the properties of vegetable oils like viscosity, cetane number, combustion have been improved. In this study, degummed non edible vegetable oils and diesel have been blended in the ratio of 10%, 20%, 30% and 40% and tested on Richard variable compression engine under the varying load condition 0-2.7 kW and the performance is compared. They have concluded that the overall performance of jatropha is good at high loads in all respect and diesel engine has given satisfactory performance using 20% blend with diesel at 45° bTDC timing, 1200 rpm, 20 compression ratio.

Rashid [57] et al. reported the production of biodiesel by using safflower oil through base-catalyzed trans-esterification process. It studied that yield of safflower oil methyl ester at different temperature, concentration of catalyst, molar ratio and rate of stirring with respected to time. In this experimental work, it studied various parameters such as oil to methanol molar ratio (1:3, 1:6, 1:9, 1:12, 1:15 and 1:18) and reaction temperature (30, 45, 60°C) and rate of stirring (180, 360, 600 rpm) and types of catalyst (NaOH, KOH, $NaOCH_3$, $KOCH_3$) with concentration (0.25, 0.50, 0.75, 1.00, 1.25, 1.50 %) were used for obtaining the maximum conversion of safflower oil into its methyl ester. The catalyst sodium methoxide ($NaOCH_3$) have greater potential for better quality and high yield of biodiesel is produced in this case. Catalyst $NaOCH_3$ with 1% concentration, oil to methanol molar ratio 1:6 and rate of stirring 600 rpm at fixed reaction temperature 60°C and constant reaction time of 120 min give the maximum methyl ester yield. It is concluded that below and beyond these parametric limit, the yield of safflower oil methyl ester (SOME) decreased with respect to time. Catalyst sodium methoxide ($NaOCH_3$) offered 98% yield of methyl ester with 1% concentration and 6:1 molar ratio.

Chapter 3

Experimental Setup and Methodology

The present study deals with optimization of biodiesel production from safflower oil and kusum oil as well as evaluation of performance and emission characteristics of three blends (B10, B20, B30) of these two oil methyl ester used in VCR engine. The optimized parameters for biodiesel production are methanol to oil molar ratio, catalyst concentration and time of reaction. The performance and emission parameters have been studied in this experimental work namely brake power (BP), brake specific fuel consumption (BSFC), brake thermal efficiency (BTE), mechanical efficiency (MEff), exhaust gas temperature (EGT), carbon monoxide emission (CO), hydrocarbon (HC) and nitrogen oxide (NOx).

3.1 Materials and Method

3.1.1 Materials

The safflower seed oil and kusum seed oil were purchased from Surajbala Export Pvt. Ltd, Delhi, India. All reagents such as methanol (GR grade, moisture<0.02%) and analytical grade catalyst potassium hydroxide (KOH) were obtained from local chemical store and used as received.

3.1.2 Procedure of production of safflower oil methyl ester

- 50 g of safflower oil was taken in a 250 ml glass vessel and preheated up to 105-110 °C to remove the moisture content of oil and then allowed to cool up to 45-50 °C.
- Now methyl alcohol (CH_3OH) was taken with the distinct molar ratio (methanol: oil) 4:1, 6:1, 8:1 and catalyst potassium hydroxide (KOH) was taken as 0.5 wt% (weight percent), 1.0 wt% and 1.5 wt% of the oil taken. The methyl alcohol and catalyst KOH were mixed together.
- This homogeneous mixture of methyl alcohol and catalyst KOH is mixed with 150 g safflower oil.
- The conical flask containing the mixture of oil, alcohol and catalyst was heated at constant temperature 50-60 °C [45, 52] and it was stirred simultaneously inside a water bath shaker at about 200 rev/min for 60 min, 75 min, and 90 min respectively.

- After completion of the reaction time, the products were poured into the separating funnel and kept 1-2 hour for separation of phases [51]. In separating funnel, products were separated into two layers. Due to higher specific weight, glycerol was settled down at the bottom and the upper layer was biodiesel (Fig. 3.2 (a)). The glycerol was taken away.
- After separation, the biodiesel was then washed with hot distilled water in order to remove remained methyl alcohol, catalyst, and impurities present in biodiesel fuel.
- Finally, the biodiesel was placed in the hot air oven and heated at 100 °C to remove excess water content present in biodiesel fuel (Fig. 3.2 (b)).

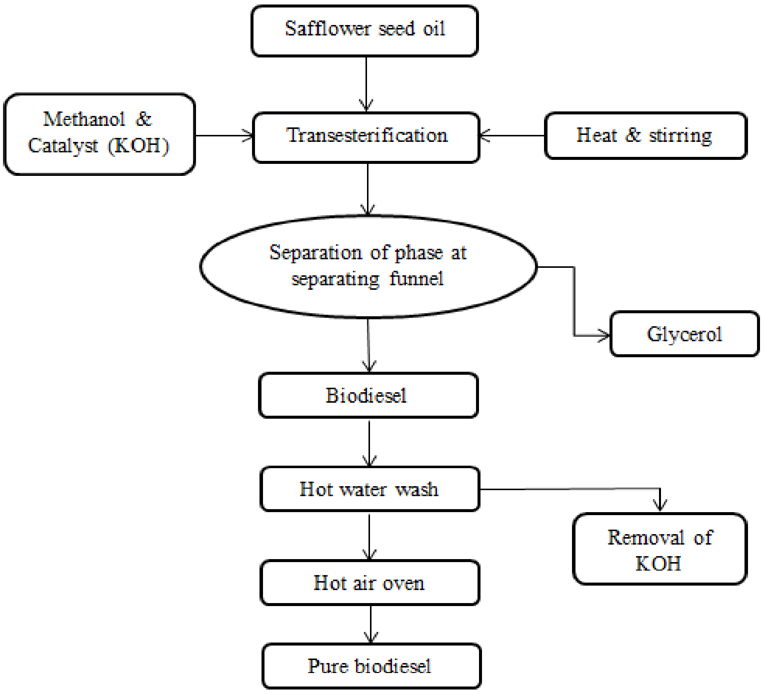


Figure 3.1: Process flow diagram of biodiesel production by transesterification process

(a) (b)

Figure 3.2: (a) Different phases of methyl ester, (b) Safflower biodiesel

3.1.3 Procedure of production of kusum oil methyl ester

The main purpose of this experimental investigation is to produce the kusum oil biodiesel by using raw kusum seed oil. Due to high content of FFA of kusum oil, the objective has been achieved in two steps namely (i) acid esterification, (ii) alkaline esterification.

(i) Acid esterification

The acid esterification was carried out at 4:1-6:1 molar ratio with varied H_2SO_4 (0.5-2.0%) at 50-60°C and 60-90 min reaction time. Preheated oil, methanol and acid H_2SO_4 were mixed together as per desired proportion and stirred at 200 rpm. After completing the acid esterification reaction, treated was taken into beaker (Fig. 3.4 (a)) and heated up to 60°C [58].

(ii) Alkaline esterification

After acid treatment, 50 g oil was taken in a 250 ml flask and preheated up to 100°C to eliminate dissolved moisture content in the kusum oil. Now required amount of methanol (4:1, 6:1, 8:1) were mixed with distinct percentage of KOH catalyst concentration (0.5, 1.0, 1.5). This homogeneous mixture of methanol and catalyst KOH was mixed with the kusum oil and stirred with 200 rpm at varied reaction temperature 50-60°C. The reaction was stopped after 60, 75 and 90 min. After completion of transesterification reaction, kusum oil methyl ester was separated from glycerol by separating funnel (Fig. 3.4 (b)) and then the separated methyl ester was washed with hot distilled water. At last biodiesel was heated in the hot air oven to remove excess water content (Fig. 3.4 (c)) [51].

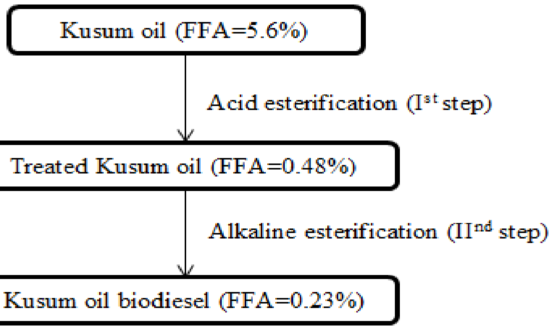
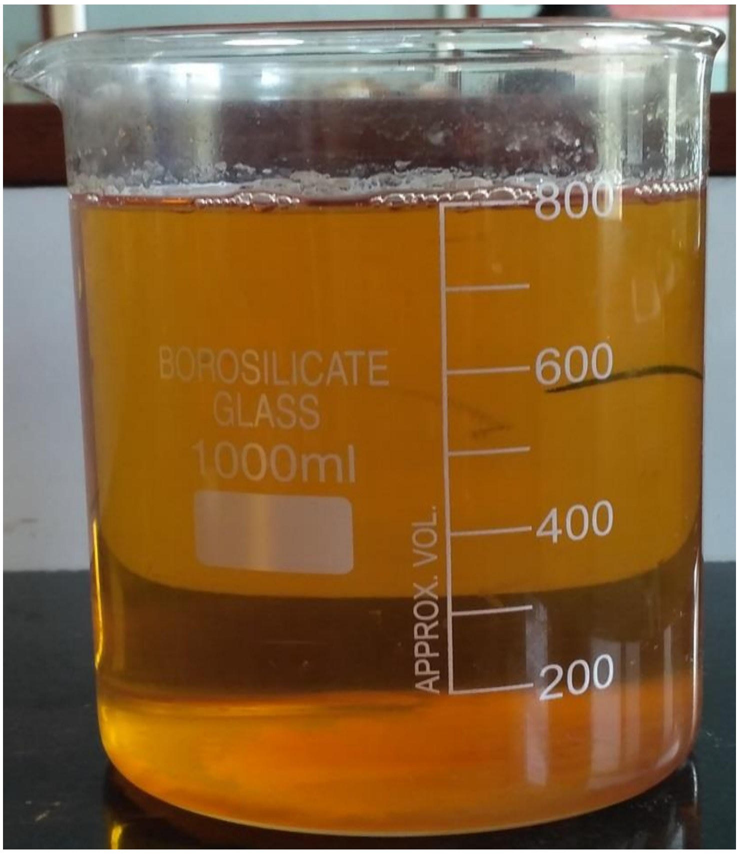


Figure 3.3: Process flow diagram kusum oil treatment

(a) (b)



(c)

Figure 3.4: (a) Acid esterification, (b) Alkaline esterification, (c) Kusum biodiesel

3.2 Determination of biodiesel properties

Several properties of biodiesel fuel have been determined in this experimental investigation. These are

- Free fatty acid content
- Density
- Kinematic viscosity
- Flash point
- Fire point
- Cloud point
- Pour point
- Higher heating value
- Water content

3.3 Apparatus used for transesterification and estimation of biodiesel fuel properties

3.3.1 Water bath shaker reactor

The water bath shaker as shown in Fig. 3.5 is commonly used for transesterification reaction for biodiesel production. The water bath shaker provided the ideal mixing of solvent at specified operating temperature and speed.

Figure 3.5: Water bath shaker

In water bath shaker reactor, a brushless induction derive motor connect with the tray and this tray immersed into water bath which possess heating coil for heating the water. Firstly, the conical flask of solvent kept inside the reciprocating tray which has holder to hold the flask. After achieving the operating reaction temperature, switch on the motor and set the constant speed by speed regulator and run this setup for specified reaction time.

3.3.2 Redwood viscometer

The Redwood viscometer (Fig. 3.6) is commonly used to determine the viscosity of petroleum product in terms of seconds which is known as Redwood seconds. This is the time taken by the oil when it passes through orifice and collect this oil into 50 ml measuring cylinder.

Figure 3.6: Redwood viscometer

Procedure of measuring the viscosity by Redwood viscometer:

Firstly the viscometer cup was cleaned properly and filled with the oil to the specified level indicated by leveling screw. Before filling the cup with oil, it was assured that the orifice should be closed by stopper and 50 ml measuring cylinder was placed just below the orifice jet. The water bath was filled with the water and heat at uniform temperature. When the oil attained required temperature, the stopper was lifted and the oil was allowed to pass through the orifice and collected in 50 ml measuring cylinder. The time taken to complete this work was recorded in seconds.

There are two different equations (Eq. (3.1) and Eq. (3.2)) presented to convert the redwood second into kinematic viscosity (unit centistokes).

If t > 100 sec

$$V_k(cSt) = 0.24t - 50/t \tag{3.1}$$

If t < 100 sec

$$V_k(cSt) = 0.26t - 179/t \tag{3.2}$$

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

3.3.3 Bomb calorimeter

The bomb calorimeter is employed for determination of the energy liberated per kg of fuel burnt. It is used for measuring the calorific value (CV) of solid fuel as well as liquid fuel. The bomb calorimeter was shown in Fig. 3.7.

Figure 3.7: Bomb calorimeter

Procedure of measuring the calorific value of fuel by bomb calorimeter:

In bomb calorimeter, firstly a known quantity (less than 5 ml) of fuel is filled in the crucible. After filling the fuel sample in the crucible, start the stirrer and note down the initial temperature of water. When current start through the crucible then the fuel sample burn in the presence of oxygen and hence rises the water temperature because of heat liberated during combustion of fuel was taken by water. Finally note down the steady state temperature of water. The below Eq. (3.3) is used for calculation of higher calorific value.

$$Higher\ calorific\ value\ of\ fuel\ (kJ/kg) = (m_1 + m_2) \times (T_c + T_1 - T_2) \times C_w / m_f \quad (3.3)$$

Where,

m_1 and m_2 are the mass of water in the copper calorimeter and water equivalent of bomb calorimeter respectively.

m_f is the mass of fuel sample whose calorific value is to be determined.

T_1 and T_2 are the final and initial temperature of the water sample. Tc is temperature correction for radiation losses.

C_w is specific heat of water.

3.3.4 Pensky Martens apparatus

For determining the flash and fire point, Pensky Martens apparatus is used (Fig. 3.8). The fuel sample was poured in the oil cup up to mark and verified that flame exposure device fixed at the top.

Figure 3.8: Pensky Martens apparatus

The apparatus was heated until the temperature of oil increases 5-6°C per minute and stirred continuously at constant. The temperature of oil was measured via inserted thermometer in it. At every 1°C rise of oil temperature, the test flame was introduced to the oil vapor by operating the shutter. The minimum temperature at which a distinct flame was observed in interior cup causes introducing of test flame is known as flash point. After continuously heating of oil at rate 1°C/min and introduce the test flame, the temperature at which oil vapors provide bluish flash and stay this flash minimum 5 second, is reported as flash point of oil.

3.3.5 Cloud and pour point apparatus

The apparatus used for cloud and pour point was shown in Fig. 3.9. This apparatus consists of a glass tube, thermometer, cork, cooling bath and jacket. First the oil was poured into the glass tube and closed this tube by cork tightly which carry thermometer. This glass tube is placed inside the air jacket. Then the jacket containing glass tube put in the cooling bath which is filled by crushed ice and sodium chloride catalyst. After every 1°C fall of the oil temperature, the glass tube removed from the jacket for monitoring the cloud and replaced immediately. The process was continued until it achieve that minimum temperature at which cloudiness and haziness seen in the oil near the bottom of the glass tube. This minimum temperature was known as cloud point.

The oil was made moisture free at first and then poured into glass tube. Thereafter, the glass tube was placed in the apparatus and observed till its particles stop their movement i.e. the oil sample reaches its pour point.

Figure 3.9: Cloud and pour point apparatus

3.3.6 Free fatty acid content

The percentage free fatty acid (% FFA) of oil was determined by titration method. Following steps were described for calculating the % FFA content of testing fuel.

- Firstly the oil was taken in a conical flask between 0.1gm to 10gm.
- It is mixed with the 50 ml ethanol.
- After that 4-5 drop of phenolphthalein was added in the mixture of ethanol and oil.
- Prepared 0.1 N NaOH or KOH solutions and filled in burate.
- The oil was then titrated with 0.1 N KOH solution till the pink color appears and sustains for at least 10 sec.

Eq. (3.4) and Eq. (3.5) were used for calculation of % FFA content and acid value respectively.

$$\% FFA = (N \times M \times B)/W \tag{3.4}$$

N=Normality of KOH or NaOH solution

M=Molecular weight of KOH or NaOH

B=Burate reading

W=Sample weight (oil)

$$Acid\ value\ (Av) = 2 \times \%FFA\ content \tag{3.5}$$

It should not be greater than 0.5% for biodiesel and unit of acid value is mg of KOH/g.

3.4 Apparatus used for engine performance and emission evaluation

3.4.1 Variable compression ratio engine

This experimental investigation was carried out on kirloskar made VCR engine (product code 234). It was connected with the control panel unit which consist rotameter, water temperature indicator, loading switch, speed indicator and fuel flow transmitter etc. (Fig. 3.10). The following engine performance and combustion parameters such as brake power (BP), brake specific fuel consumption (BSFC), brake thermal efficiency (BTE), mechanical efficiency (MEff), heat balance, cylinder pressure and heat release rate were determined by engine performance analysis software (EnginesoftLV).

Figure 3.10: Variable compression ratio engine

The below Table 3.1 was illustrated the detailed specification of the VCR engine.

Table 3.1: Specification of variable compression ratio engine

Engine type	Four stroke VCR engine (Make Kirloskar)
No. of cylinder	Single cylinder
Engine capacity	661 cm^3
Bore	87.5 mm
Stroke	110 mm
Compression ratio	17.5:1

Power	3.5 kW at 1500 RPM
Dynamometer type	Eddy current, water cooled, unit loading
Software	“EnginesoftLV” Engine performance analysis
Injection timing	23° bTDC

3.4.2 Eddy current dynamometer

The eddy current dynamometer coupled with the engine output shaft (Fig. 3.11) for measuring the power and torque. The dynamometer connected with a load cell and different load applied on an engine (0-12 kg) by load cell. These load cells joined with the load sensors which signaled the load on the load indicator.

Figure 3.11: Dynamometer

The below Table 3.2 showed the technical specification of eddy current dynamometer.

Table 3.2: Specification of eddy current dynamometer

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

3.4.3 Exhaust gas analyzer

For determination of different species of gases in the emission, the exhaust gas analyzer was used as shown in Fig. 3.12. The following emission species such as carbon monoxide (CO), unburned hydrocarbon (HC), oxide of nitrogen (NOx) and exhaust gas temperature (EGT) were observed.

Figure 3.12: Exhaust gas analyzer

The below Table 3.3 was shown the specification of exhaust gas analyzer.

Table 3.3: Specification of exhaust gas analyzer

Parameters	**Range**	**Resolution**	**Accuracy**
O_2	0 to 21%	0.1%	±2% of reading
CO	0 to 5000 ppm	1 ppm	±10 ppm < 400 ppm ±5% of reading>400 ppm
CO_2 Derived	0 to 21%	0.1% of reading	±0.3% of reading
HC	0 to 2000 ppm	0.01%	±10% of reading
NOx	0 to 5000 ppm	1 ppm	±5% of reading
Type CRAL Thermocouple	0 to 600°C	1°C	±3% of reading

3.5 Experimental procedure

This experimental investigation was done with diesel fuel as well as three different blends B10, B20 and B30 of SOME and KOME. The procedure is discussed below:

- At first the primary fuel tank was filled with diesel fuel.
- The desire compression ratio was adjusted i.e. 17:1 by lock nut of adjuster.

- After starting the water pump, the cooling water rotameter flow rate and calorimeter rotameter flow rate was adjusted at 300 LPH and 70 LPH respectively.
- Ensured that the position of fuel cock at “Tank”.
- The engine was started by hand cranking and ran at no load condition at least 4-5 min.
- Now opened the “EnginesoftLV” software on monitor for engine performance analysis.
- Increase the load 0.5 kg by adjusted DLU knob (ensure that the increased load reading same as the computer) and change the position of fuel cock from “Tank” to “Measuring”. After clicking on “Log on”, the data such as water flow to calorimeter, engine and cooling water jacket was entered into input display. At no load condition, the data was recorded for the engine and then the fuel position was changed from “Measuring” to “Tank”.
- The same procedure was applied for different loads.

3.6 Exhaust gas emission measuring procedure

The exhaust gas emission was evaluated with the five gas analyzer. The procedure of measuring of exhaust gas was described below.

- Firstly, the sensor probe was connected with the digital screen of gas analyzer.
- This probe was inserted into the exhaust gas outlet of engine and passing through sensors.
- These sensors were observed the value of emission species and displayed it on digital screen of gas analyzer.
- The display readings were noted and remove the sensor probe.
- The same steps were followed by different load conditions.

Chapter 4

Results and Discussions

4.1 Optimization of biodiesel production

The optimization of biodiesel production by transesterification process have been done under the consideration of variation of three process parameters such as methanol to oil molar ration, concentration of catalyst (KOH) and reaction time. The optimized result has been obtained on the behalf of maximum biodiesel yield, minimum viscosity and minimum free fatty acid (FFA).

Table 4.1: Optimization of biodiesel production from safflower oil

S. No.	Safflower oil (gm)	Molar ratio	Catalyst KOH (%)	Reaction time (min)	Reaction temperature (°C)	Yield (%)	Viscosity at 40 °C (cSt)
1	50	4:1	0.5	60	60	80.07	14.33
2	50	4:1	0.5	75	60	77.20	13.20
3	50	4:1	0.5	90	60	82.20	13.65
4	50	4:1	1.0	60	60	98.40	13.11
5	50	4:1	1.0	75	60	97.40	11.64
6	50	4:1	1.0	90	60	90.00	9.82
7	50	4:1	1.5	60	60	98.73	13.20
8	**50**	**4:1**	**1.5**	**75**	**60**	**97.07**	**5.63**
9	50	4:1	1.5	90	60	93.13	10.53
10	50	6:1	0.5	60	60	73.93	12.59
11	50	6:1	0.5	75	60	85.13	12.88
12	50	6:1	0.5	90	60	80.93	11.91
13	50	6:1	1.0	60	60	95.60	11.72
14	50	6:1	1.0	75	60	98.53	13.36
15	50	6:1	1.0	90	60	98.00	9.46
16	50	6:1	1.5	60	60	96.67	14.46

17	50	6:1	1.5	75	60	95.67	10.54
18	50	6:1	1.5	90	60	98.60	12.82

The above table shows that the optimization of biodiesel of production from safflower oil. As per consideration of maximum biodiesel yield and minimum viscosity, the optimized process parameters were 4:1 molar ratio, 1.5% KOH catalyst concentration and 75 minutes reaction time. The optimized biodiesel yield and viscosity were evaluated as 97.07% and 5.63 centipoise respectively as per optimized process parameters.

Table 4.2 represented the optimized process parameter by acid esterification and Table 4.3 showed the optimization of kusum biodiesel production from treated kusum oil. The optimized process parameters were obtained i.e. 6:1 molar ratio, 1% KOH catalyst concentration and 60 minutes reaction time. The optimized kusum biodiesel yield and viscosity were evaluated as 90.34% and 5.25 centipoise respectively as per optimized process parameters.

Table 4.2: Optimized process parameter by acid treatment

Molar ratio	6:1
% Catalyst concentration (H_2SO_4)	1.5
Reaction Time (min)	60
Reaction temperature (°C)	50

Table 4.3: Optimization of biodiesel production from kusum oil

S. No.	Kusum oil (gm)	Molar ratio	Catalyst KOH (%)	Reaction time (min)	Reaction temperature (°C)	Yield (%)	Viscosity at 40 °C (cSt)
1	50	4:1	0.5	60	60	93.37	15.13
2	50	4:1	0.5	75	60	96.77	12.82
3	50	4:1	0.5	90	60	92.33	8.63
4	50	4:1	1.0	60	60	91.77	11.54
5	50	4:1	1.0	75	60	94.15	12.01
6	50	4:1	1.0	90	60	87.85	10.36
7	50	4:1	1.5	60	60	90.96	10.04

8	50	4:1	1.5	75	60	94.97	9.30
9	50	4:1	1.5	90	60	85.77	9.93
10	50	6:1	0.5	60	60	87.21	14.55
11	50	6:1	0.5	75	60	88.07	17.09
12	50	6:1	0.5	90	60	86.65	16.21
13	**50**	**6:1**	**1.0**	**60**	**60**	**90.34**	**5.25**
14	50	6:1	1.0	75	60	88.07	15.90
15	50	6:1	1.0	90	60	86.65	16.96
16	50	6:1	1.5	60	60	83.52	9.60
17	50	6:1	1.5	75	60	85.55	8.32
18	50	6:1	1.5	90	60	79.21	10.51
19	50	8:1	0.5	60	60	94.22	16.13
20	50	8:1	0.5	75	60	94.98	17.30
21	50	8:1	0.5	90	60	91.81	18.31
22	50	8:1	1.0	60	60	94.50	9.40
23	50	8:1	1.0	75	60	95.16	13.64
24	50	8:1	1.0	90	60	87.77	17.96
25	50	8:1	1.5	60	60	90.89	8.53
26	50	8:1	1.5	75	60	93.41	14.59
27	50	8:1	1.5	90	60	88.55	17.25

4.2 Effect of parameters on transesterification of safflower oil and kusum oil

This section presented the influence of various process parameters such as molar ratio, catalyst concentration and reaction time etc. on biodiesel production from safflower oil and kusum oil by transesterifiction process.

4.2.1 Effect of % catalyst concentration and reaction time on SOME formation

In this experimental study, catalyst KOH was used in transesterification reaction due to its low cost and effective in nature. This experimental work was carried out using 4:1, 6:1 methanol to oil molar ratio with differ catalyst concentrations and reaction times and at constant reaction temperature of 60°C. The influences of these parameters on methyl ester production are shown in Fig. 4.1 and Fig. 4.2.

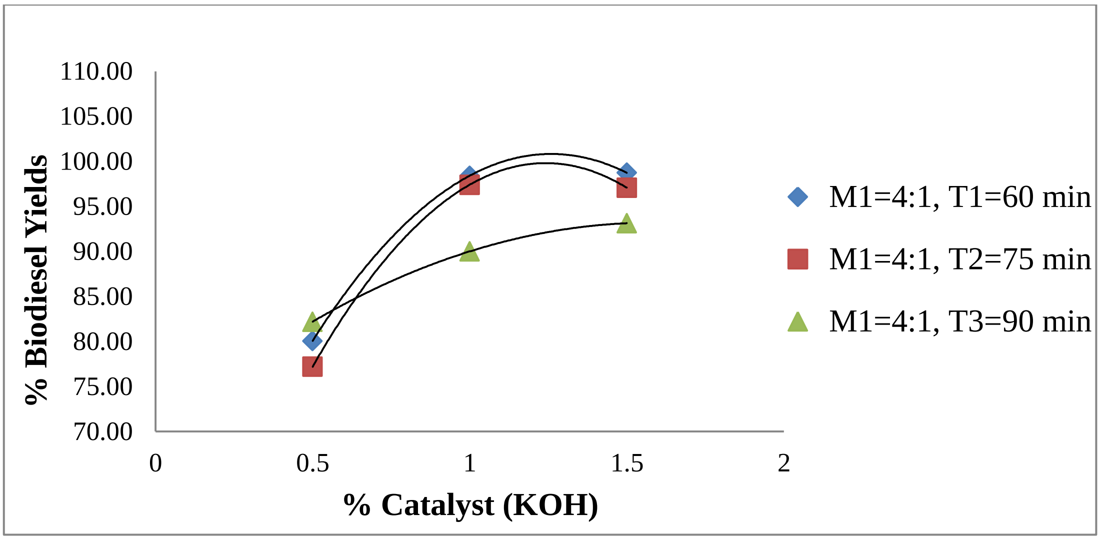


Figure 4.1: Variation of SOME yield with KOH concentration and reaction time at 4:1 molar ratio

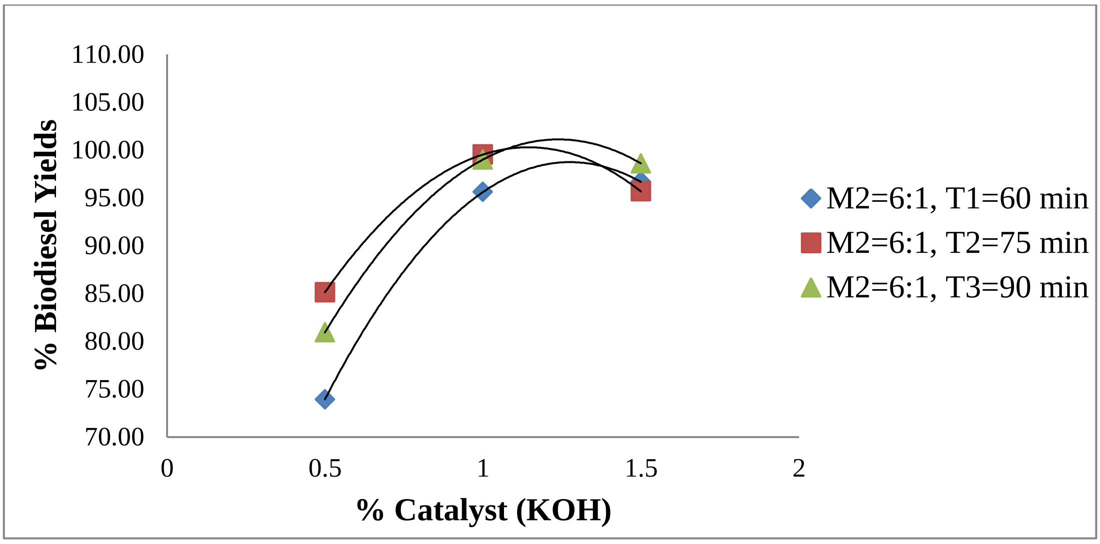


Figure 4.2: Variation of SOME yield with KOH concentration and reaction time at 6:1 molar ratio

The results found that catalyst concentration was a significant influencing parameter of transesterification reaction. As concentration of catalyst is raised from 0.5% to 1.5%, both Fig. 4.1 and Fig. 4.2 show that increasing trend of methyl ester formation at 30 minutes reaction time. Further increasing in % amount of catalyst concentrations were responsible of decreasing of methyl ester formation due to incomplete reaction because of soap formation.

This is due to high FFA content present in the oil which deactivated the catalyst and present extra catalyst was responsible to form emulsion which raised the viscosity, lead to form gels and difficulty associated with glycerol separation and loss in ester yield [59].

It is also seen that reaction time is an important factor in production of biodiesel. As increasing reaction time from 60 minutes to 90 minutes, the yield grows or drops depending upon % catalyst concentration. The maximum yield is obtained 98.73% with catalyst concentration 1.5% at 60 minutes reaction time and the yield almost constant until reaction time up to 90 minutes.

4.2.2 Effect of methanol to oil molar ratio and reaction time on SOME formation

After analysis of effect of catalyst concentration, it is observed that the maximum yield of biodiesel was obtained at 1.5% catalyst concentration. Figure 4.3 shows the influence of molar ratio and reaction time on methyl ester yield at reaction temperature 60° C with 1.5% catalyst concentration. It was noticed that as the methanol to oil molar ratio increases from 4:1 to 6:1, the yield also increase with respect to reaction time. The cause is this, transesterification reaction is reversible in nature due to this additional methanol is needed to shift the equilibrium towards product side (higher yield of methyl ester) [60]. But generally higher molar ratio is not selected because of more consumption of energy required for recovering unreacted methanol and presence of excess methanol suspended into by product glycerin which is responsible to makes separation difficult. It is also observed that maximum methyl ester yield i.e. 98.73% was acquired with 4:1 molar ratio at 60 minutes reaction time.

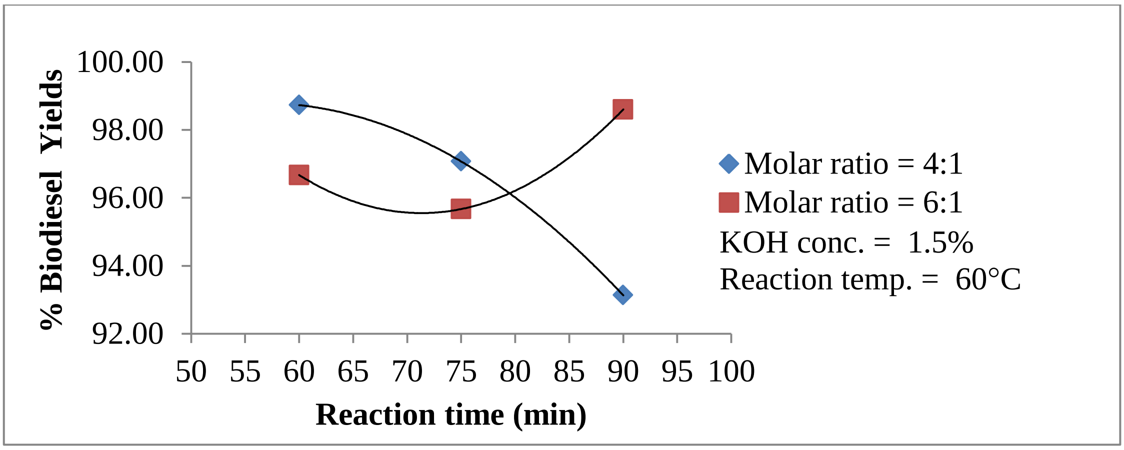


Figure 4.3: Variation of SOME yield with molar ratio and reaction time at 1.5% KOH concentration

4.2.3 Effect of methanol to oil molar ratio and reaction temperature on SOME viscosity

The influence of increasing molar ratio and catalyst KOH concentration was illustrated in the Fig. 4.4. It was found that as the molar ratio increases from 4:1 to 6:1, viscosity of methyl ester increases. This is due to excess molar ratio increase the methanol solubility in glycerin which makes separation difficult and the remains glycerin in solution cause high viscosity of methyl ester. As per project requirement, the minimum viscosity has been obtained at 4:1 molar ratio and 75 minutes reaction time.

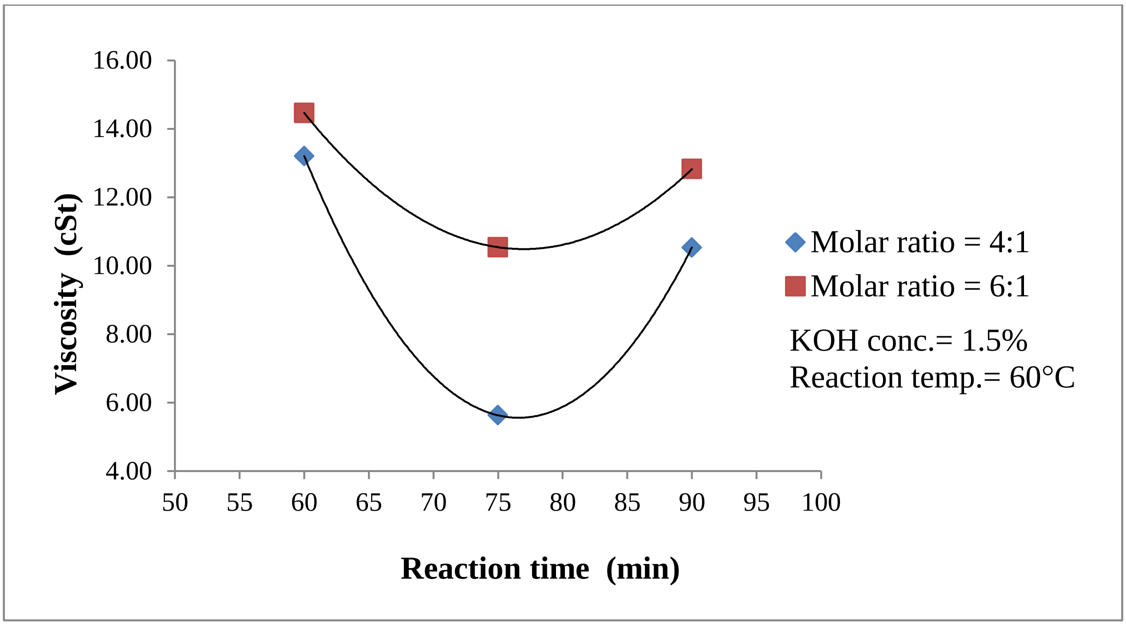


Figure 4.4: Variation of SOME viscosity with molar ratio and reaction time at 1.5% KOH concentration

4.2.4 Effect of % catalyst concentration and reaction time on KOME formation

In this experimental study, catalyst KOH was used in transesterification reaction due to its low cost. This experimental work was carried out using 4:1, 6:1, 8:1 methanol to oil molar ratio with differ catalyst concentrations and reaction times and at constant reaction temperature of 60°C. The influences of these parameters on methyl ester production are shown in Fig. 4.5, Fig. 4.6 and Fig. 4.7.

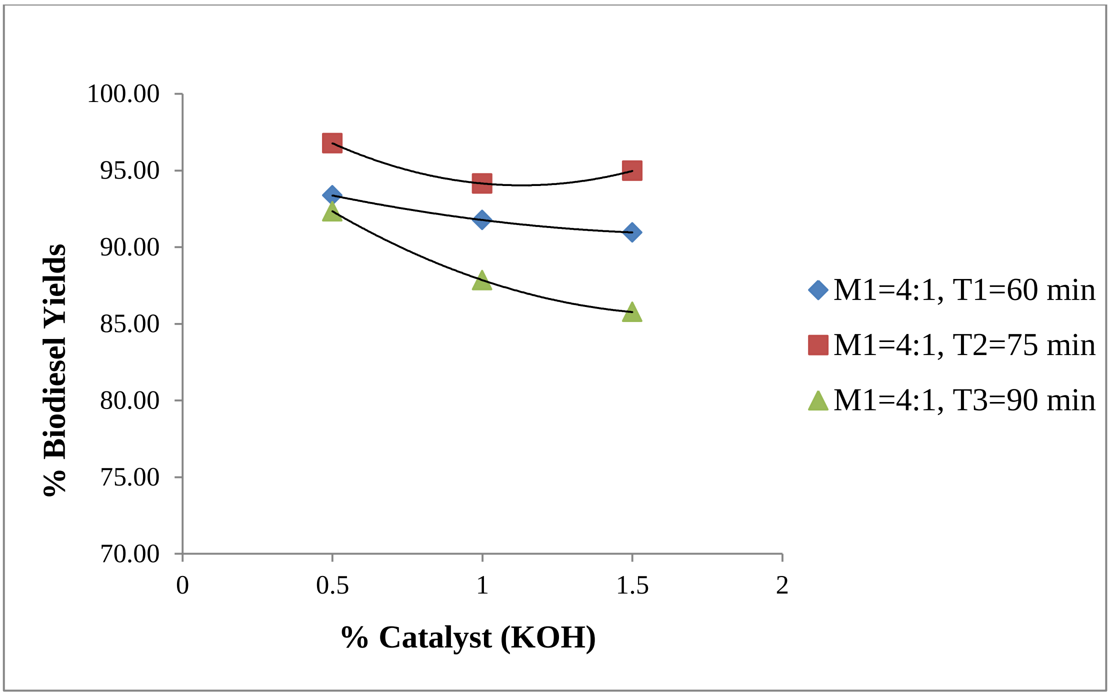


Figure 4.5: Variation of KOME yield with KOH concentration and reaction time at 4:1 molar ratio

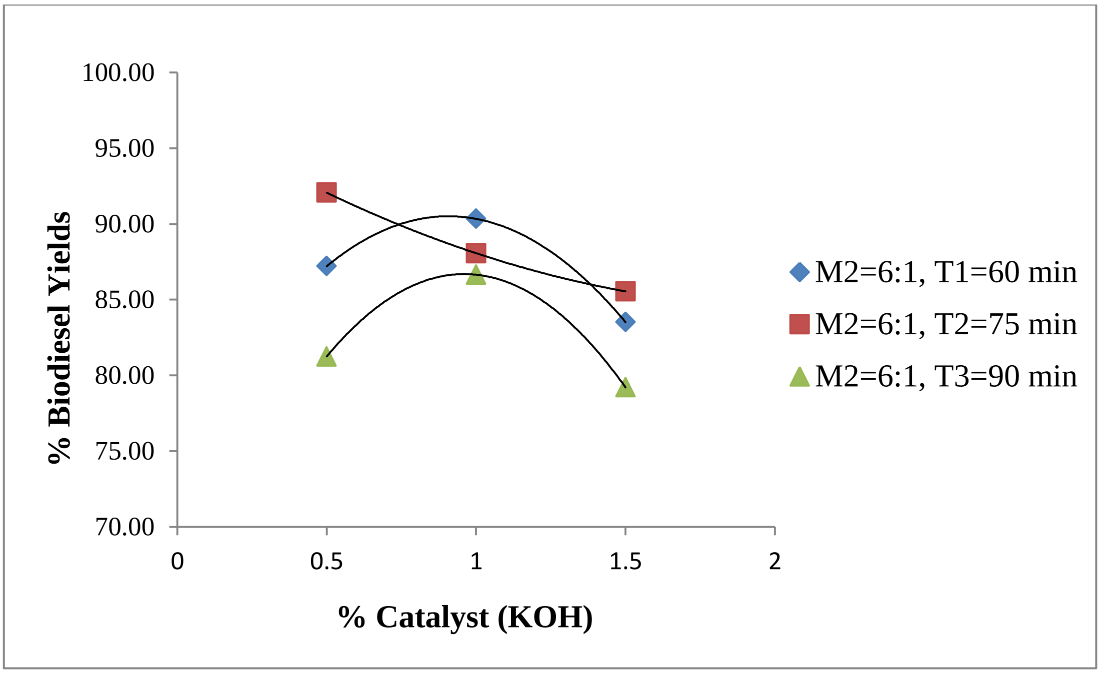


Figure 4.6: Variation of KOME yield with KOH concentration and reaction time at 6:1 molar ratio

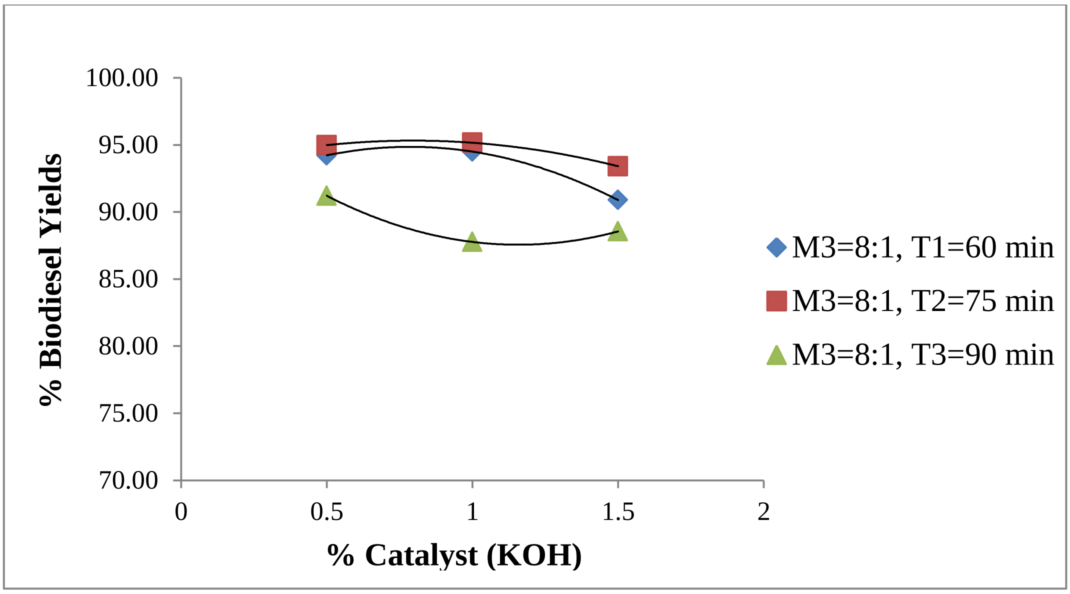


Figure 4.7: Variation of KOME yield with KOH concentration and reaction time at 8:1 molar ratio

The results found that catalyst concentration was a significant influencing parameter of transesterification reaction. As concentration of catalyst is raised from 0.5% to 1.5%, Fig. 4.5, Fig. 4.6 and Fig. 4.7 show that increasing trend of methyl ester formation at 30 minutes reaction time. Further increasing in % amount of catalyst concentrations were responsible of decreasing of methyl ester formation due to incomplete reaction because of soap formation. This is due to high FFA content present in the oil which deactivated the catalyst and present extra catalyst was responsible to form emulsion which raised the viscosity, lead to form gels and difficulty associated with glycerol separation and loss in ester yield [59].

It is also seen that reaction time is an important factor in production of biodiesel. As increasing reaction time from 60 minutes to 90 minutes, the yield grows or drops depending upon % catalyst concentration. The maximum yield is obtained 96.77% with catalyst concentration 0.5% at 75 minutes reaction time and the yield almost constant until reaction time up to 90 minutes.

4.2.5 Effect of methanol to oil molar ratio and reaction time on KOME formation

After analysis of effect of catalyst concentration, it is observed that the maximum yield of biodiesel was obtained at 0.5% catalyst concentration. Figure 4.8 shows the influence of molar ratio and reaction time on methyl ester yield at reaction temperature 60° C with 0.5%

catalyst concentration. It was noticed that as the methanol/oil molar ratio increases from 4:1 to 8:1, the yield also increase with respect to reaction time. The cause is this, transesterification reaction is reversible in nature due to this additional methanol is needed to shift the equilibrium towards product side (higher yield of methyl ester) [60]. But generally higher molar ratio is not selected because of more consumption of energy required for recovering unreacted methanol and presence of excess methanol suspended into by product glycerin which is responsible to made separation difficult. It is also observed that maximum methyl ester yield i.e. 96.77% was acquired with 4:1 molar ratio at 75 minutes reaction time.

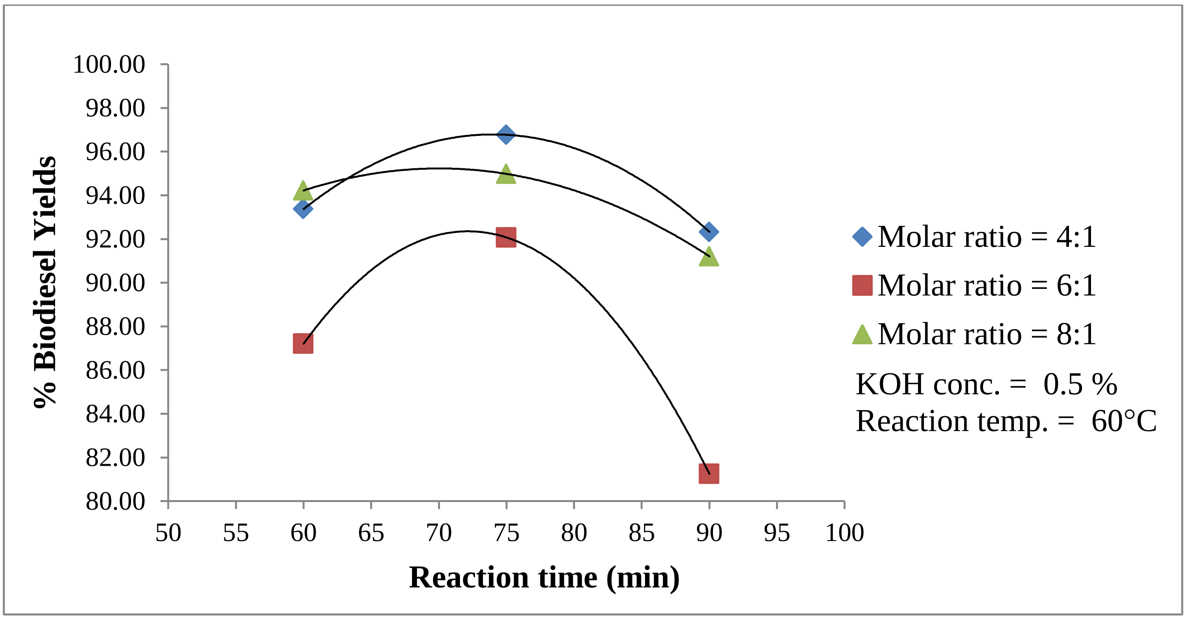


Figure 4.8: Variation of KOME yield with molar ratio and reaction time at 0.5% KOH concentration

4.2.6 Effect of % catalyst concentration and reaction time on KOME viscosity

The influence of increasing molar ratio and catalyst KOH concentration was illustrated in the Fig. 4.9. It was found that as the molar ratio increases from 4:1 to 8:1, viscosity of methyl ester increases. This is due to excess molar ratio increase the methanol solubility in glycerin which makes separation difficult and the remains glycerin in solution cause high viscosity of methyl ester. As per project requirement, the minimum viscosity 5.25 cSt has been obtained at 6:1 molar ratio, 1% catalyst concentration and 60 minutes reaction time.

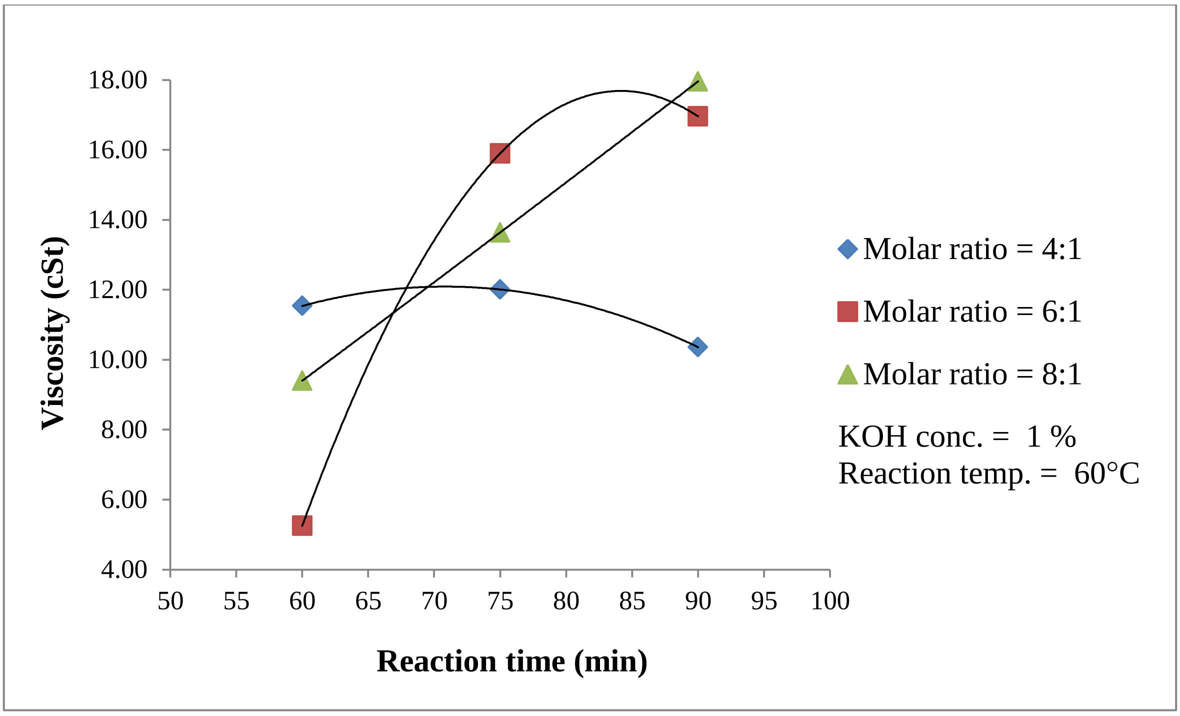


Figure 4.9: Variation of KOME viscosity with molar ratio and reaction time at 1% KOH concentration

4.3 Analysis of Safflower oil (SO) and Kusum oil (KO) and its methyl ester

Table 4.4 represents the physicochemical properties of safflower and kusum oil and its methyl ester.

Table 4.4: Physicochemical properties of safflower and kusum oil and its methyl ester

Parameters	Standard	ASTM	SO	SOME	KO	KOME	Diesel [52]
Density at 15°C (kg/m^3)	IS: 1448 [P: 32]: 1992	860-900	897.92	870.32	902.32	880.12	820-860
Free fatty acid content (%)	-	-	2.46	0.24	5.6	0.23	-
Kinematic viscosity at 40°C (cSt)	IS : 1448 [P : 25] 1976	1.9-6.0	34.21	5.63	36.63	5.25	2.5-3.5
Flash point (°C)	IS: 1448	>93	226.8	185	240	146	>55

Fire point (°C)	[P: 32]: 1992	-	240	200	260	153	-
Cloud point (°C)	IS: 1448	<3	-4	-3	-5	-4	-16
Pour point (°C)	[P: 10]: 1970	-	-6	-7	-7	-8	-33
Higher Heating value (MJ/kg)	IS: 1448 [P: 6]: 1984	-	40.2	42.45	39.47	42.89	42.7
Water content (mg/kg)	-	Max. 500	443.79	229.54	436.21	215.32	-

4.4 Engine performance and emission parameters of blend of SOME and KOME fuel

In this experimental work, three types of blend namely B10, B20 and B30 have been used and all the experiments have been carried out at constant compression ratio i.e. 17:1. The parameters such as brake power (BP), brake specific fuel consumption (BSFC), brake thermal efficiency (BTE), mechanical efficiency (MEff), carbon monoxide emission (CO), unburned hydrocarbon (HC), nitrogen of oxide (NOx) and exhaust gas temperature (EGT) were evaluated in this investigation.

4.4.1 Performance and emission parameters of SOME blend fuel

(a) Brake power (BP)

Figure 4.10 presented the variation of brake power of tested fuel under various load conditions. It was observed that the brake power of all blends (SB10, SB20 & SB30) and diesel fuel were increased linearly with engine load. As per Fig. 4.10, the brake power obtained for all blends are almost similar to diesel fuel because of higher density and oxygen content of biodiesel fuel than that of diesel fuel. This higher density of biodiesel fuel lead to more fuel consumption for compensation of lower heating value of biodiesel fuel blends and better combustion characteristics was observed followed by higher oxygen content [61, 62]. The average brake power for diesel fuel was found to be 1.45kW which 1.82%, 3.08% and 4.91% higher than that of biodiesel fuel blends SB10, SB20 and SB30 respectively.

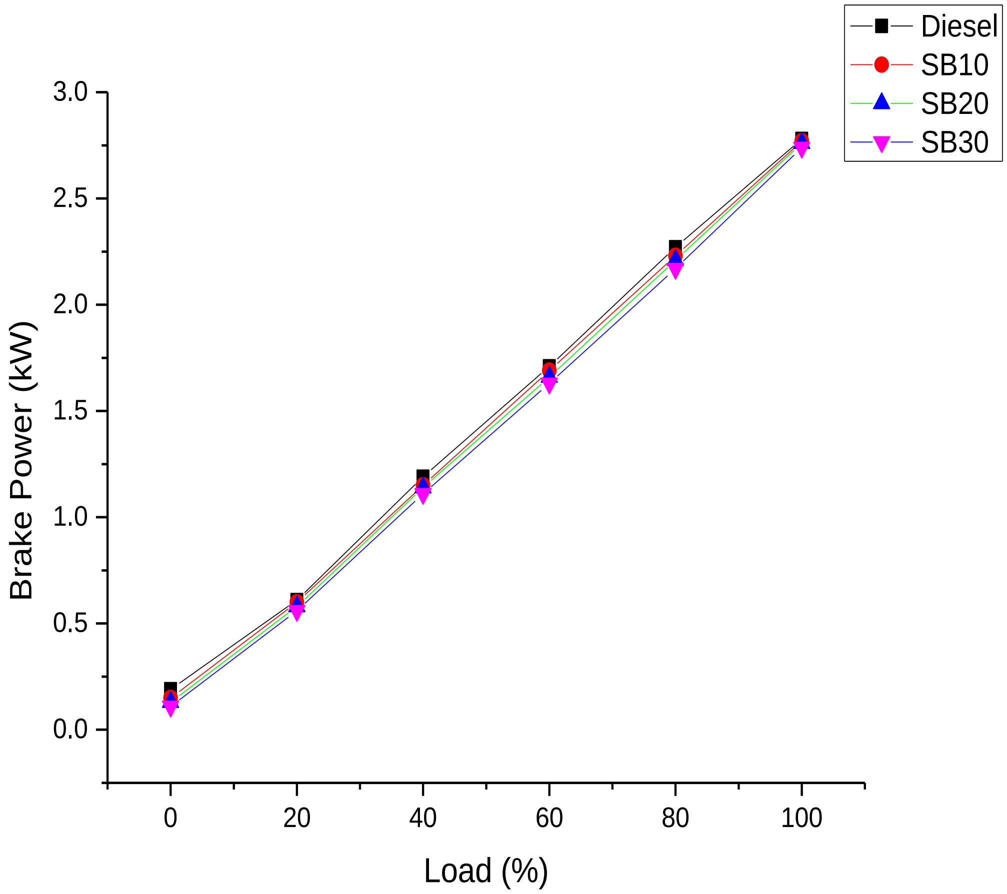


Figure 4.10: Variation of brake power of SOME blend and diesel fuel with load

(b) Brake specific fuel consumption (BSFC)

The brake specific fuel consumption variation for distinct blends (SB10, SB20 and SB30) and diesel fuel were shown in Fig. 4.11. For all fuel blends, BSFC was decreased with increase the engine load. The maximum BSFC was obtained 2.19 kg/kWh for SB30 blend at no load condition and further increasing the engine load, BSFC was found that just about constant for all fuel blends and diesel fuel (40-100% load). The average BSFC for different blends (SB10, SB20, SB30) and diesel fuel were observed 0.591 kg/kWh, 0.655 kg/kWh, 0.716 kg/kWh and 0.521 kg/kWh respectively. The reason of increasing the BSFC for all blends in comparison of diesel fuel is that for same power output mass of fuel consumption of blended fuel more due to longer injection duration than that of diesel fuel and higher density of biodiesel fuel blends.

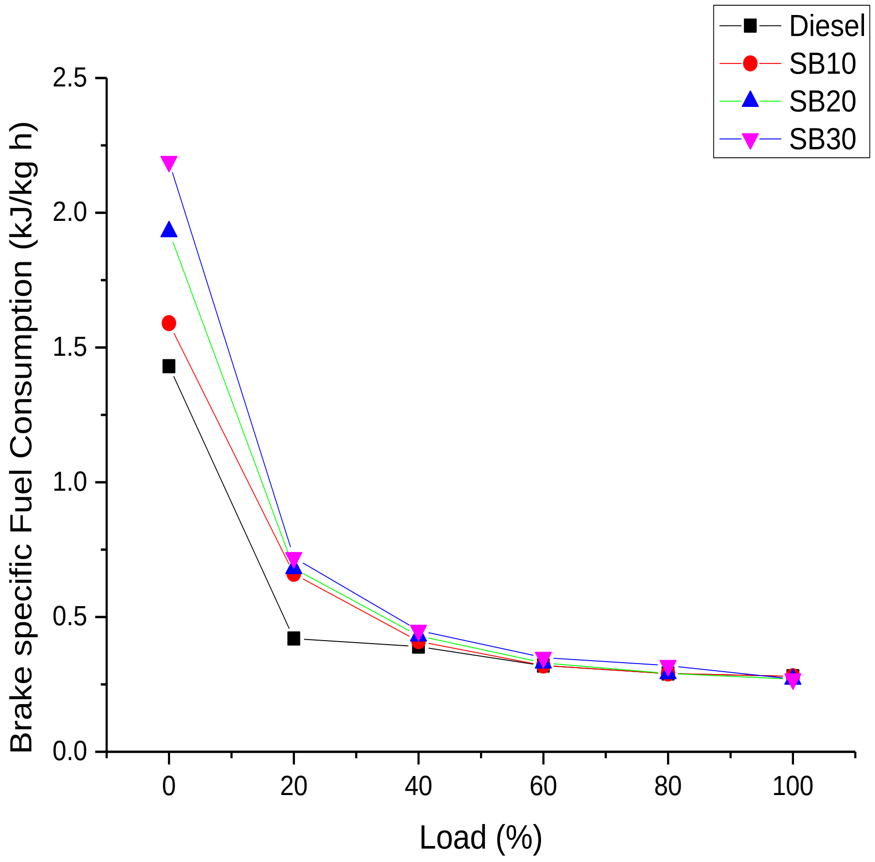


Figure 4.11: Variation of brake specific fuel consumption of SOME blend and diesel fuel with load

(c) Brake thermal efficiency (BTE)

Figure 4.12 shows the variation of brake thermal efficiency for different blends and diesel fuel under various load condition (0-100%). For all the cases, the brake thermal efficiency increased with increasing the engine load because of less heat loss and increased in power output [63]. The highest brake thermal was found that 30.28% at full load condition (100%) for SB30 blended fuel which is 5.84%, 5.94% and 0.36% higher than that of diesel, SB10 and SB20 fuel respectively. The average brake thermal efficiency blended fuel SB10, SB20, SB30 and standard diesel fuel are 19.36%, 19.92%, 19.29% and 20.87% respectively. Lower brake thermal efficiency of blended fuel may be responsible of integrated influence of lower heating value and higher fuel consumption [64].

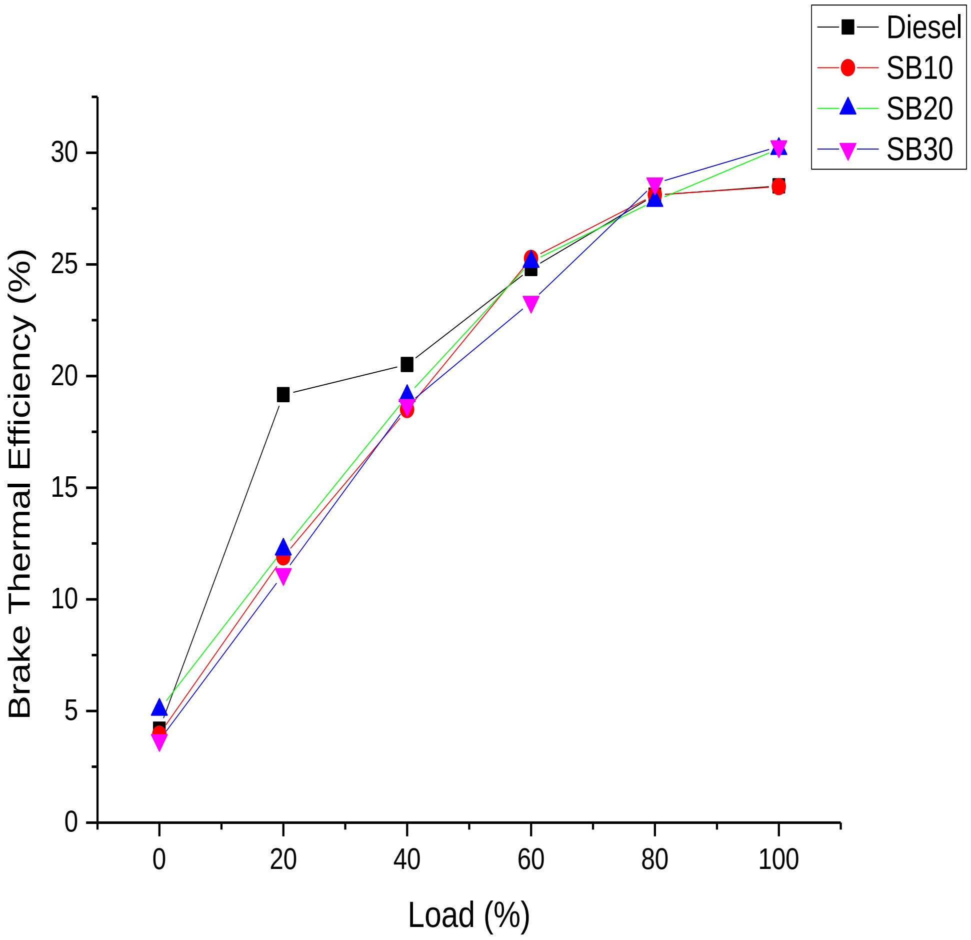


Figure 4.12: Variation of brake thermal efficiency of SOME blend and diesel fuel with load

(d) Mechanical efficiency (MEff)

Figure 4.13 shows that the variation of mechanical efficiency under various loading condition for all cases. It was observed that the mechanical efficiency increased with increasing the engine load and found that mechanical efficiency for all blended fuel under various load condition very adjacent to standard diesel fuel. The highest mechanical efficiency was obtained for standard diesel fuel than that of blended fuel at full load condition. The mechanical efficiency of standard diesel fuel, SB10, SB20 and SB30 were observed about 47.10%, 46.61%, 45.09% and 45.40% respectively under full load condition. The cause of increasing the mechanical efficiency of blended fuel may be good atomization characteristics of fuel and reduction in heat loss [65].

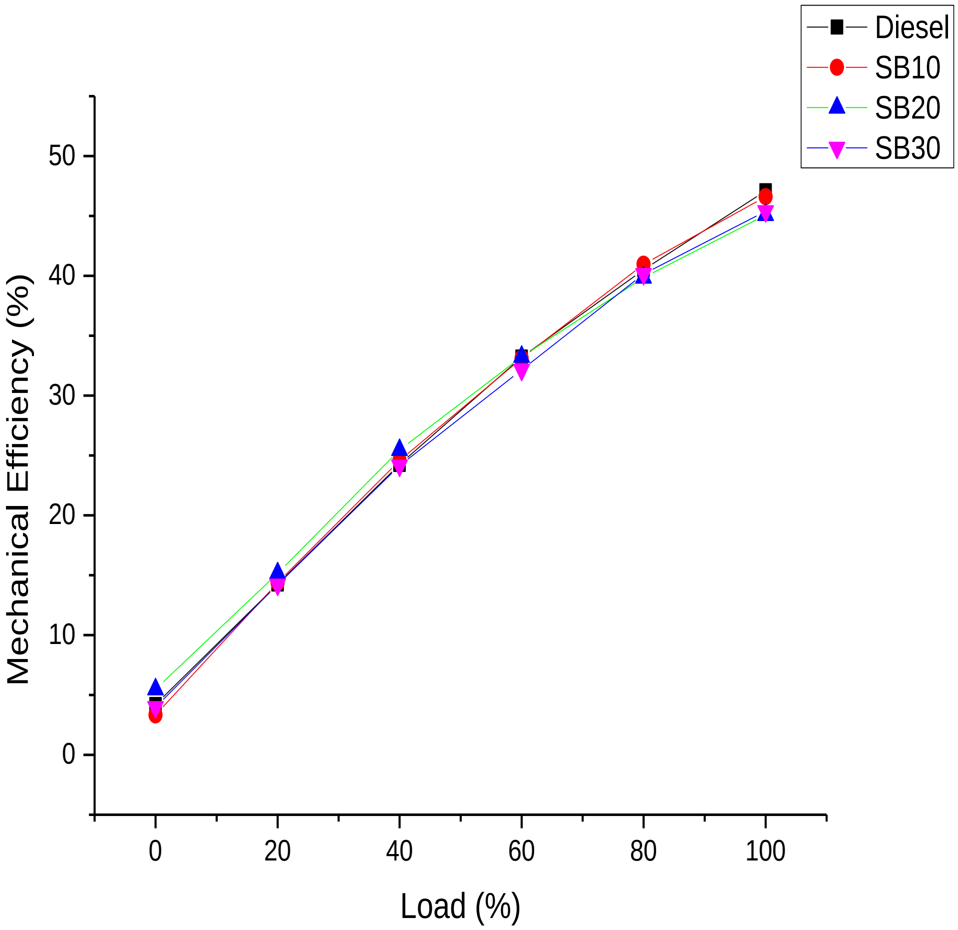


Figure 4.13: Variation of mechanical efficiency of SOME blend and diesel fuel with load

(e) Exhaust gas temperature (EGT)

The exhaust gas temperature for diesel fuel and its blend fuels with biodiesel (SB10, SB20, SB30) under different load conditions were presented in Fig. 4.14. It was observed that the exhaust gas temperature for all tested fuel increases with load. The exhaust gas temperature of diesel fuel was found minimum in comparison of blend fuels due to incomplete combustion of diesel fuel. It can be seen that in Fig. 4.14, the highest exhaust gas temperature was obtained for SB30 blend fuel at all load conditions because of extra oxygen content present in biodiesel fuel which promotes the more complete combustion. The average exhaust gas temperature for diesel, SB10, SB20 and SB30 fuels are 66.5°C, 74.16°C, 77.33°C and 80.83°C respectively.

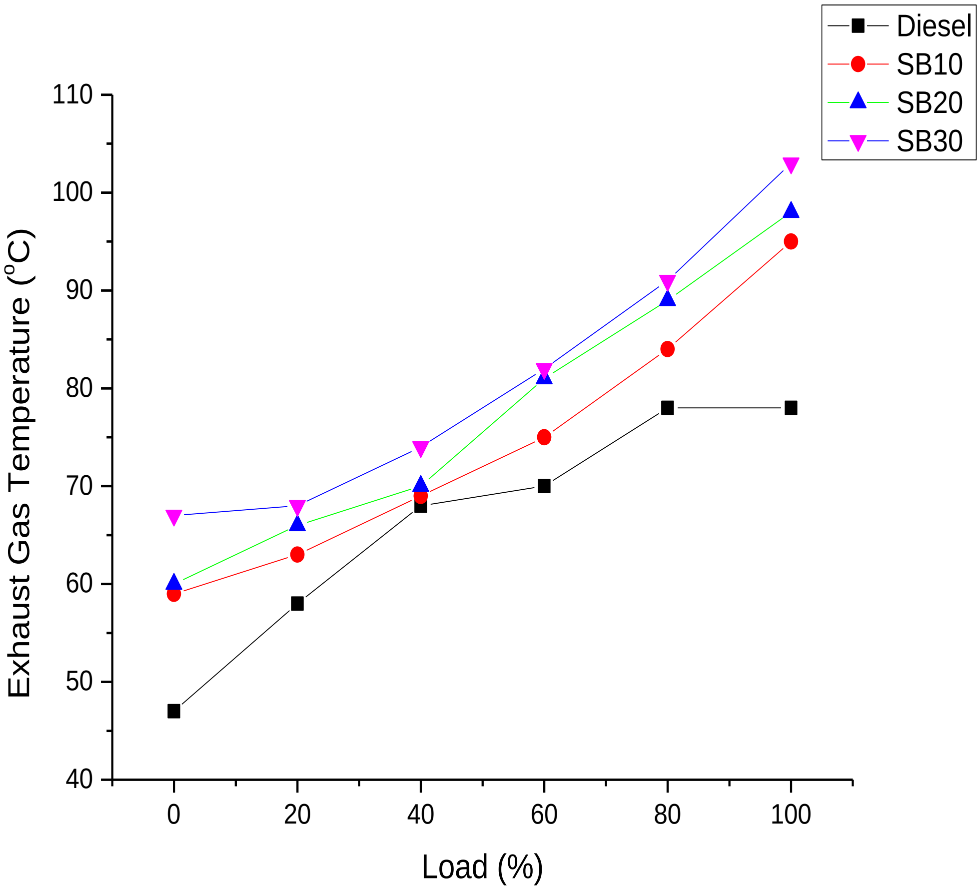


Figure 4.14: Variation of exhaust gas temperature emission of SOME blend and diesel fuel with load

(f) Carbon monoxide emission (CO)

CO emission for diesel fuel and its different blends with biodiesel (SB10, SB20 and SB30), under various load conditions are shown in Fig. 4.15. It was seen that CO emission decreases with increases percentage of biodiesel content in the blends. It may be due to higher oxygen content, lower carbon to hydrogen ratio and higher cetane number of biodiesel fuel. The higher amount of oxygen content in biodiesel promotes the more complete combustion which leads reduction in CO emission and higher cetane number prevent the rich fuel mixture zone which improves combustion quality and reduces CO emission [66, 67]. At different load conditions, the lowest CO emission was found for SB30 blend fuel in comparison of other respective blend fuels (SB10, SB20) and diesel fuel. The average CO emission was noticed that 329.33 ppm, 294 ppm, 257.66 ppm and 243.33 ppm for diesel, SB10, SB20 and SB30 blend fuels respectively.

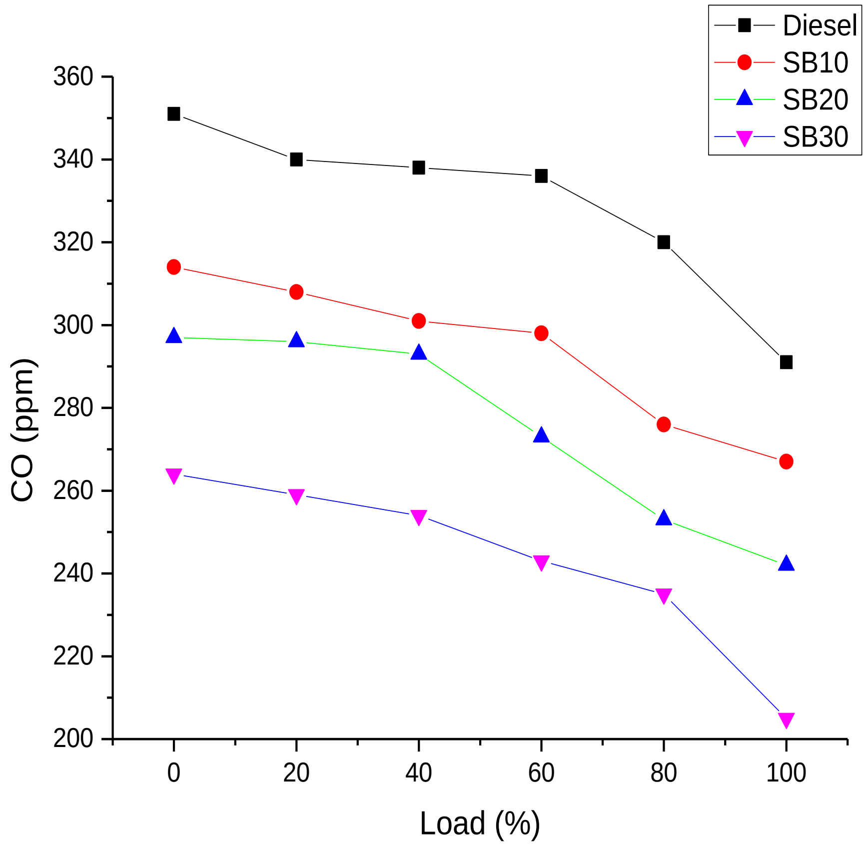


Figure 4.15: Variation of carbon monoxide emission of SOME blend and diesel fuel with load

(g) Hydrocarbon emission (HC)

Figure 4.16 shows the variation of hydrocarbon emission under various load conditions for diesel fuel and blended fuels these are SB10, SB20 and SB30. The hydrocarbon emission for all tested fuels was decreased with increasing engine load and almost similar results were observed for blend SB20, SB30 at different loading conditions as per shown in Fig. 4.16. In present study, the maximum hydrocarbon emission have been found for diesel fuel due to its higher volatility and lack of oxygen may available for vaporization of final fraction of diesel fuel which results higher hydrocarbon emission [51]. At part load and full load condition, the hydrocarbon emission of blend fuel SB10, SB20, SB30 were diminished 9.36%, 10.29%, 26.24% and 4.31%, 4.47%, 25.68% respectively than that of diesel fuel.

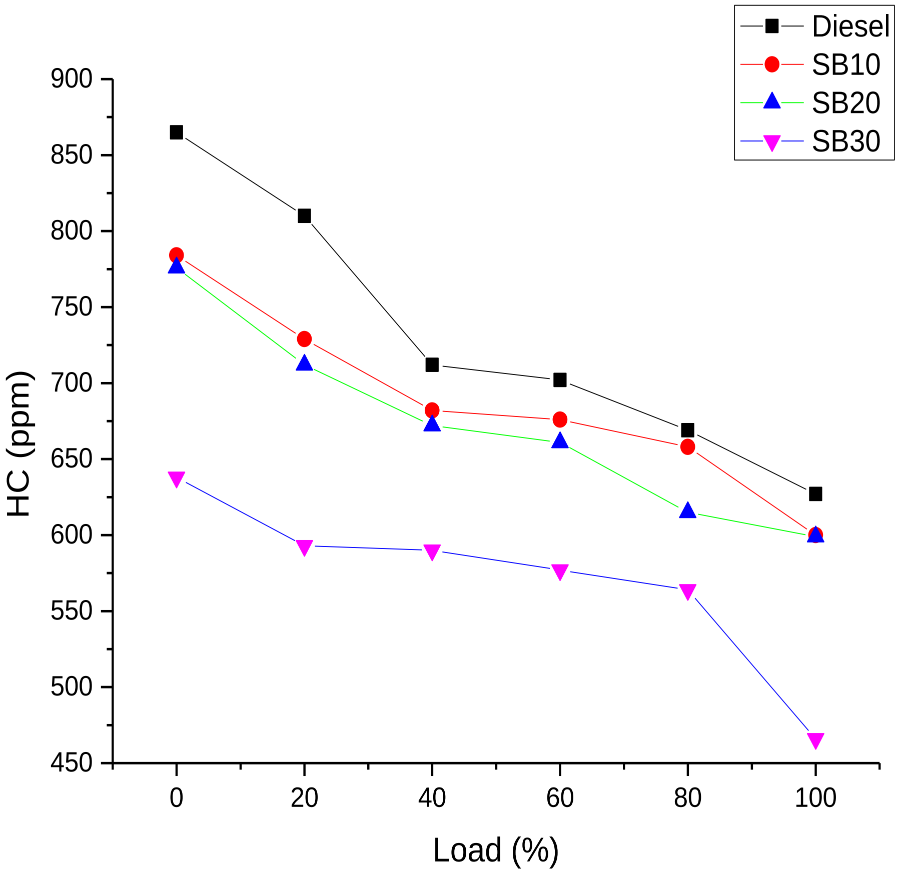


Figure 4.16: Variation of unburned hydrocarbon emission of SOME blend and diesel fuel with load

(h) Nitrogen oxide emission (NOx)

The variation of nitrogen oxide (NO_x) emission of diesel fuel and its blend fuels (SB10, SB20, SB30) in the VCR engine are shown in Fig. 4.17. For a particular load of application, the NO_x emission increase with increases the proportion of biodiesel fuel in blend fuels. The maximum NO_x emission was obtained for SB30 blend fuel as shown in Fig. 4.17 which is higher than that of diesel fuel and other blend fuels i.e. SB10, SB20. The reason of NO_x production is higher oxygen content in biodiesel fuel which promotes proper combustion and thus increases the temperature in the combustion chamber which results higher rate of NO_x reaction occur in the combustion chamber. Another reason is higher cetane number of biodiesel fuel which leads pre- ignition by reducing ignition delay time and thus increase NO_x formation reaction rate [51]. It was observed that at full load condition increase in NO_x emission 29.87%, 57.14% and 62.33% for respective blend fuels SB10, SB20 and SB30 than that of diesel fuel.

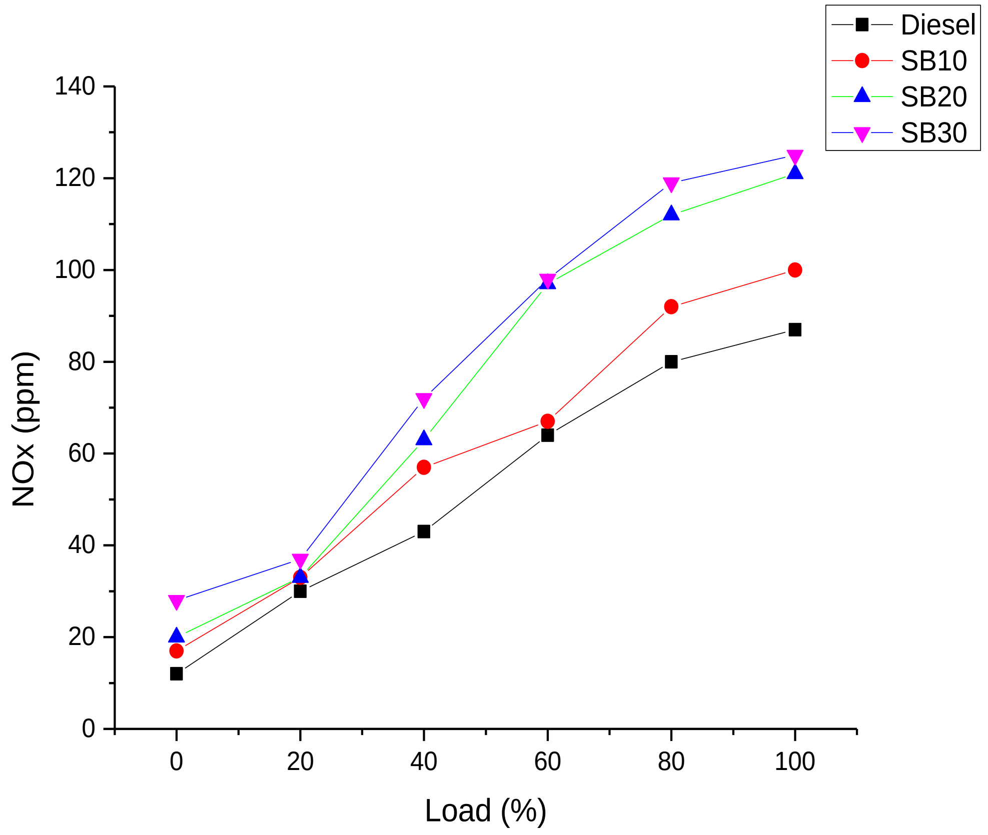


Figure 4.17: Variation of oxide of nitrogen emission of SOME blend and diesel fuel with load

4.4.2 Performance and emission parameters of KOME blend fuel

(a) Brake power (BP)

Figure 4.18 presents the variation of brake power at different load conditions for all tested fuel. The brake power of all tested fuel increased with load and shows good results. It was found that there was no remarkable difference noticed in brake power of blend fuels (KB10, KB20, KB30) and diesel fuel. Blend KB20 was contributing the maximum brake power at no load and full load because of higher fuel consumption which compensate lower heating value of blend fuel and proper combustion followed by higher inherent oxygen content in biodiesel fuel. At full load condition, the brake power of blend fuels KB10, KB30 and diesel fuel were 2.78kW, 2.76kW and 2.78kW respectively which is 1.76%, 2.47%, 1.76% less than that of KB20 blend fuel.

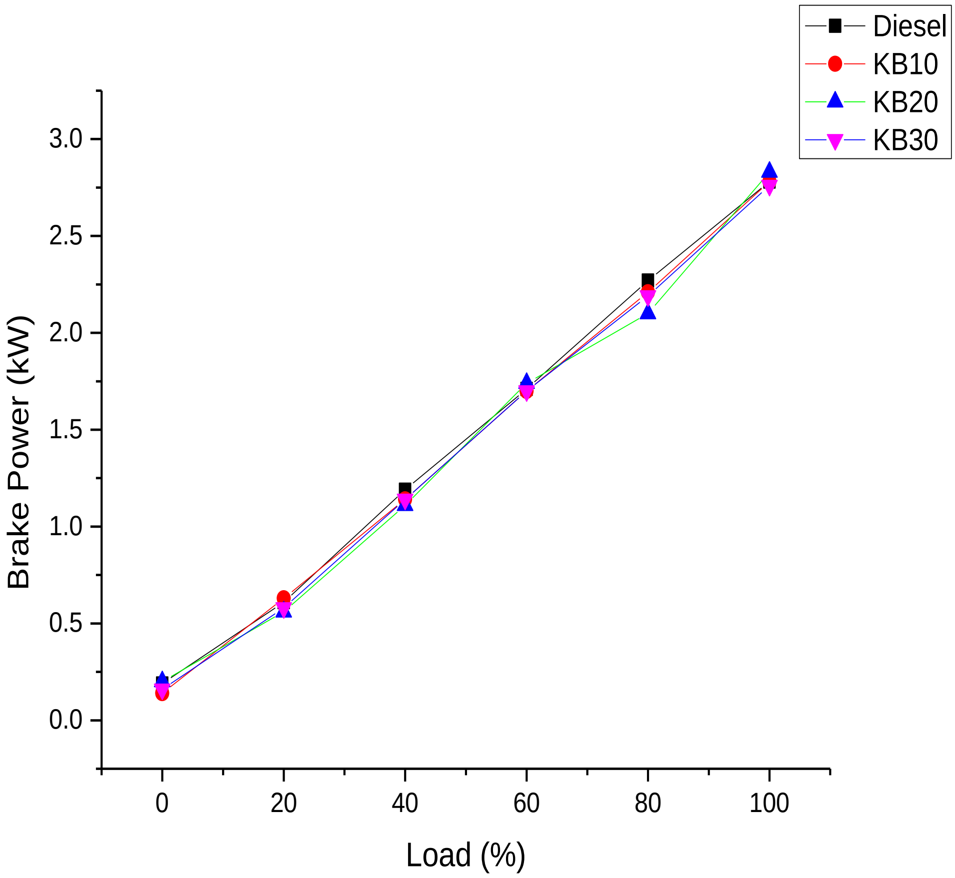


Figure 4.18: Variation of brake power of KOME blend and diesel fuel with load

(b) Brake specific fuel consumption (BSFC)

Figure 4.19 shows the brake specific fuel consumption for all blend fuels and diesel fuel at various load conditions. The brake specific fuel consumption of all tested fuel was decreased with increase in the engine load and almost same at 40% to 60% load. At no load condition, the brake specific fuel consumption of KB30 blend fuel was observed maximum and minimum for diesel fuel. This higher consumption of blend fuel was followed by higher viscosity, density and lower heating value of biodiesel fuel than that of diesel fuel. The average brake specific fuel consumption of all blend fuels KB10, KB20, KB30 and diesel fuel were 0.63 kg/kW h, 0.56 kg/kW h, 0.67 kg/kW h and 0.60 kg/kW h respectively.

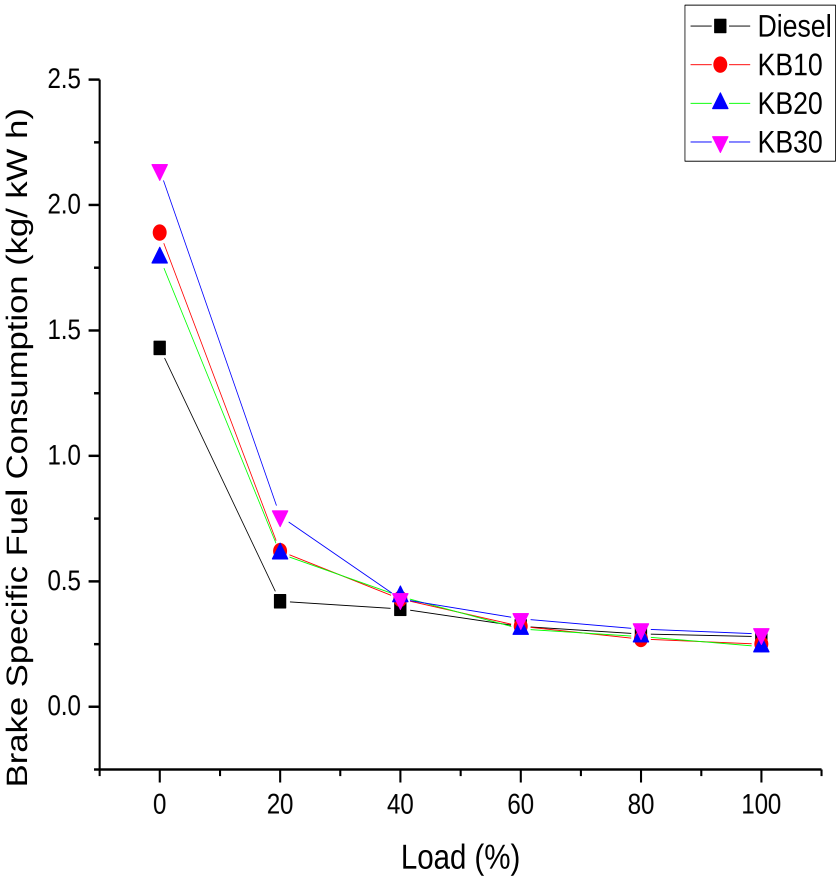


Figure 4.19: Variation of brake specific fuel consumption of KOME blend and diesel fuel with load

(c) Brake thermal efficiency (BTE)

Figure 4.20 shows the variation of brake thermal efficiency versus load. It was observed that brake thermal efficiency was increased with because of less loss of heat and higher engine power. The maximum brake thermal efficiency was found for KB20 blend fuel at no load and full load condition in comparison of other tested fuels. The average brake thermal efficiency was obtained 20.19%, 20.78%, 18.44% blend fuel KB10, KB20, KB30 respectively which is 3.29%, 0.47%, 11.67% less than that of diesel fuel.

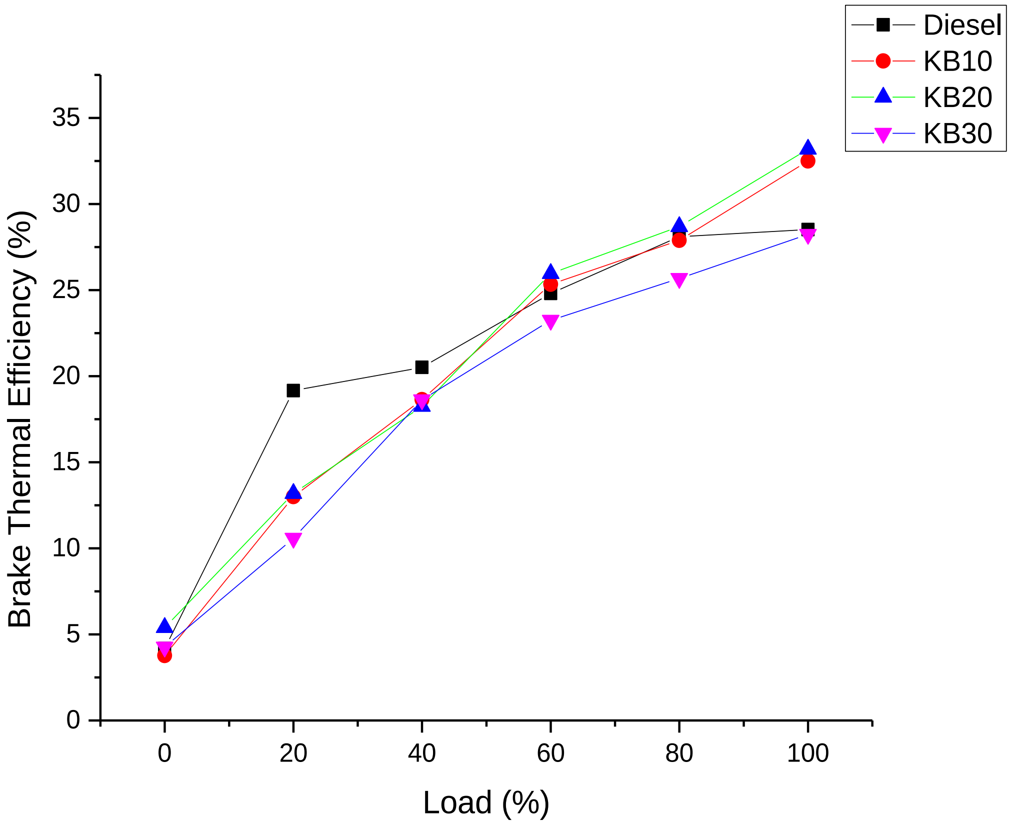


Figure 4.20: Variation of brake thermal efficiency of KOME blend and diesel fuel with load

(d) Mechanical efficiency (MEff)

The mechanical efficiency at different load conditions for all blend fuels and diesel fuel were shown in Fig. 4.21. It has been observed the increasing trend of mechanical efficiency with engine load. The highest mechanical efficiency was found for KB20 blend fuel and lowest for KB10 blend fuel for all load conditions. The higher in mechanical efficiency for blend fuels may be due to less loss of heat, high reaction rate and improved spray quality [68, 65]. At full load condition, there was no significant variation observed for diesel, KB20, KB30 fuel and the mechanical efficiency was obtained 47.10%, 48.43% and 47.61% respectively.

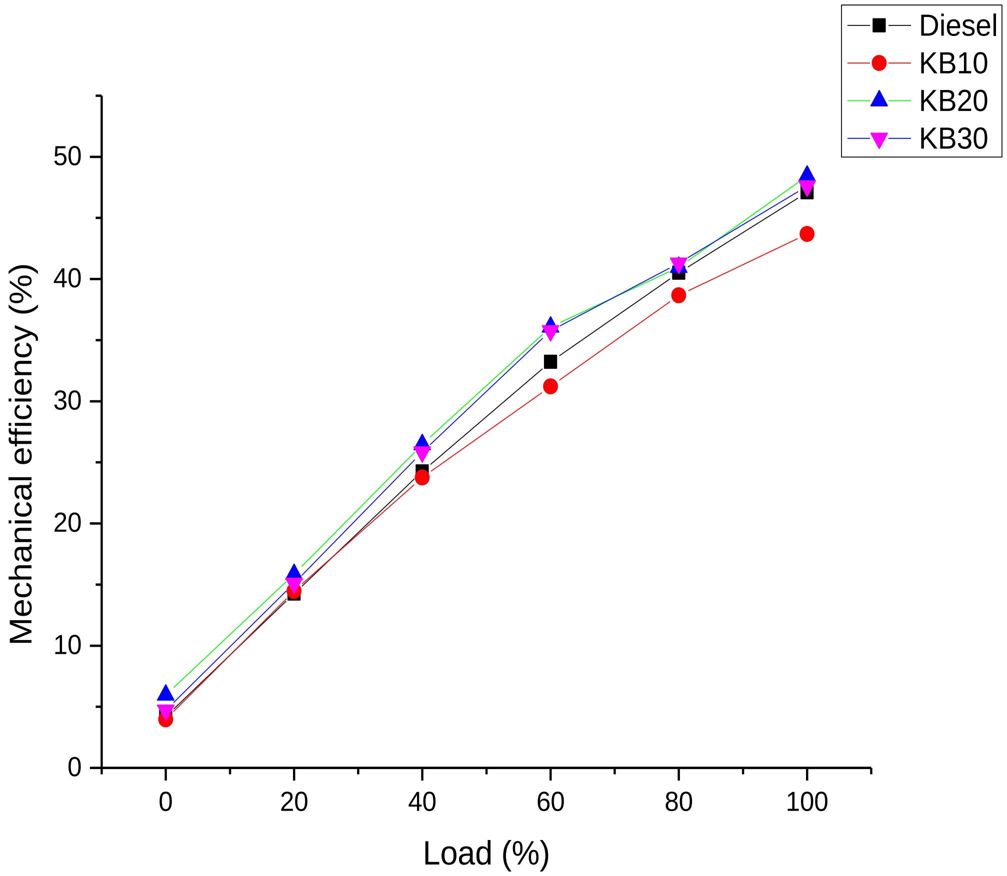


Figure 4.21: Variation of mechanical efficiency of KOME blend and diesel fuel with load

(e) Exhaust gas temperature (EGT)

The exhaust gas temperature of the all blend fuels and diesel fuel were shown in Fig. 4.22. The exhaust gas temperature was increased as the engine load increase. From Fig. 4.22, it can be seen that highest exhaust gas temperature was observed for blend fuel KB10, KB20 than that of diesel fuel at all load condition. At full load condition, the maximum exhaust gas temperature was obtained for KB30 blend fuel i.e. 101°C which is 0.99%, 11.88% and 22.77% higher than that of KB10, KB20 and diesel fuel respectively.

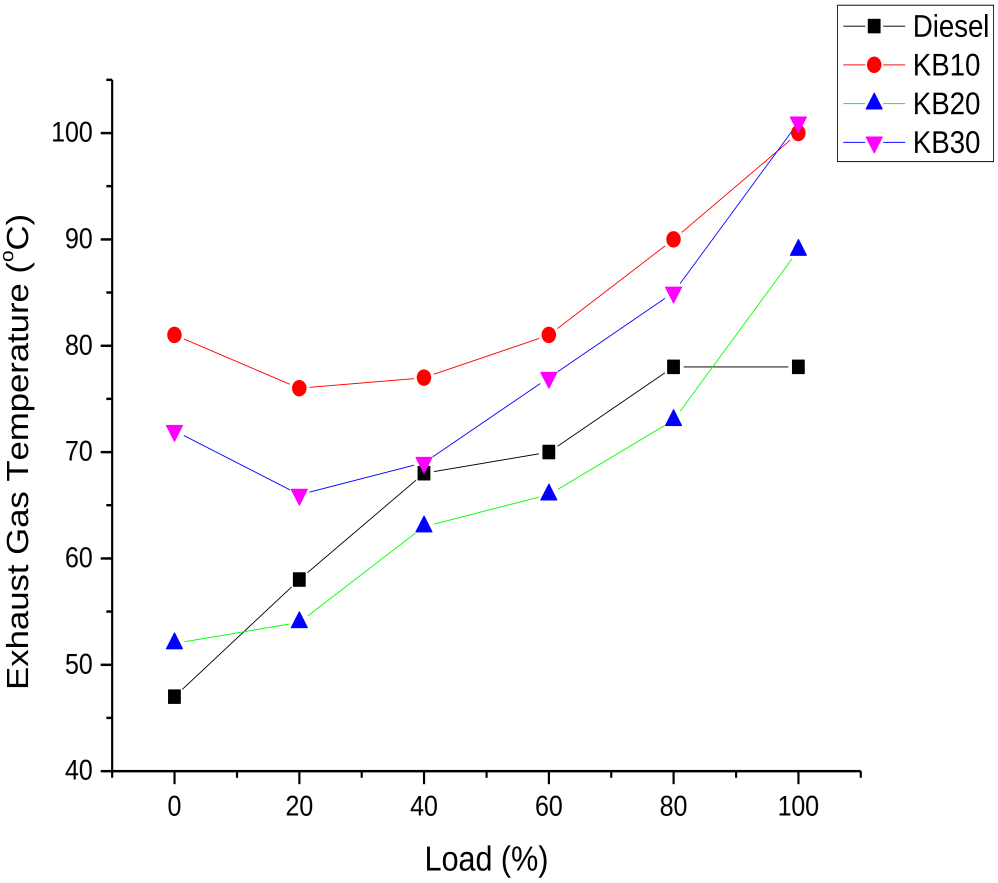


Figure 4.22: Variation of exhaust gas temperature of KOME blend and diesel fuel with load

(f) Carbon monoxide emission (CO)

Figure 4.23 shows the variation of CO emission at various load conditions of blend fuels and diesel fuel tested in VCR engine. It was observed that the lowest CO emission for blend KB30 because of higher percentage of biodiesel blend which contain inherently higher oxygen content and it was terminated the fuel rich mixture zone in the combustion chamber followed to be proper combustion of fuel. The CO emission for diesel fuel was found to be highest among the all tested fuel and it was decrease as the engine load increase until 100% due to higher combustion chamber temperature which promotes to more complete combustion [32]. At full load condition, the CO emission of blend fuel KB10, KB20, KB30 and diesel fuel were obtained 267ppm, 268ppm, 224ppm and 291ppm respectively.

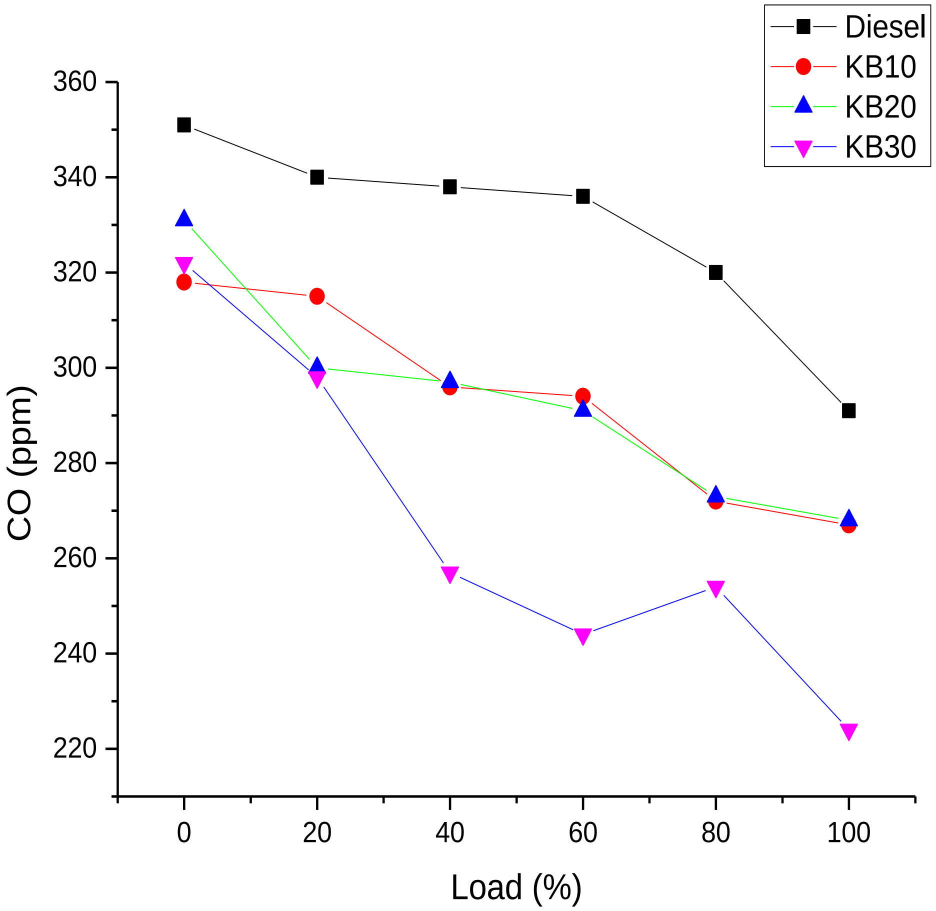


Figure 4.23: Variation of carbon monoxide emission of KOME blend and diesel fuel with load

(g) Hydrocarbon emission (HC)

The variation of hydrocarbon emission under various load conditions for all tested fuels in VCR engine is depicted in Fig. 4.24. The hydrocarbon emission decreased corresponding with increasing the engine load until 100%. Maximum hydrocarbon emission was observed for diesel fuel and minimum for blend fuels at all load condition. This can be due to higher oxygen content present in biodiesel fuel which promotes to more complete combustion results to reduce the hydrocarbon emission with increasing percentage biodiesel content in blend fuels. The average hydrocarbon emission of blend fuel KB10, KB20, KB30 and diesel fuel were found 703.16ppm, 453.66ppm, 606.5ppm and 730.83ppm respectively.

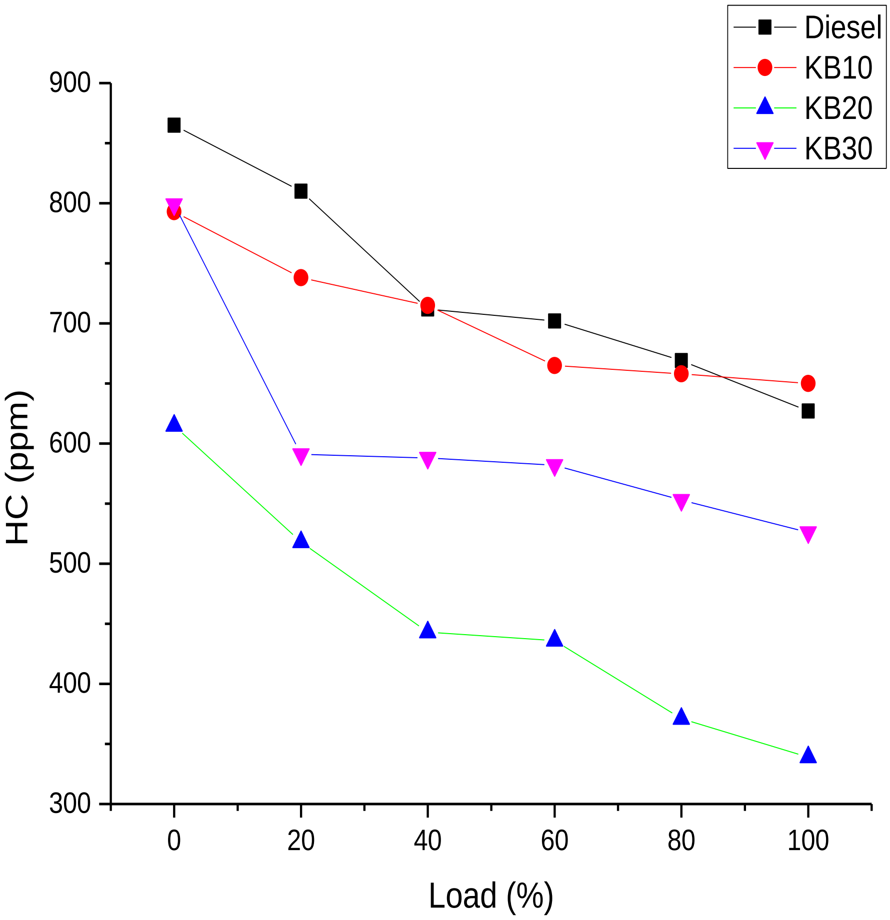


Figure 4.24: Variation of unburned hydrocarbon emission of KOME blend and diesel fuel with load

(h) Nitrogen oxide emission (NOx)

The variation of NOx emission at different load conditions can be seen in Fig. 4.25. It was observed that the NOx emission of blend fuel KB10, KB30 and diesel fuel are closed to each other, no remarkable difference was noticed. It was seen that at no load and full load condition, higher NOx emission were found for blend fuel KB10, KB30 than that of standard diesel fuel but it has been less for KB20 blend fuel. This can be due to combined effect of combustion chamber temperature, mean effective pressure and fuel blend etc. [69, 70]. The average NOx emission of all blend fuel KB10, KB20, KB30 and diesel fuel were found 56.66ppm, 45.16ppm, 52.16ppm and 51.5 ppm respectively.

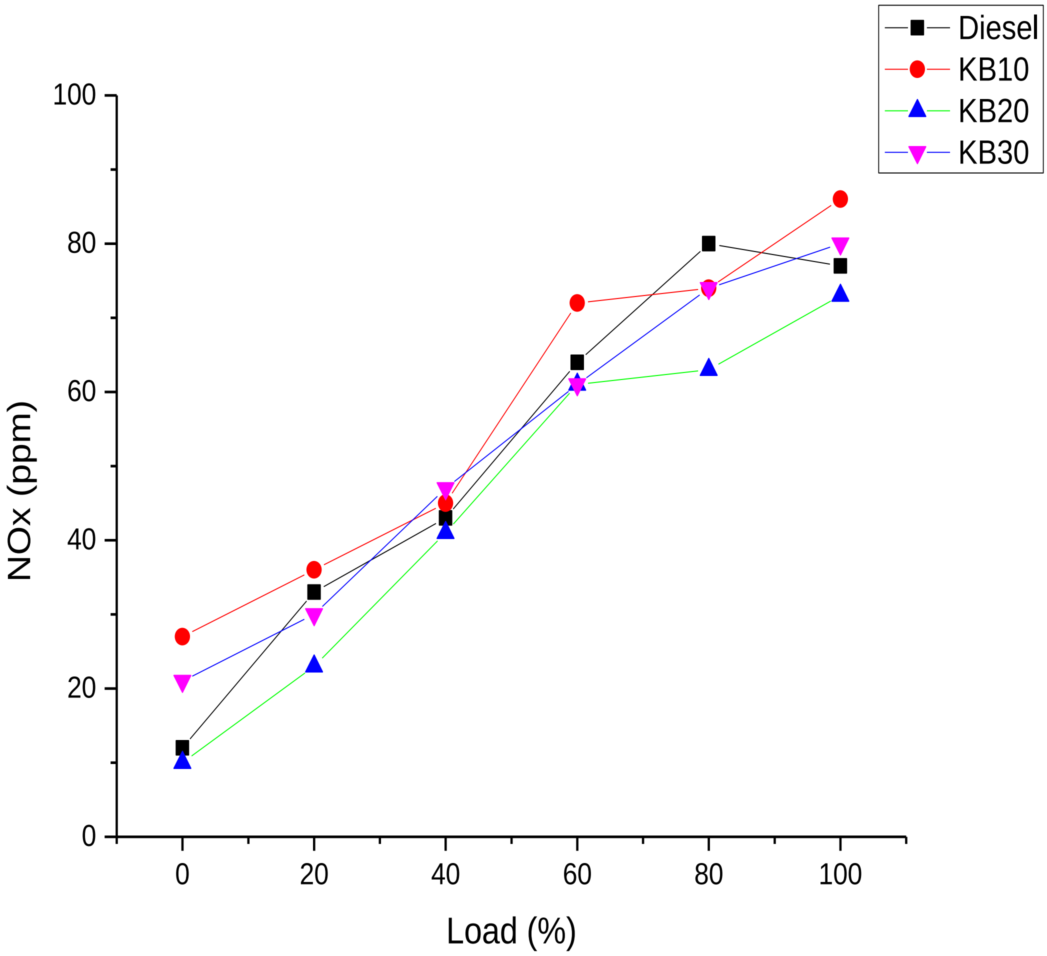
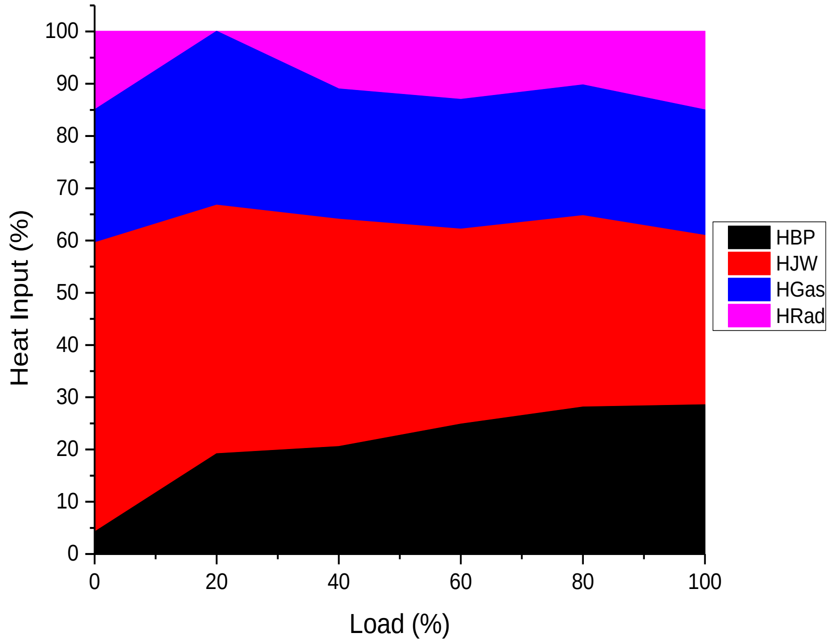


Figure 4.25: Variation of oxide of nitrogen emission of KOME blend and diesel fuel with load

4.5 Heat balance

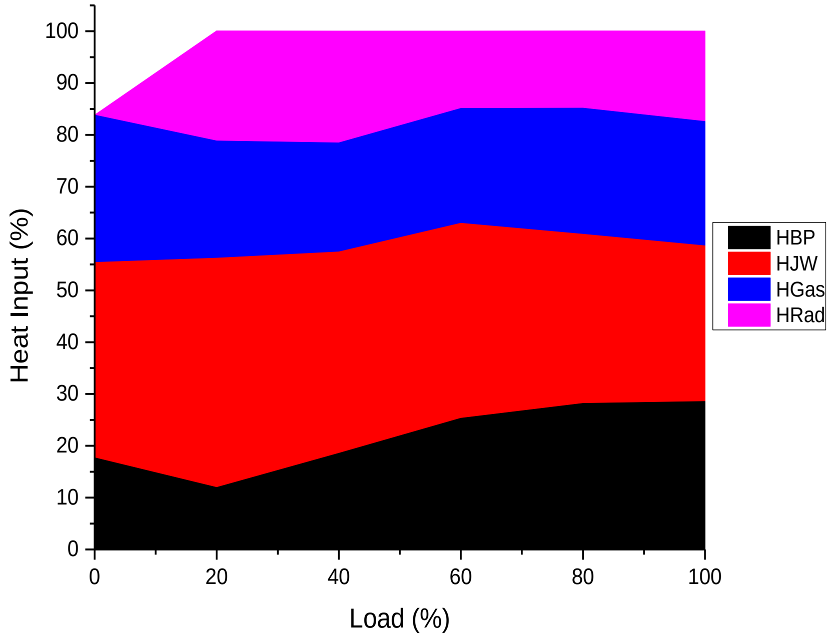
Energy input to an engine is in the form of chemical energy (heat value of fuel in kW) which is generated by burning of fuel. As per second law of thermodynamic, the some part of this chemical energy convert into useful work and rest of part of that energy waste or utilized in other special application. Two part of that energy lost in the form of heat carried away by cooling water and exhaust gas. For preparation of heat balance sheet, it required brake power, cooling water flow rate, temperature of exhaust gas, cooling water temperature, specific heat of exhaust gas and it was seen that there are some uncounted heat losses exist such as heat loss by radiation and incomplete combustion. The heat balance for all blend fuels (SOME & KOME) and diesel fuel were shown in below given Fig. 4.26 (a), (b), (c), (d), (e), (f) & (g).

Heat balance for diesel fuel



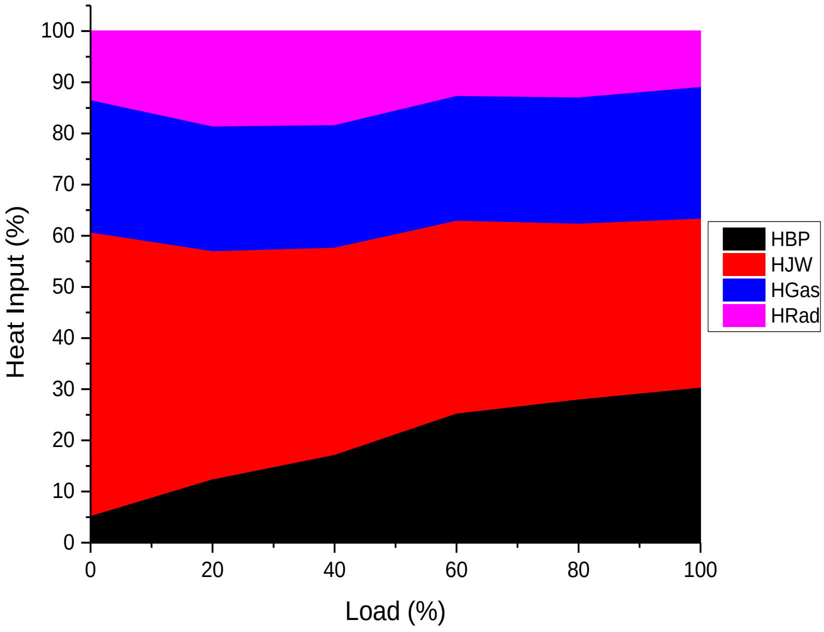
(a)

Heat balance for SB10 blend fuel



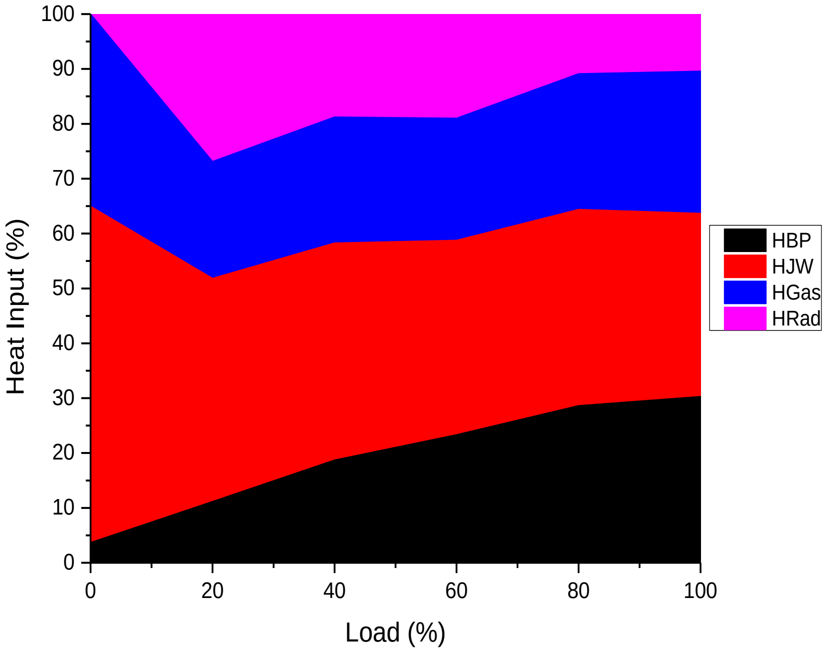
(b)

Heat balance for SB20 blend fuel



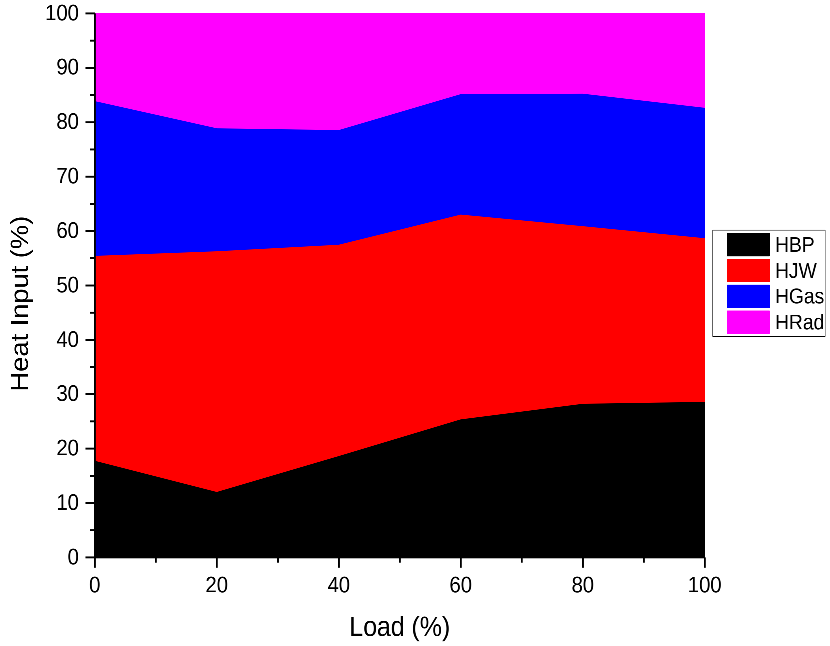
(c)

Heat balance for SB30 blend fuel



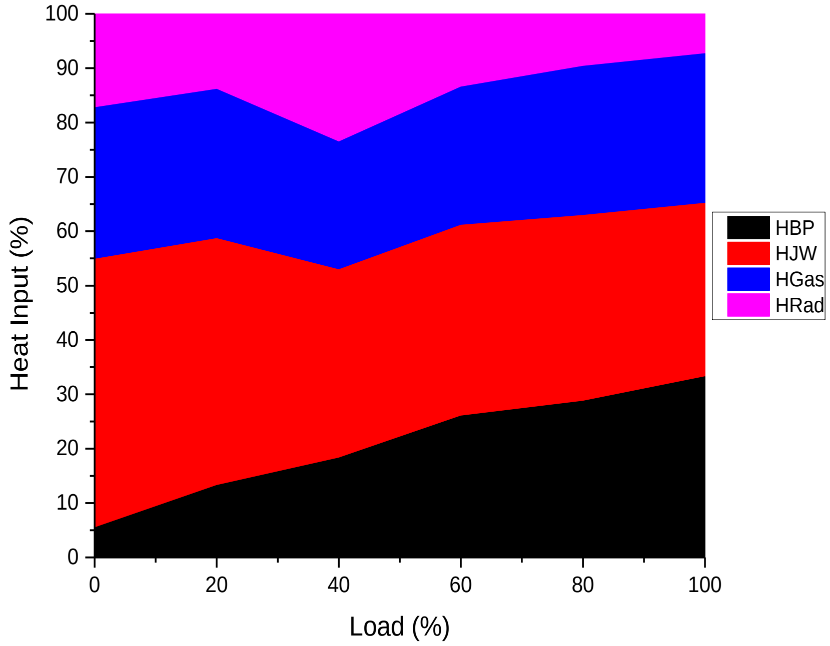
(d)

Heat balance for KB10 blend fuel



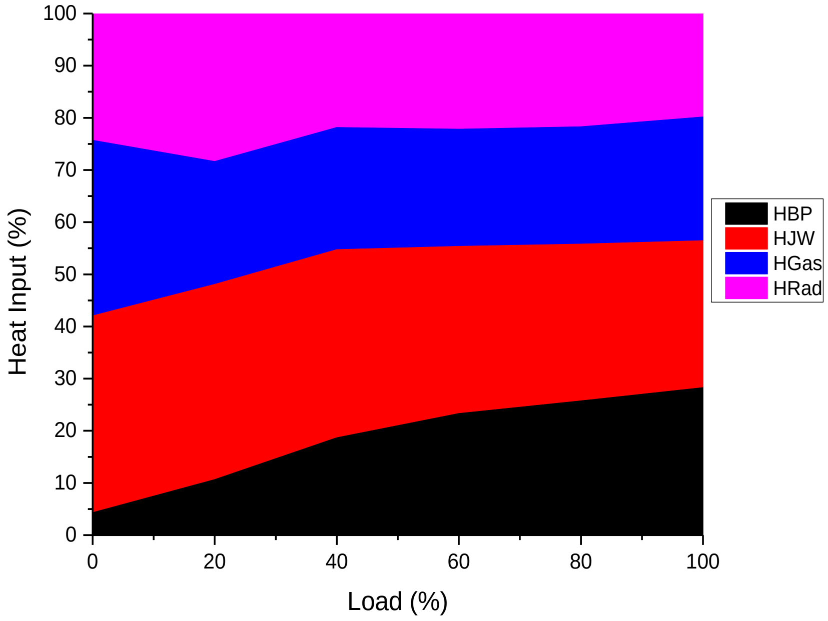
(e)

Heat balance for KB20 blend fuel



(f)

Heat balance for KB30 blend fuel



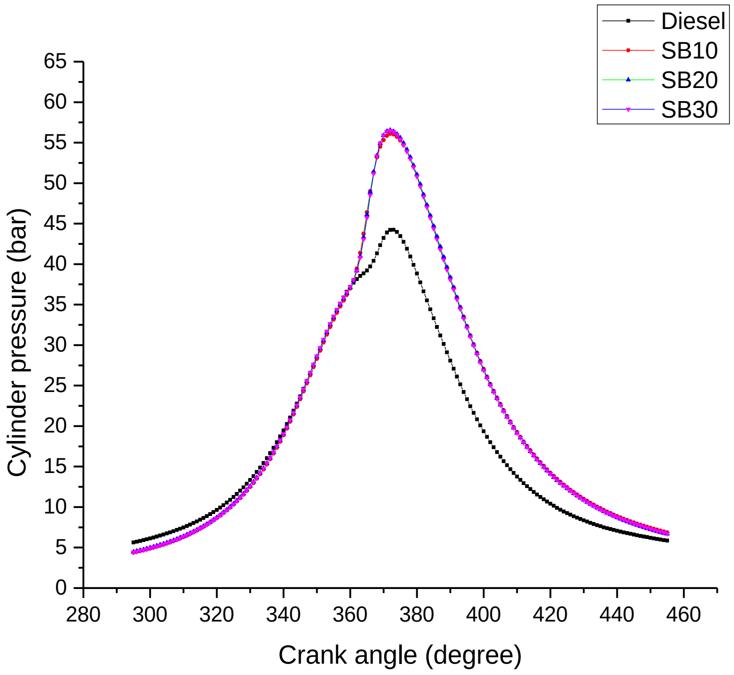
(g)

Figure 4.26: Percentage heat input with load for (a) diesel fuel, (b) SB10 blend fuel, (c) SB20 blend fuel, (d) SB30 blend fuel, (e) KB10 blend fuel, (f) KB20 blend fuel, (g) KB30 blend fuel

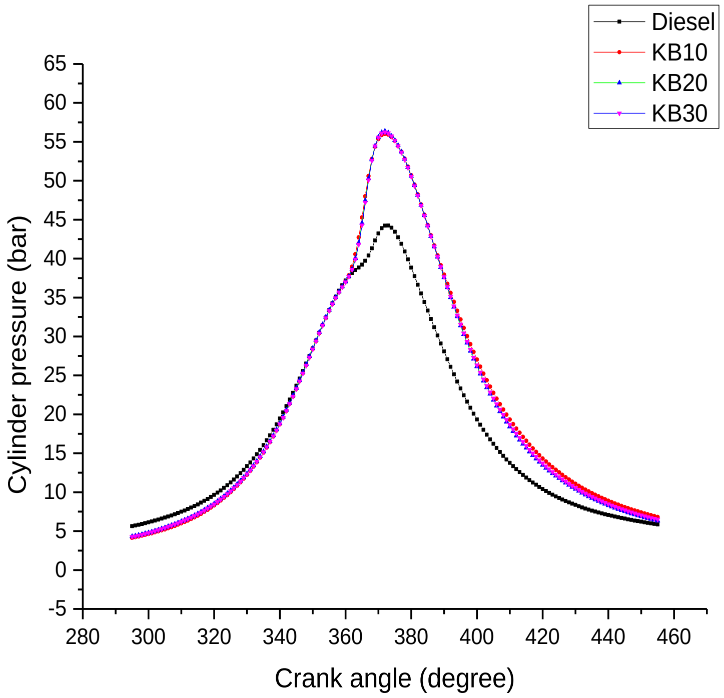
4.6 Cylinder pressure and heat release rate (HRR)

4.6.1 Cylinder pressure (bar)

The cylinder pressure variation with crank angle for all tested fuel at full load condition (100%) was shown in Fig. 4.27 (a) and (b) respectively. It was observed that initially the cylinder pressure constant during starting of combustion and further increased with increases the engine load. The peak pressure of cylinder initially depends on the combustion rate followed by mass of fuel intake per cycle [68, 18]. From the Fig. 4.27 (a) and (b), it was seen that same trend of cylinder pressure curve was obtained for all tested fuel. There were no significant differences found in cylinder pressure curve of all tested blend fuel [32]. It has been observed that the peak pressure 44.24 bar and 56.10 bar, 56.53 bar, 56.49 bar were recorded for standard diesel fuel and SOME blend fuel SB10, SB20, SB30 respectively as well as 56.03 bar, 56.38 bar, 56.26 bar were recorded for KOME blend fuel KB10, KB20, KB30 respectively. The peak pressure of SOME blend fuel and KOME blend fuel were evaluated higher than that of standard diesel fuel because of higher viscosity and lower volatility of biodiesel fuel [27].



(a) Cylinder pressure of safflower oil biodiesel blend fuels and diesel fuel

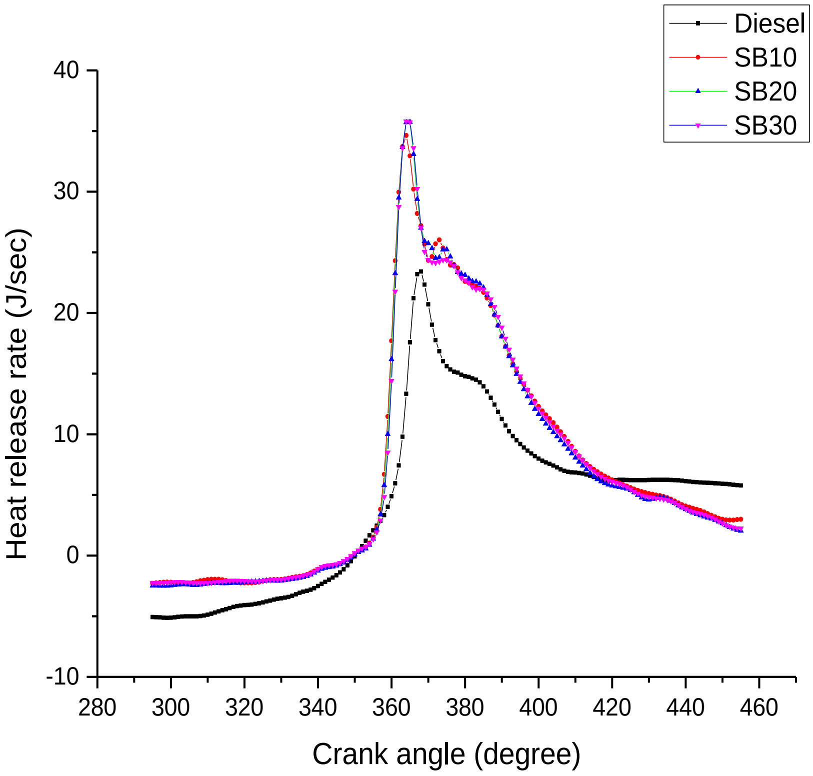


(b) Cylinder pressure of kusum oil biodiesel blend fuels and diesel fuel

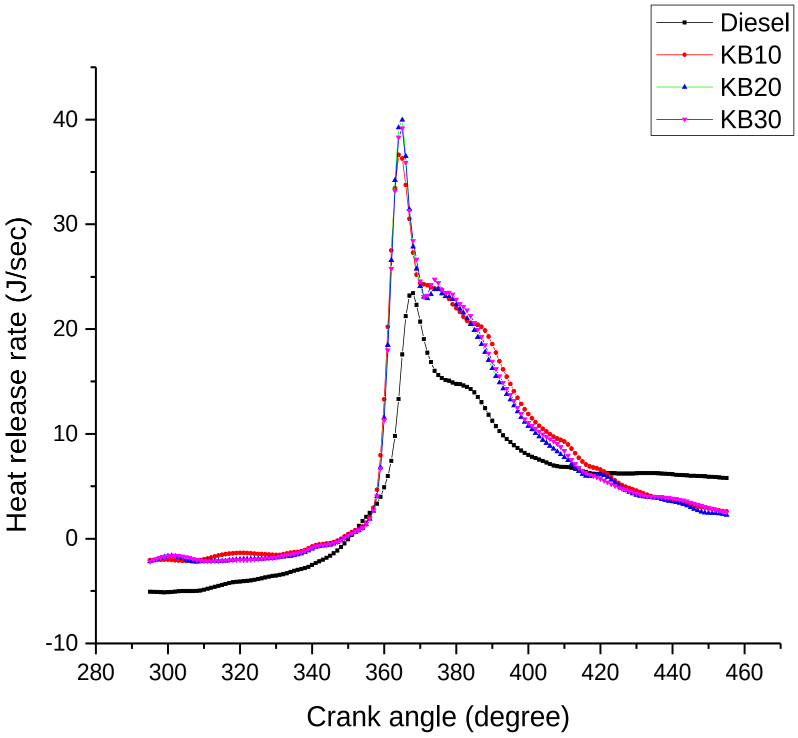
Figure 4.27: Variation of cylinder pressure with crank angle at full load condition (a) safflower oil biodiesel blend fuels and diesel fuel, (b) kusum oil biodiesel blend fuels and diesel fuel

4.6.2 Heat release rate

The formation of heat release rate curve with different crank angle at full load condition (100%) for standard diesel fuel and different blend fuels were shown in Fig. 4.28 (a) and (b). It is reported that heat release rate of 23.42 J/sec and 34.63 J/sec, 35.74 J/sec, 35.81 J/sec have been observed for standard diesel fuel and SOME fuel blend SB10, SB20, SB30 respectively as well as 36.63 J/sec, 39.96 J/sec, 39.18 J/sec for KOME blend fuel KB10, KB20, KB30 respectively. Initially heat release rate decrease and further increases because of lower air-fuel mixing rate and influence of viscosity of blended fuel [18]. For all blended fuel higher heat release rate was found than that of standard diesel fuel.



(a) Heat release rate of safflower oil biodiesel blend fuels and diesel fuel



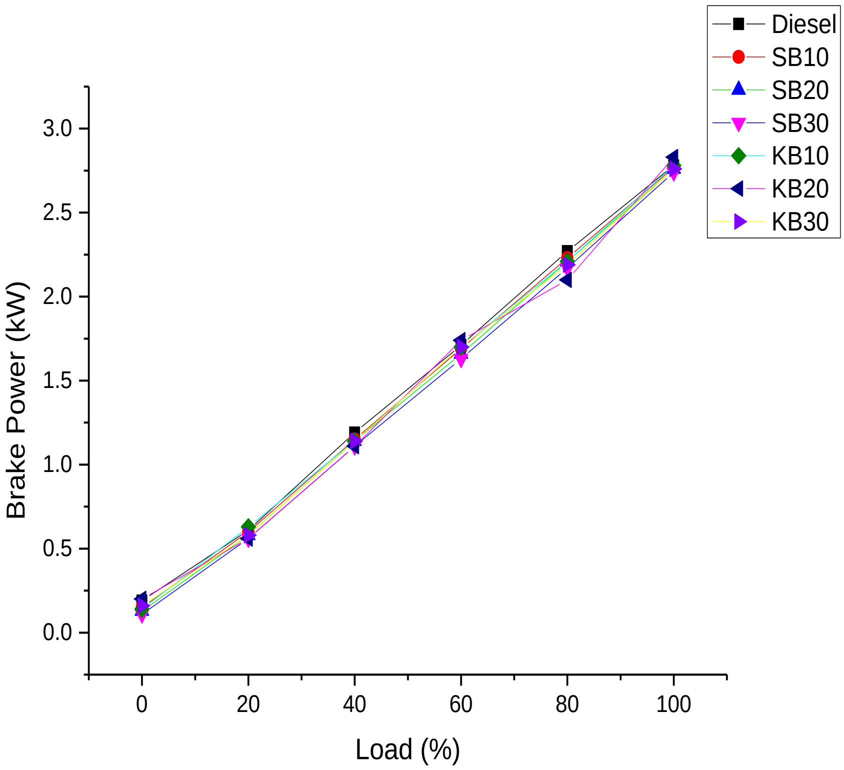
(b) Heat release rate of kusum oil biodiesel blend fuels and diesel fuel

Figure 4.28: Variation of heat release rate with crank angle at full load condition (a) safflower oil biodiesel blend fuels and diesel fuel, (b) kusum oil biodiesel blend fuels and diesel fuel

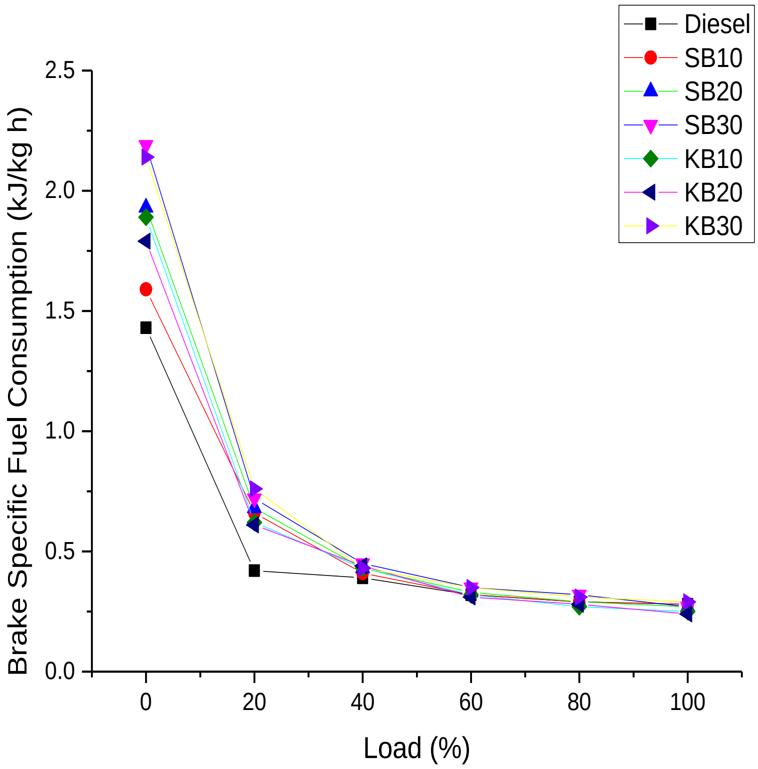
4.7 Comparison of parameters of SOME and KOME blend fuels with diesel fuel

4.7.1 Comparison of performance parameters of SOME and KOME blend fuels

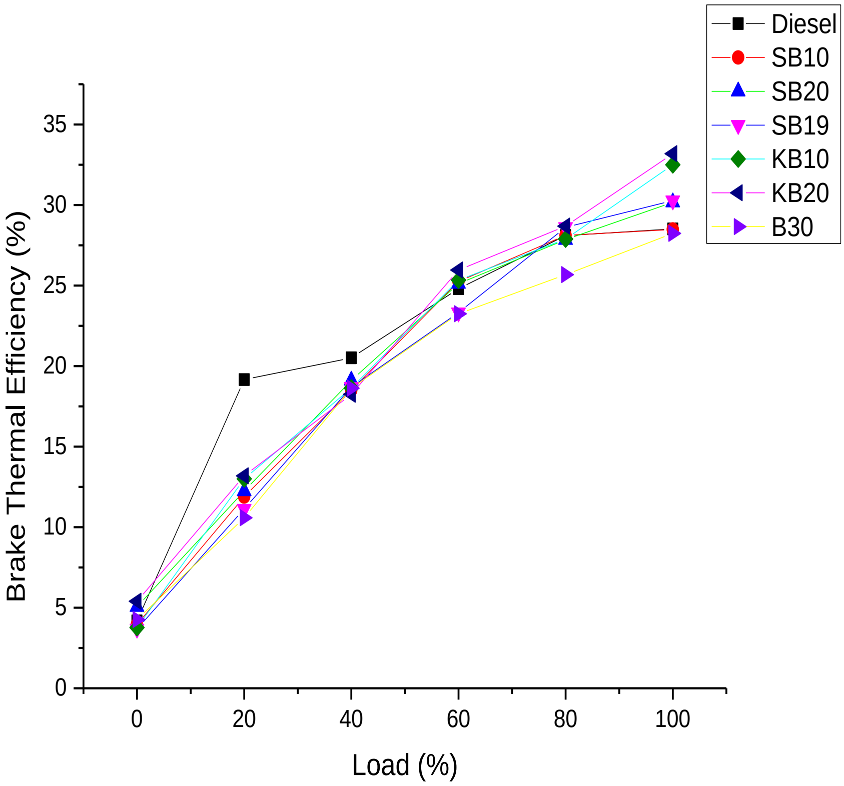
Figure 4.29 (a), (b), (c), (d) and (e) show the comparison of performance parameters of different blend of SOME and KOME under various load conditions. It was found that at full load condition, the maximum brake power, brake thermal efficiency, mechanical efficiency and brake specific fuel consumption were observed for KB20 and KB30 blend fuel respectively. The brake power for all blend fuel of SOME and KOME are almost similar at different load conditions. Initially (no load condition), BSFC of all blend fuels have been seen higher than that of diesel fuel and decrease when the load increase until 100%. At last it was reported that the overall performance of KOME blend fuels have been noticed better than that of SOME blend fuels.



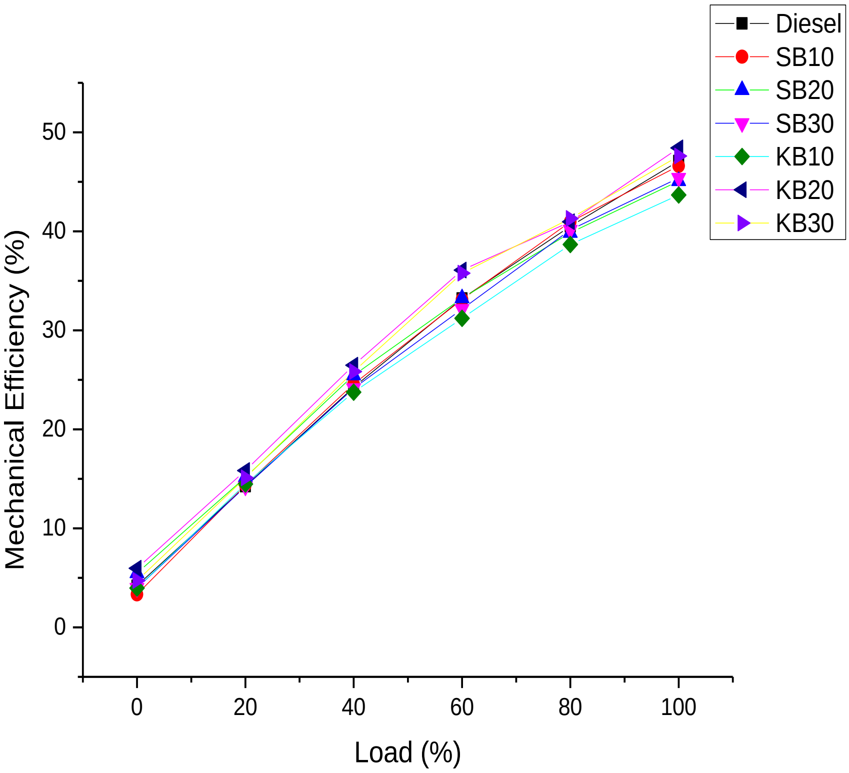
(a) BP vs. load



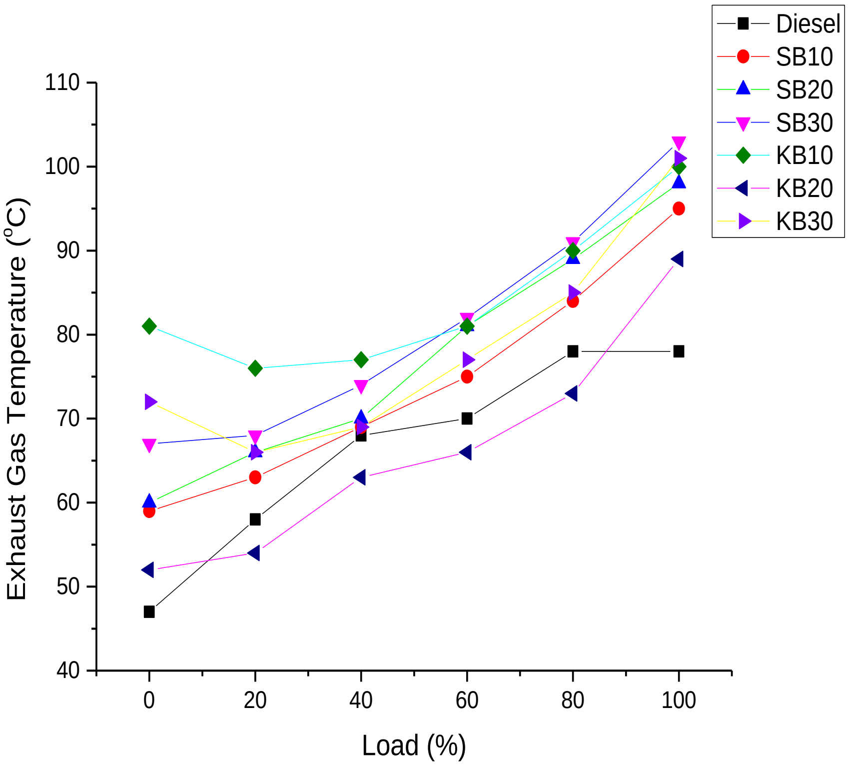
(b) BSFC vs. load



(c) BTE vs. load



(d) MEff vs. load

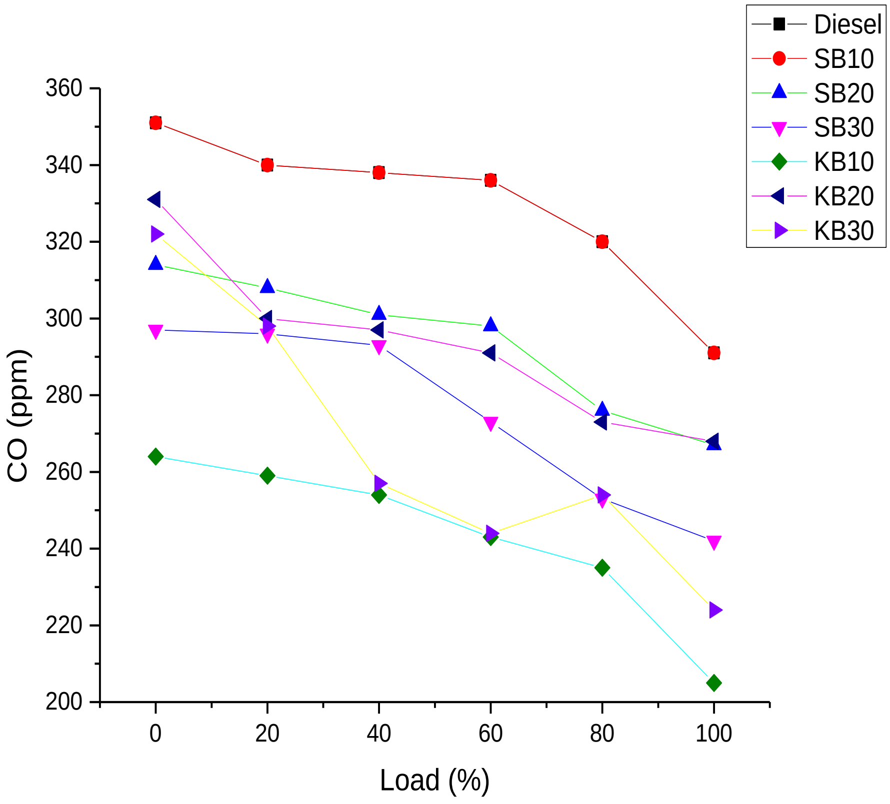


(e) EGT vs. load

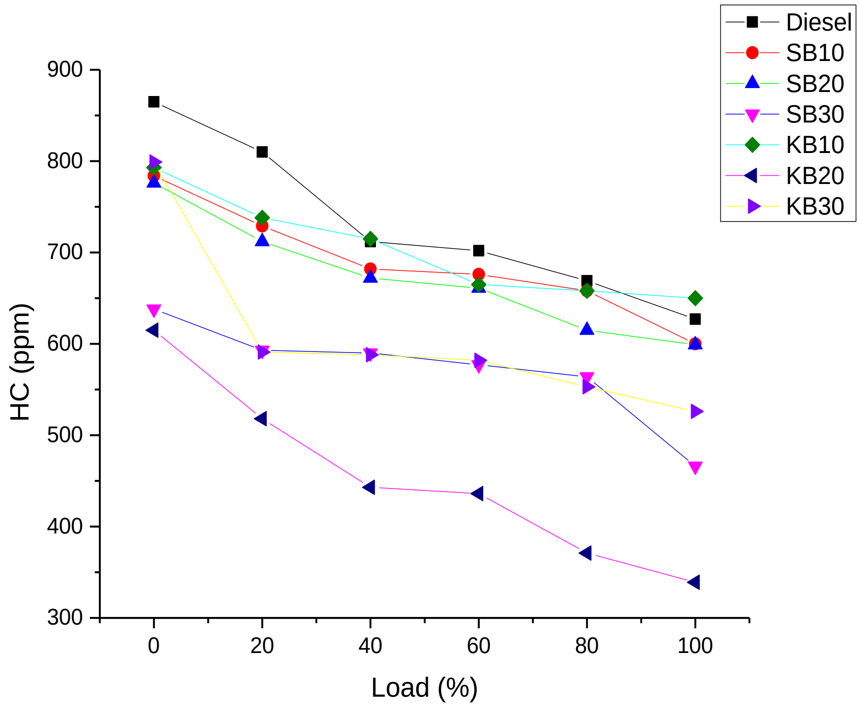
Figure 4.29: Comparison of performance parameters of all tested fuels (a) BP vs. load, (b) BSFC vs. load, (c) BTE vs. load, (d) MEff vs. load, (e) EGT vs. load

4.7.2 Comparison of emission parameters of SOME and KOME blend fuels

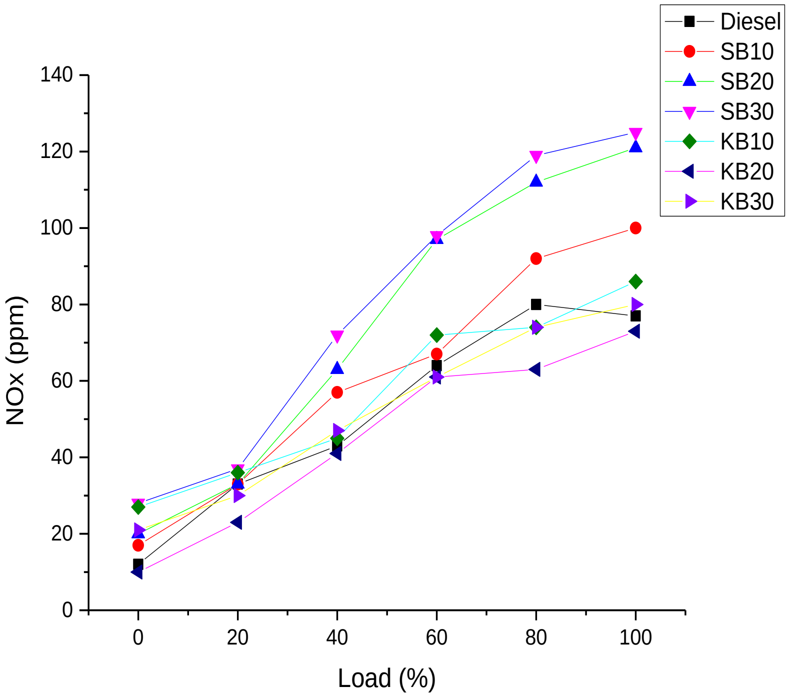
Figure 4.30 (a), (b) and (c) presented the variation of emission parameters of SOME and KOME blended fuels under different load condition. It was observed that the average emission of SOME blend fuels have been seen higher in comparison of KOME blend fuels. At full load condition, the maximum CO, HC, NOx and HC emission were obtained for SB10, KB10, SB30 and SB30 respectively.



(a) CO vs. load



(b) HC vs. load



(c) NOx vs. load

Figure 4.30: Comparison of emission parameters of all tested fuels (a) CO vs. load, (b) HC vs. load, (c) NOx vs. load

Chapter 5

Conclusions and Future Scope

5.1 Conclusions

The optimization of methyl ester production from safflower oil and kusum oil was based on the property of biodiesel i.e. viscosity. Transesterification process was used for optimization of biodiesel production. Three types of blends B10, B20 and B30 of each methyl ester (safflower and kusum oil methyl ester) have been used in present study and compared its performance and emission characteristics with standard diesel fuel. The following conclusions have been drawn from this experimental study.

- As per consideration of maximum biodiesel yield and minimum viscosity, the optimized process parameters for safflower oil methyl ester production were 4:1 molar ratio, 1.5% KOH catalyst concentration and 75 minutes reaction time. The optimized biodiesel yield and viscosity were evaluated as 97.07% and 5.63 centipoise respectively as per optimized process parameters.
- The optimized results were obtained at 6:1 molar ratio, 1% KOH catalyst concentration and 60 minutes reaction time. The optimized kusum biodiesel yield and viscosity were evaluated as 90.34% and 5.25 centipoise respectively as per optimized process parameters.
- The FFA content of safflower oil and kusum oil after transesterification process were obtained 0.24% and 0.23% respectively.
- It was found that viscosity of optimized methyl ester of KO and SO are 5.63 cSt and 5.25 cSt respectively which are slightly greater than that standard diesel fuel.
- The calorific value of SOME and KOME are 4.88% and 3.89% lower than that of diesel fuel respectively.
- As per above discussion, the performance of VCR engine for all blend fuels (B10, B20, B30) of safflower oil methyl were found almost similar to the standard diesel fuel. No significant difference was observed when compared to standard diesel fuel.
- Except nitrogen oxide (NOx), all the emission parameters such as carbon monoxide (CO), hydrocarbon (HC) have been showed the minimum value for B30 blend fuel of safflower biodiesel than that of other blend fuels B10, B30 and standard diesel fuel.

- The above discussed graphical results showed the better performance of VCR engine for B20 blend fuel of kusum biodiesel fuel when compared with standard diesel fuel and blend fuel B10, B30.
- For all kusum biodiesel belnd fuels (B10, B20, B30), the emissions were reduced except NOx than that of standard diesel fuel. In between tested fuels, the average emission characteristics of B20 blend fuel were found satisfactory.
- By comparing the SOME and KOME, it was reported that the overall performance of KOME blend fuels have been noticed better than that of SOME blend fuels.
- For both biodiesel, there were no significant difference found in peak pressure and heat release rate of blend fuels and both the parameters have maximum value than that of diesel fuel in both cases.

5.2 Future scope

Biodiesel derived from vegetable oil (edible or non-edible) has an advantages used as an automotive fuel. The initial cost of biodiesel may be higher depends on feedstock use. Multiple feedstock availability may solve this problem and play an important role reduction in cost of biodiesel production and this may be making the fuel economically viable.

The following point may be studied before introducing the fuel in India.

- As per government of India announcement in august 2015, 10% blending of biodiesel has been mandated and set the objective to achieved 20% blending till 2017 end and higher blend ratio could be recommended by government in future for proper utilization of biodiesel.
- The Nox emissions from safflower and kusum biodiesel were found higher than that of diesel fuel. To overcome this problem some modifications have been required in an engine such as use of EGR (exhaust gas recirculation). Further research work could be done to reduce NOx emission.
- Research could be done to make more effective biodiesel (like standard diesel fuel) by introducing heterogeneous catalysts which attract the use of 100% blend fuel in en engine.
- Long hour test to be conducted in single cylinder and multi-cylinder engine for studying the compatibility and durability of engine in future.

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