Experimental Investigation on Effect of Biodiesel and its blends with Additive in a VCR Engine.

A Dissertation Submitted
in partial fulfilment of requirements
for the degree of

Master of Engineering
in
Thermal Engineering

Submitted by
Gurpinder Singh
Registration No.: 801683013

Under the Supervision of

Dr. S. K. MOHAPATRA
(Senior Professor)

Dr. S. S. RAGIT
(Assistant Professor)

THAPAR INSTITUTE
OF ENGINEERING & TECHNOLOGY
(Deemed to be University)

DEPARTMENT OF MECHANICAL ENGINEERING
TIET, PATIALA
JUNE, 2018

CERTIFICATE

I hereby declare that the thesis report entitled "**Experimental Investigation on Effect of Biodiesel and its blends with Additive in a VCR Engine.**" is an authentic record of my work carried out as requirements for the award of the degree of **Master of Engineering** in **Thermal Engineering** at **TIET, Patiala** under the supervision of **Dr. S. K. Mohapatra** (Senior Professor, MED) and **Dr. S. S. Ragit** (Assistant Professor, MED). No part of the matter embodied in this report has been submitted to any other university or institute for the award of any degree.

Date: **18th June, 2018**
Place: **Patiala**

Gurpinder Singh
801683013
TIET, Patiala

It is certified that the above statement made by the student is correct to the best of our knowledge and belief.

18/6/18

Dr. S. K. Mohapatra
Senior Professor, MED
TIET, Patiala – 147001

S.S. Ragit

Dr. S. S. Ragit
Assistant Professor, MED
TIET, Patiala - 147001

Dedicated to

My parents

ACKNOWLEDGEMENTS

I wish to express my thanks to my supervisors, Dr. S. K. Mohapatra, Department of Mechanical Engineering, Thapar Institute of Engineering and Technology, Patiala, for their valuable guidance and encouragement. The present work is the convergence of their ideas. Working under their guidance is of immense pleasure and very worthful in the context of knowledge. I also deeply indebted to Dr. S. S. Ragit, Department of Mechanical Engineering, Thapar Institute of Engineering and Technology, Patiala, for his constant encouragement and valuable support and help throughout my time working on this project. His expertise, innovative ways of thinking, constant interest and follow up were the crucial factors in enabling this research work to take its final shape.

I also wish to thank Dr. K. Kundu, Scientist-E1 and Head, Department of Bio fuel, Mechanical Engineering Research and Development Organization (MERADO), Ludhiana for his support and staff of internal combustion engine laboratory, Thapar Institute of Engineering and Technology who supervised me during the estimation of performance and emission characteristics of the C.I. engine.

I am very thankful to my parents, friends and colleagues for their encouragement and support in building up this thesis report.

Gurpinder Singh
801683013
TEIT, Patiala

ABSTRACT

Biodiesel is an alternative fuel derived from the fats of animals and plants. As energy demands increase and fossil fuels are limited, research is directed towards alternative renewable fuels. The main advantages of using this alternative fuel are its renewability, biodegradability and better quality of exhaust gases. The aim of this experiment investigation is to optimize biodiesel production from waste grape seed oil followed by transesterification process. As per consideration of maximum biodiesel yield, the optimum parameters were 4:1 molar ratio, 0.5% KOH catalyst concentration, 60 minutes reaction time at 60° C. The yield and viscosity of grapeseed oil methyl ester corresponding to optimized process parameters was 98.41% and 4.14 cSt respectively. Three types of blended fuels B10, B20 and B30 of grape seed methyl ester and with diethyl ether as an additive have been studied and all tests were carried out in variable compression ratio (VCR) engine at 1500 rpm at different compression ratio 14:1, 16:1 and 18:1 under different load conditions. The various performance, emissions and combustion characteristics like brake power (BP), brake thermal efficiency (BTE), brake specific fuel consumption (BSFC), mechanical efficiency (MEff), carbon monoxide (CO), hydrocarbon (HC), nitrogen oxide (NOx), exhaust gas temperature (EGT) are evaluated. It was observed that the performance of all blended fuels of grape seed oil methyl ester almost same to the diesel fuel. The emissions of CO and NOx decreased by increased percentage proportion of biodiesel in blend fuel. Apart from that HC emissions was found to be slightly higher than diesel fuel. It was concluded that GSOME10%DEE10% (80% diesel, 10% grape seed biodiesel and 10% diethyl ether) blend fuel showed better performance among all other blends and diesel fuel at compression ratio 18:1.

CONTENTS

Description **Page No.**

REFERENCES

PUBLICATIONS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

GSO	Grape seed oil
GSOME	Grape seed oil methyl ester
DEE	Diethyl ether
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
GSOME10%	Blend of 10% GSOME & 90% diesel fuel
GSOME20%	Blend of 20% GSOME & 80% diesel fuel
GSOME30%	Blend of 30% GSOME & 70% diesel fuel
GSOME5%DEE5%	Blend of 5% GSOME, 5% DEE & 90% diesel fuel
GSOME10%DEE10%	Blend of 10% GSOME, 10% DEE & 80% diesel fuel
GSOME15%DEE15%	Blend of 15% GSOME, 15% DEE & 70% diesel fuel
HBP	Heat Eq. to BP
HJW	Heat Eq. to cooling water
HGas	Heat Eq. to exhaust gases
HRad	Unaccounted losses

CHAPTER 1

INTRODUCTION

Biodiesel is a fuel which is produced through synchronous biological processes, such as agriculture digestion and anaerobic digestion. It is far better than other fuels, such as coal, petroleum and those involved in the formation of fossil fuels and which are produced by geological processes. Biodiesel fuel is a renewable fuel which is synthesized both directly and indirectly method from plants as well as from agricultural, commercial, domestic, and/or industrial waste (Agarwal 2007; Akarte 2004). Biodiesel is an eco-friendly and renewable resource which has become quite popular recently (Janaun and Ellis 2010).

Previous studies have aimed to produce more new varieties of plants with fast growth rates and high oil yields. Plants which produce unpalatable, non-edible oils (e.g., Pangium edule oil, Jatropha oil, Shorea Robusta oil, Amla oil, Senna Occidentalis oil, etc.) are the main substances used for the production of biodiesel (Murugesan and Avinash 2017; Muthukumaran et al. 2017; Kakati, Gogoi, and Pakshirajan 2016). In India, there are many biofuel projects that have been introduced in 18 states across 200 districts (Bijalwan, Sharma, and Kediyal 2006; Abdul Kalam 2005; Subba 2005). Fuels like coal, petrol, and diesel are gradually depleting as they are not able to meet the energy demands of the quickly developing world (Aransiola et al. 2013). Different types of derived fuels, such as methyl ester from vegetable oils and liquid fuels produced from biomass, have been analysed as potential substitutes for fossil fuels. Vegetable oils have high viscosity and low volatility, and so they cannot be used directly in engines as they could cause some problems to the engine. Hence, vegetable oil is converted to a fatty acid alkyl ester to make it usable in engines without any damage occurring. A process known as the transesterification process has been proposed as a method for this conversion (Karthikeyan, Prathima, and Elango 2015; Atabani et al. 2014).

Vitis vinifera grape varieties like Carbernet, Sauvignon, Chardonnay, Pinot noir and Ugni blanc are used for wine production in India. The annual production of wine grapes is 50,000 tonnes grown over an area of 5000 hectors. Maharashtra contributes more both in production as well as in area followed by Karnataka, Tamil Nadu and Andhra Pradesh. Contribution from Northern states such as Himachal Pradesh, Haryana, Uttar Pradesh is very little.

1.1 History

The method of making biofuel from biomass is the same which was used in 1800s. The introduction of gasoline was seen in early 20th century to powered automobiles. Oil companies were used to refine the crude oil for supplying gasoline and surplus left behind after distillate is a good fuel and much cheaper than vegetables oil. Whereas on the other side, resources were getting depleting day by day. Therefore, work on biodiesel production from vegetable oil has been continued.

The process used to convert vegetable oils or animal fats into fatty acid methyl esters is known as transesterification. Biodiesel fuel was invented by inventor Rudolph Diesel in 1890s when diesel engine has become more powerful, reliable and fuel economy worldwide. Experimentation on vegetables oil was conducted by Dr. Diesel himself only along with the help of French government. He envisioned that in remote areas of the world, pure vegetable oil could power early diesel engines for agriculture at that time when there was no availability of petroleum. Modern biodiesel has its root in research in Belgium in 1930s but there was no biodiesel industry established till late of 1980s.

The early diesel engine has very complex injection systems and were designed to run on different kind of fuel such as kerosene oil, coal dust etc. After sometime, someone discovered that vegetable oils would make excellent fuel due to higher energy content present in it. The first oil based diesel engine was introduced publically in 1900 World's Fair which was run on peanut oil. And that time French government was interested in vegetable oils for their African colonies as a domestic fuel. Dr. Diesel continued in his research work on vegetable oil fuels as he believed that farmers could benefit by providing fuel by their own. This idea takes almost century to widespread reality.

Vegetable oils gained less attention due to more availability and cheaper petroleum diesel fuel until unless when the price of petro-diesel was high. After World War II and oil crises in 1970s saw brief interest in vegetable oils. But unfortunately, the modified diesel engine unable to run on vegetable oil due to higher viscosity of vegetable oil. So, it was necessary to lower the viscosity of vegetable oil. Many different methods such as pyrolysis, blending with solvents, emulsifying etc. were performed, but none of them provided with reasonable solution. In 1937s, it was a Belgian inventor who proposed the transesterification process first. Transesterification process was the suitable solution which helps in lower the viscosity of vegetable oils and the replacement of diesel in engines.

Researchers did pioneer work mostly in Europe and South Africa which furthered developed biodiesel fuel industry in the early 1990s. Pacific biodiesel became first biodiesel plant in the US in 1996 to start biodiesel production from waste cooking oil on the island Maui in Hawaii. In 2005, overall biodiesel production was 1.1 billion gallons with most fuel production by European Union.

1.2 Different types of methods for biodiesel production

1.2.1 Pyrolysis (Thermal cracking)

Pyrolysis or thermal cracking is the method to convert one form of substance to other by means of heating without supply of oxygen in the presence of catalyst. The fuel produced by this method consists of same chemical properties as compared to standard diesel fuel. Pyrolysis process can be classified into three different categories such as conventional pyrolysis, fast pyrolysis and flash pyrolysis. Many studies were made on pyrolysis process to produce capable biodiesel which can be used in place of diesel engine (Sonntag 1979; Demirbas 2008).

1.2.2 Micro- emulsification

To lower the viscosity of vegetable oil, micro emulsification formation is one of the potential solutions. Micro-emulsification is defined as type of stable isotropic fluids. The range in micro-emulsions of droplet diameter is 100 to 1000 Å. The animal fats or vegetable oils can be used for micro-emulsification with an ester which is used as co-solvent or of vegetable oils and a surfactant and alcohol and a cetane improver. All micro-emulsions that are made with butanol, octanol and hexanol met the required viscosity for diesel fuel (Schwab et al. 1988; Jain and Sharma 2010).

1.2.3 Dilution

Due to higher viscosity, vegetable oils cannot be used directly in diesel engine. Therefore, dilution is the method to reduce the viscosity and density of vegetable oils. The performance parameter such brake specific fuel consumption decreases with the addition of 4% ethanol while brake thermal efficiency and brake power increases. The boiling point of ethanol is lower than diesel fuel so it could help in combustion process.

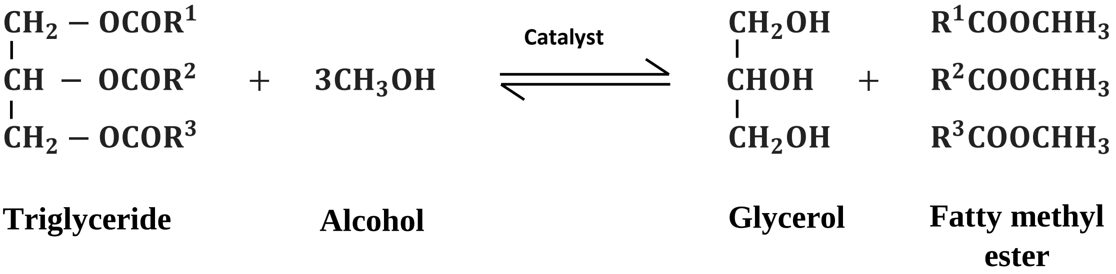
1.2.4 Transesterification

Basically transesterification of vegetable oil carried out by two different ways.

1. Catalytic Transesterification
2. Supercritical Methanol Transesterification

1. Catalytic Transesterification

The transesterification process is defined as the process in which animal fats or vegetable oils are used to react with alcohol in the presence of catalyst to produce esters is known as catalytic transesterification. The characteristics of vegetable oils are determined by the nature of fatty acid fastened to the glycerine.



$$\begin{array}{l} CH_2-OCOR^1 \\ | \\ CH-OCOR^2 \\ | \\ CH_2-OCOR^3 \end{array} + 3CH_3OH \underset{}{\overset{\text{Catalyst}}{\rightleftharpoons}} \begin{array}{l} CH_2OH \\ | \\ CHOH \\ | \\ CH_2OH \end{array} + \begin{array}{l} R^1COOCHH_3 \\ R^2COOCHH_3 \\ R^3COOCHH_3 \end{array}$$

The transesterification reaction become successful only when upper layer is made of ester and lower layer is of glycerine due to higher density after the reaction time is over (Ma and Hanna 1999). Due to high density, the glycerol settles down and biodiesel or ester separated to upper layer and glycerol then disposed. Catalytic transesterification is categorized into three process:

a) Acid catalyzed transesterification

The transesterification process is defined as the process in which animal fats or vegetable oils are used to react with alcohol in the presence of acid catalyst such as sulphuric acid and sulphonic acid to produce esters is known as acid catalyzed transesterification (Chongkhong et al. 2007; Haldar, Ghosh and Nag 2009). The biodiesel yield is high with acid catalyzed transesterification. But this is not preferable widely due to slow reaction, requires temperature above 100 °C. It must also be noted that to avoid the production of carboxylic acid, reaction should be takes place in the absence of water.

b) Alkaline catalyzed transesterification

The transesterification process is defined as the process in which animal fats or vegetable oils are used to react with alcohol in the presence of alkaline catalyst such as alkaline metal hydroxides and alkoxides as well as carbonates of sodium and potassium to produce ester is known as alkaline catalysed transesterification (Duz, Saydut and Ozturk 2011; Ilkilic et al. 2011; Ramadhas, Jayaraj and Muraleedhara 2005). Because of less corrosive and reaction is faster than the acid catalyzed transesterification, used widely in industries. There is rise in saponification of oil due to presence of water and free acid which causes incomplete reaction.

c) Lipase catalyzed transesterification

The transesterification process is defined as the process in which animal fats or vegetable oils are used to react with alcohol in the presence of lipase enzymes as a catalyst is known as lipase catalysed transesterification (Shah, Sharma and Gupta 2004, Kumari, Sharma and Gupta 2007). This transesterification process to the conventional process is more environmentally attractive option. There are no complex operations to eliminate the catalyst as well as soap and for recovery of glycerol but this process is still unfavourable due to low biodiesel yield and higher the reaction time.

2. Supercritical Methanol Transesterification

There are two problems confronted in transesterification process which are discussed above i.e. reaction time is higher and some operations are to be performed to eliminate catalyst and saponified impurities from biodiesel. But these problems are no faced during super critical transesterification process. In fact, there is no tendency to form two phase formation when vegetable oil mixed with alcohol. A single phase found in supercritical state at 340 °C and 43 MPa and reaction is completed within 2 – 4 minutes without presence of any catalyst which helps in purification of biodiesel easily (Demirbas 2005).

1.3 Advantages and disadvantages of biodiesel

Advantages:

- Biodiesel is non-toxic, biodegradable and without sulphur content.
- There is less emissions generated as compared to diesel engine.
- Biodiesel has better lubricating properties as compared to diesel engine.
- Cetane number and combustion efficiency of biodiesel is higher than the diesel.

Disadvantages:

- Biodiesel is expensive as compared to diesel.
- Biodiesel has higher cloud and pour point, injector choking, engine compatibility and higher engine wear.
- There is difficulty in fuel pumping due to higher viscosity.
- Biodiesel has low energy content which give rise to cold start problems.
- NOx emissions are higher than the diesel.

1.4 Objectives of present work

1. Optimization of biodiesel production derived from grapeseed oil by transesterification process.
2. Determination of physicochemical properties of optimized biodiesel.
3. Evaluation of performance parameters such as brake thermal efficiency, brake power, mechanical efficiency, brake thermal fuel consumption of grapeseed oil methyl ester and grapeseed oil methyl ester with additives in different proportion and comparison with diesel engine.
4. Evaluation of various emission characteristics of grape seed biodiesel and grape seed biodiesel using Diethyl ether as additive.

CHAPTER 2

LITERATURE REVIEW

2.1 Review of literature

Many studies have been carried out on biodiesel by many researchers since from past era. In this chapter previous work were surveyed. Many books and journals were considered, which are reviewed in this chapter.

Aydin et al., 2015 investegated the emissions and performance of four stroke diesel engine when fuelled with safflower biodiesel and kerosene oil in distinct proportion of S50K50 (50% safflower biodiesel and 50% kerosene), S75k25 (75% safflower biodiesel and 25% kerosene) and S90K10 (90% safflower biodiesel and 10% kerosene). The safflower biodiesel was produced by transesterification method. The experiment was conducted on four cylinder diesel engine at 1500 rpm engine speed at different loads i.e. 3.6 kW, 7.2 kW and 10.2 kW. There was reduction in NOx emissions with percentage of 68.2%, 56.9% and 55.1% when engine fuelled with S50K50, S75K25 and S90K10 respectively whereas on the other hand unburned HC emissions were increased little bit. Brake specific fuel consumption and mass fuel consumption were also slightly increased for blends S75K25 and S90K10. Brake thermal efficiency was increased by 3% for blend S50K50 as compared to diesel fuel.

Abedin et al., 2014 studied the biodiesel production from palm and Jatropha oil by transesterification method. The emission, heat loss and performance for blends B5, B10 and B20 of Jatropha and palm biodiesel fuel was also investigated in this study. Experiments were conducted on four cylinder, water cooled diesel engine at speed range of 1000 to 4000 rpm. It is observed that brake power was decreased by 2.3% to 10.7% for blends B10 and B20 for both palm and Jatropha oil and brake specific fuel consumption was increased by 26.4% for PB20 and JB20 blends. There was also reduction in carbon monoxide and hydrocarbon emission for blend B20 and NOx emission by 3.3% for blend PB10 and PB20 of palm biodiesel whereas on the other hand there was increase in NOx emission by 3% for blend JB10 and JB20 of Jatropha biodiesel.

Awad et al., 2014 examined the properties of jojoba ethyl ester production and blends with ethanol. Transesterification process was used for the production of biodiesel from jojoba oil. The physical as well as chemical properties of jojoba biodiesel J100 (100% jojoba ethyl ester) and its blends such as J95E5 (95% JEE and 5% ethanol), J90E10 (90% JEE and 10% ethanol), J85E15 (85% JEE and 15% ethanol) and J80E20 (80% JEE and 20% ethanol) with ethanol in distinct ratios were examined. The results of flash point, cetane index and kinematic viscosity were described by Fig. 2.1, Fig. 2.2 and Fig. 2.3.

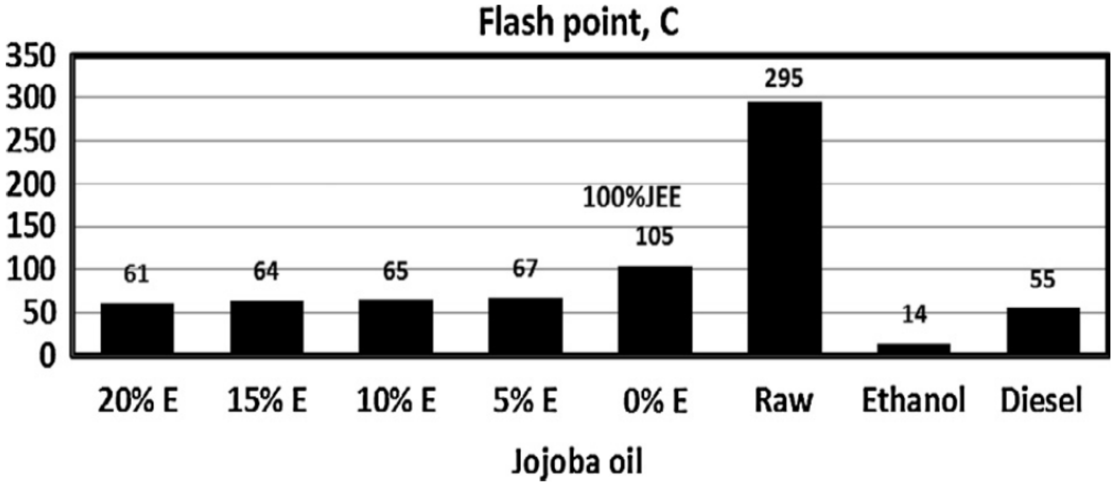


Figure 2.1: Flash point for the jojoba ethyl ester as compared to diesel and blends with ethanol

Figure 2.1 showed that the flash point of pure jojoba ethyl ester (100% JEE) was 105 °C and ranges from 61 °C to 67 °C when it mixed with ethanol in different proportions.

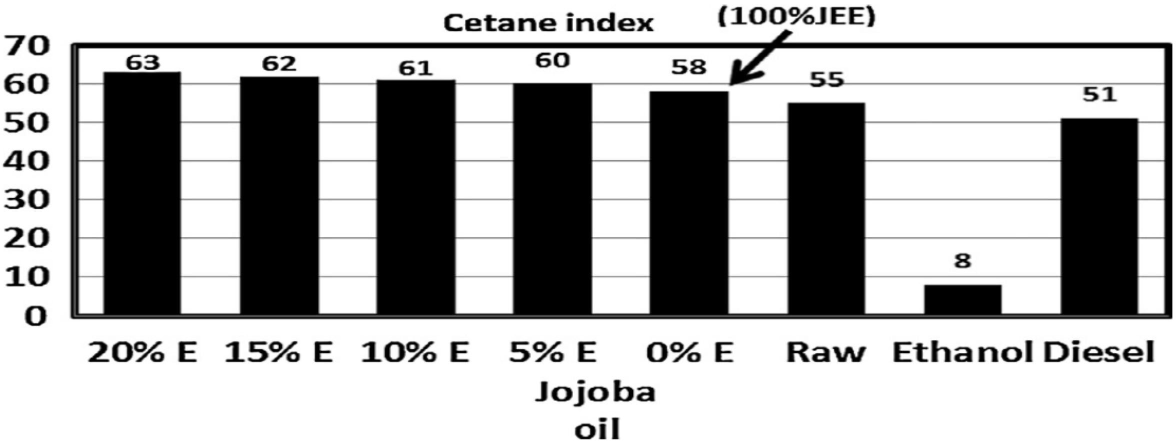


Figure 2.2: Cetane index for the jojoba ethyl ester as compared to diesel and blends with ethanol

Figure 2.2 showed that the cetane index for pure jojoba ethyl ester (100% JEE) was 58 and reached to 63 when 20% ethanol was added.

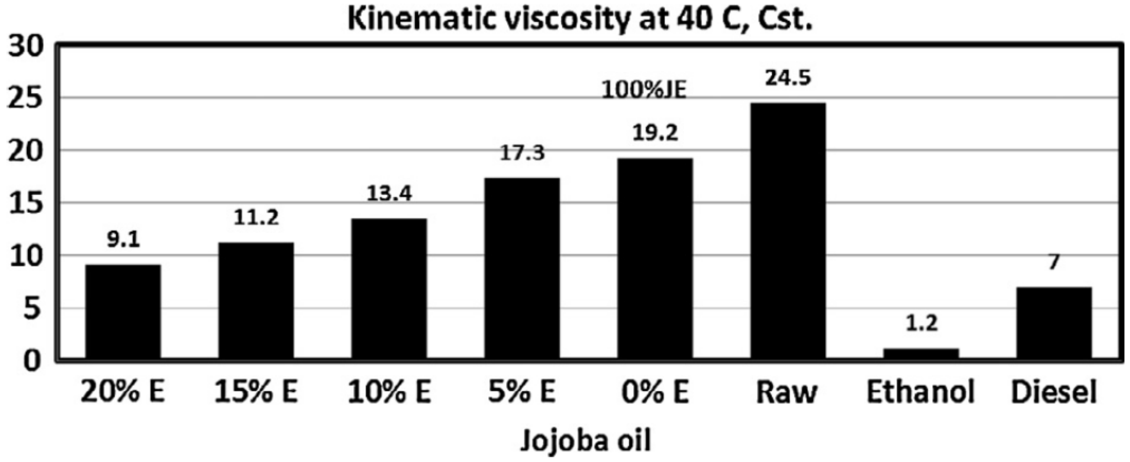


Figure 2.3: Kinematic viscosity for the jojoba ethyl ester as compared to diesel and blends with ethanol

Figure 2.3 showed that viscosity of raw jojoba oil found to be 24.5 cSt and 19.2 cSt of pure jojoba ethyl ester. The kinematic viscosity varies from 9.1 cSt to 17.3 cSt when JEE blends with ethanol in distinct proportions.

It is observed that maximum production of jojoba ethyl ester is obtained by using 7% ethanol during transesterification process and with the increase in proportion of ethanol in the mixture, there is reduction in density and calorific value.

Jayaprabakar et al., 2017 investigated the effect on diesel engine when neem oil methyl ester blended with diethyl ether. Transesterification process was used for biodiesel production from neem oil. This experimental work was conducted on a single cylinder direct injection diesel engine at constant speed. It was found that there was improvement in combustion process and reduction in particulate matter when neem oil methyl ester blended with diethyl ether. Emission parameters such as oxides of nitrogen, hydrocarbon and carbon monoxide reduced significantly when diethyl ether added at 10% and 20% proportion in neem oil methyl ester.

Saydut et al., 2016 examined the optimization of methyl ester produced from sunflower oil, hazelnut oil and their hybrid feedstock. The reaction parameters which were used during alkali esterification found to be 6:1 molar ratio, 0.7 wt% KOH catalyst at 60 °C for 2 hours. Ester yield production was observed to be 97.3%, 97.5% and 97.9% for sunflower, hazelnut and hybrid feedstock respectively. The kinematic viscosities were found to be for hazelnut methyl ester was 4.51 cSt, for sunflower methyl ester 4.04 cSt and for hybrid feedstock was 4.57 cSt.

Perumal et al., 2017 examined the biodiesel production from Senna occidentalis non edible oil using two step transesterification process. First of all, due to having high free fatty acid (17% FFA) in oil, acid transesterification of Senna occidentalis oil was done using 1% by volume sulphuric acid (H_2SO_4) and 0.35% (volume %) for 1 hour. Further, Senna occidentalis oil was treated with alkaline transesterification process. The reaction parameters were found to be methanol 0.25% (volume %) and 0.7% (wt %) KOH for 1 hour. The kinematic viscosity and yield production of Senna occidentalis biodiesel at 40 °C was found to be 4.01 cSt and 98% respectively.

Gangil et al., 2016 investigated the impact of karanja methyl ester on the engine performance. In this study, karanja oil was used for the production of biodiesel. The experimental work was conducted on single cylinder four stroke diesel engine with compression ratio 16.5:1 at 1500 rpm and rated power 3.7 kW using different types of blends i.e. B20, B40, B60, B80 and B100. Emissions and performance characteristics of diesel engine was evaluated. It is found that there was reduction in gaseous emissions such as HC and CO excluding NOx when karanja oil blended with diesel and improves the thermal efficiency when biodiesel blended with diesel at low concentration.

Nayak et al., 2014 investigated the emissions and performance characteristics of Mahua methyl ester with additive. Transesterification process was used for the production of Mahua oil biodiesel. This experiment was performed on water cooled, single cylinder diesel engine under different varieties of load. It is observed that brake thermal efficiency (BTE) and brake power (BP) have been increased when percentage of additive increased in Mahua oil methyl ester. On the other hand parameters such as exhaust gas temperature (EGT), brake specific fuel consumption (BSFC) and emissions characteristics (HC, NOx, CO and Smoke) was reduced.

Acharya et al., 2014 studied the effects on emissions characteristics of preheated karanja and Kusum oil. Kusum and karanja oil was preheated with the help of shell and tube type heat exchanger before entering to engine and emission characteristics were evaluated. All experimental work was conducted on single cylinder, water cooled four stroke diesel engine with 16.5:1 compression ratio and 1500 rpm. It is found that with the increase of engine load, the emission components such as carbon dioxide (CO_2), hydrocarbon (HC), and carbon monoxide (CO) were increased. The variation of NOx with respect to engine load was discussed by Fig. 2.4 and Fig. 2.5.

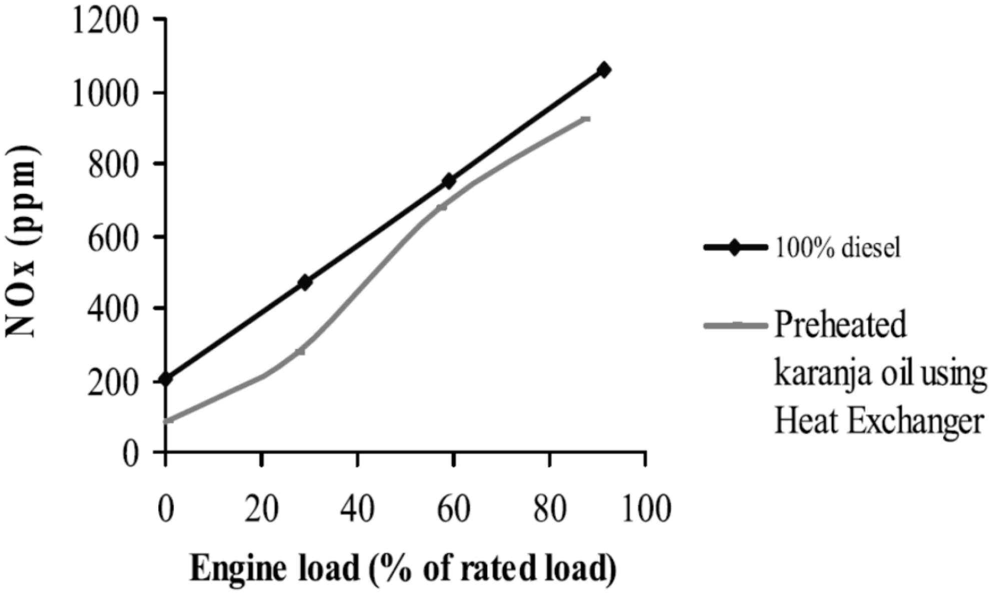


Figure 2.4: Variation of NOx emissions with engine load of preheated karanja oil

Figure 2.4 showed the linear representation of NOx formation and engine load of preheat karanja oil as compared to diesel fuel. It is found that there was reduction in NOx formation from 10 to 15% when preheated karanja oil was used.

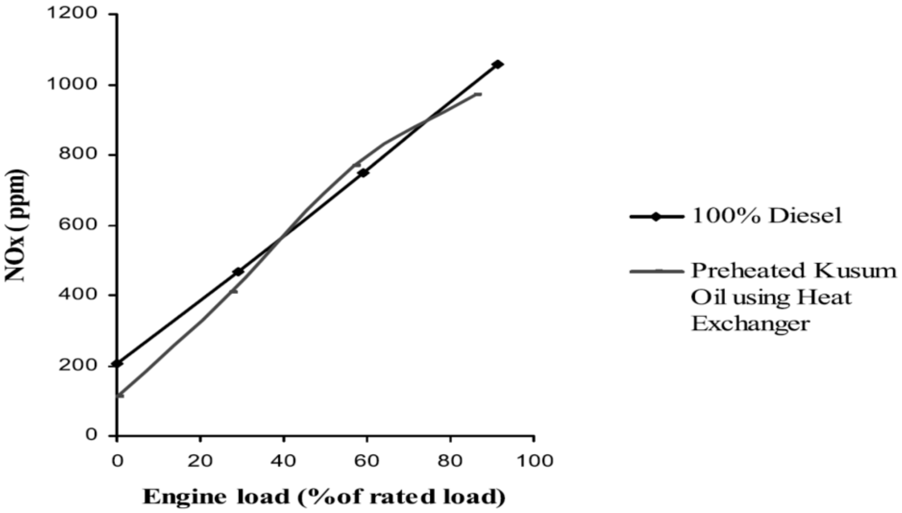


Figure 2.5: Variation of NOx emission with engine load of preheated kusum oil

Figure 2.5 displayed that formation of NOx emission increased after 45% engine load and further it was decreased when rated load reaches to 80% in comparison of diesel fuel. It is concluded that NOx formation was decreased from 5-7% as compared to diesel fuel.

Rashid et al., 2008 studied the utility of Moringa oleifera methyl esters (MOME) as a source of biodiesel fuel. Alkali catalysed transesterification was used to produce biodiesel from Moringa oleifera oil. MOME properties were evaluated and comparison was done with other biodiesel fuels. The reaction parameters were observed to be methanol to oil molar ratio was 6:1, catalyst concentration ($NaCHO_3$) was 1 wt% for 1 hour at 60 °C. It is found that Moringa oleifera oil can be used as feedstock for biodiesel. Important fuel properties such as oxidation stability, cloud point and cetane number show better results when compared to diesel fuel.

Bouaid et al., 2008 investigated the production of biodiesel from Brassica Carinata oil with methyl alcohol and catalyst KOH. It was found that catalyst concentration and temperature played the significant role in yield of biodiesel. Response surface methodology (RSM) was used to determine the optimum condition for better yield. According to this, the maximum yield can be obtained when reaction operated at temperature 25 °C with 1.5 wt% catalyst concentration and molar ratio of 6:1. It is found that the peroxide value, viscosity and acid value increased while there was reduction in iodine value with increased in storage time of biodiesel.

Phan et al., 2008 studied the production of biodiesel from waste cooking oil using alkali catalysed transesterification process. In this study, the effects of potassium hydroxide concentration, temperature and methanol to oil molar ratio on the biodiesel production were investigated. It is found that the maximum biodiesel yield (88-90%) was obtained at the methanol to oil molar ratio of 7:1–8:1, 0.75 wt% catalyst concentration (KOH) and temperatures of 30–50 °C. The physical properties of waste cooking oil biodiesel and its blends with diesel were evaluated and then compared with biodiesel standard EN14214.

Meher et al., 2006 studied the formation of biodiesel from Pongamia Pinnata oil by the means of transesterification process. It was noted that the best biodiesel yield was obtained i.e. above 97% by using catalyst concentration (KOH) 1 wt%, methanol to oil molar ratio 12:1 at 65 °C and 360 rpm for 3 hours. It was observed that the yield of biodiesel decreases with the increase in catalyst concentration. There are very less study which investigated on biodiesel production from non-edible oils, among which karanja oil is the most valuable species to produce biodiesel due to its higher availability in India which can become the opportunities for new generation of rural areas to develop themselves and improving environment.

Lu et al., 2009 described the production of biodiesel from crude Jatropha Curcas L. oil by the means of two steps process. Firstly, pre-esterification was done followed by transesterification process. In this study, it was investigated that the methanol to oil molar ratio, catalyst concentration, temperature and reaction time played the vital role in the conversion of pre-esterification reaction. The reaction rate was influenced by the temperature. The maximum yield of biodiesel obtained at the temperature ranges from 35 °C to 65 °C and conversion increased with the increase in reaction time. Almost 90% conversion was completed in first 15 minutes which was fastest period of reaction. The biodiesel yield was higher than 98% by transesterification process in 20 minutes using 1.3 wt% catalyst concentration (KOH) and methanol to oil molar ratio of 6:1 at 64 °C.

Ullah et al., 2009 studied the pre-treatment of methoxide with molecular sieve which can increase the yield of biodiesel and the production of biodiesel by means of base catalysed transesterification process of wild apricot kernel oil. The maximum biodiesel yield i.e. 93% was obtained when sodium hydroxide pellets dissolved in methanol for the formation of sodium methoxide and was treated with molecule sieve before the process of transesterification. There was only 89% conversion takes place when methoxide was not treated with molecular sieve.

Sinha et al., 2008 studied the production of biodiesel from rice bran oil by transesterification process. The optimized parameters for maximum yield such as catalyst concentration, methanol to oil molar ratio, reaction time and temperature were also investigated. The optimum conditions for maximum biodiesel production were found to be 0.75 wt% catalyst concentration (NaOH) with 9:1 molar ratio for 1 hour reaction time at 55 °C. Rice bran oil methyl ester was found to be suitable as fuel for engine. The physical properties Rice bran oi methyl ester were far similar to other biodiesel properties except higher cetane number and calorific value. The viscosity of rice bran oil reduces significantly after transesterification process. The properties such as flash point, cloud and pour point and density were higher of rice bran oil methyl ester than those of mineral diesel.

Balaji et al., 2012 studied the effect of antioxidant with methyl ester of cottonseed oil with oxide of nitrogen (NOx) and hydrocarbon (HC) emissions. In this study, it was concluded that biodiesel is much better fuel over the conventional diesel fuel. There was decrement in the emissions characteristics such as particulate matter, unburned hydrocarbon and carbon monoxide emissions. While on the other hand NOx emissions increased by 13% when compared with conventional diesel fuel. This experimental operation was conducted on single cylinder, water cooled four stroke diesel engine of rated 3.5 kW power. According to this experimental study, when antioxidant (L-ascorbic acid) mixed with cottonseed oil methyl ester as additive, there was reduction in NOx as well as in HC emissions.

Rajan et al., 2014 investigated the emissions, combustion and performance characteristics when Pongamia biodiesel blended with diethyl ether (DEE) as additive at different loads. Two different blends were used i.e. 10 % (90% biodiesel and 10% DEE) and 15 % (85% Biodiesel and 15% DEE). The characteristics such as nitrogen oxide (NOx), hydrocarbons (HC), Carbon monoxide (CO), smoke, exhaust gas temperature (EGT), brake thermal efficiency (BTE) and brake specific fuel (BSFC) consumption were evaluated and compared with diesel fuel. There was reduction in smoke and NOx emissions using 15% DEE when compared with Pongamia biodiesel at full load condition. There was also reduction in heat release rate, ignition delay and peak pressure while maximum rate of pressure rises. In this study, it is found that when Pongamia biodiesel blended with 15% DEE, it shows the better result as when compared with pure biodiesel.

Can et al., 2017 studied the production of biodiesel from canola oil and different blends were used (5%, 10%, 15% and 20%) at four different loads (48, 3.6, 2.4 and 1.2 bar BMEP). All experimental work was conducted on single cylinder direct ignition diesel engine. Due to earlier combustion time for all loads of canola biodiesel blends, it gave rise to shorter ignition delay. There was reduction in heat release rate with the minimizing of premixed combustion fractions while on other hand, the diffusion combustion fraction increases with increased in canola biodiesel ratio. There was increment in the value of brake specific fuel consumption up to 6.56% and brake thermal efficiency reduces to 4.2% when blends of canola biodiesel increased up to 20%. It is found that NOx emissions, HC and CO generally increases.

Ahmad et al., 2009 revealed that the peanut oil was suitable for biodiesel production due to presence of low free fatty acid in it. Transesterification process was used for maximum yield of biodiesel from crude peanut oil at 6:1 molar ratio with NaOH as catalyst at 60 °C. The physical properties oil peanut oil biodiesel such as density, specific gravity, kinematic viscosity, cloud and pour point, flash point and sulphur content were evaluated and compared with American Standard Testing Material (ASTM).

CHAPTER 3

EXPERIMENTAL SETUP AND METHODOLOGY

In this study, optimization of biodiesel production from grape seed oil as well as emission and performance characteristics with three different blends (B10, B20. B30) with diesel in VCR engine was observed. The optimized parameters for production of biodiesel are molar ratio, time of reaction and catalyst concentration. The performance and emission parameters such as mechanical efficiency (MEff), brake power (BP), brake thermal efficiency (BTE), brake specific fuel consumption (BSFC), hydrocarbon (HC), carbon monoxide emission (CO), nitrogen oxide (NOx) and exhaust gas temperature (EGT).

3.1 Materials and methods

3.1.1 Materials

Wine waste was collected from Heritage Grape Winery Pvt. Ltd., which is located in Bangalore, Karnataka. Grape seeds were extracted from wine waste after being dried in an open atmosphere for 3-4 days (Fernandez et al. 2010). The grape seed oil was extracted by pressing, followed by solvent extraction using a Soxhlet extraction apparatus. Additives (diethyl ether), methanol and potassium hydroxide (KOH), were used as catalysts; these were collected from Sardar Lamichems Pvt Ltd, Patiala, India.

3.1.2 Procedure for production of grape seed oil methyl ester (GSOME)

The grape seed oil was used for biodiesel production via the alkaline transesterification process outlined in Figure 1.

1) 100 g of grape seed oil was poured into a conical flask and heated up to 100-105˚C to eliminate the water contents from the raw oil. The oil was then kept aside to cool down.
2) The methyl alcohol (CH_3OH) and catalyst (KOH) were mixed together at different ratios (4:1, 6:1, and 8:1) and catalyst concentrations by weight percent (0.5, 1.0, and 1.5) of the sample oil.
3) The uniform mixture of the catalyst (KOH) and methanol (CH_3OH) was blended with 100 g of grape seed sample oil.
4) The flask containing the mixture of methanol, the catalyst, and oil was stirred continuously by placing a flask inside a water bath shaker at a 60 ˚C temperature at around 700 rev/min for periods of 60 min, 75 min, and 90 min.

5) Once the reaction time was reached, the sample was emptied into a separating flask and left for 3-4 hours for the separation of phases. The sample separated into two layers. The bottom layer was of glycerol (due to its higher specific weight, it settled down), which was disposed of, leaving behind biodiesel were shown in Figure 3.2.
6) Once the process of separation was completed, the biodiesel was treated with a hot water wash to eliminate any remaining impurities as well as the methyl alcohol and catalyst.
7) Eventually, the biodiesel was heated to 110˚C using a hot air oven to eliminate any remaining moisture.

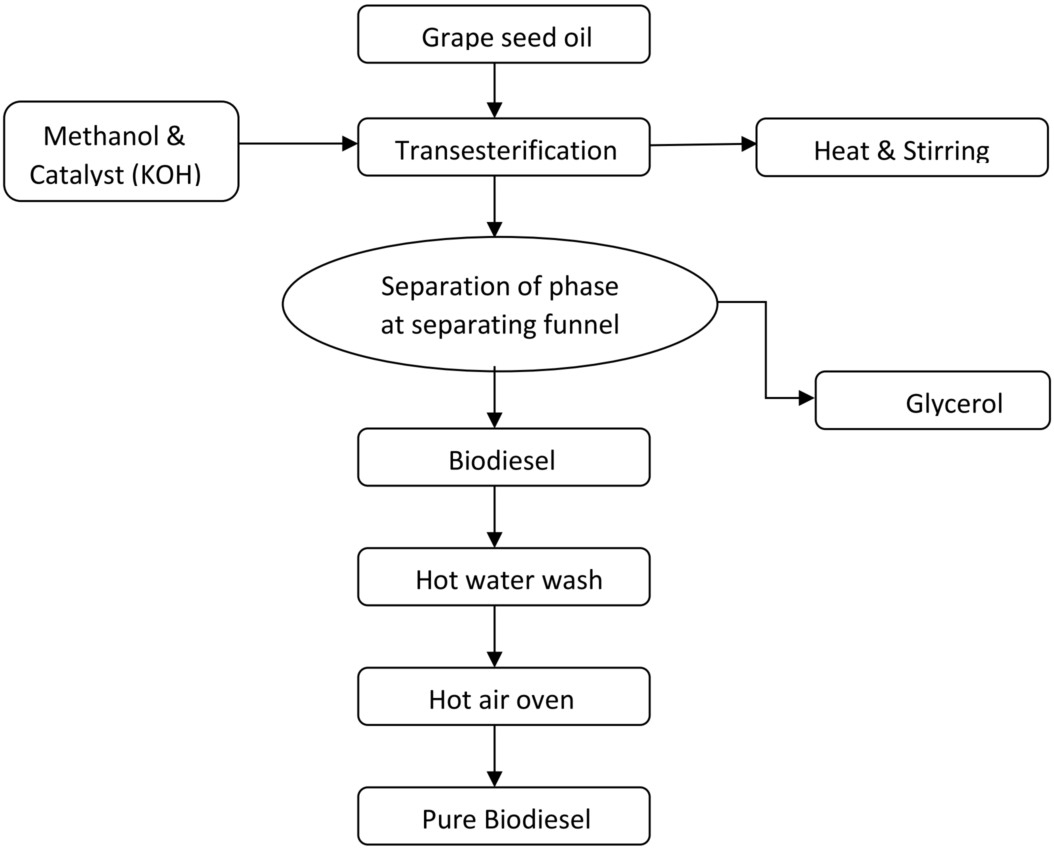
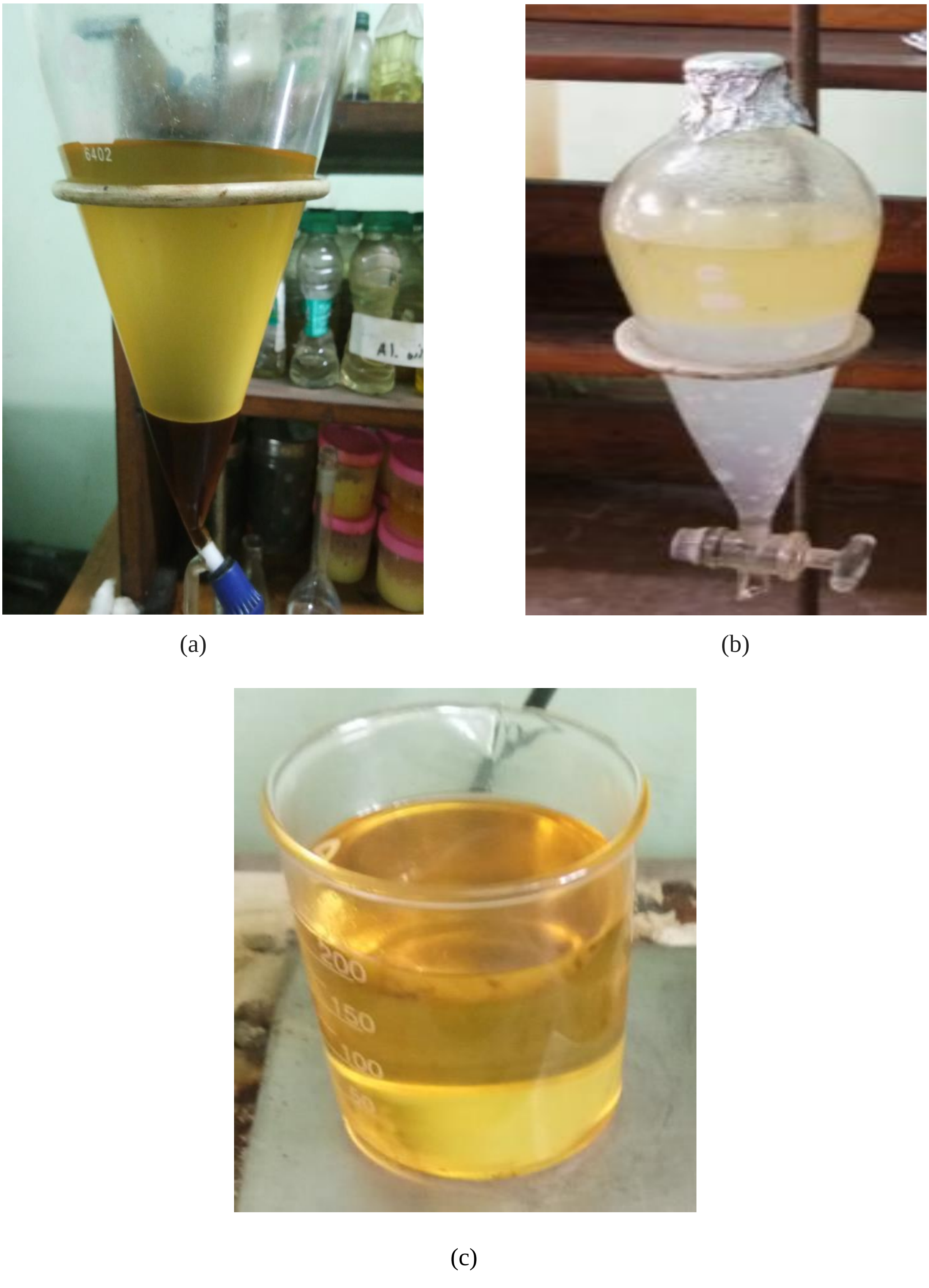


Figure 3.1: Process flow diagram of biodiesel production by transesterification process



(a) (b)

(c)

Figure 3.2: (a) Biodiesel on upper side & glycerol on lower side i.e. Separation of phase, (b) Biodiesel after hot water wash i.e. hot water treatment, (c) Pure biodiesel

3.2 Determination of methyl ester properties

Following properties have been determined during experimental work. These are

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

3.3 Apparatus used for biodiesel production

3.3.1 Water bath shaker

The water bath shaker is generally used for transesterification process for production of biodiesel. The water bath shaker helps in proper mixing of solvent at required temperature as well as speed.

Figure 3.3: Water bath shaker

The water bath shaker consist of induction motor which is connected to the tray and tray is submerged in water. There is also heating coil present within the tray for heating the water to particular temperature. The induction motor derives the tray in reciprocating motion which holds the conical flask having solvents in holders present on the tray. The desired temperature is set with the help of temperature regulator present on water bath shaker. The motor is immediately switch on after achieving the desired temperature of water and after motor starts, required speed is set with speed regulator present besides the temperature regulator and run the shaker for specified time.

3.3.2 Redwood viscometer

Redwood viscometer is generally used to determine the viscosity of fluid at different temperatures in terms of seconds known as Redwood seconds. The redwood viscometer consist of vertical cylindrical cup surrounded by the water bath with an orifice having diameter 1.70mm and 12mm in length in the centre of its base. The cylindrical cup is 88.90mm deep and 47.625mm in diameter. The orifice is closed and open with the help of stopper. The water bath helps in maintain the temperature of the fluid or oil at which it is to be tested. The oil in the cylindrical cup is heated with the help water bath by means of electric heater immersed in the water bath. The water stirred continuously in water bath to maintain the uniform temperature. Thermometer is used to record the temperature of water and oil in cylindrical cup.

Figure 3.4: Redwood viscometer

To measure the viscosity by the means of redwood viscometer, it should be assured that viscometer should be cleaned up properly and orifice should be closed by stopper. The cylindrical cup was filled with the oil whose viscosity to be measured to the specified level pointed by levelling screw. The oil was heated up to the desired temperature. After attaining the required temperature, the stopper was lifted up and allowed the oil to pass through orifice and collected in 50ml measuring cylinder. The time taken by oil to fill the 50ml cylinder was noted in the terms of seconds.

There are two types of equations are available which converted redwood seconds into kinematic viscosity in terms of centistokes.

$\mu \text{ (cSt)} = At - B/t$

where t = time in seconds, μ = Kinematic viscosity in centistokes (cSt)

If $t < 100$ sec

$A = 0.26$

$B = 176$

If $t > 100$ sec

$A = 0.24$

$B = 50$

3.3.3 The bomb calorimeter

The Bomb calorimeter is commonly used to determine of calorific value of solid as well as liquid fuel i.e. energy liberated per kg of fuel.

Figure 3.5 Bomb calorimeter

The calorimeter has a water filled insulated box inside which is the heart of the calorimeter the bomb. The bomb is a strong steel container in which exothermic reaction is carried out at the near explosive rate and the reactants and product are combine to constant volume. The reactant sample of known mass is taken in the metal cup in the bomb. The bomb is then filled with oxygen at a pressure of 30 atmosphere. The reaction is initiated with an electric ignition wire. The stir is used to make the uniform temperature. The heat of the reaction is determined from the temperature rise in the water that surrounds the bomb. The highest temperature recorded by the thermometer is noted. The highest calorific value is determined using the equation as follows:

$$HCV\ (kJ/Kg) = (W + w) * (T_2 - T_1) * C_W / m$$

Where W and w are the mass of water filled in the copper bomb calorimeter and water equivalent of calorimeter respectively.

T_1 and T_2 are initial and final temperature of water in °C respectively.

C_W is specific heat capacity of water.

m is the mass of fuel sample.

3.3.4 Pensky Martens apparatus

Pensky martens apparatus is generally used to determine the flash and fire point. The cup must be clean and dry and filled with the fuel sample up to the indicated level present in the cup.

Figure 3.6: Pensky Martens apparatus

Put the filled cup on the stove and place the lid on the top and verified that flame ignition device should be fixed at the lid. Now put the thermometer through hole present on the lid and sure that the bulb of thermometer must be dipped in the fuel sample placed in the cup. Now switch ON the apparatus and heat the apparatus until the temperature of fuel sample increases 5-6 °C per minute and stirred continuously for uniform temperature. Test flame was introduced for every 1 °C rise in fuel temperature through the vapour shutter present on the lid. The lowest temperature at which flash or briefly ignite flame was observed when exposure to test flame is known as flash point. The temperature at which fuel vapours started to produce flame and the flame continuously burnt for minimum 5 seconds, that temperature is known as fire point.

3.3.5 Cloud and pour point apparatus

This apparatus is used to determine the cloud and pour point of the liquid fuel. This apparatus consists of a glass tube surrounded by air jacket, cork with a hole at centre to fit the thermometer easily and cooling bath.

Figure 3.7: Cloud and pour point apparatus

First of all, the oil was poured in the glass tube and closed tightly with the help of cork. Placed the thermometer in the glass tube through opening present on the cork. After that placed the glass tube in the air jacket and put it in the cooling bath containing crushed ice and sprinkle sodium chloride on the ice to decrease the melting rate of ice. For every 1 °C fall in temperature of oil, removed the glass tube from the jacket to determine the cloud and replaced as soon as possible. The minimum temperature at which oil forms cloudiness and wax type, that temperature is known as cloud point.

The temperature at which oil losses its flow characteristics and stop its movement, that temperature is known as pour point.

3.3.6 Free fatty acid content

Titration method was obtained to determine percentage of free fatty acid content (%FFA). Following steps were followed for calculating free fatty acid content in the sample fuel.

- First of all, 0.1gm to 10gm oil was poured in the conical flask.

- Add 50 ml of ethanol in the oil sample and mixed uniformly
- In the mixture, 4-5 drops of phenolphthalein was added.
- Burate was filled with 0.1 N KOH solutions.
- The oil titration was done with 0.1 N KOH solution until the mixture attained pink colour and sustains minimum for 10 seconds.

Equation used for calculation for % FFA content was:

$$\%FFA = (28.2 * N * KOH\ consumed)/ W$$

Where N = Normality of KOH solution

W = weight of sample

3.4 Apparatus used for engine performance and emission evaluation

3.4.1 Variable compression ratio engine

VCR engine made by the company named as kirloskar was selected for experimental investigation whose product code is 234 which was connected to the control panel unit consists of rotameter, indicator that indicates the water temperature, speed indicator, fuel flow transmitter and loading regulator switch etc.

Figure 3.8: Variable compression ratio engine

Figure 3.9: Dynamometer

Table 3.1: Detailed specification of VCR Engine

Type of engine	4 stroke diesel engine with variable compression ratio (Kirloskar)
Cylinder type	Single type cylinder
Capacity of Engine	661 cc
Bore diameter	87.5 mm
Stroke length	110 mm
Compression ratio	17.5:1
Engine power	3.5 kW at 1500 RPM
Type of Dynamometer	Water cooled, eddy current, unit loading
Water inlet	1.6 bar
Torque	11.5 Nm
Maximum speed	10000 rpm
Fuel Tank	15 litre capacity with glass metering column
Temperature Sensor	Type RTD, PT100 and Thermocouple, Type K`, Range 0-1200 °C
Load indicator	Digital type, Supply 230VAC
Load sensor	Load cell. Type strain guage
Pump	Monoblock type
Propeller shaft	With universal joints
Crank angle Sensor	Resolution 1°, speed 5500 rpm with TDC pulse
Software	“EnginesoftLV” Engine performance analysis software
Overall Dimension	W 2000 x D 2500 x H 1500 mm

The engine output shaft is further connected with the eddy current dynamometer which is used to measure the power and torque. There is a load cell connected to the dynamometer and various types of load are applied on the engine (0-10 kg). These load cells are attached to the sensors which indicated the load on the load indicator. The parameters of engine performance and combustion such as mechanical efficiency (MEff), brake power (BP), brake thermal efficiency (BTE), brake specific fuel consumption (BSFC), heat release rate, heat balance and cylinder pressure were observed by engine performance analysis software named as EnginesoftLV.

3.4.2 Exhaust gas analyzer

The exhaust analyzer was used to determine the different types of gases or species released during emission. Analyzer consists of digital meter with ON/OFF button present on it.

Figure 3.10: Exhaust gas analyser

Table 3.2: Specification of exhaust gas analyzer

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

The long thin pipe with holes on it was inserted in the exhaust pipe which further connected to the exhaust analyser. After some time it analysed the exhaust species such as carbon monoxide (CO), unburnt hydrocarbons (HC), oxide of nitrogen (NOx) and exhaust gas temperature (EGT) and were displayed on the digital meter.

3.5 Experimental procedure

The experimental investigation was done on VCR engine with diesel and other three different types of blends B10, B20 and B30 of GSOME and GSOME with different proportion of DEE (5%, 10% & 15%) as additive. The procedure is illustrated below:

- At first, filled up the fuel tank with diesel fuel.
- The required compression ratio was maintained i.e. 18:1 with the help of lock nut.
- Before starting the engine, water pump was opened to regulate the cool water with 300 LPH flow rate of water rotameter and 70 LPH was adjusted to calorimeter rotameter flow rate.
- The position of fuel cock must be at “Tank”.
- The engine was started by the means of hand cranking and ran for few minutes without any load.
- Opened the software named as “EnginesoftLV” on the monitor of computer for analysis of engine performance.
- Now the load 0.5 kg was increased by DLU knob (check simultaneously that there must be increased load reading same as that on the computer) and knob of fuel should be placed at “Measuring” from “Tank” position. After clicking on “Log on”, data such as flow of water and cooling water jacket was submitted into input display. The performance data was recorded at no load condition for the engine and the position of fuel was turned to “Tank” from “Measuring”.
- The same process was followed for different loads.

3.6 Procedure for measuring exhaust gas emission

The following steps was followed to measure the exhaust gas.

- The sensor probe which was thin and long cylindrical probe, was connected to gas analyser.
- At the exhaust outlet pipe of the engine, the sensor probe was inserted and tightened carefully.
- The exhaust emission gas then passed through the sensors.
- These sensors were calculated the emission values and displayed on the digital meter of analyser.
- Same procedure were followed for other different loads.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Optimization of production of methyl ester

Transesterification process was used for the biodiesel production under three different process parameters such as catalyst concentration (KOH), Methanol to oil molar ratio and reaction time. Biodiesel production was optimized on the basis of minimum viscosity and maximum yield.

Table 4.1: Optimization of methyl ester production from grape seed oil

S. No.	Grapeseed oil (gm)	Molar ratio	Catalyst KOH (%)	Reaction time (min)	Reaction temperature (˚C)	Yield (%)	Viscosity at 40˚C (cSt)
1	**100**	**4:1**	**0.5**	**60**	**60**	**98.41**	**4.14**
2	100	4:1	0.5	75	60	79.43	7.72
3	100	4:1	0.5	90	60	96.51	5.92
4	100	4:1	1.0	60	60	91.02	4.78
5	100	4:1	1.0	75	60	76.48	9.08
6	100	4:1	1.0	90	60	94.10	5.85
7	100	4:1	1.5	60	60	93.14	5.20
8	100	4:1	1.5	75	60	91.28	7.42
9	100	4:1	1.5	90	60	97.47	5.81
10	100	6:1	0.5	60	60	80.25	4.93
11	100	6:1	0.5	75	60	82.30	7.19
12	100	6:1	0.5	90	60	74.12	6.08
13	100	6:1	1.0	60	60	96.90	7.46
14	100	6:1	1.0	75	60	92.47	4.58
15	100	6:1	1.0	90	60	86.59	6.69
16	100	6:1	1.5	60	60	97.50	5.05
17	100	6:1	1.5	75	60	94.51	6.49
18	100	6:1	1.5	90	60	92.83	7.16

19	100	8:1	0.5	60	60	92.50	5.53
20	100	8:1	0.5	75	60	98.18	8.48
21	100	8:1	0.5	90	60	94.28	7.45
22	100	8:1	1.0	60	60	83.65	4.54
23	100	8:1	1.0	75	60	93.78	10.35
24	100	8:1	1.0	90	60	84.26	4.38
25	100	8:1	1.5	60	60	92.18	8.49
26	100	8:1	1.5	75	60	95.28	4.66
27	100	8:1	1.5	90	60	87.30	4.26

The above table represents that the optimization of methyl ester production from grape seed oil. The optimized process parameters for maximum yield and minimum viscosity were found to be 4:1 methanol to oil molar ratio, 0.5% catalyst concentration (KOH), 60 minutes reaction time at temperature of 60 ˚C. The optimized biodiesel yield and viscosity were evaluated as 98.41% and 4.04 centistokes respectively as per optimized process parameters.

Table 4.2: Optimized process parameters of grape seed oil methyl ester

Molar ratio	4:1
Catalyst concentration (wt. %) (KOH)	0.5
Reaction time (min)	60
Reaction temperature (˚C)	60

4.2 Parameters effects on transesterification of grape seed oil

In this segment presented the impact of various parameters i.e. catalyst concentration, molar ratio and reaction time etc. on methyl ester production from grape seed oil by the means of transesterification process.

4.2.1 Effect of catalyst and reaction time on GSOME formation

In this experimental work, alkaline transesterification process was used. Due to cheaper and effective in nature, alkaline catalyst potassium hydroxide (KOH) was used at different concentration with molar ratio 4:1, 6:1 and 8:1 at constant temperature of 60 ˚C. The impact of these parameters over biodiesel production are shown in Figure 4.1, Figure 4.2 and Figure 4.3.

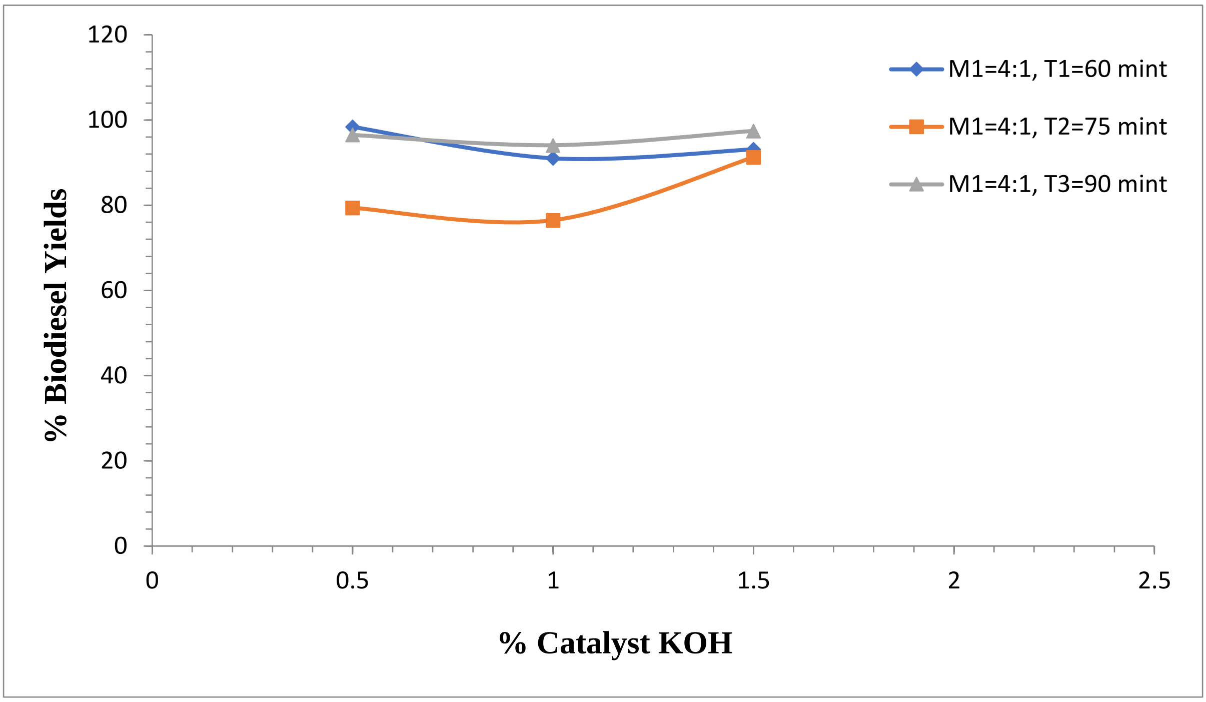


Figure 4.1: Variation of GSOME yield with KOH concentration and reaction time at 4:1 molar ratio

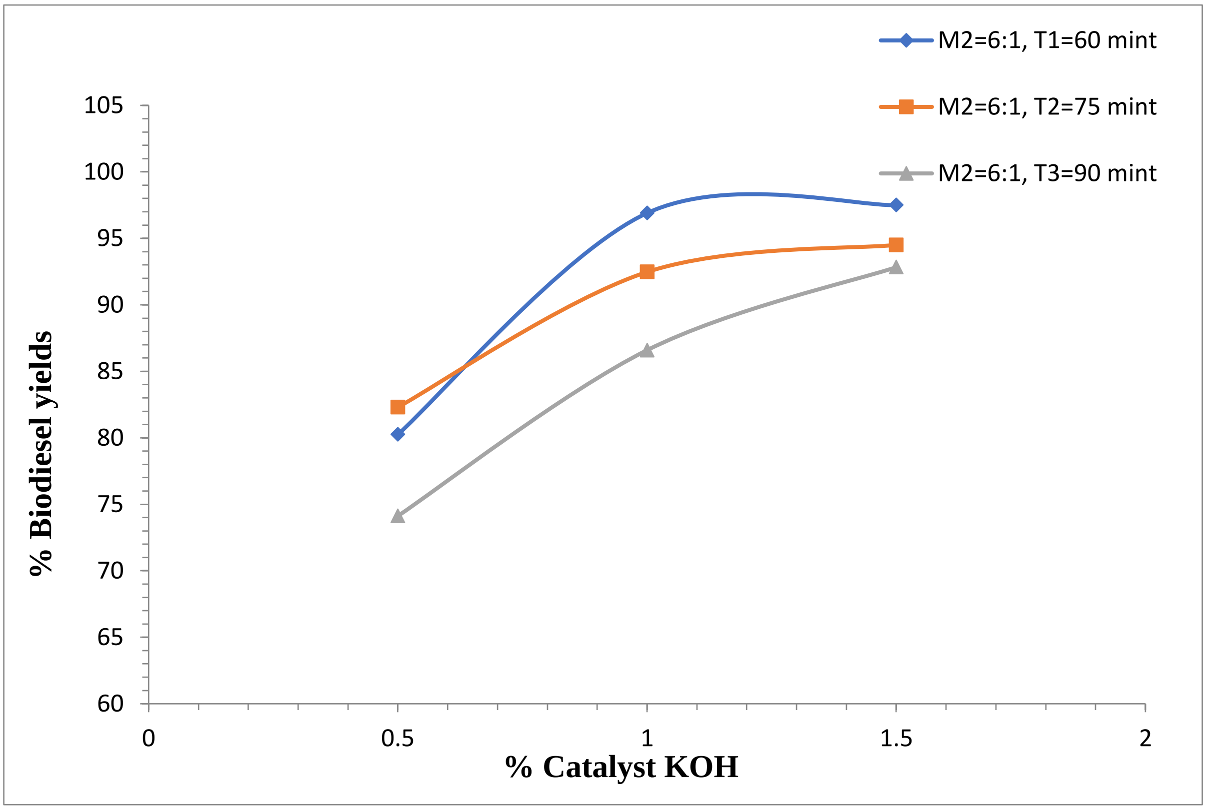


Figure 4.2: Variation of GSOME yield with KOH concentration and reaction time at 6:1 molar ratio

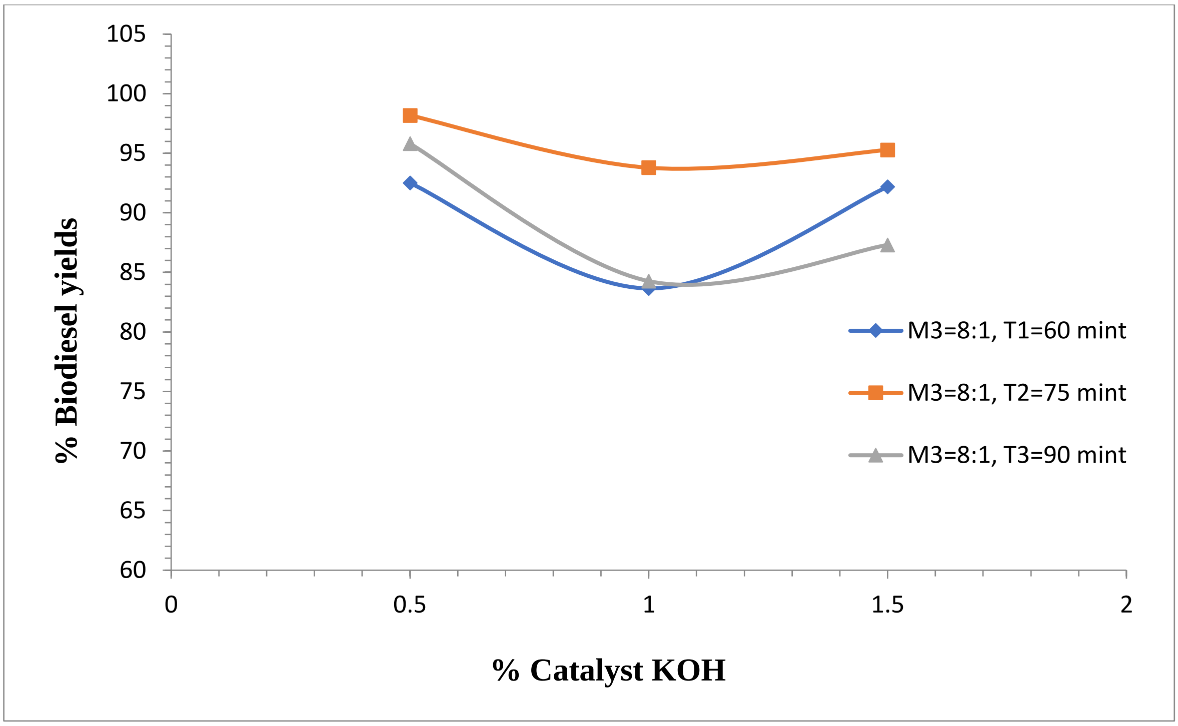


Figure 4.3: Variation of GSOME yield with KOH concentration and reaction time at 8:1 molar ratio

It is found that catalyst concentration played a vital role during transesterification process. As catalyst concentration is raised from 0.5% to 1.0%, Fig. 4.1 and Fig. 4.3 shows the decreasing trend of biodiesel production at 60 minutes reaction time because of formation of soap increases and incomplete reaction takes place. Further, when catalyst concentration raised from 1.0% to 1.5%, the biodiesel production increases. In Fig. 4.2, it is found that the biodiesel yield increases with the increase of catalyst concentration at molar ratio of 6:1.

It is also found that reaction time is one of the important factor which play vital role in biodiesel production. As time of reaction increases from 60 minutes to 90 minutes, the biodiesel yield rises or falls depending upon the concentration of catalyst used. The maximum production of biodiesel i.e. 98.41% is obtained with concentration of catalyst 0.5% (weight %) at 60 minutes.

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

Methanol to oil molar ratio is one of the most dominant parameters which affecting the biodiesel yield. Molar ratio is defines as the moles number of alcohol to moles number of triglycerides in the oil. Figure 4.4 represents the variation of reaction time and molar ratio on the grape seed methyl ester production with 0.5% KOH concentration at 60 °C reaction temperature. It is found that as molar ratio increases from 4:1 to 8:1, the biodiesel yield increases with respect to time of reaction. This is due to transesterification reaction, which is reversible in nature. The yield of biodiesel increases with addition in ratio of methanol. But, we generally don't use higher molar ratio due to more power and energy consumption for recovering methanol which being left unreacted and difficult in separation of by product thereby increasing the production cost. The maximum production of biodiesel is obtained at 4:1 i.e. 98.41% with methanol to oil molar ratio 4:1 at 60 minutes time of reaction.

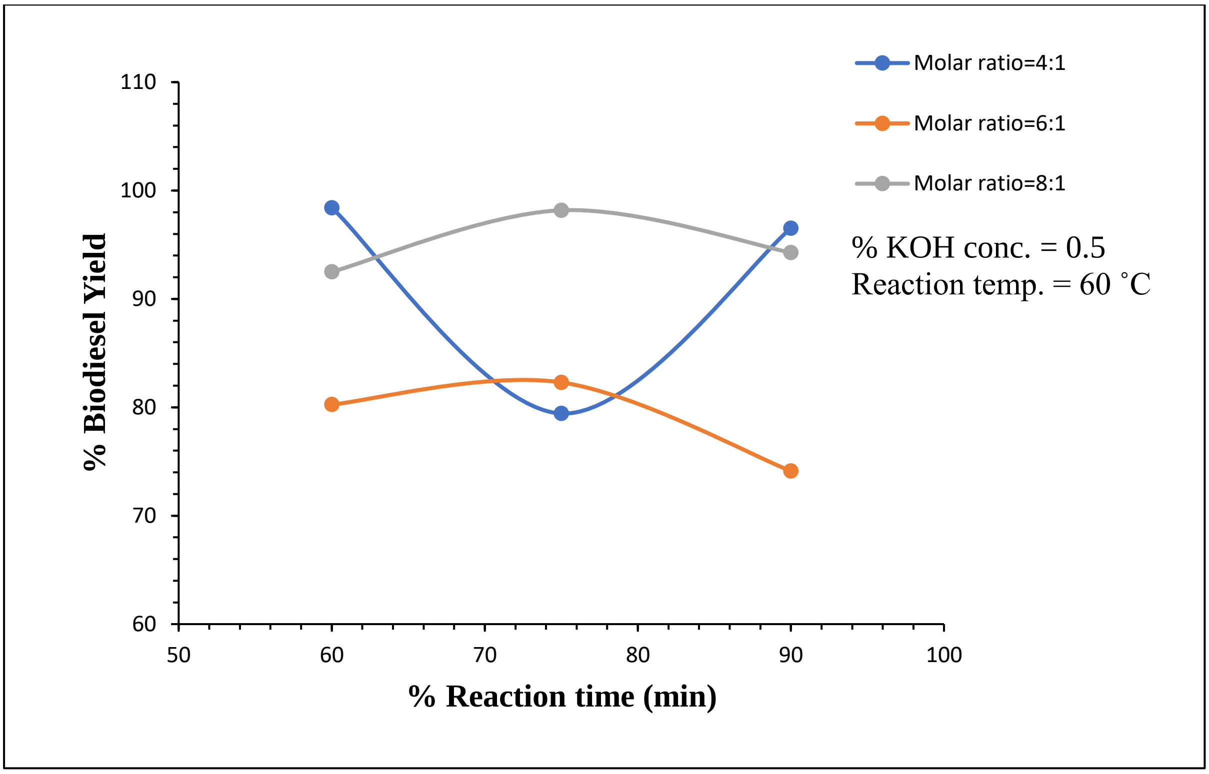


Figure 4.4: Variation of GSOME yield with molar ratio and reaction time at 0.5% KOH concentration

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

From Fig. 4.5, it is clearly identified that molar ratio plays an important role in viscosity of the biodiesel. It was found that viscosity of grape seed oil methyl ester increases when molar ratio increases from 4:1 to 8:1. This cause due to methanol solubility in glycerin which increases with increase in methanol to oil molar ratio and becomes difficult during separation process. Hence, left behind glycerin in solution which give rise to higher the viscosity of biodiesel. As per requirement of the project, the least viscosity has been found at 4:1 methanol to oil molar ratio and 60 minutes time of reaction.

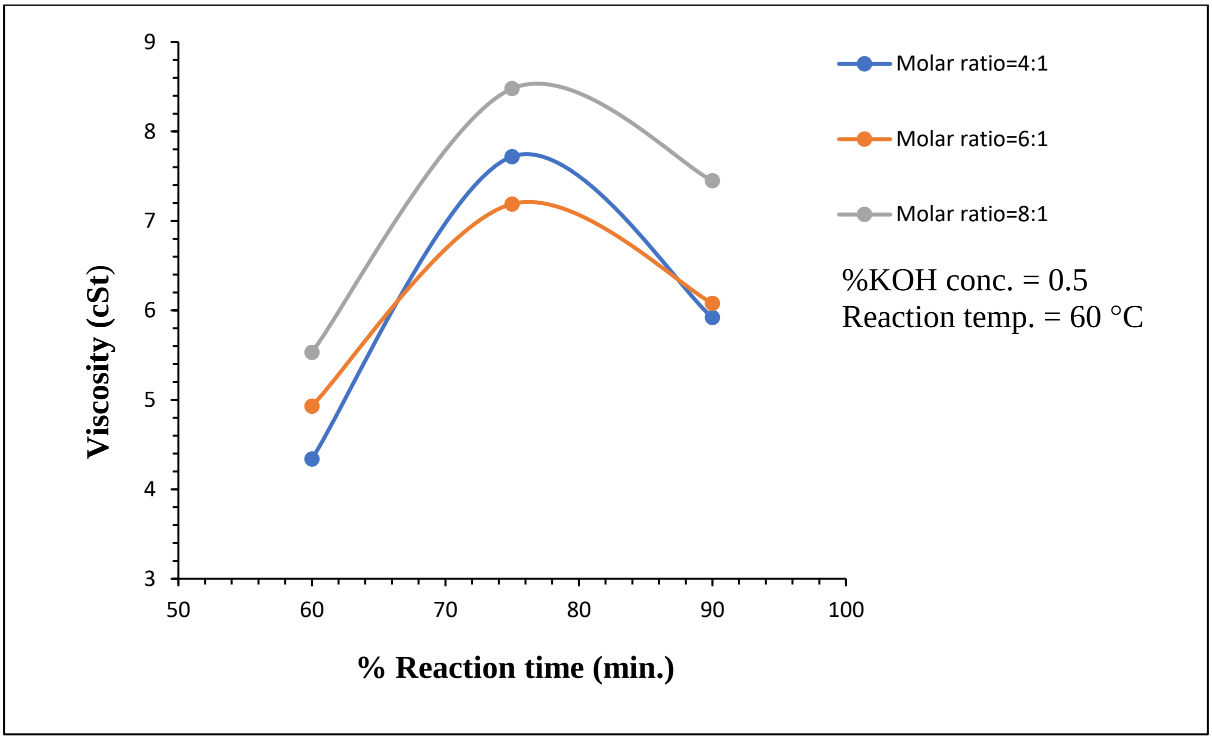


Figure 4.5: Variation of GSOME viscosity with molar ratio and reaction time at 0.5% KOH concentration

4.3 Analysis of grape seed oil and its methyl ester

Table 4.3 shows the Physicochemical properties of grape seed oil (GSO) and grape seed oil methyl ester (GSOME).

Table 4.3: Physicochemical properties of grape seed oil (GSO) and grape seed oil methyl ester (GSOME)

Parameters	EN14214	GSO	GSOME	DEE	Diesel
Density at 15 °C, kg/m^3	860-900	922.17	880.2	713.4	820-860
Free fatty acid content, %	-	0.6	0.18	-	-
Kinematic viscosity at 40 °C (cSt)	3.5-5.0	26.92	4.14	0.24	3.12

Flash point, °C	>101	250.7	174	-45	>55
Fire point, °C	-	262	182	-	-
Cloud point, °C	<3	-7	-5	-	-16
Pour point, °C	-	-4	-6	-	-33
Higher heating value (MJ/kg)	-	37.7	39.52	33.9	42.7
Water content (mg/kg)	Max. 500	390.8	202.5	-	-

4.4 Performance and emissions characterization for GSOME blended fuel

In this study, three different blends were used namely B10, B20, and B30 and all the experiments were conducted at different compression ratio i.e. 14:1, 16:1 and 18:1. The parameters such as brake specific fuel consumption (BSFC), brake power (BP), mechanical efficiency (MEff), brake thermal efficiency (BTE) and exhaust emissions such as unburned hydrocarbon (HC), carbon monoxide (CO), exhaust gas temperature (EGT) and nitrogen of oxide (NOx) were evaluated.

4.4.1 Effect of load on brake power for different blends

Figure 4.6, Figure 4.7 and Figure 4.8 represented the variation of brake power with respect to load under various conditions at different compression ratio. It was found that the brake power of all biodiesel blends (GSOME10%, GSOME20% and GSOME30%) and diesel fuel were increased with the increase in engine load. From figure, it was clearly observed that the brake power of all biodiesel blends are very similar to diesel fuel. This is due to the higher content of oxygen and density of biodiesel fuel which leads to more consumption of fuel for indemnification of lesser heating value of biodiesel blends and improve the combustion characteristics. The average brake power of biodiesel blends was found to be 1.71 kW which was 0.57% lower than diesel fuel i.e. 1.72 kW.

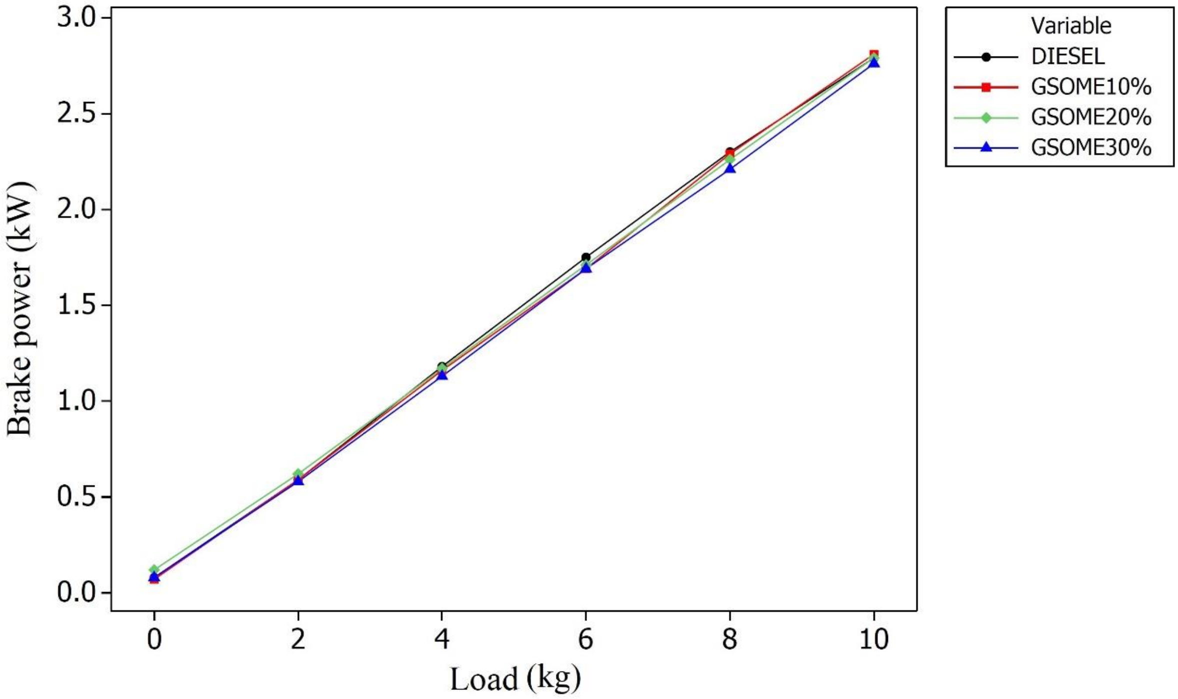


Figure 4.6: Variation of BP of GSOME blend and diesel fuel with load at compression ratio 14:1

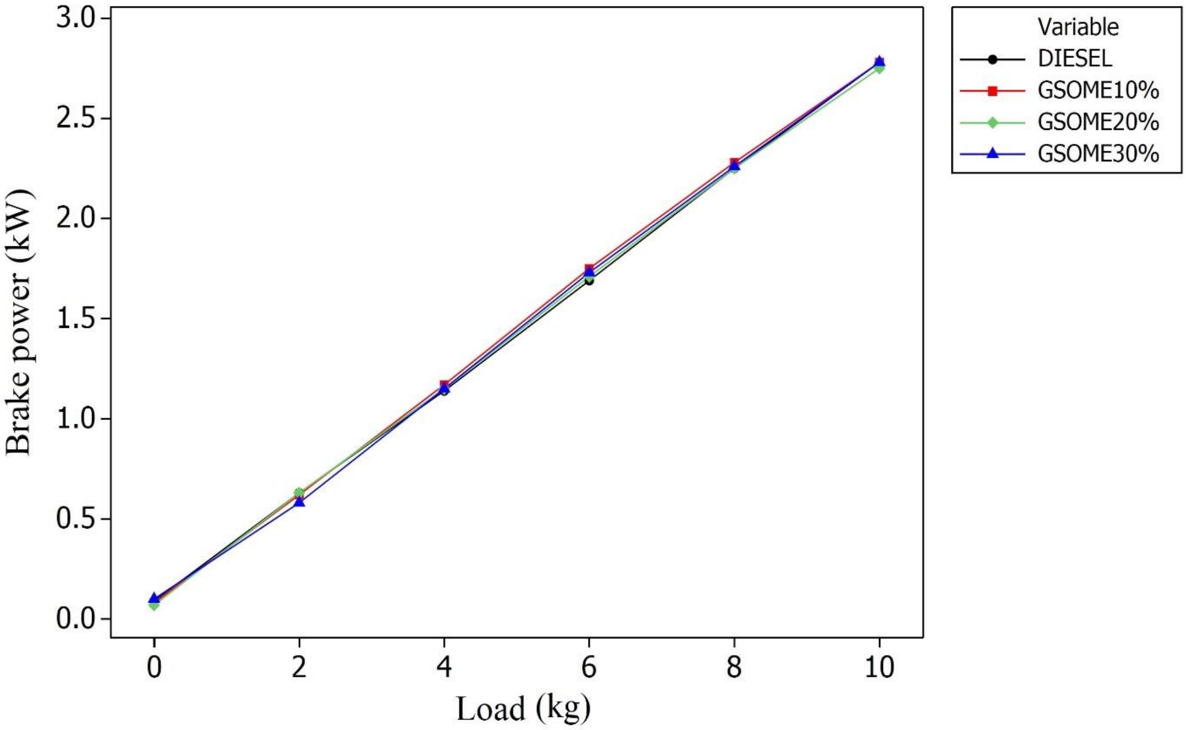


Figure 4.7: Variation of BP of GSOME blend and diesel fuel with load at compression ratio 16:1

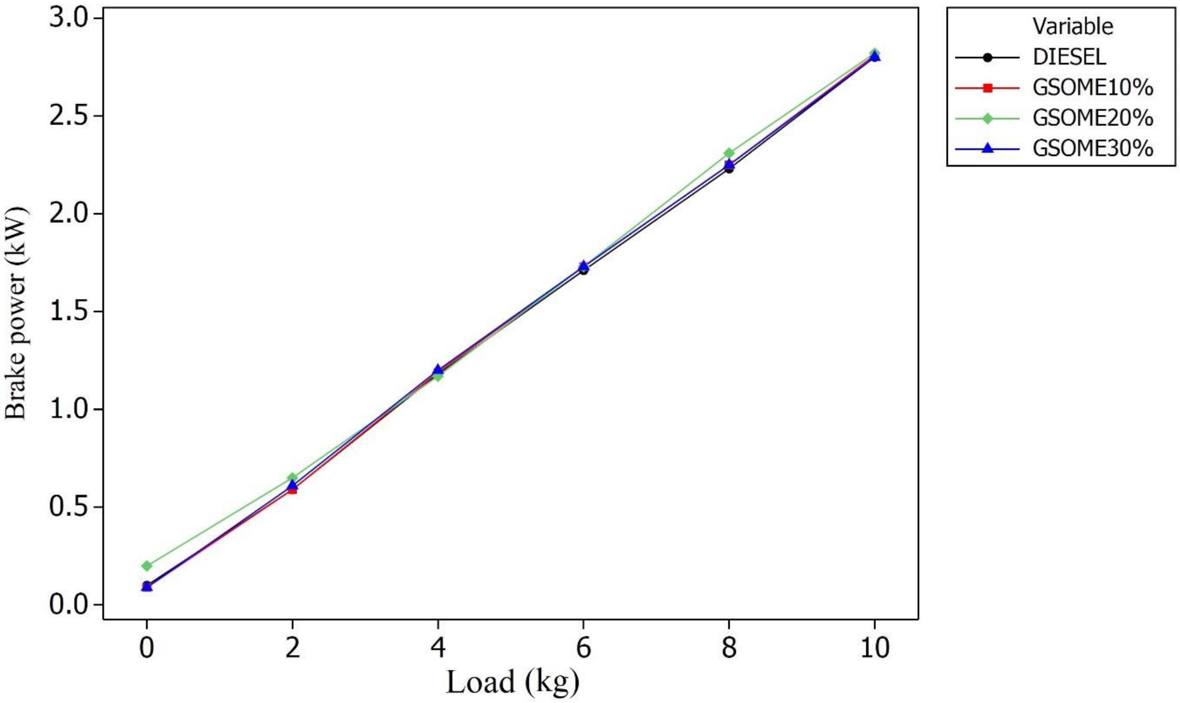


Figure 4.8: Variation of BP of GSOME blend and diesel fuel with load at compression ratio 18:1

4.4.2 Effect of load on brake specific fuel consumption for different blends

The brake specific fuel consumption for diesel fuel and various biodiesel fuel blends (GSOME10%. GSOME20% & GSOME30%) with respect to load at different compression ratio i.e. 14:1, 16:1 and 18:1 were shown in Figure 4.9, Figure 4.10, and Figure 4.11. It was found that brake specific fuel consumption decreases with increase in engine load for all biodiesel fuel blends and diesel fuel. The maximum brake specific fuel consumption was obtained 5.39 kg/kWh for GSOME10% blend at no load condition and on further increasing in load condition BSFC found to be constant for diesel fuel and all biodiesel fuel blends. Brake specific fuel consumption for D100, GSOME10%, GSOME20% & GSOME30% blends varied from 4.23 to 0.3, 5.39 to 0.32, 3.78 to 0.34 and 3.88 to 0.38 kg/kWh respectively with respect to load increased from no load condition to full load condition at compression ratio 14:1. Brake specific fuel consumption for D100, GSOME10%, GSOME20% & GSOME30% blends varied from 3.23 to 0.3, 3.84 to 0.32, 3.42 to 0.34 and 3.51 to 0.32 kg/kWh respectively with respect to load increased from no load condition to full load condition at compression ratio 16:1. Brake specific fuel consumption for D100, GSOME10%, GSOME20% & GSOME30% blends varied from 2.89 to 0.28, 3.16 to 0.28, 3.51 to 0.28 and 3.74 to 0.32 kg/kWh respectively with respect to load increased from no load condition to full load condition at compression ratio 18:1. The brake specific fuel consumption for all biodiesel fuel blends were higher than diesel fuel because of higher fuel consumption for blended fuel due to longer injection duration for same power output.

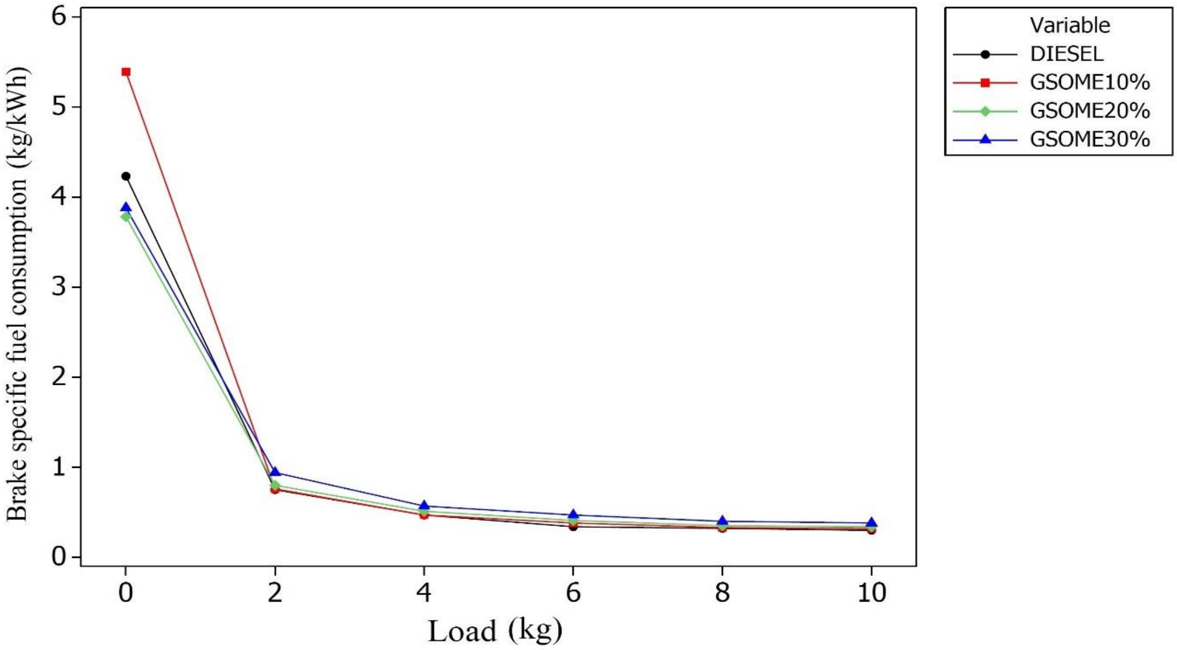


Figure 4.9: Variation of BSFC of GSOME blend and diesel fuel with load at compression ratio 14:1

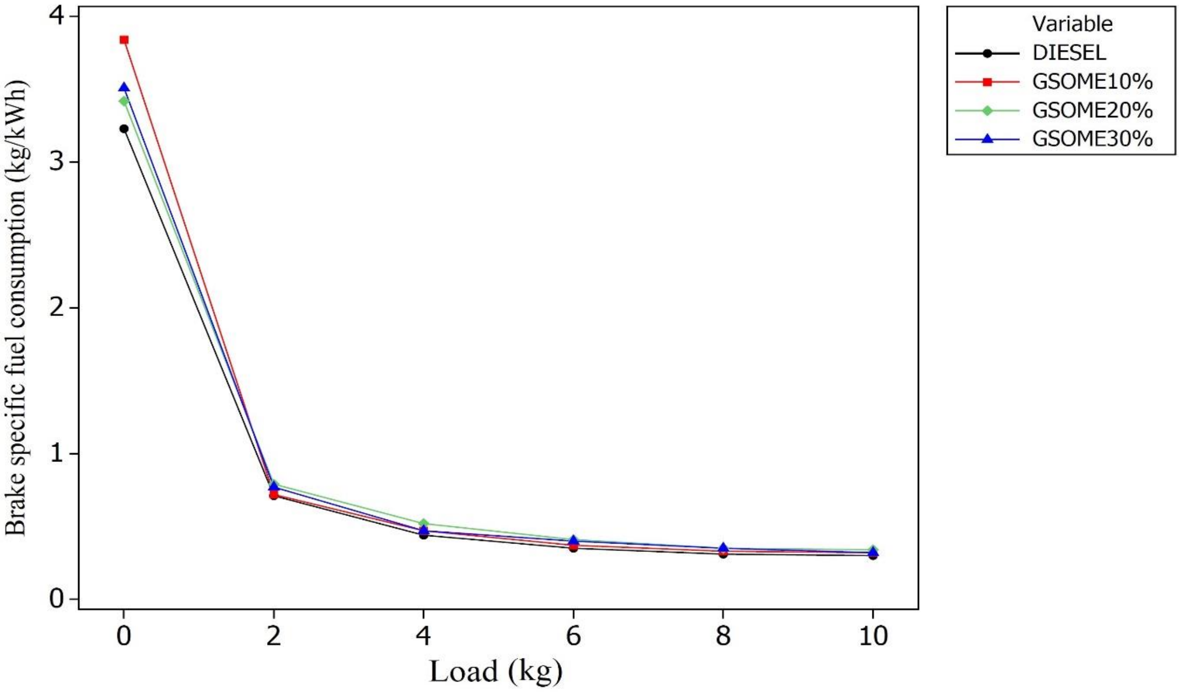


Figure 4.10: Variation of BSFC of GSOME blend and diesel fuel with load at compression ratio 16:1

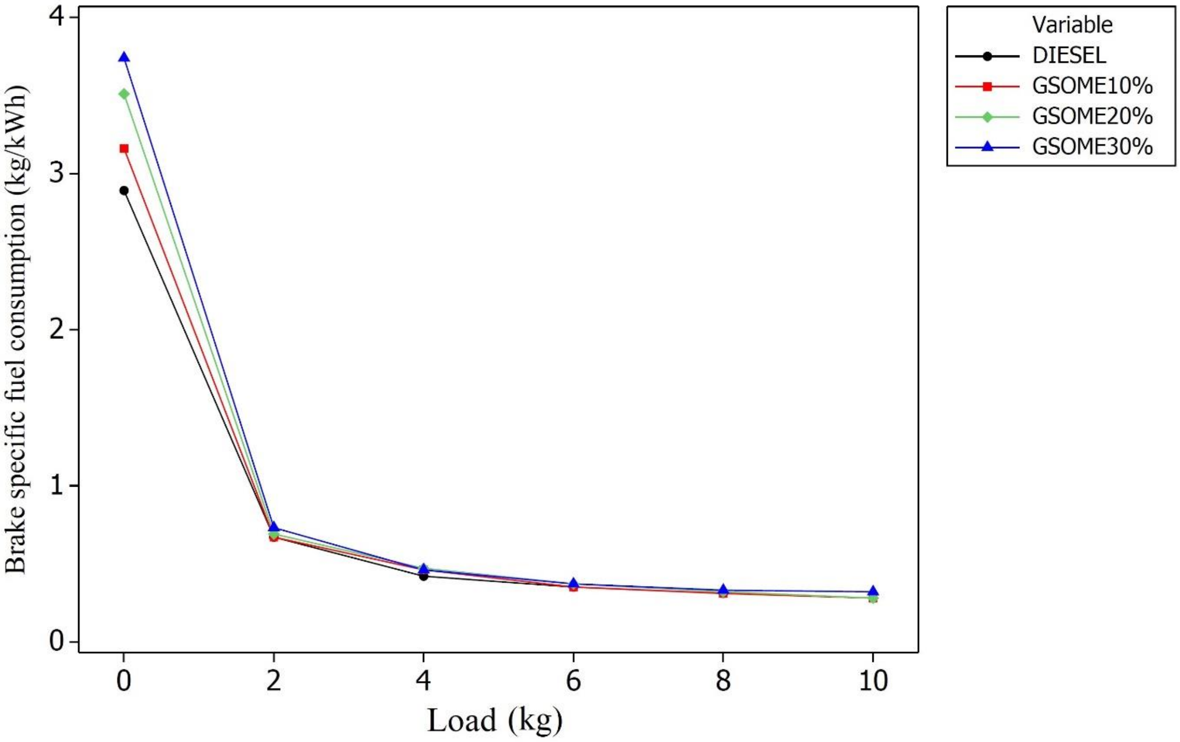


Figure 4.11: Variation of BSFC of GSOME blend and diesel fuel with load at compression ratio 18:1

4.4.3 Effect of load on brake thermal efficiency (BTE) for different blends

The deviation of brake thermal efficiency with respect to engine load for diesel and biodiesel fuel blends were shown in Figure 4.12, Figure 4.13 & Figure 4.14. It was clearly observed that brake thermal efficiency increases with increase in engine load from no load to full load condition. The maximum BTE of 30.18% was found at full load condition for GSOME10% at compression ratio 18:1. The brake thermal efficiency for D100, GSOME10%, GSOME20% & GSOME30% blends were found to be 28.21, 26.88, 25.31 and 22.6% respectively for compression ratio 14:1 under full load condition. The brake thermal efficiency for D100, GSOME10%, GSOME20% & GSOME30% blends were found to be 28.10, 26.63, 24.92 and 24.62% respectively for compression ratio 16:1 under full load condition. The brake thermal efficiency for D100, GSOME10%, GSOME20% & GSOME30% blends were found to be 30.14, 30.18, 29.37 and 29.74% respectively for compression ratio 18:1 under full load condition. The reason for increasing the brake thermal efficiency with increase in engine load because of increased in power and reduction in heat loss.

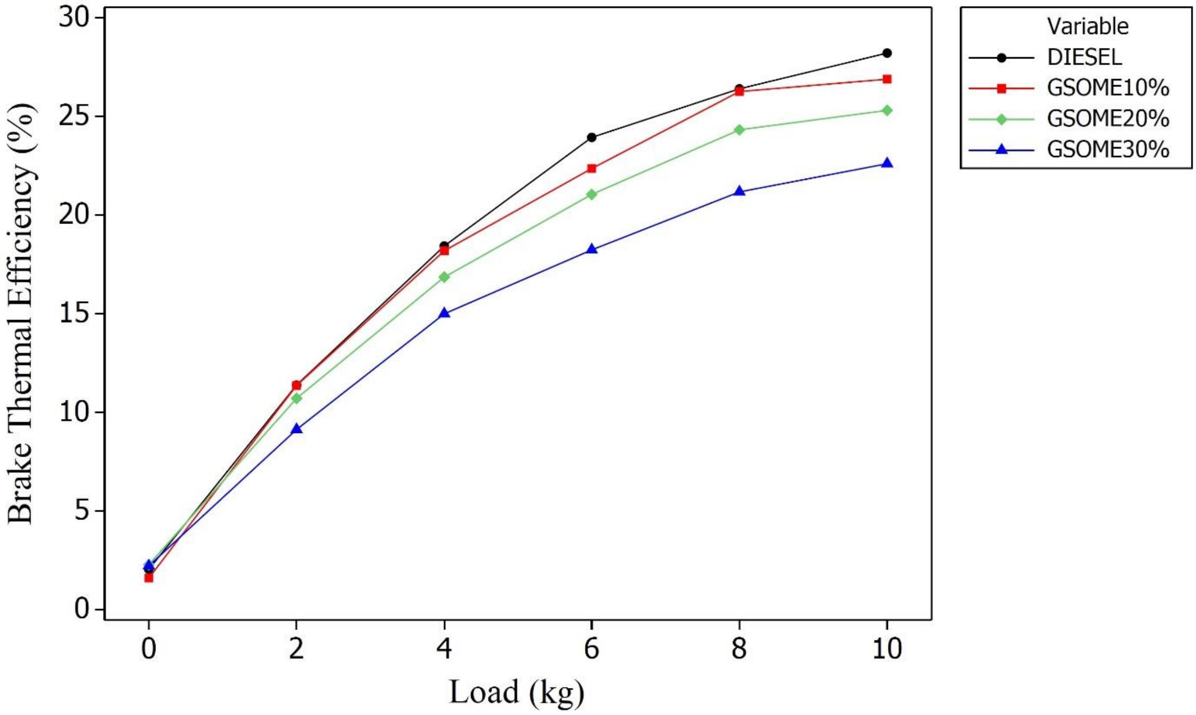


Figure 4.12: Variation of BTE of GSOME blend and diesel fuel with load at compression ratio 14:1

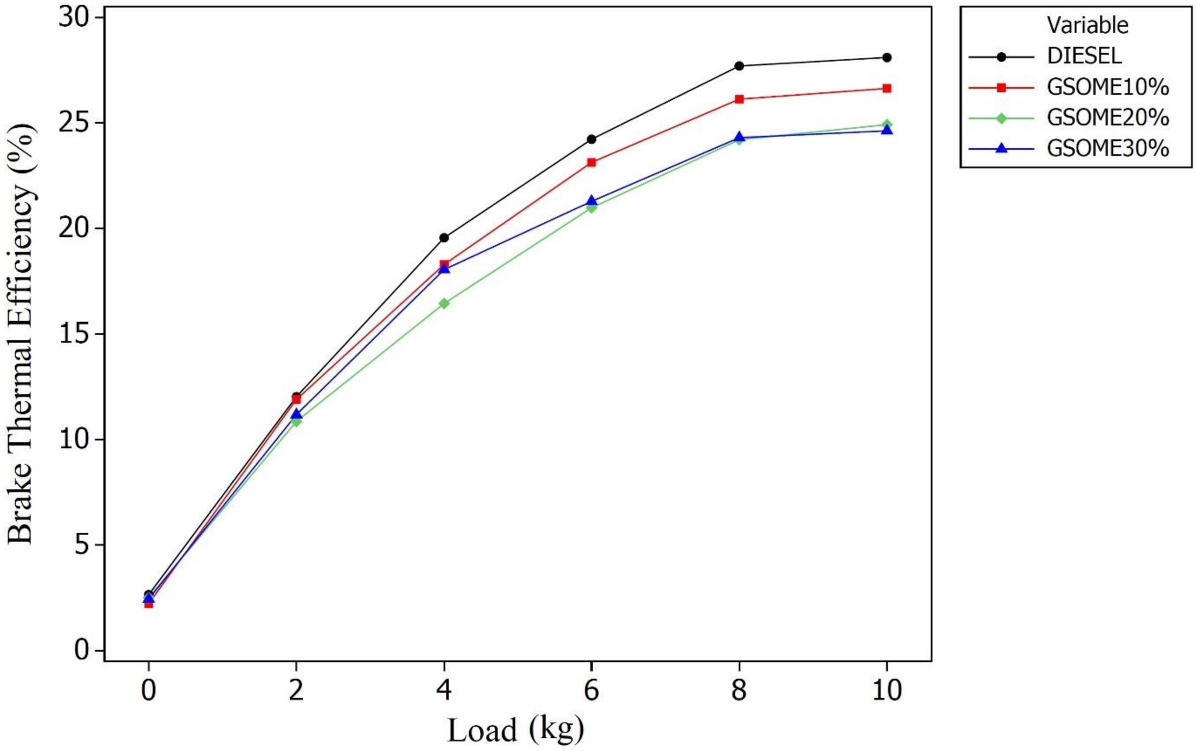


Figure 4.13: Variation of BTE of GSOME blend and diesel fuel with load at compression ratio 16:1

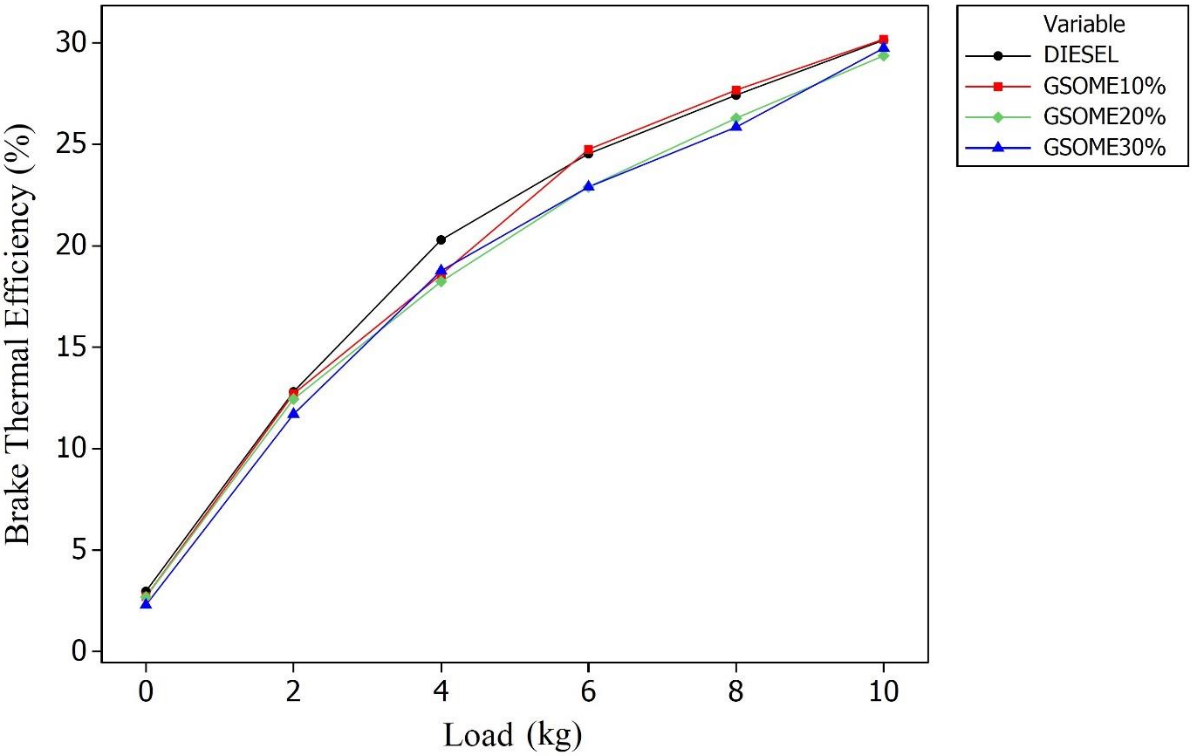


Figure 4.14: Variation of BTE of GSOME blend and diesel fuel with load at compression ratio 18:1

4.4.4 Effect of load on mechanical efficiency for different blends

Figure 4.15 to 4.17 shows that the deviation of mechanical efficiency with respect to load for various fuel blends at different compression ratios. It was found that the mechanical efficiency for diesel and biodiesel fuel blends increases with the increase in engine load. The maximum mechanical efficiency i.e. 41.04% was obtained for GSOME20% under full load condition at compression ratio 16:1. The mechanical efficiency for D100, GSOME10%, GSOME20% & GSOME30% blends were found to be 35.04, 38.77, 33.94 and 37.16% respectively for compression ratio 14:1 under full load condition. The brake thermal efficiency for D100, GSOME10%, GSOME20% & GSOME30% blends were found to be 32.26, 37.24, 41.04 and 33.48% respectively for compression ratio 16:1 under full load condition. The brake thermal efficiency for D100, GSOME10%, GSOME20% & GSOME30% blends were found to be 30.41, 34.29, 31.51 and 33.92% respectively for compression ratio 18:1 under full load condition. The reason for increasing mechanical efficiency may be reduction in heat loss and good automization characteristics.

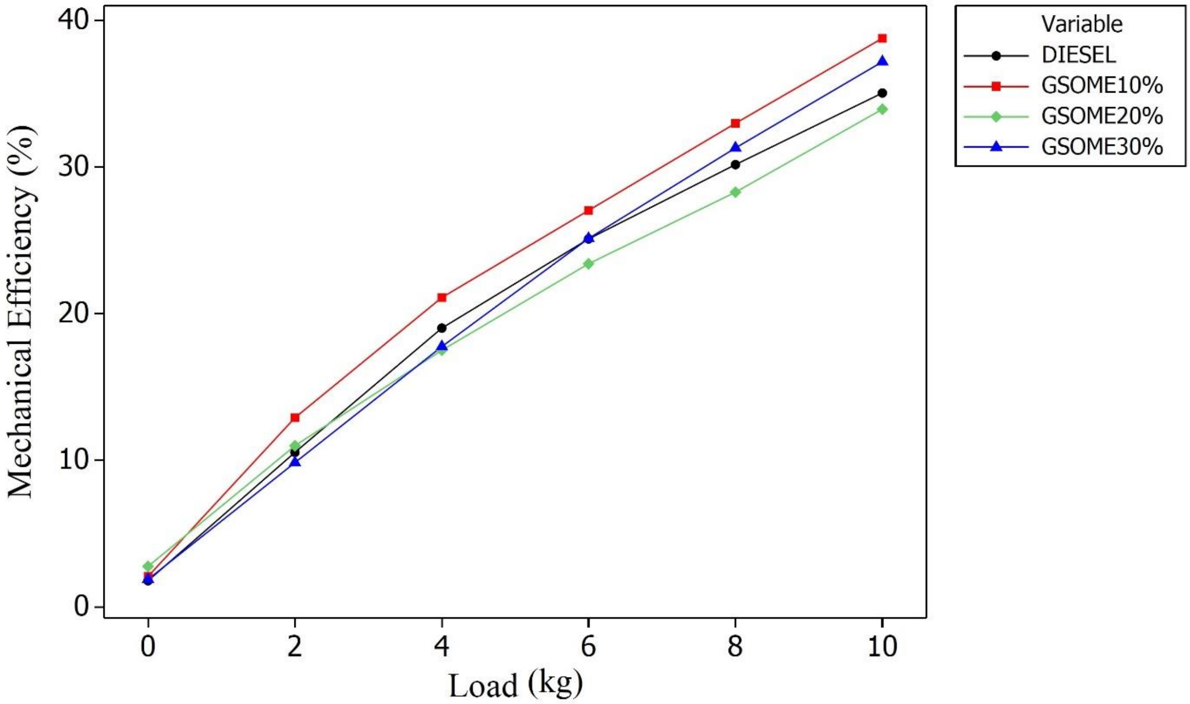


Figure 4.15: Variation of mechanical efficiency of GSOME blend and diesel fuel with load at compression ratio 14:1

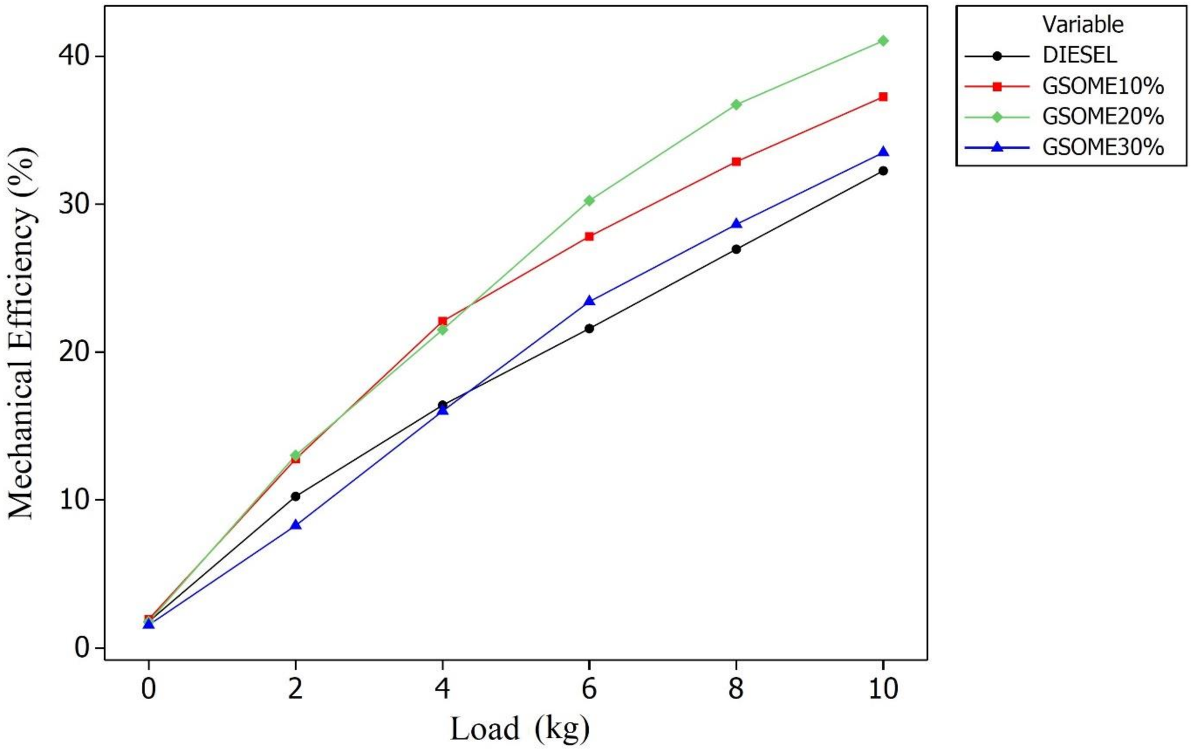


Figure 4.16: Variation of mechanical efficiency of GSOME blend and diesel fuel with load at compression ratio 16:1

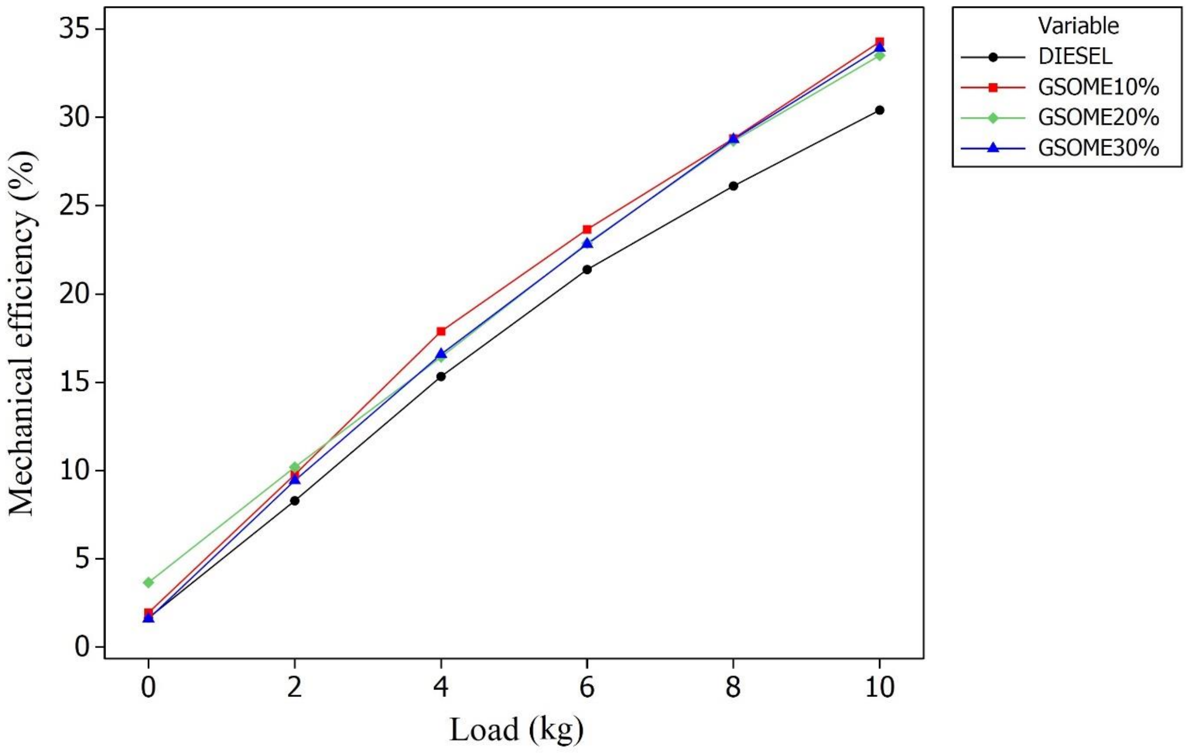


Figure 4.17: Variation of mechanical efficiency of GSOME blend and diesel fuel with load at compression ratio 18:1

4.4.5 Effect of load on exhaust gas temperature (EGT) for different blends

Figure 4.18 to 4.20 represents that the variation of EGT with respect to engine load for various fuel blends and diesel fuel. It was observed that the exhaust gas temperature increases with the increase in engine load. The maximum exhaust gas temperature i.e. 346.95 °C was obtained for GSOME30% under full load condition at compression ratio 14:1. The exhaust gas temperature for D100, GSOME10%, GSOME20% & GSOME30% blends were found to be 293.32, 294.27, 292.96 and 346.95 °C respectively for compression ratio 14:1 under full load condition. The exhaust gas temperature for D100, GSOME10%, GSOME20% & GSOME30% blends were found to be 277.71, 287.21, 312.21 and 284.29 °C respectively for compression ratio 16:1 under full load condition. The exhaust gas temperature for D100, GSOME10%, GSOME20% & GSOME30% blends were found to be 260.13, 262.17, 250.73 and 265.91 °C respectively for compression ratio 18:1 under full load condition. This was due to more fuel injected with the increase in engine load thereby, increases the heat in combustion chamber.

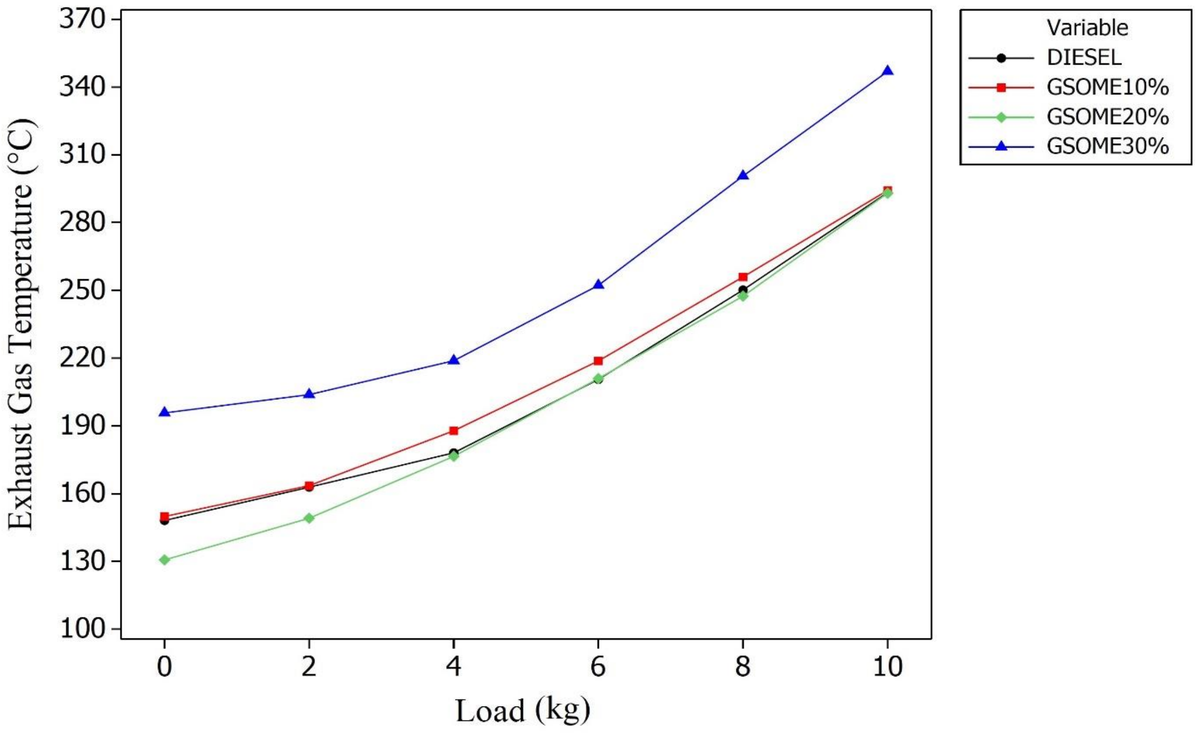


Figure 4.18: Variation of exhaust gas temperature of GSOME blend and diesel fuel with load at compression ratio 14:1

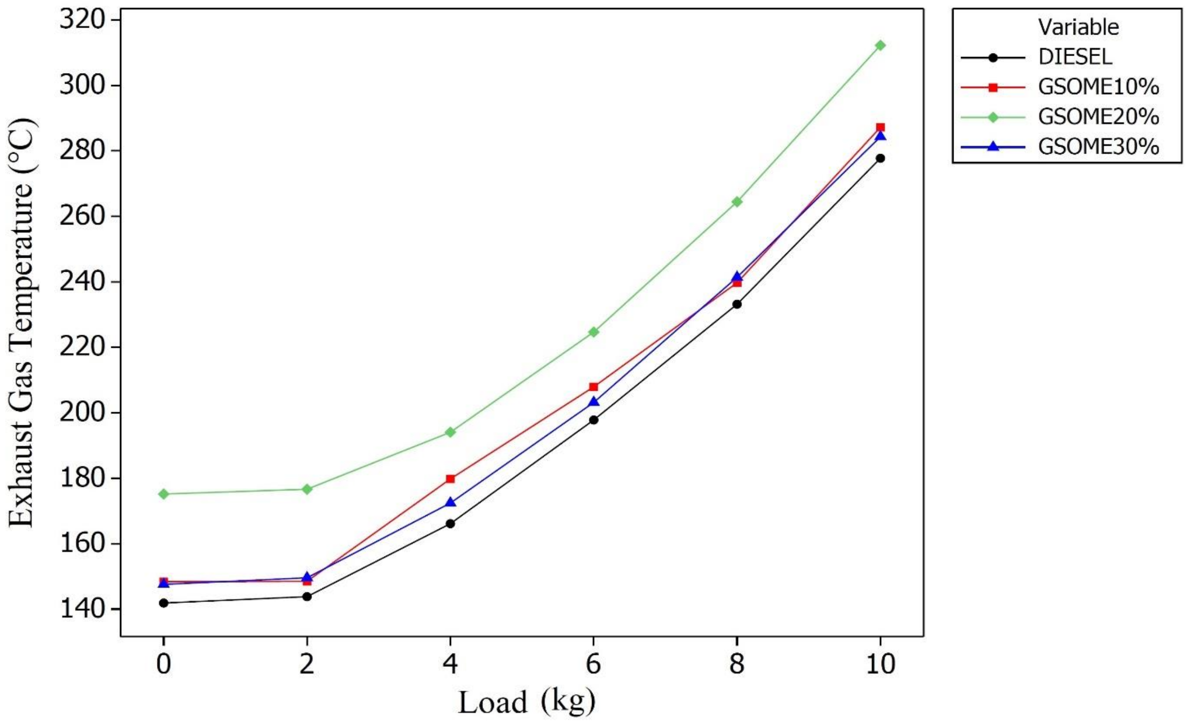


Figure 4.19: Variation of exhaust gas temperature of GSOME blend and diesel fuel with load at compression ratio 16:1

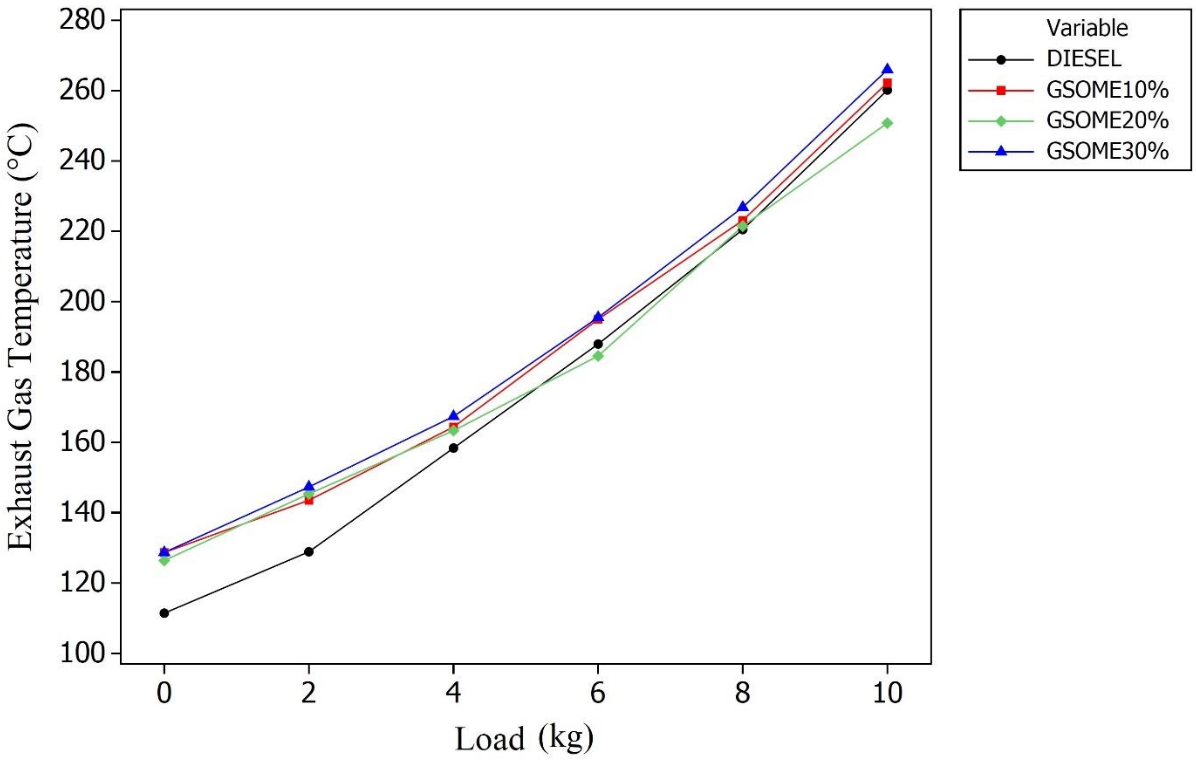


Figure 4.20: Variation of exhaust gas temperature of GSOME blend and diesel fuel with load at compression ratio 18:1

4.4.6 Effect of load on oxides of nitrogen (NOx) for different blends

The variation of oxides of nitrogen emissions of biodiesel fuel blends (GSOME10%, GSOME20% & GSOME30%) and diesel fuel with respect to engine load were shown in Figure 4.21 to 4.23 at different compression ratio. It was found that the oxides of nitrogen increases with the increase in engine load. The maximum oxides of nitrogen was obtained at GSOME10% at compression ratio 18:1 shown in Figure 4.23 which was higher than that of other biodiesel fuel blends i.e. GSOME20% & GSOME30% and diesel fuel. The increasing of NOx emissions was due to the higher oxygen content present in biodiesel fuel which produces improved combustion thereby increasing the temperature of combustion chamber. It also may be due to reducing ignition delay time because of higher cetane number of methyl ester fuel. The NOx emissions for D100, GSOME10%, GSOME20% & GSOME30% blends were found to be 187, 182, 179 and 185 ppm respectively for compression ratio 14:1 under full load condition. The NOx emissions for D100, GSOME10%, GSOME20% & GSOME30% blends were found to be 167, 155, 149 and 158 ppm respectively for compression ratio 16:1 under full load condition. The NOx emissions for D100, GSOME10%, GSOME20% & GSOME30% blends were found to be 148, 157, 151 and 136 ppm respectively for compression ratio 18:1 under full load condition.

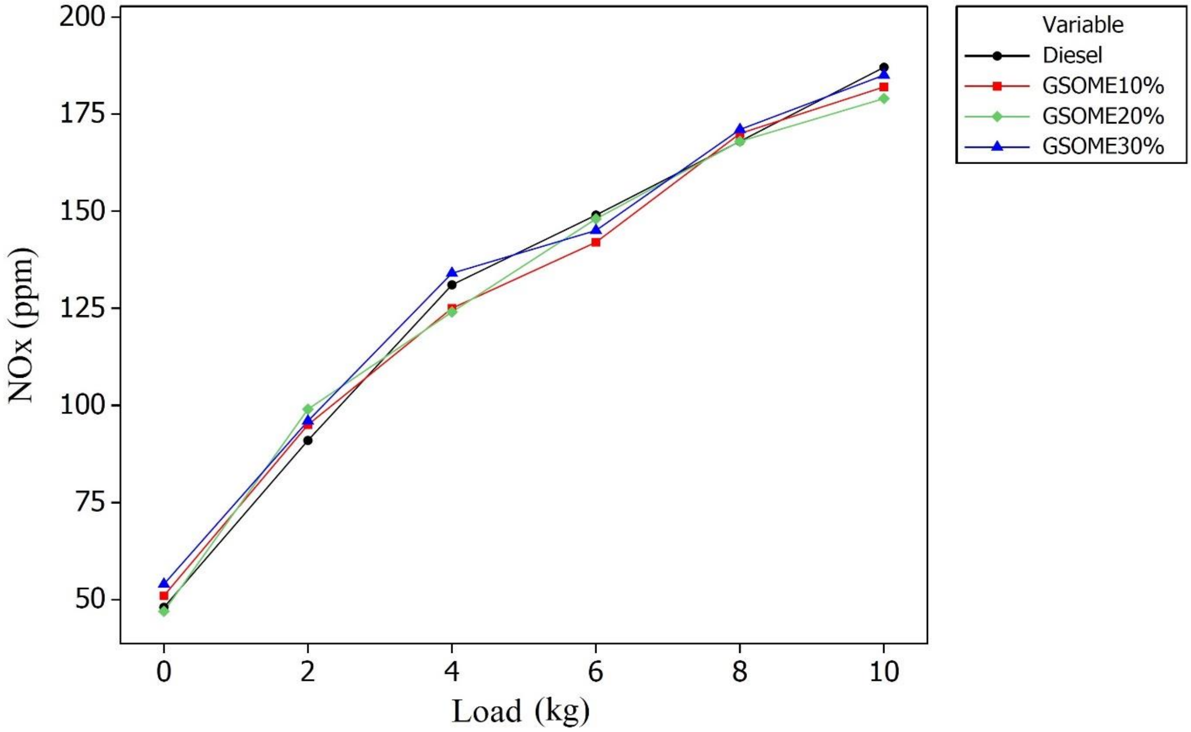


Figure 4.21: Variation of oxides of nitrogen of GSOME blend and diesel fuel with load at compression ratio 14:1

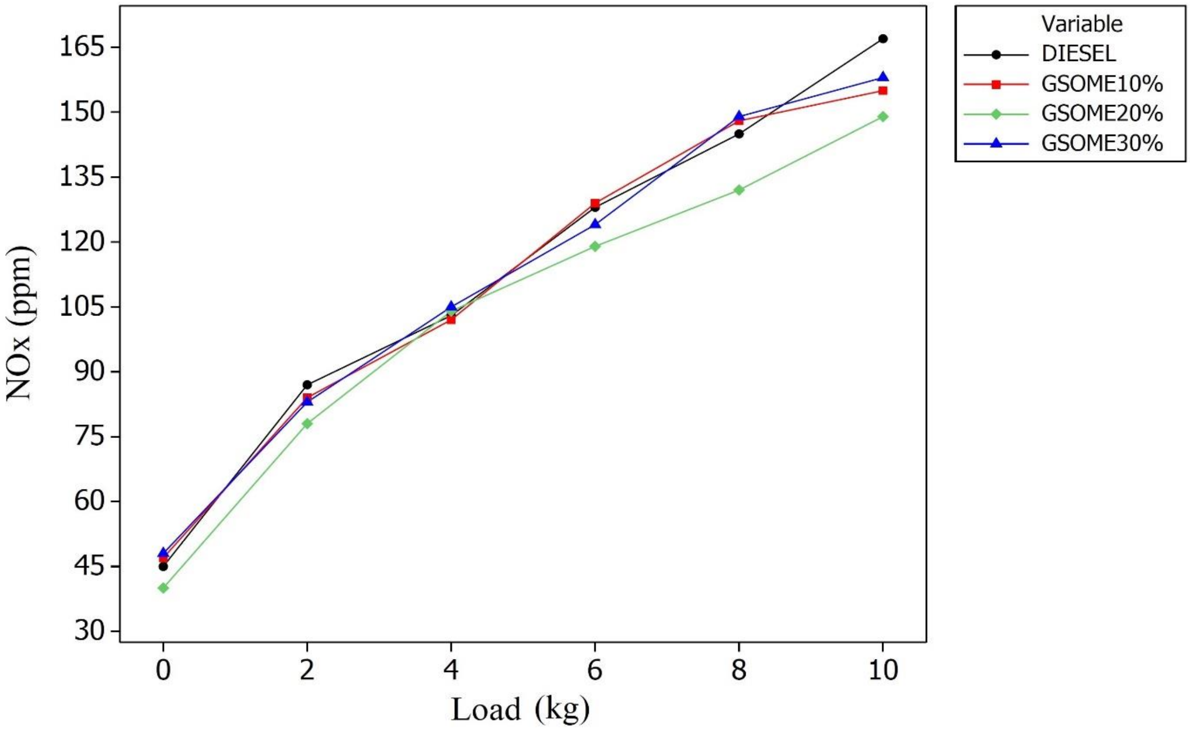


Figure 4.22: Variation of oxides of nitrogen of GSOME blend and diesel fuel with load at compression ratio 16:1

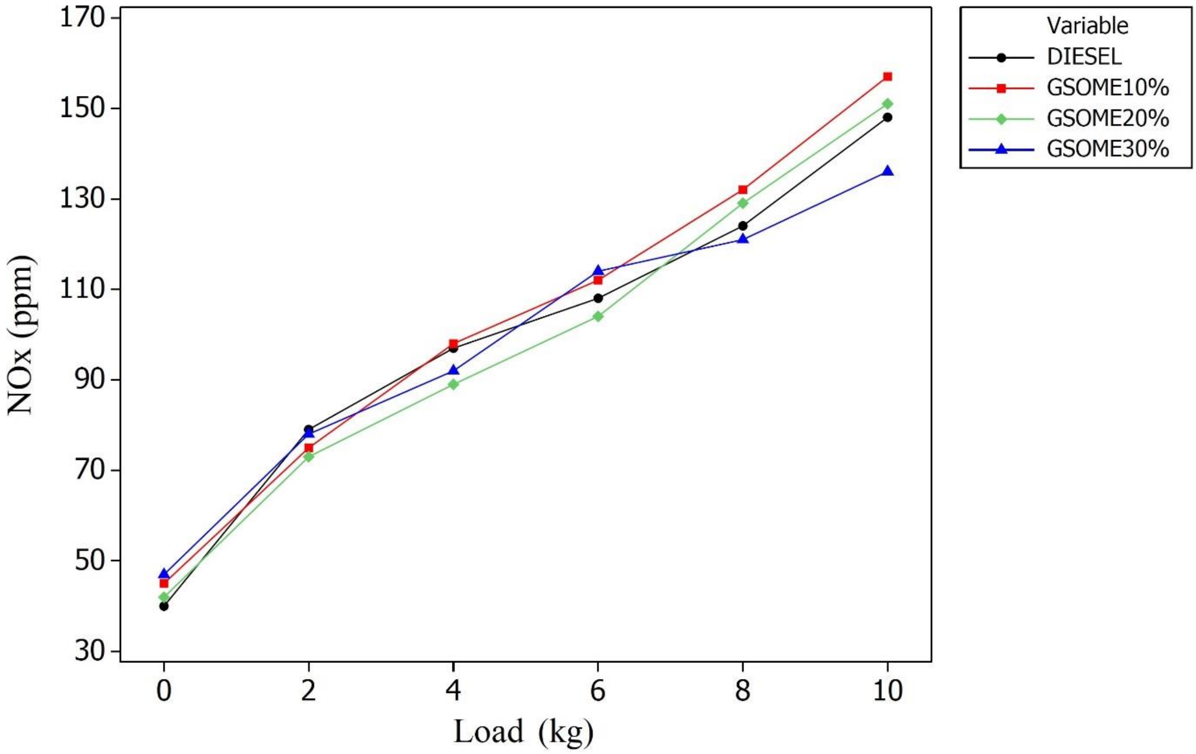


Figure 4.23: Variation of oxides of nitrogen of GSOME blend and diesel fuel with load at compression ratio 18:1

4.4.7 Effect of load on carbon monoxide (CO) for different blends

The variation of carbon monoxide emissions of biodiesel fuel blends and diesel fuel with respect to engine load at different compression ratios were shown in Figure 4.24 to 4.26. It was observed that the emissions of carbon monoxide increase with the increase in engine load. This was due to fuel consumption which was increases with increased in engine load and because of not proper supply of air in the combustion chamber leads to incomplete combustion of fuel therefore, CO increases. It was also observed that the emissions of CO reduced with the increase in percentage of biodiesel. This was may be due to higher oxygen content in biodiesel fuel blends which increased the combustion efficiency in terms of greater the brake thermal efficiency. The lowest average emissions of carbon monoxide i.e. 471.5 ppm was found for the biodiesel fuel blend GSOME20% from no load to full load condition at compression ratio 18:1.

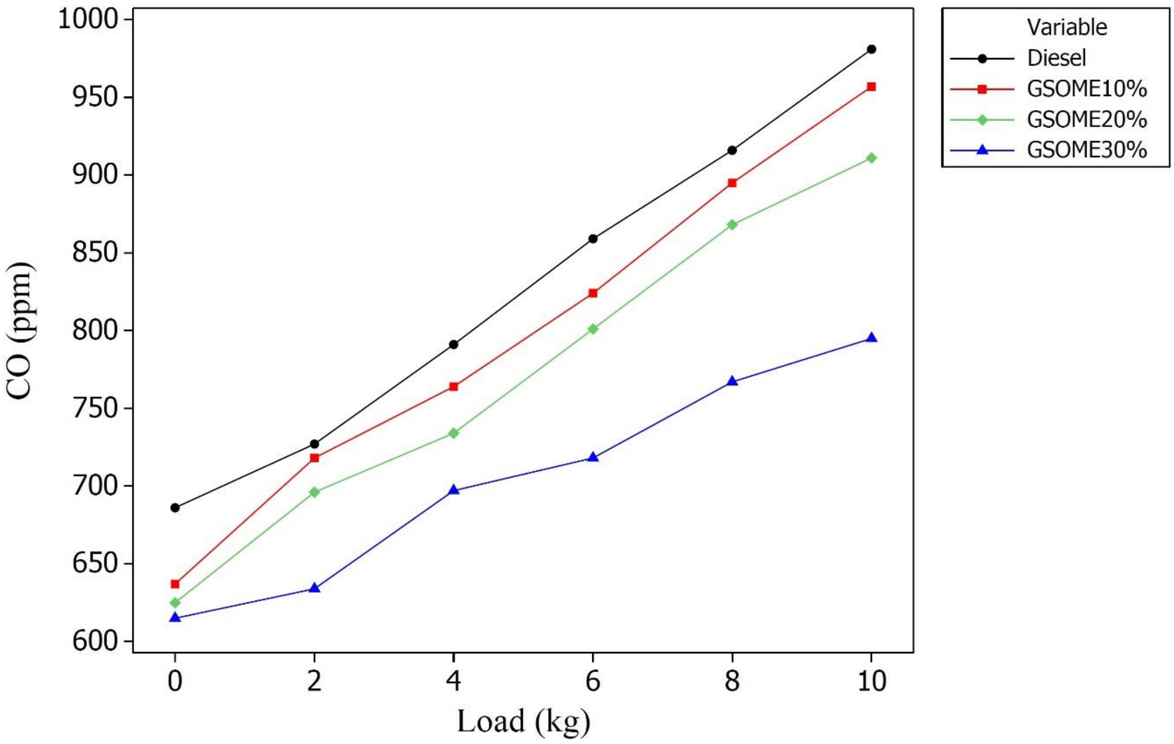


Figure 4.24: Variation of carbon monoxide of GSOME blend and diesel fuel with load at compression ratio 14:1

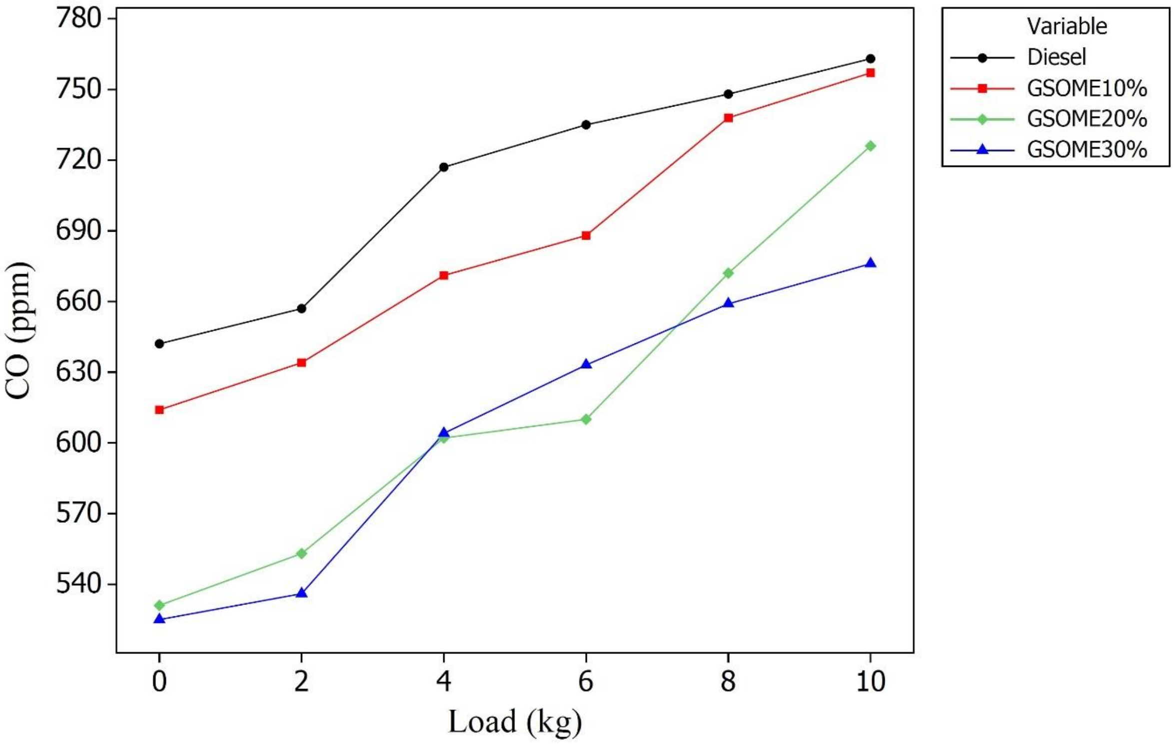


Figure 4.25: Variation of carbon monoxide of GSOME blend and diesel fuel with load at compression ratio 16:1

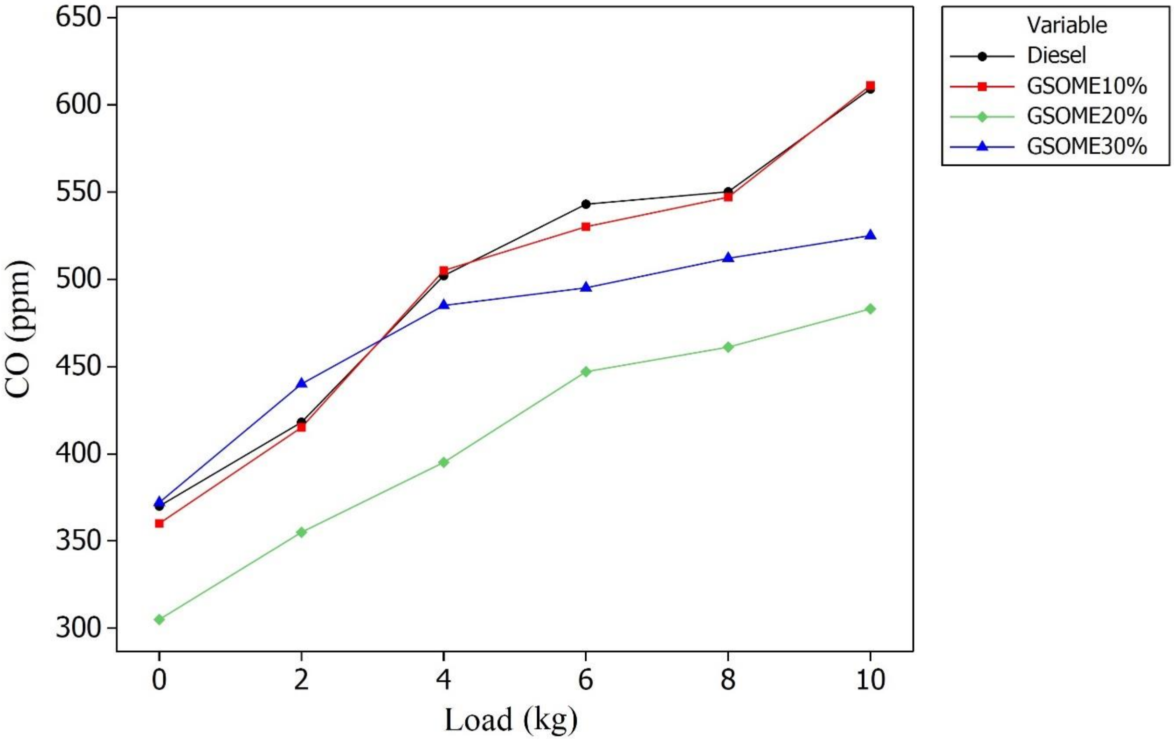


Figure 4.26: Variation of carbon monoxide of GSOME blend and diesel fuel with load at compression ratio 18:1

4.4.8 Effect of load on unburned hydrocarbon (HC) for different blends

The variation of unburned hydrocarbon emissions with respect to engine load for various biodiesel blends at different compression ratios were shown in Figure 4.27 to Figure 4.29. Hydrocarbon emissions takes place due to incomplete combustion. The unburned hydrocarbon (HC) emissions for D100, GSOME10%, GSOME20% & GSOME30% blends were found to be 1124, 1317, 1596 and 1637 ppm respectively for compression ratio 14:1 under full load condition. The unburned hydrocarbon (HC) emissions for D100, GSOME10%, GSOME20% & GSOME30% blends were found to be 1016, 1203, 1231 and 1249 ppm respectively for compression ratio 16:1 under full load condition. The unburned hydrocarbon (HC) emissions for D100, GSOME10%, GSOME20% & GSOME30% blends were found to be 899, 1271, 1355 and 1288 ppm respectively for compression ratio 18:1 under full load condition.

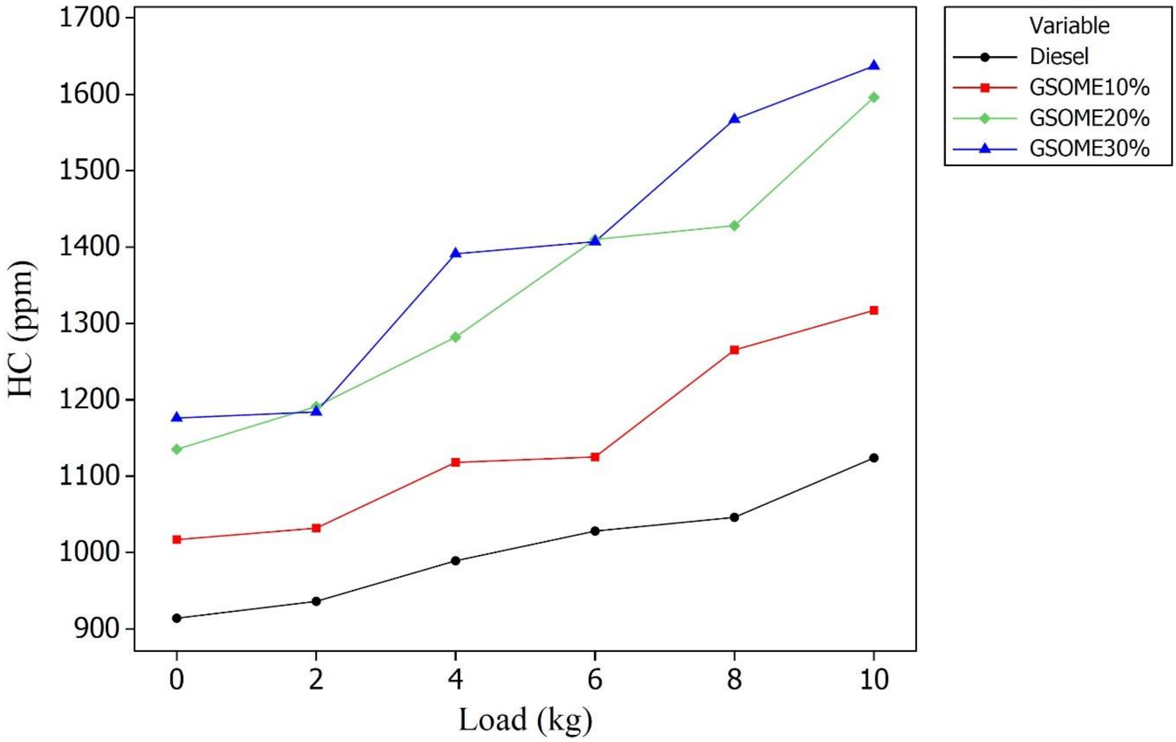


Figure 4.27: Variation of hydrocarbon (HC) of GSOME blend and diesel fuel with load at compression ratio 14:1

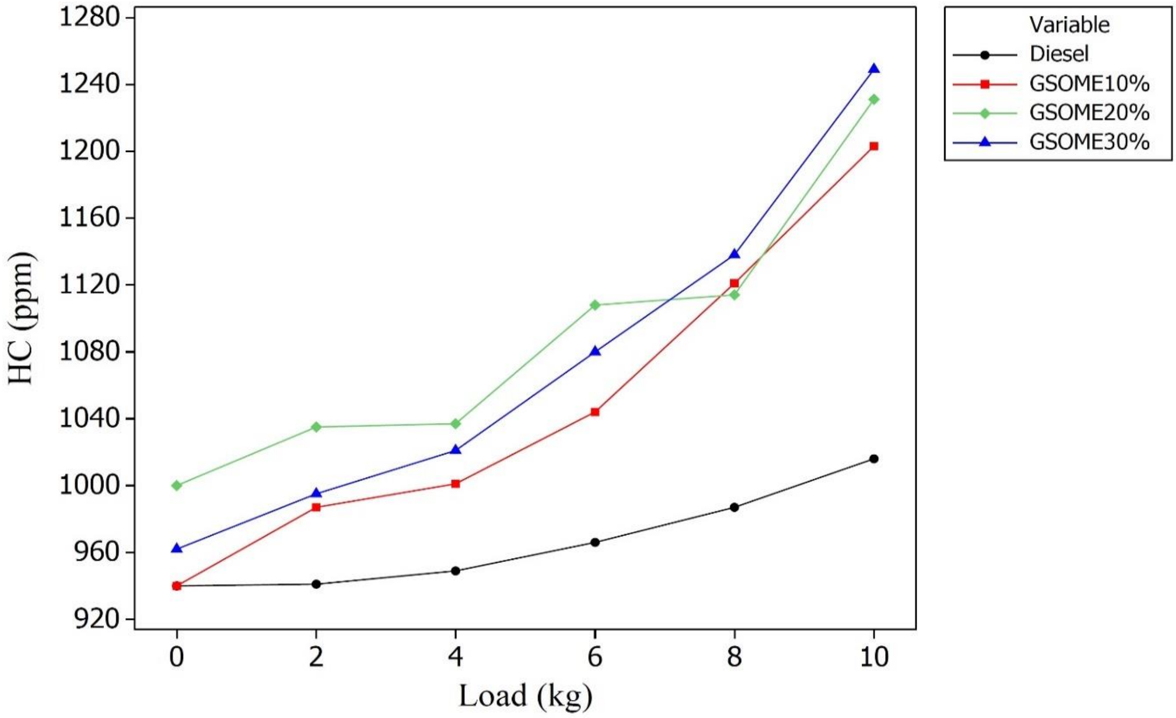


Figure 4.28: Variation of hydrocarbon (HC) of GSOME blend and diesel fuel with load at compression ratio 16:1

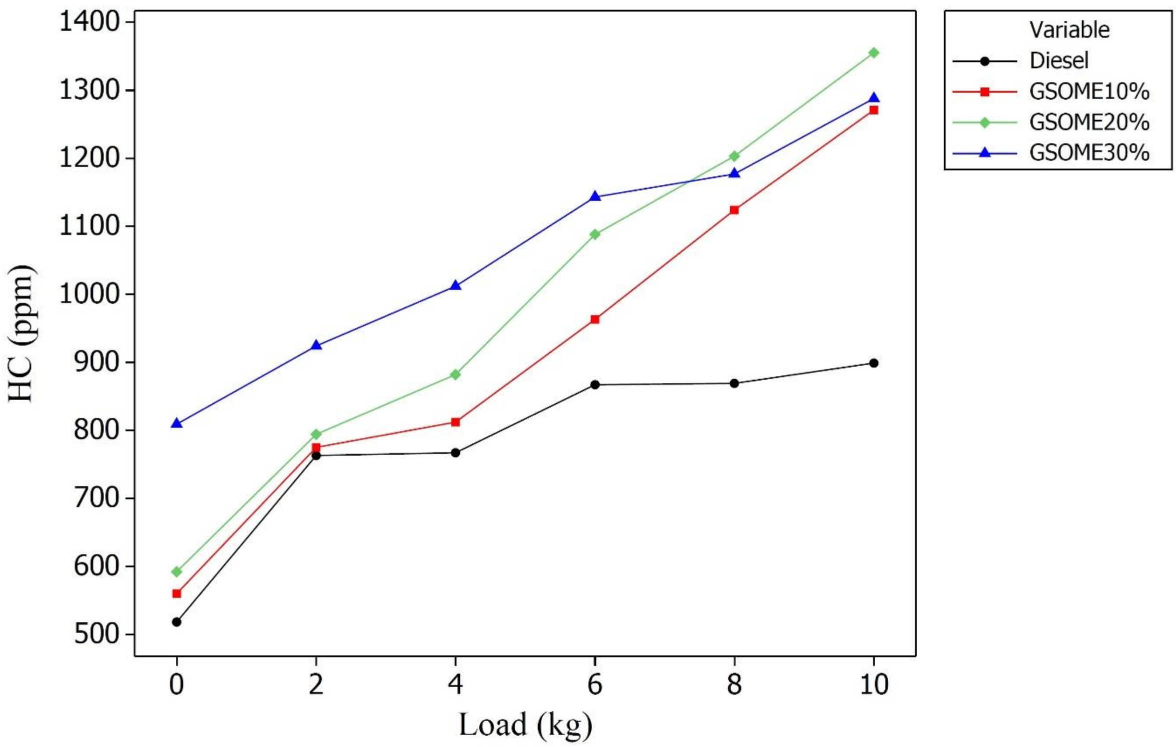


Figure 4.29: Variation of hydrocarbon (HC) of GSOME blend and diesel fuel with load at compression ratio 18:1

4.5 Performance and emissions characterization for GSOME blended fuel with diethyl ether as an additive

4.5.1 Effect of load on brake power for different blends

Figure 4.30, Figure 4.31 and Figure 4.32 represented the variation of brake power with respect to load under various conditions for various biodiesel blends with diethyl ether as an additive at different compression ratio. It was found that the brake power of all biodiesel blends with diethyl ether (GSOME5%DEE5%, GSOME10%DEE10% and GSOME15%DEE15%) and diesel fuel were increased with the increase in engine load and no remarkable difference noticed. This was due to higher fuel consumption and proper combustion because of higher oxygen molecules in biodiesel blends. Brake power i.e. 2.79, 2.78, 2.75 and 2.74 kW was obtained under full load condition for D100, GSOME5%DEE5%, GSOME10%DEE10% & GSOME15%DEE15% respectively at compression ratio 14:1.

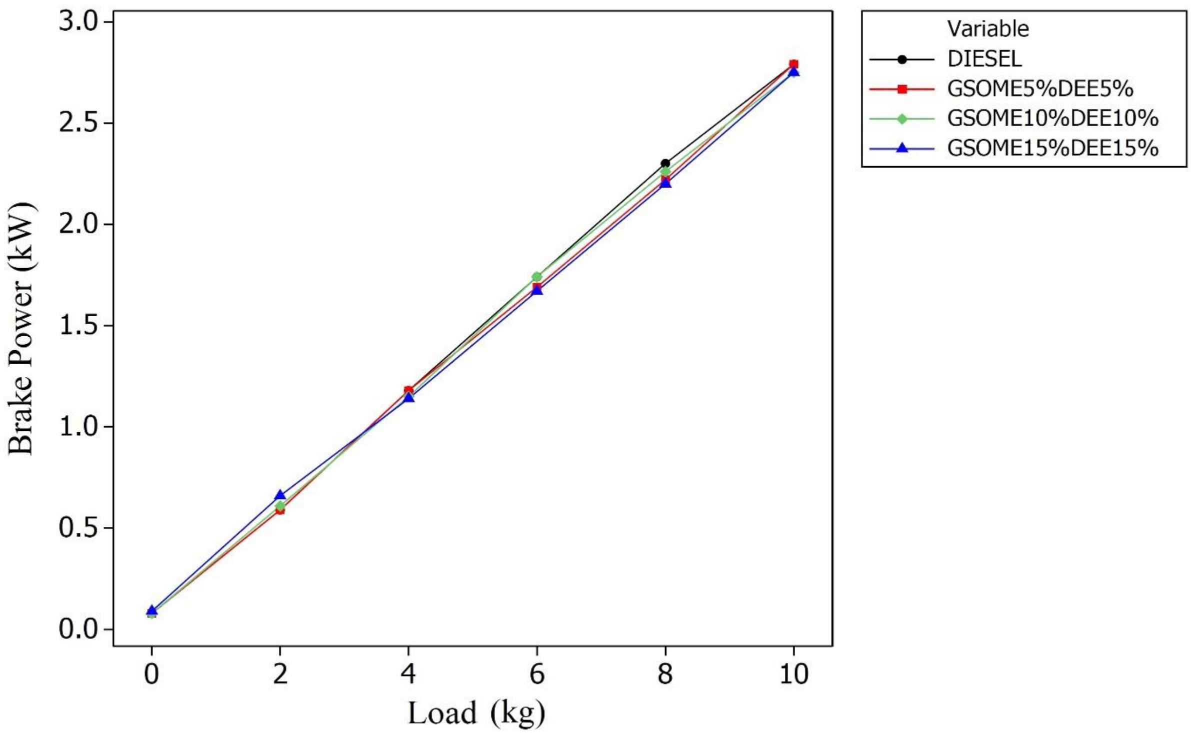


Figure 4.30: Variation of BP of GSOME blend with DEE and diesel fuel with load at compression ratio 14:1

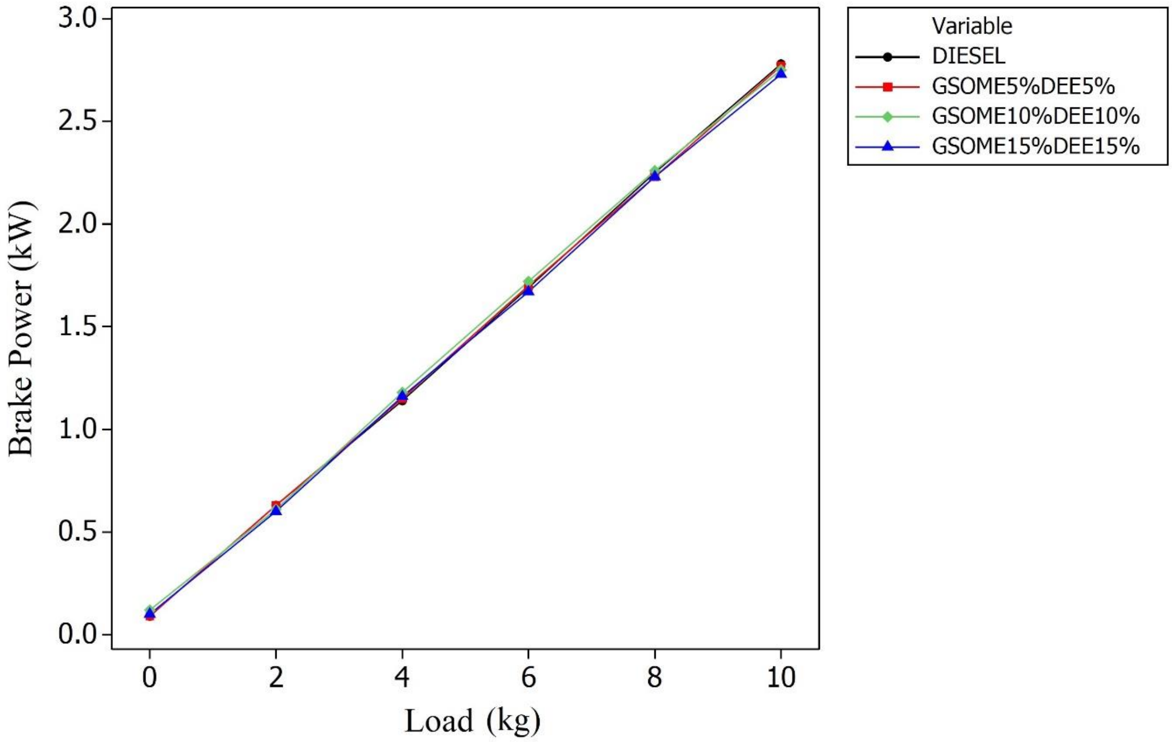


Figure 4.31: Variation of BP of GSOME blend with DEE and diesel fuel with load at compression ratio 16:1

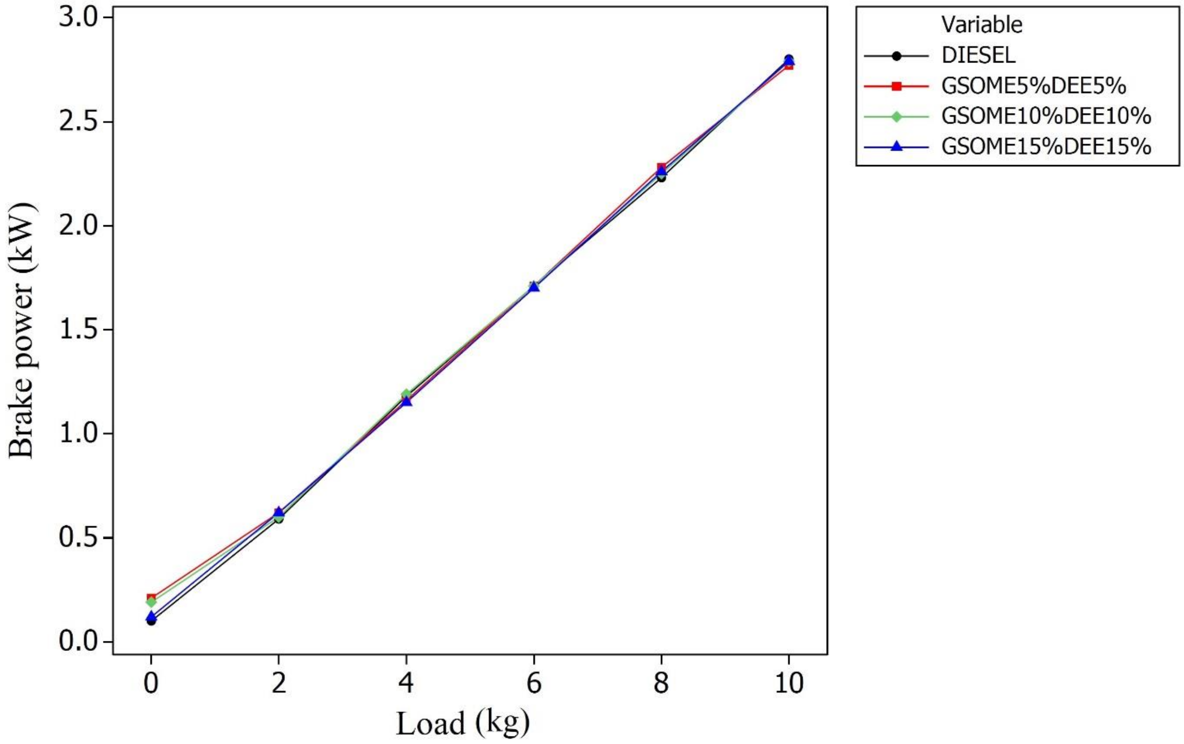


Figure 4.32: Variation of BP of GSOME blend with DEE and diesel fuel with load at compression ratio 18:1

4.5.2 Effect of load on brake specific fuel consumption for different blends

Brake specific fuel consumption for diesel fuel and various biodiesel fuel blends with diethyl ether (GSOME5%DEE5%, GSOME10%DEE10% & GSOME15%DEE15%) with respect to load at different compression ratio i.e. 14:1, 16:1 and 18:1 were shown in Figure 4.33, Figure 4.34, and Figure 4.35. It was found that brake specific fuel consumption decreases with increase in engine load for all biodiesel fuel blends and diesel fuel. The reason for decreasing BSFC was injection of fuel for longer duration because of higher fuel consumption. The maximum brake specific fuel consumption was obtained 5.02 kg/kWh for GSOME10% blend at no load condition at compression ratio 14:1. Brake specific fuel consumption i.e. 0.3, 0.34, 0.35, and 0.38 kg/kWh was obtained for D100, GSOME5%DEE5%, GSOME10%DEE10% & GSOME15%DEE15% blends respectively at compression ratio 14:1 under full load condition. The minimum BSFC i.e. 0.30 kg/kWh was found at compression ratio 18:1 under full load condition for blend GSOME10%DEE10% which is slightly higher than diesel fuel whose BSFC was found to be 0.28 kg/kWh at same compression ratio.

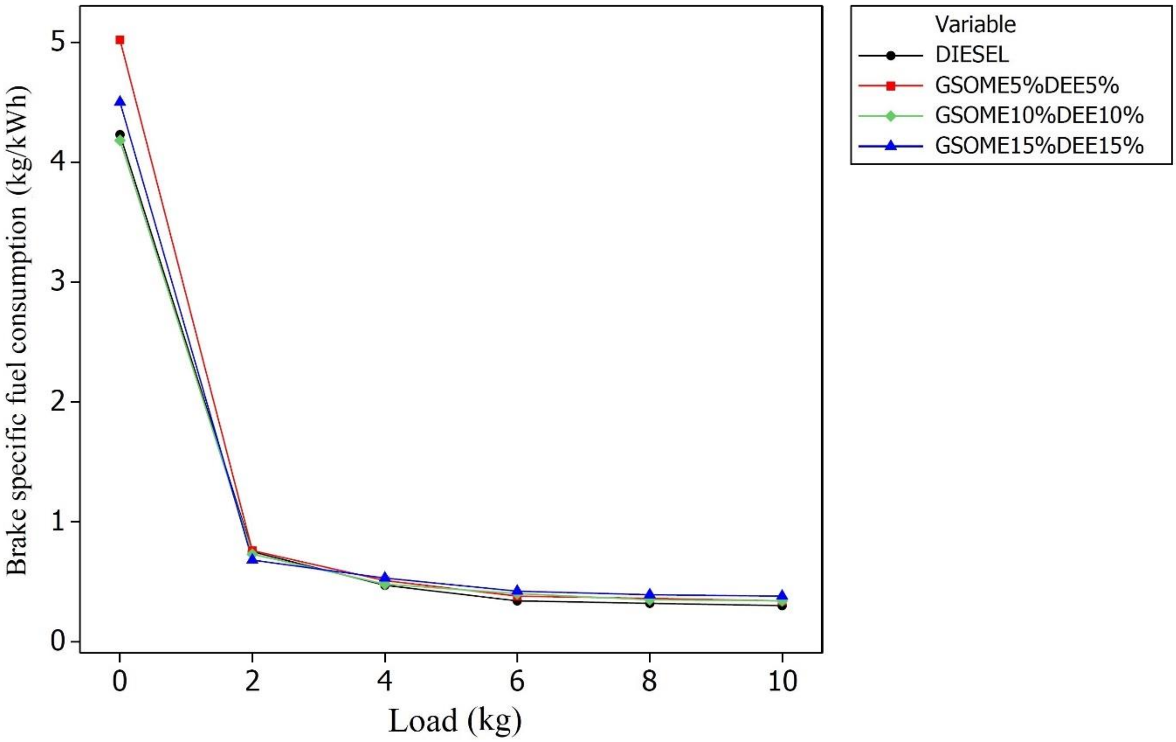


Figure 4.33: Variation of BSFC of GSOME blend with DEE and diesel fuel with load at compression ratio 14:1

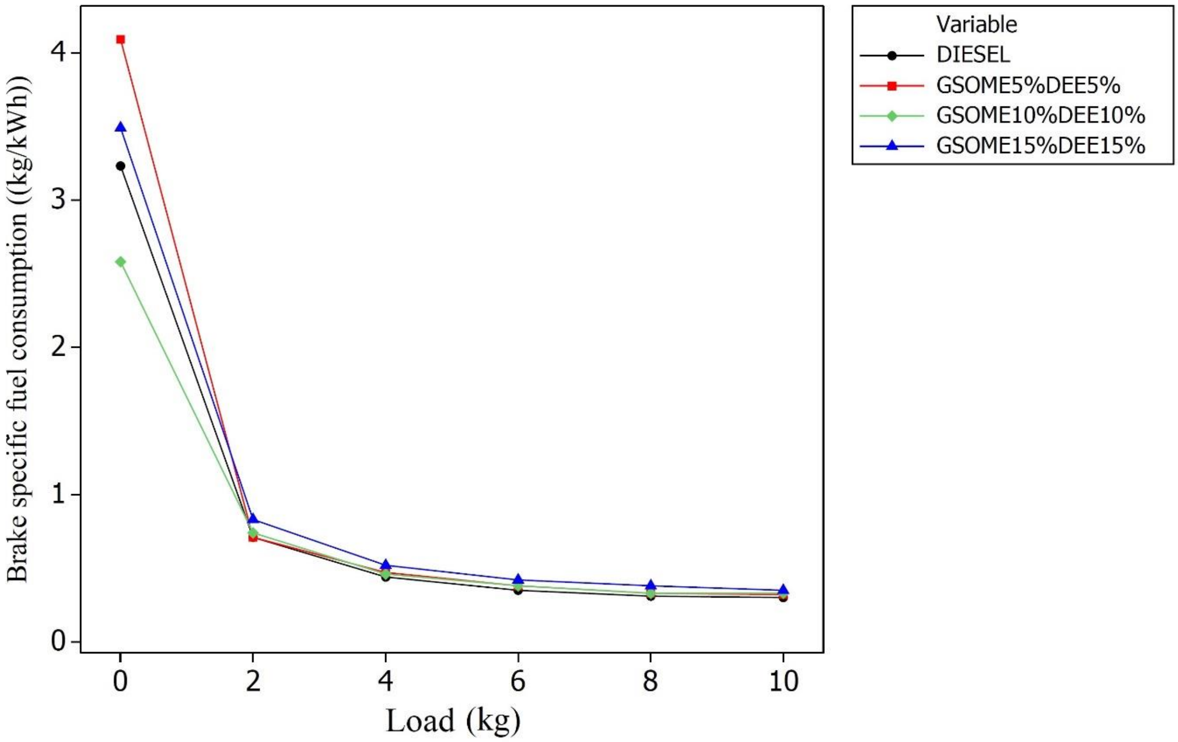


Figure 4.34: Variation of BSFC of GSOME blend with DEE and diesel fuel with load at compression ratio 16:1

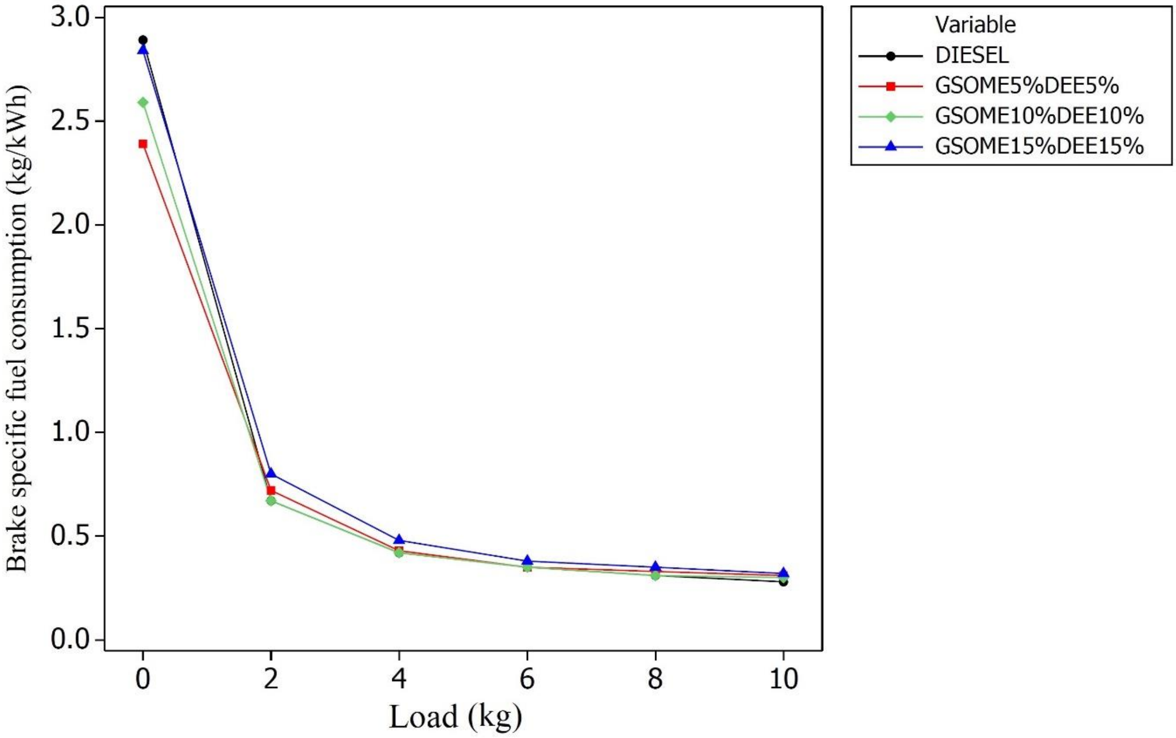


Figure 4.35: Variation of BSFC of GSOME blend with DEE and diesel fuel with load at compression ratio 18:1

4.5.3 Effect of load on brake thermal efficiency (BTE) for different blends

Figure 4.36 to Figure 4.38 represents the deviation of brake thermal efficiency with respect to engine load for diesel and biodiesel fuel blends with diethyl ether i.e. GSOME5%DEE5%, GSOME10%DEE10% & GSOME15%DEE15%. It was clearly observed that brake thermal efficiency increases with increase in engine load from no load to full load condition. This was due to increased power and decreased in heat loss. The maximum BTE of 28.22% was found at full load condition for GSOME10%DEE10% at compression ratio 18:1. The brake thermal efficiency i.e. 28.21, 25.30, 24.9 and 22.56% was obtained for D100, GSOME5%DEE5%, GSOME10%DEE10% & GSOME15%DEE15% blends respectively at compression ratio 14:1 under full load condition. The brake thermal efficiency i.e. 28.1, 26.5, 26.29 and 24.75% was obtained for D100, GSOME5%DEE5%, GSOME10%DEE10% & GSOME15%DEE15% blends respectively at compression ratio 16:1 under full load condition. The brake thermal efficiency i.e. 30.14, 28.07, 28.22 and 26.7% was obtained for D100, GSOME5%DEE5%, GSOME10%DEE10% & GSOME15%DEE15% blends respectively at compression ratio 18:1 under full load condition.

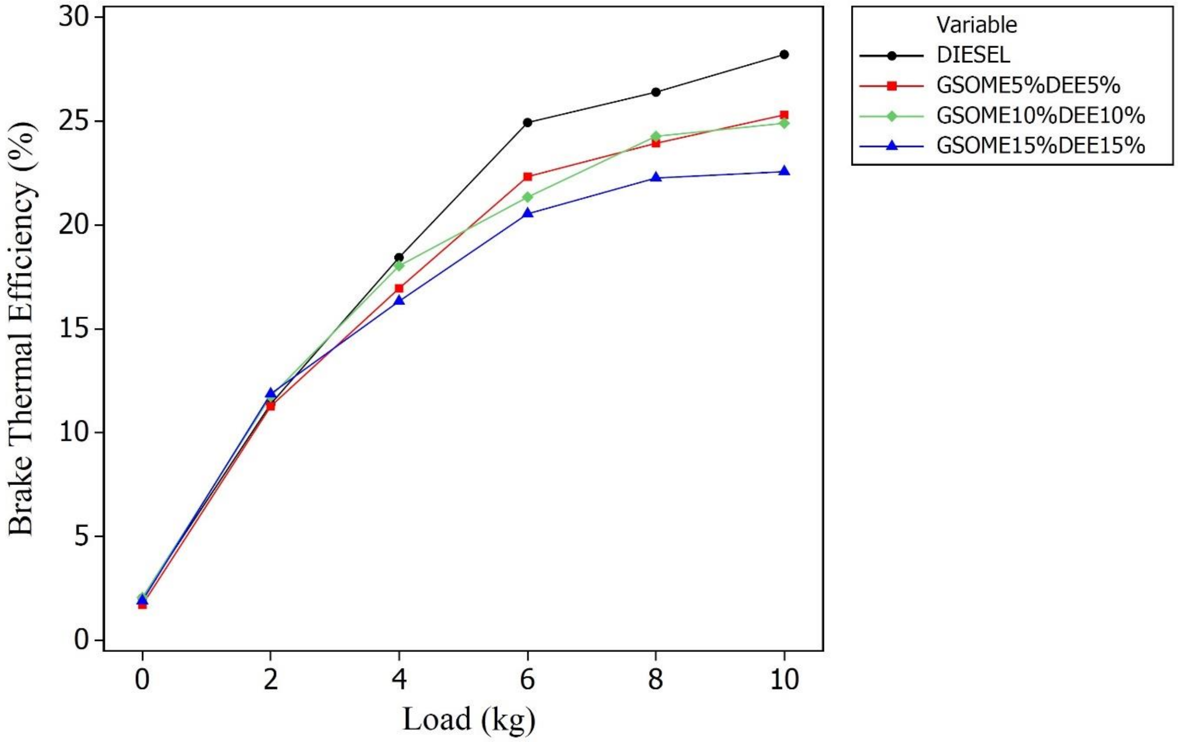


Figure 4.36: Variation of BTE of GSOME blend with DEE and diesel fuel with load at compression ratio 14:1

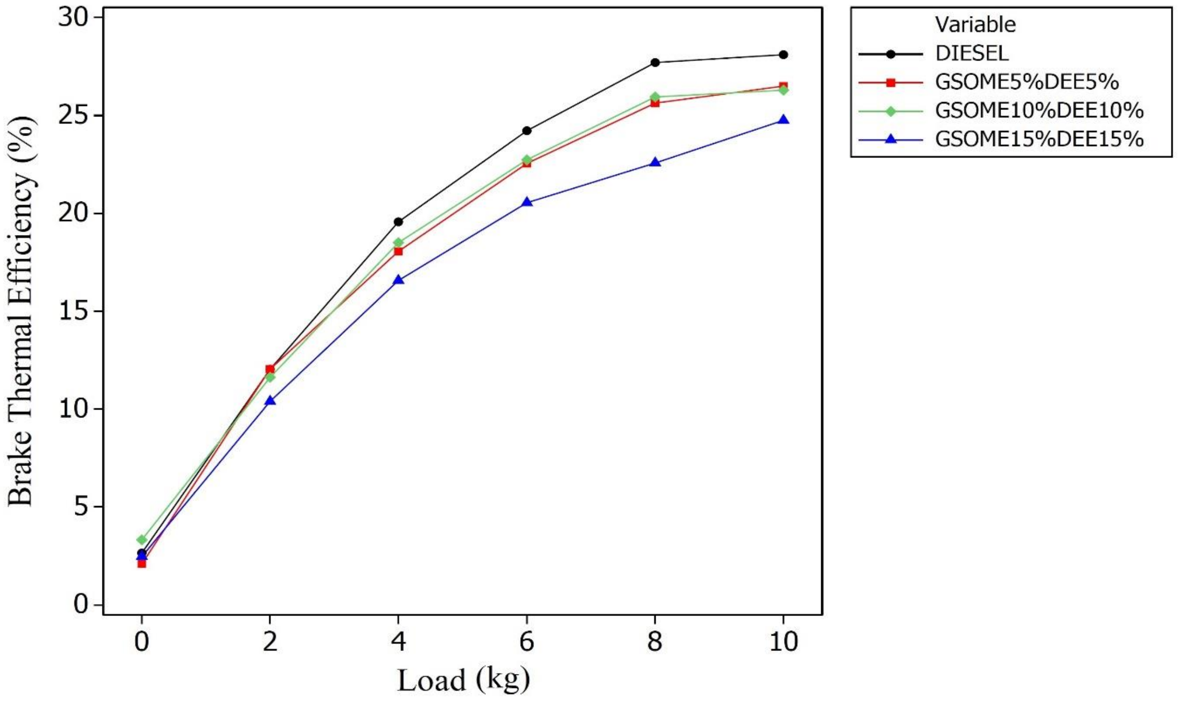


Figure 4.37: Variation of BTE of GSOME blend with DEE and diesel fuel with load at compression ratio 16:1

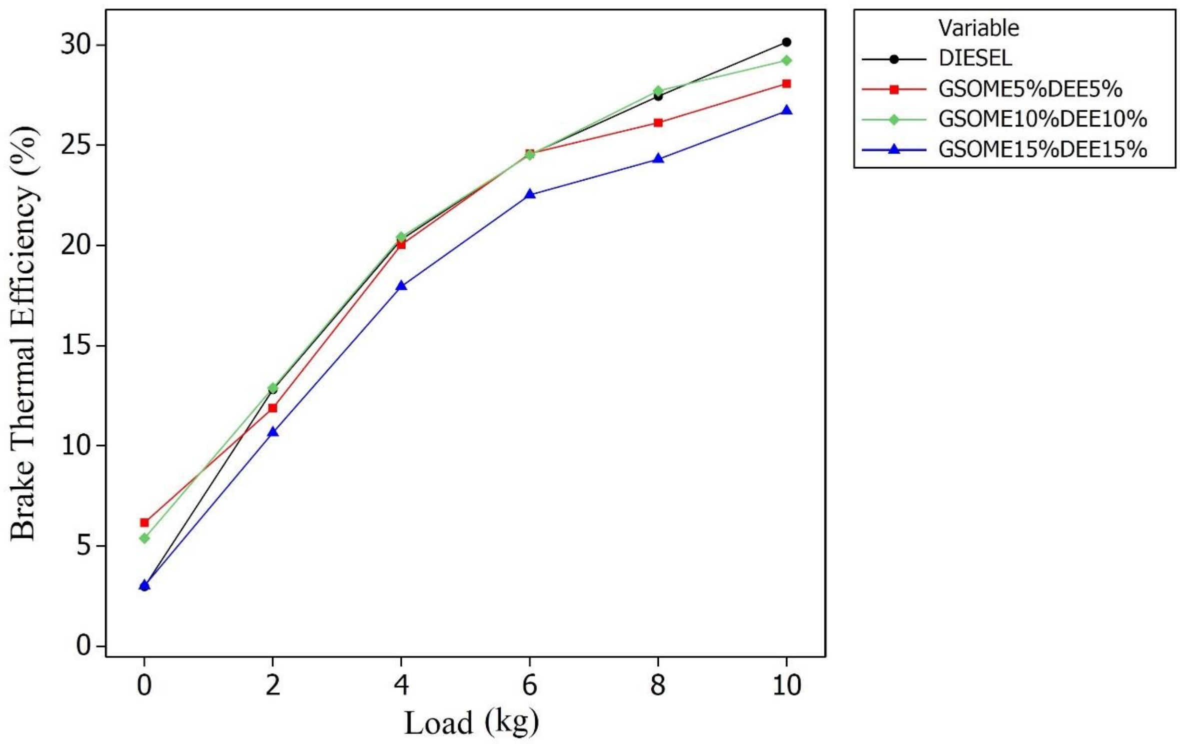


Figure 4.38: Variation of BTE of GSOME blend with DEE and diesel fuel with load at compression ratio 18:1

4.5.4 Effect of load on mechanical efficiency for different blends

Figure 14.39 to 14.41 shows that the deviation of mechanical efficiency with respect to load for various fuel blends with diethyl ether at different compression ratios. It was found that the mechanical efficiency for diesel and biodiesel fuel blends increases with the increase in engine load. The reason for increasing mechanical efficiency may be reduction in heat loss and good automization characteristics. The maximum mechanical efficiency i.e. 40.21% was obtained for GSOME15%DEE15% under full load condition at compression ratio 14:1. The mechanical efficiency i.e. 35.04, 36.52, 36.53 40.21% was obtained for D100, GSOME5%DEE5%, GSOME10%DEE10% & GSOME15%DEE15% blends respectively at compression ratio 14:1 under full load condition. The mechanical efficiency i.e. 32.26, 35.91, 36.25 and 36.57% was obtained for D100, GSOME5%DEE5%, GSOME10%DEE10% & GSOME15%DEE15% blends respectively at compression ratio 16:1 under full load condition. The mechanical efficiency i.e. 30.41, 35.30, 36.15 and 34.59% was obtained for D100, GSOME5%DEE5%, GSOME10%DEE10% & GSOME15%DEE15% blends respectively at compression ratio 18:1 under full load condition.

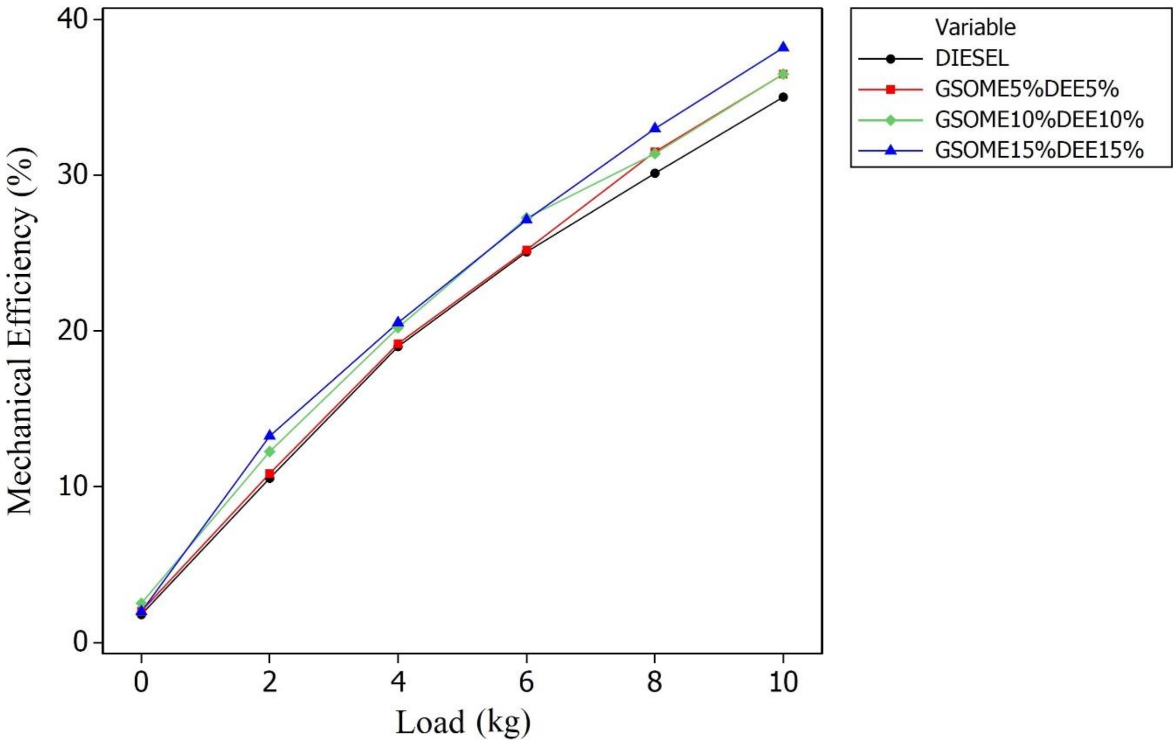


Figure 4.39: Variation of mechanical efficiency of GSOME blend with DEE and diesel fuel with load at compression ratio 14:1

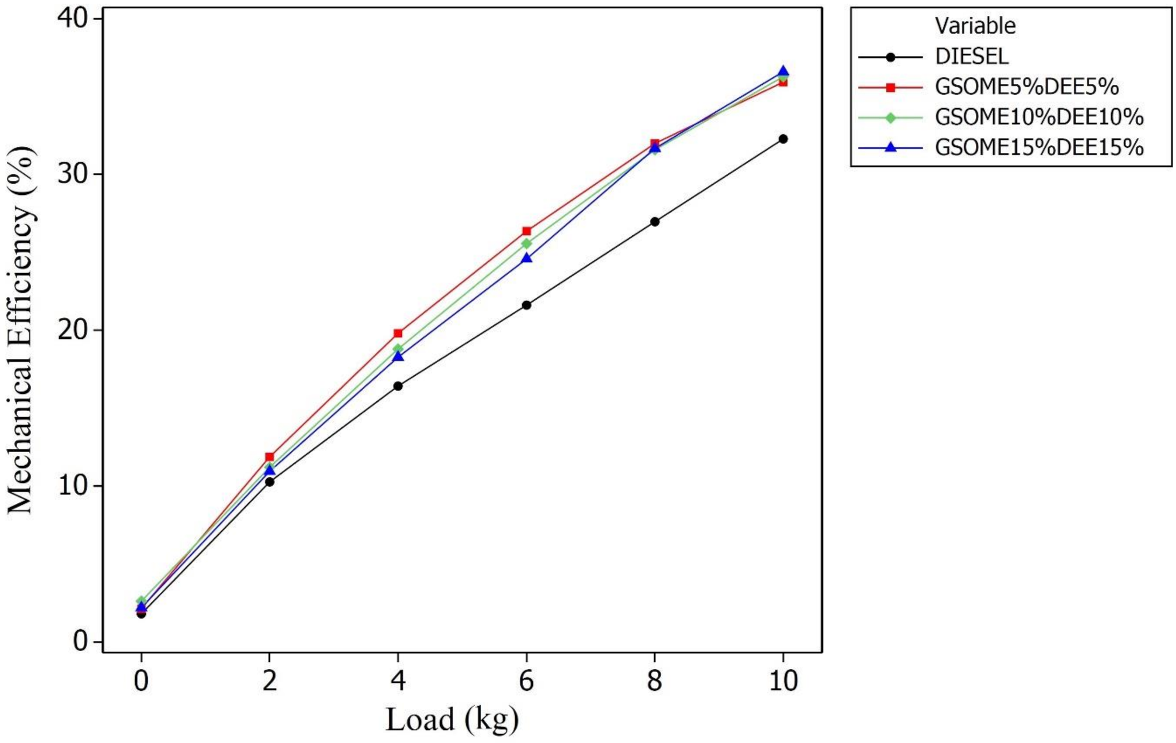


Figure 4.40: Variation of mechanical efficiency of GSOME blend with DEE and diesel fuel with load at compression ratio 16:1

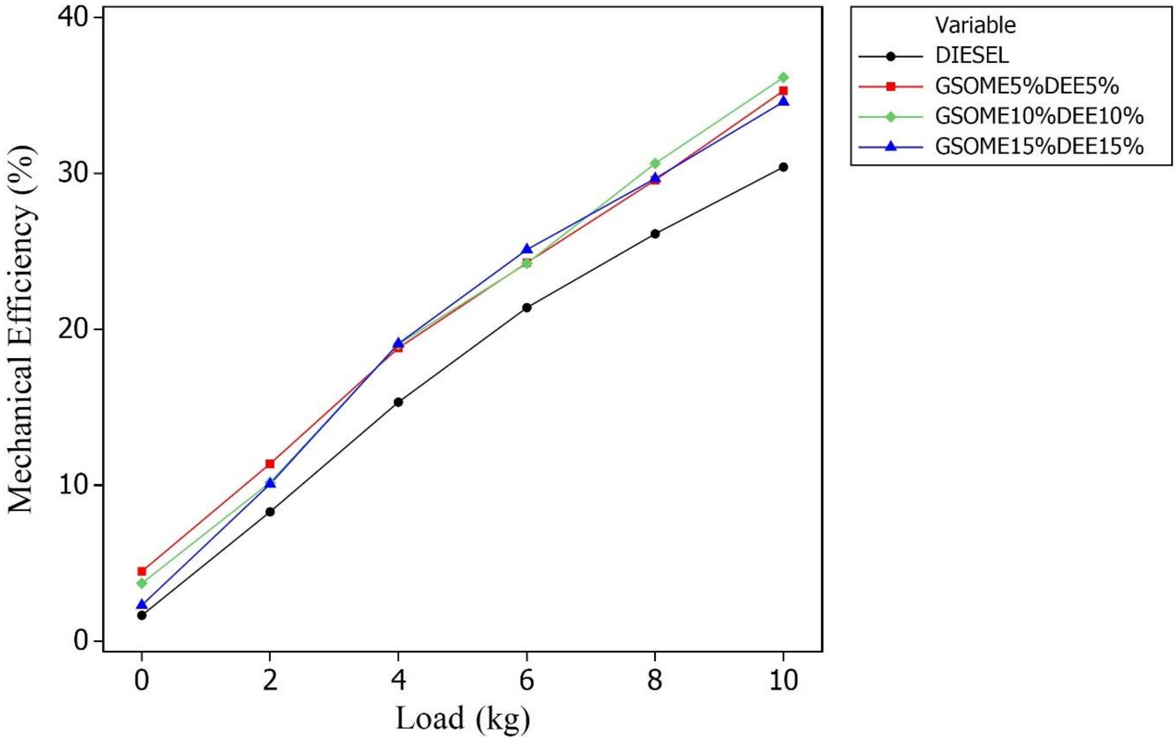


Figure 4.41: Variation of mechanical efficiency of GSOME blend with DEE and diesel fuel with load at compression ratio 18:1

4.5.5 Effect of load on exhaust gas temperature (EGT) for different blends

The variation of exhaust gas temperature with respect to engine load for various fuel blends with diethyl ether as an additive and diesel fuel were shown in Figure 4.42, Figure 4.43 and Figure 4.44 at different compression ratio. It was observed that the exhaust gas temperature increases with the increase in engine load. This was due to more fuel injected with the increase in engine load thereby, increases the heat in combustion chamber. The maximum exhaust gas temperature i.e. 343.41 °C was obtained for GSOME15%DEE15% under full load condition at compression ratio 14:1. The exhaust gas temperature i.e. 293.32, 311.43, 321.66 and 343.41 °C was obtained for D100, GSOME5%DEE5%, GSOME10%DEE10% & GSOME15%DEE15% blends respectively at compression ratio 14:1 under full load condition. The exhaust gas temperature i.e. 277.71, 295.32, 296.49 and 317.94 °C was obtained for D100, GSOME5%DEE5%, GSOME10%DEE10% & GSOME15%DEE15% blends respectively at compression ratio 16:1 under full load condition. The exhaust gas temperature i.e. 260.13, 267.38, 268.55 and 282.36 °C was obtained for D100, GSOME5%DEE5%, GSOME10%DEE10% & GSOME15%DEE15% blends respectively at compression ratio 18:1 under full load condition.

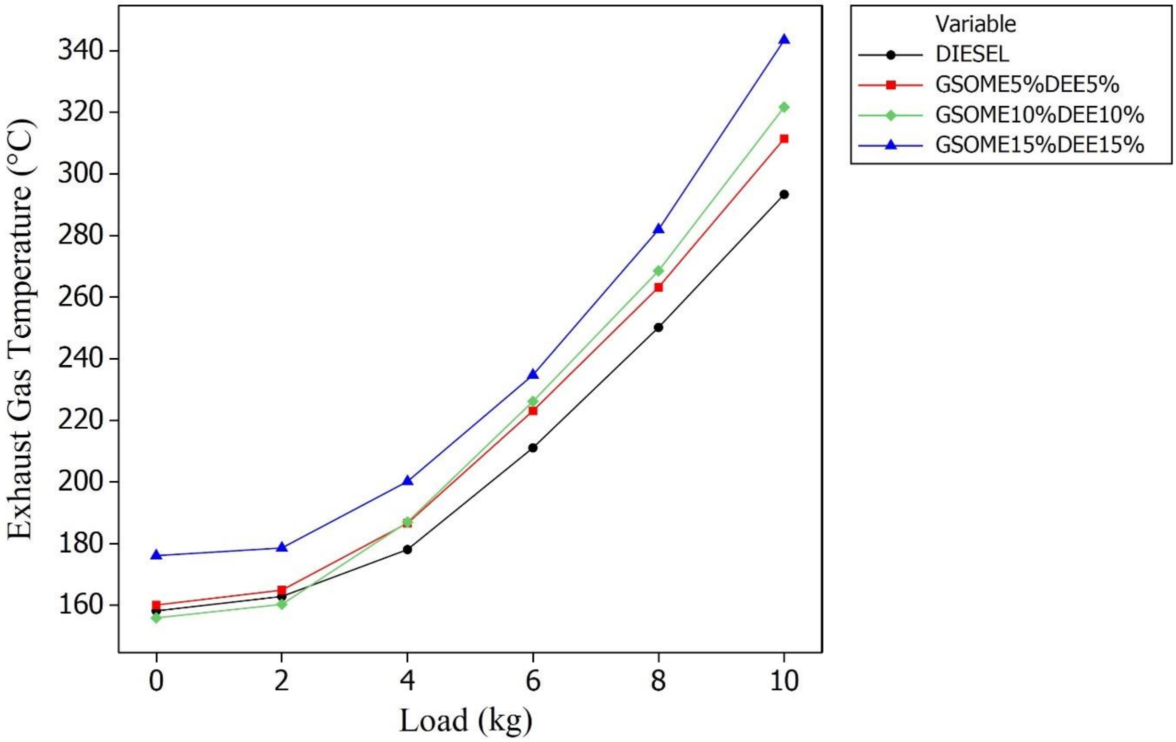


Figure 4.42: Variation of exhaust gas temperature of GSOME blend with DEE and diesel fuel with load at compression ratio 14:1

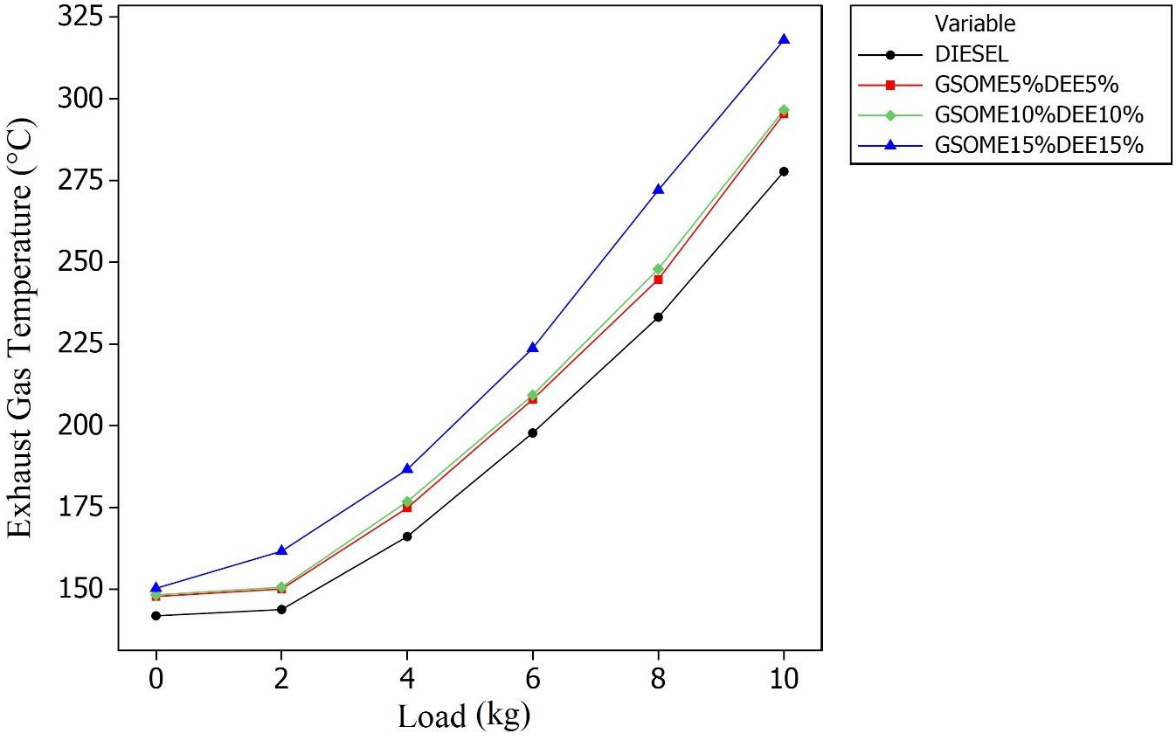


Figure 4.43: Variation of exhaust gas temperature of GSOME blend with DEE and diesel fuel with load at compression ratio 16:1

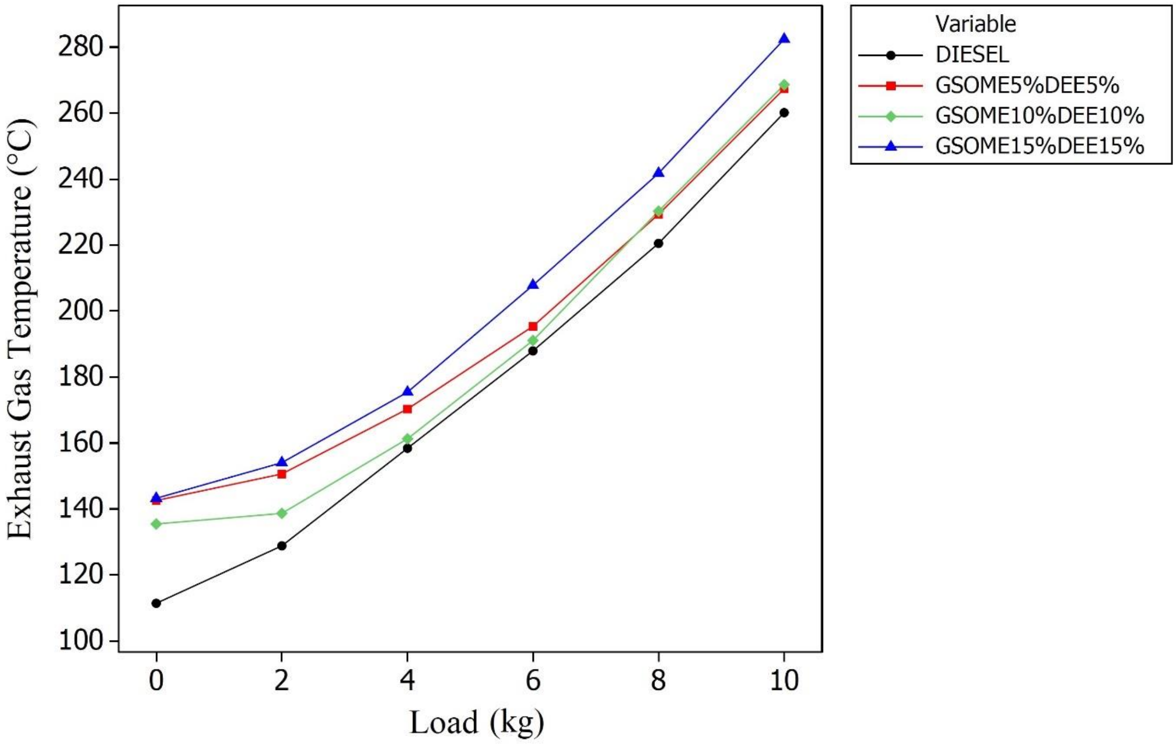


Figure 4.44: Variation of exhaust gas temperature of GSOME blend with DEE and diesel fuel with load at compression ratio 18:1

4.5.6 Effect of load on oxides of nitrogen (NOx) for different blends

The variation of oxides of nitrogen emissions of biodiesel fuel blends with diethyl ether as an additive (GSOME5%DEE5%, GSOME10%DEE10% & GSOME15%DEE15%) and diesel fuel with respect to engine load were shown in Figure 4.45 to 4.47 at different compression ratio. It was found that the oxides of nitrogen increases with the increase in engine load. The increasing of NOx emissions was due to the improved combustion which were produced by the higher oxygen content present in biodiesel fuel therefore, increasing the temperature of combustion chamber. It also might be due to reducing ignition delay time because of higher cetane number of methyl ester fuel. The maximum oxides of nitrogen i.e. 193 ppm was obtained at GSOME15%DEE15% at compression ratio 14:1 shown in Figure 4.44 which was higher than that of other biodiesel fuel blends i.e. GSOME5%DEE5% & GSOME10%DEE10% and diesel fuel. The NOx emissions i.e. 187, 179 172 and 193 ppm was obtained for D100, GSOME5%DEE5%, GSOME10%DEE10% & GSOME15%DEE15% blends respectively at compression ratio 14:1 under full load condition. The NOx emissions i.e. 167, 162, 155 and 173 ppm was obtained for D100, GSOME5%DEE5%, GSOME10%DEE10% & GSOME15%DEE15% blends respectively at compression ratio 16:1 under full load condition. The NOx emissions i.e. 148, 135, 131 and 164 ppm was obtained for D100,

GSOME5%DEE5%, GSOME10%DEE10% & GSOME15%DEE15% blends respectively at compression ratio 18:1 under full load condition.

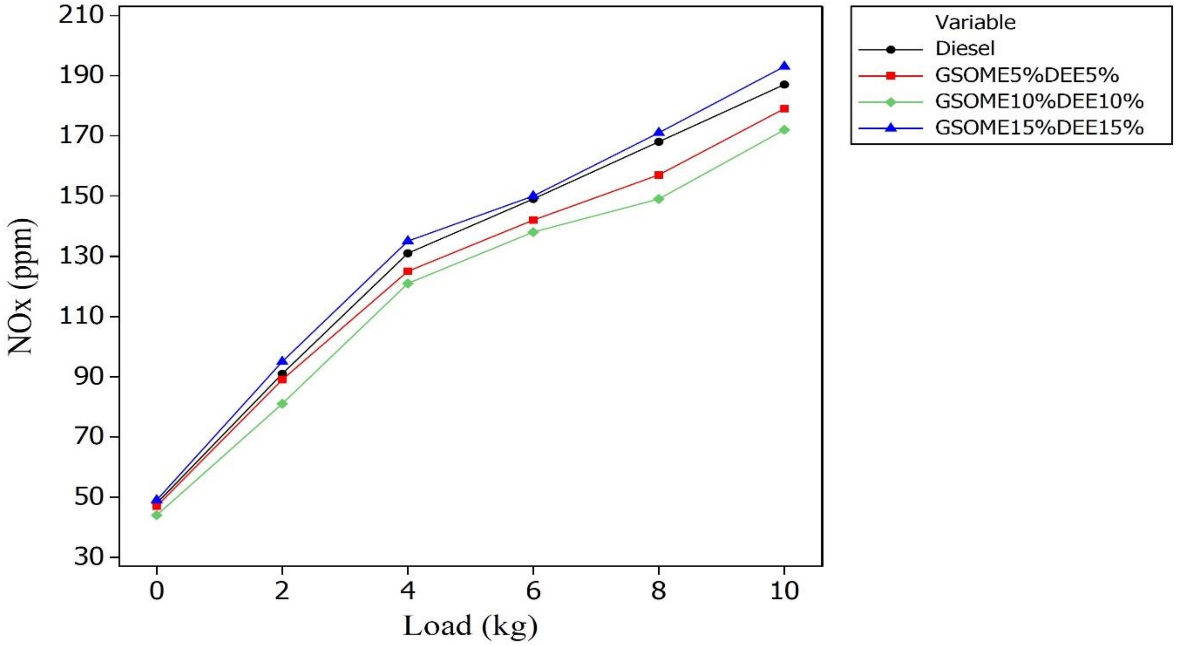


Figure 4.45: Variation of NOx of GSOME blend with DEE and diesel fuel with load at compression ratio 14:1

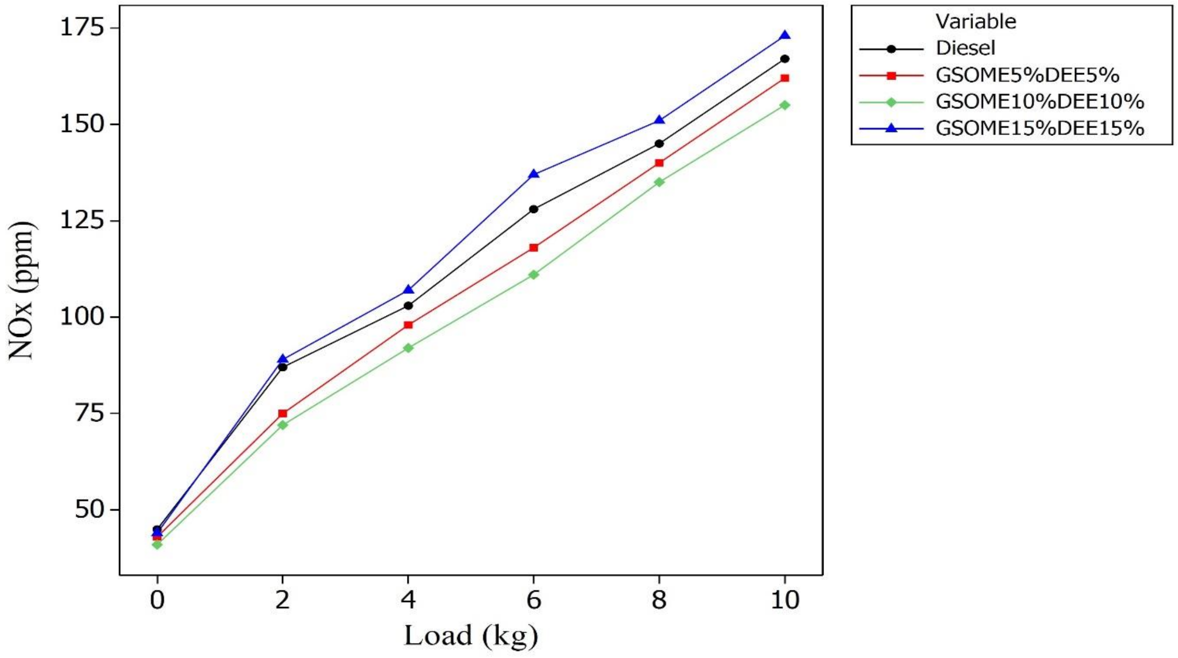


Figure 4.46: Variation of NOx of GSOME blend with DEE and diesel fuel with load at compression ratio 16:1

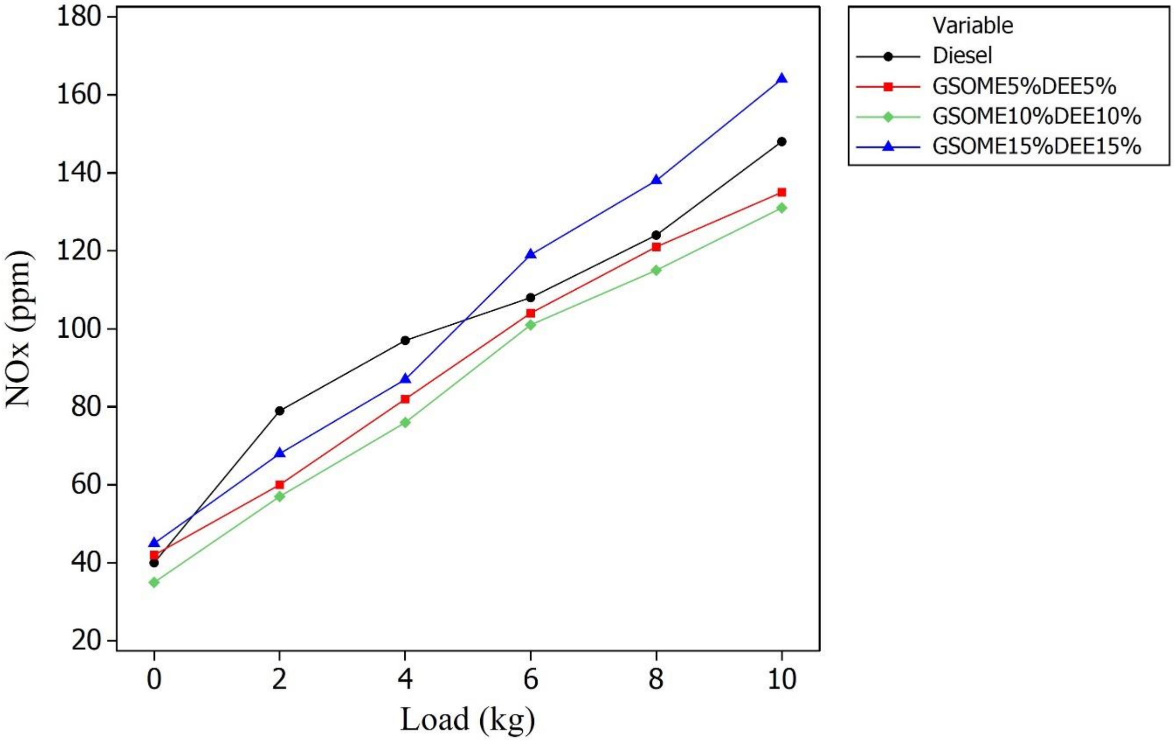


Figure 4.47: Variation of NOx of GSOME blend with DEE and diesel fuel with load at compression ratio 18:1

4.5.7 Effect of load on carbon monoxide (CO) for different blends

Figure 4.48 to 4.50 represents the variation of carbon monoxide emissions of biodiesel fuel blends with diethyl ether and diesel fuel with respect to engine load at different compression ratios. It was observed that the emissions of carbon monoxide increase with the increase in engine load. The reason for increasing CO was due to not proper supply of air in the combustion chamber which results in incomplete combustion and increase the fuel consumption. It was also observed that the emissions of CO reduced with the increase in percentage of biodiesel. This was may be due to higher oxygen content in biodiesel fuel blends which increased the combustion efficiency in terms of greater the brake thermal efficiency. The lowest average emissions of carbon monoxide i.e. 385.33 ppm was found for the biodiesel fuel blend with diethyl ether GSOME10%DEE10% from no load to full load condition at compression ratio 18:1.

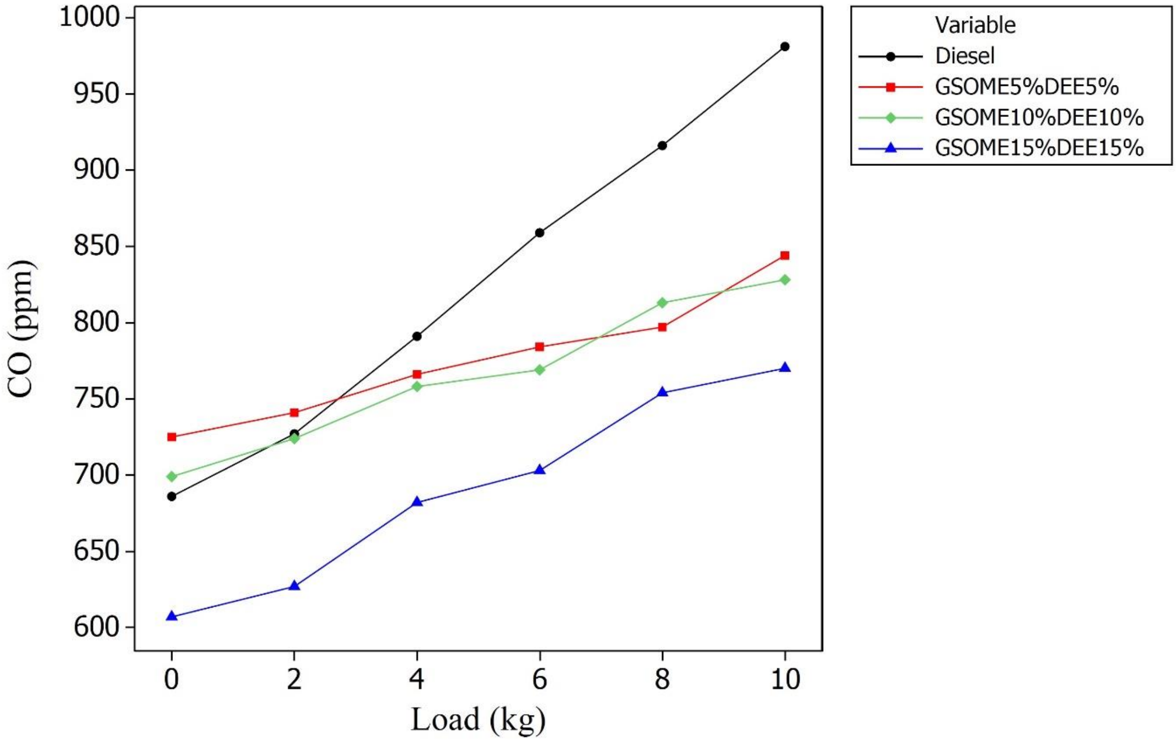


Figure 4.48: Variation of CO of GSOME blend with DEE and diesel fuel with load at compression ratio 14:1

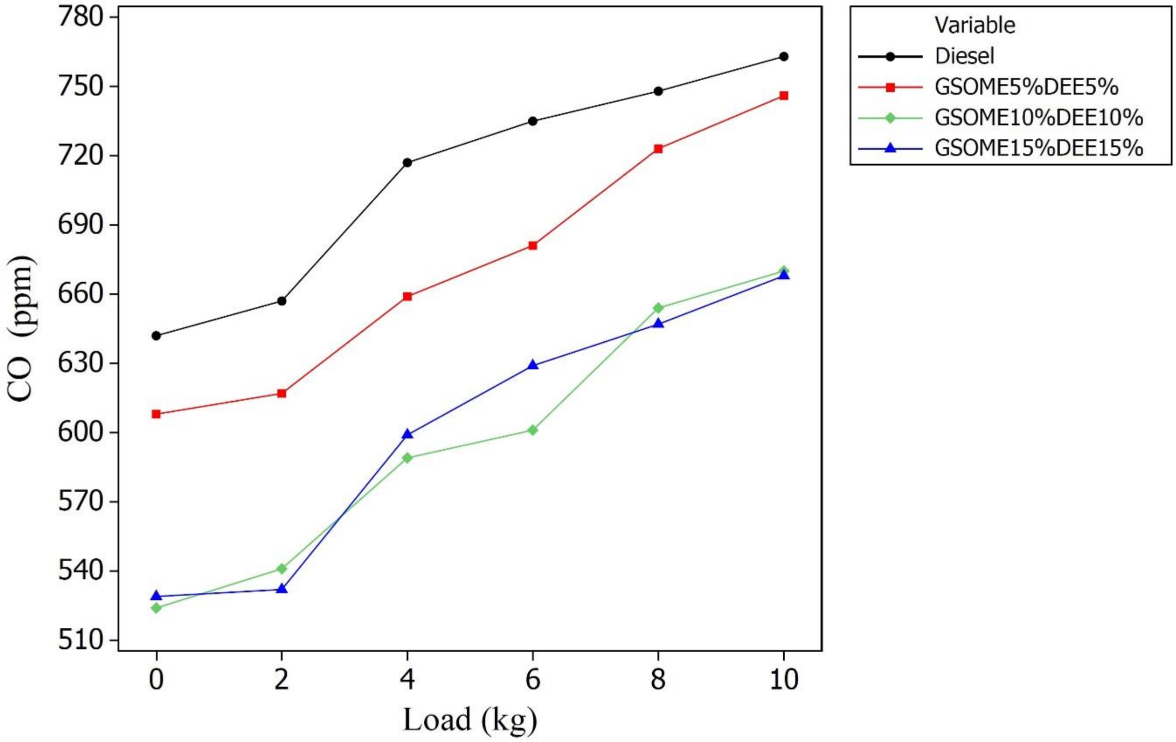


Figure 4.49: Variation of CO of GSOME blend with DEE and diesel fuel with load at compression ratio 16:1

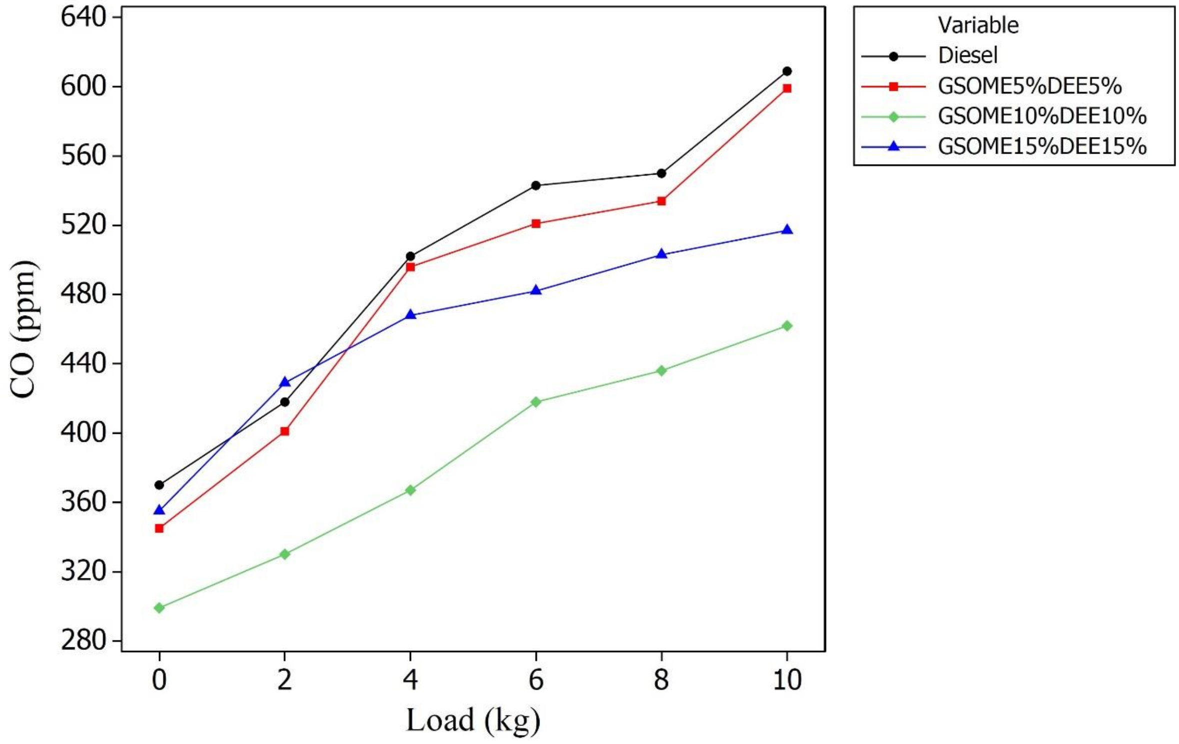


Figure 4.50: Variation of CO of GSOME blend with DEE and diesel fuel with load at compression ratio 18:1

4.5.8 Effect of load on unburned hydrocarbon (HC) for different blends

Figure 4.51 to 4.53 represents the variation of unburned hydrocarbon emissions of biodiesel fuel blends with diethyl ether and diesel fuel with respect to engine load at different compression ratios. Hydrocarbon emissions takes place due to incomplete combustion. The unburned hydrocarbon (HC) emissions i.e. 1124, 1299, 1524 and 1397 ppm was obtained for D100, GSOME5%DEE5%, GSOME10%DEE10% & GSOME15%DEE15% blends respectively at compression ratio 14:1 under full load condition. The unburned hydrocarbon (HC) emissions i.e. 1016, 1185, 1225 and 1219 ppm was obtained for D100, GSOME5%DEE5%, GSOME10%DEE10% & GSOME15%DEE15% blends respectively at compression ratio 16:1 under full load condition. The unburned hydrocarbon (HC) emissions i.e. 899, 1241, 1301 and 1262 ppm was obtained for D100, GSOME5%DEE5%, GSOME10%DEE10% & GSOME15%DEE15% blends respectively at compression ratio 18:1 under full load condition.

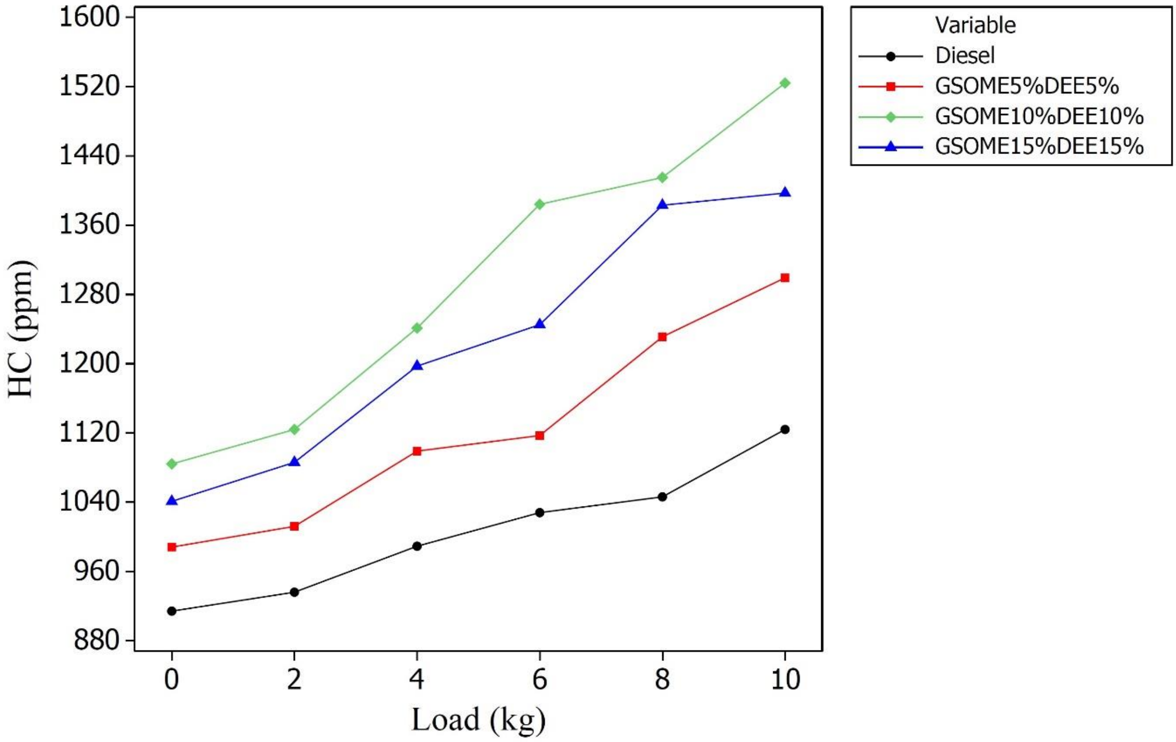


Figure 4.51: Variation of HC of GSOME blend with DEE and diesel fuel with load at compression ratio 14:1

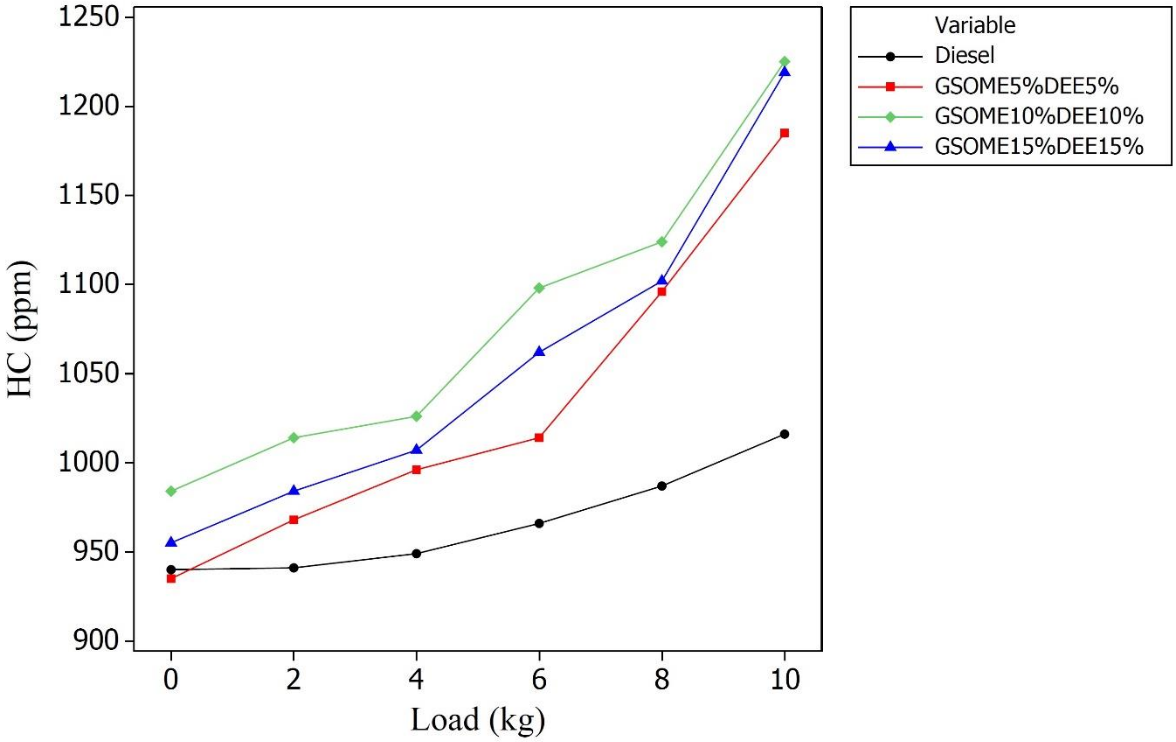


Figure 4.52: Variation of HC of GSOME blend with DEE and diesel fuel with load at compression ratio 16:1

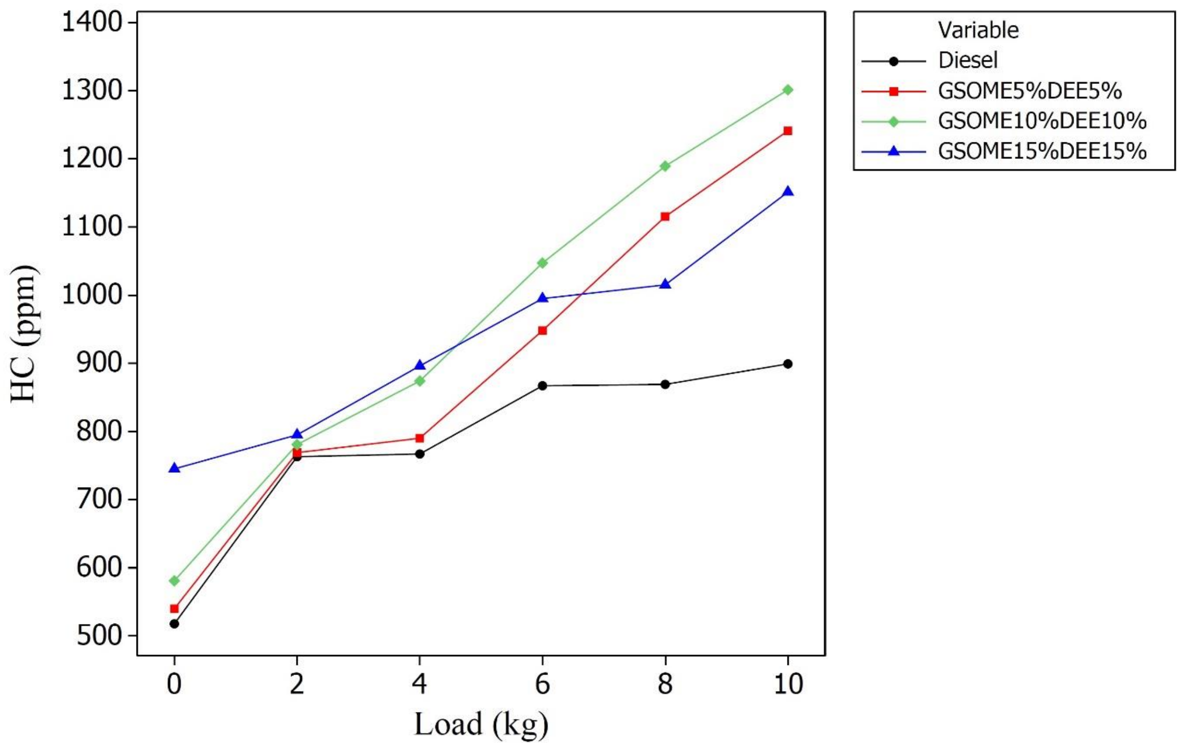
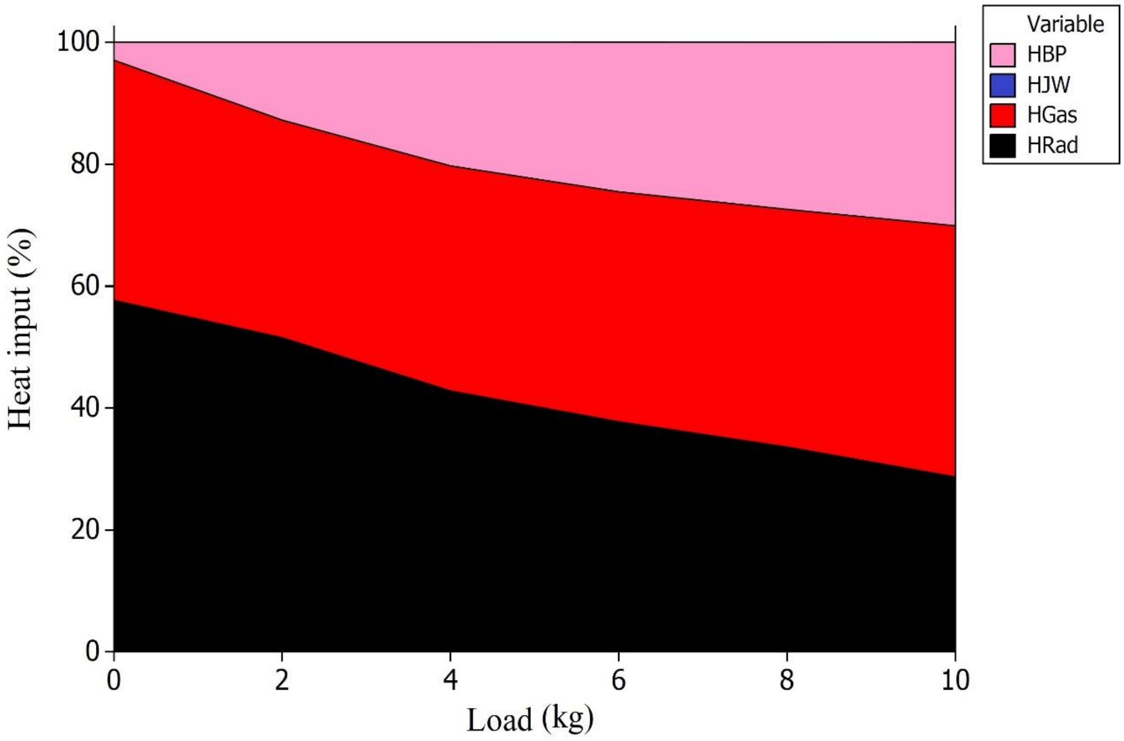


Figure 4.53: Variation of HC of GSOME blend with DEE and diesel fuel with load at compression ratio 18:1

4.6 Heat balance

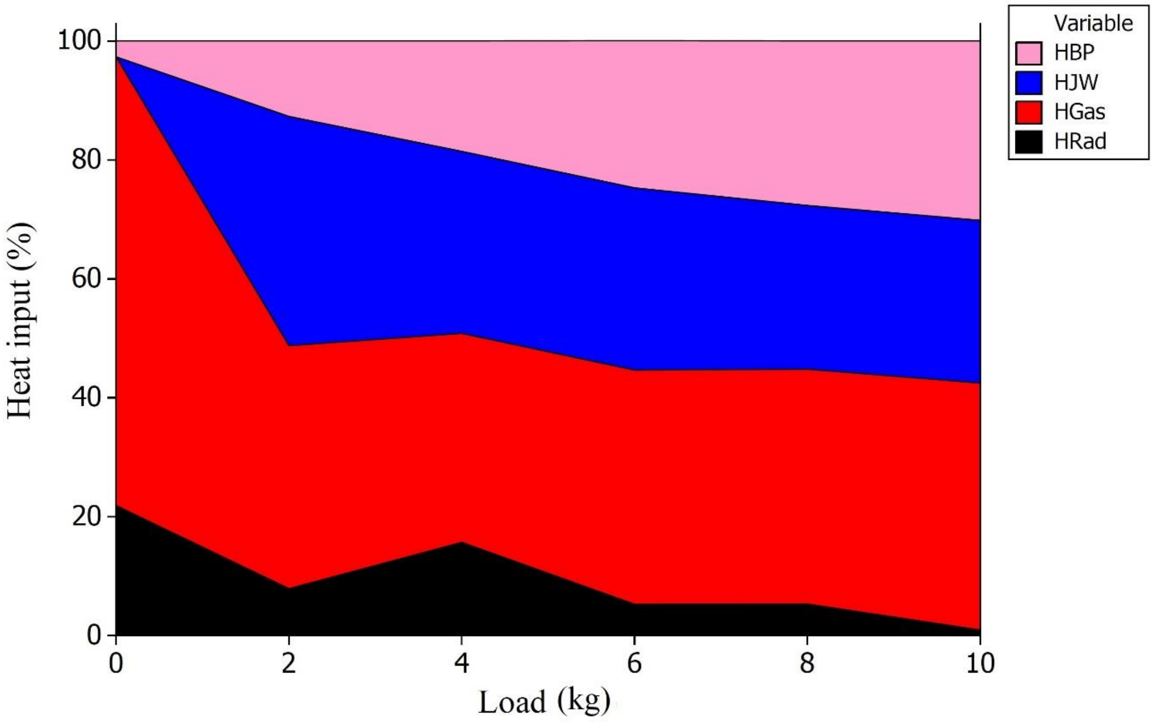
Energy generated (heat value of fuel in kW) by burning of fuel was transferred to the engine in the form of chemical energy. According to second law of thermodynamics, some part of energy is transformed into useful work and energy which is left transferred to surroundings or used by other applications. Heat carried away by exhaust gas and cooling water were two mode for energy loss. For preparation of heat balance sheet, it required temperature of exhaust gas, cooling water temperature, cooling water flow rate, brake power, specific heat of exhaust gas and it was also observed that there were heat loss due to incomplete combustion and radiation. The heat balance for diesel fuel and all blended fuels (GSOME and GSOME with diethyl ether) at compression ratio 18:1 were shown in Figure 4.54 (a), (b), (c), (d), (e), (f), and (g).

Heat balance for diesel fuel



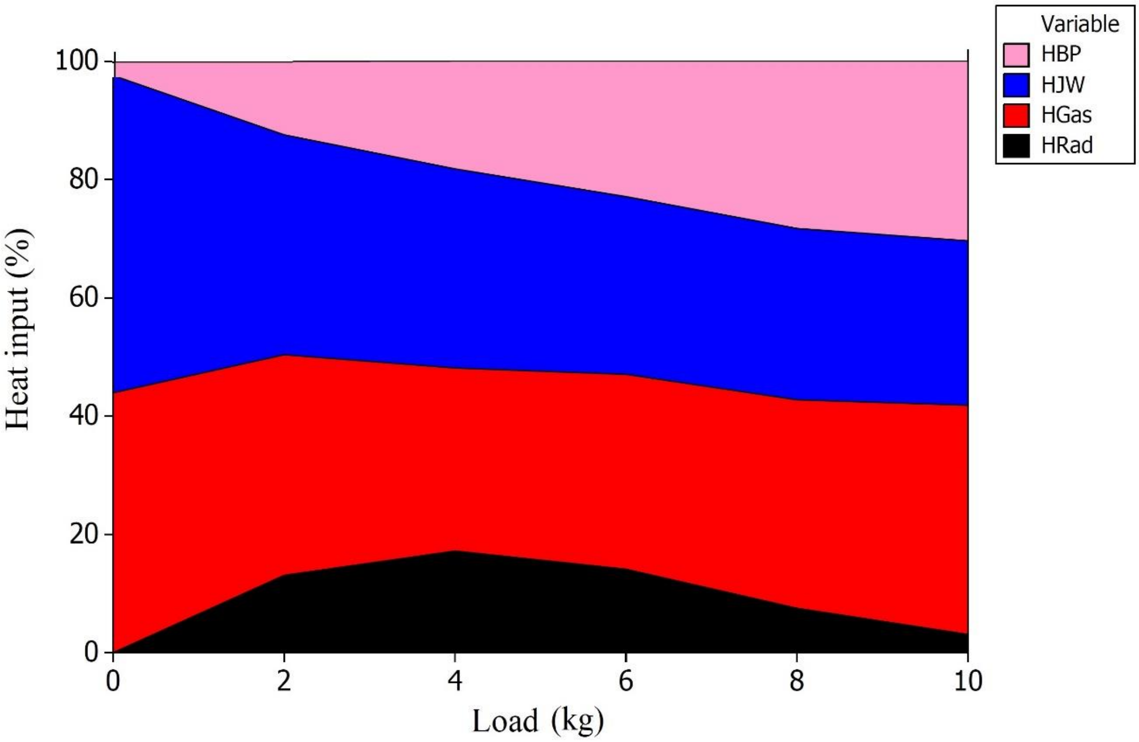
(a)

Heat balance for GSOME10% blend fuel



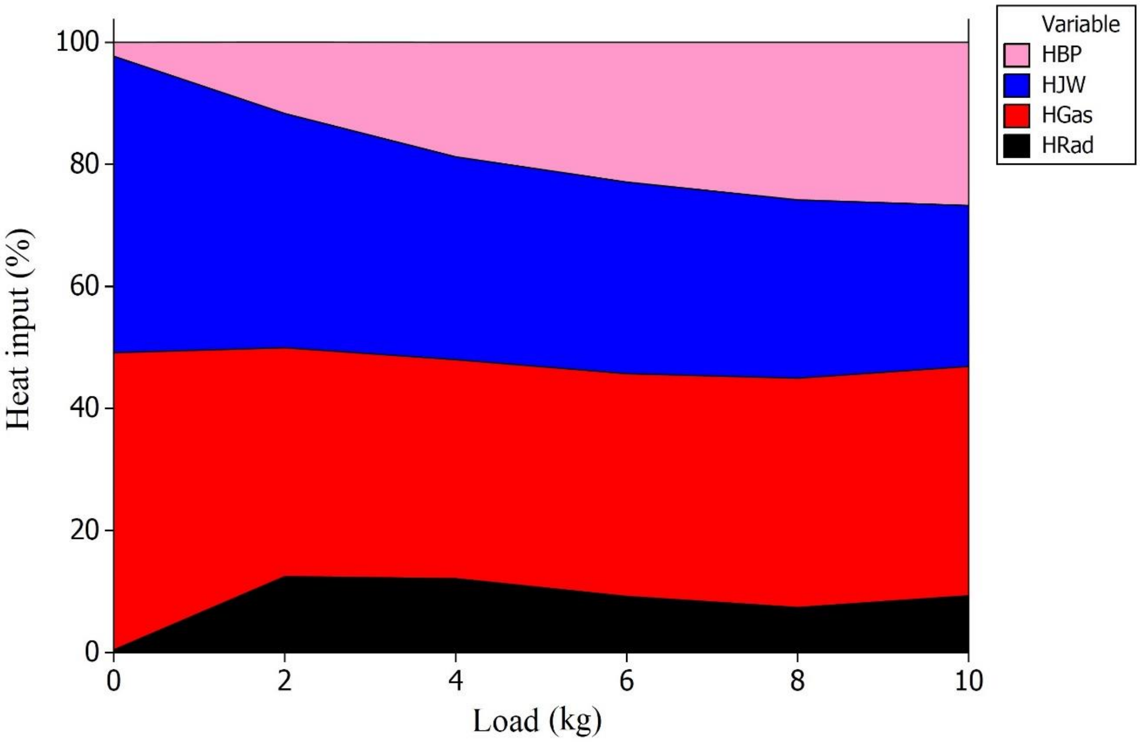
(b)

Heat balance for GSOME20% blend fuel



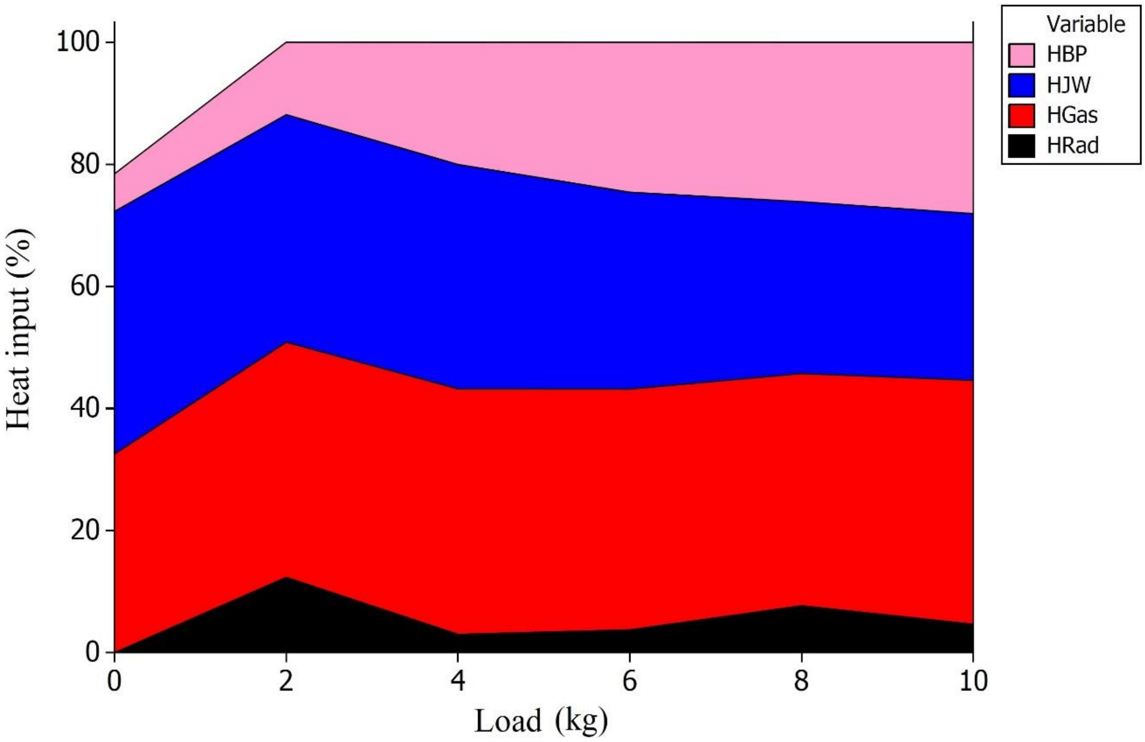
(c)

Heat balance for GSOME30% blend fuel



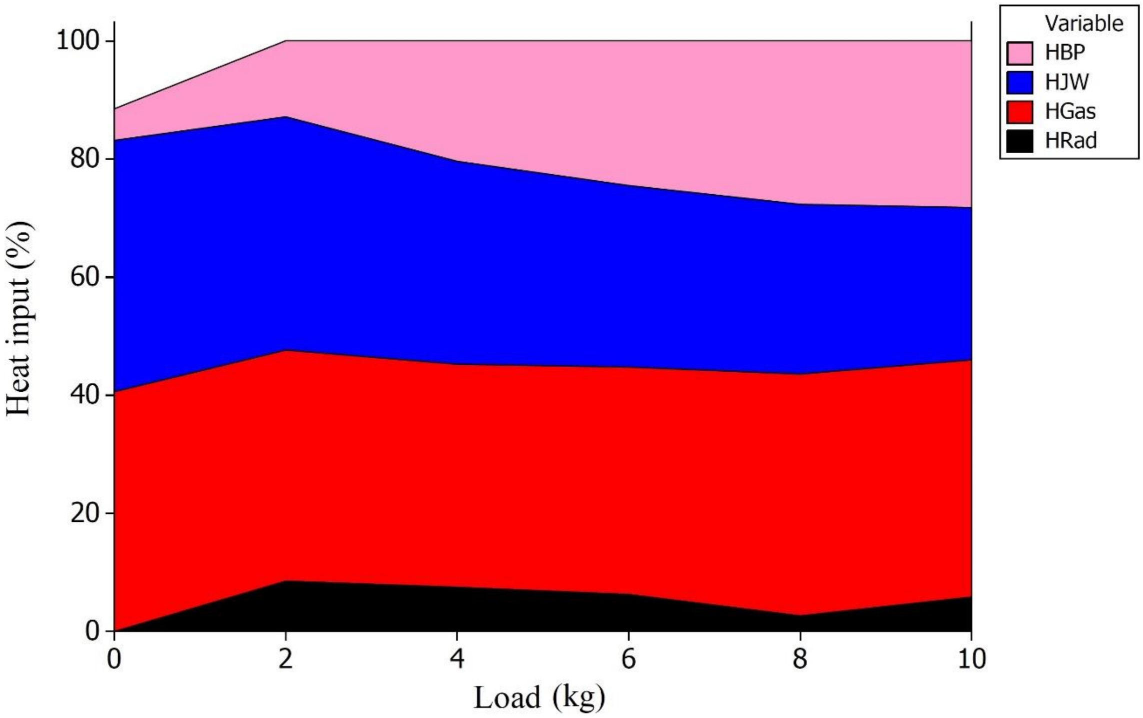
(d)

Heat balance for GSOME5%DEE5% blend fuel



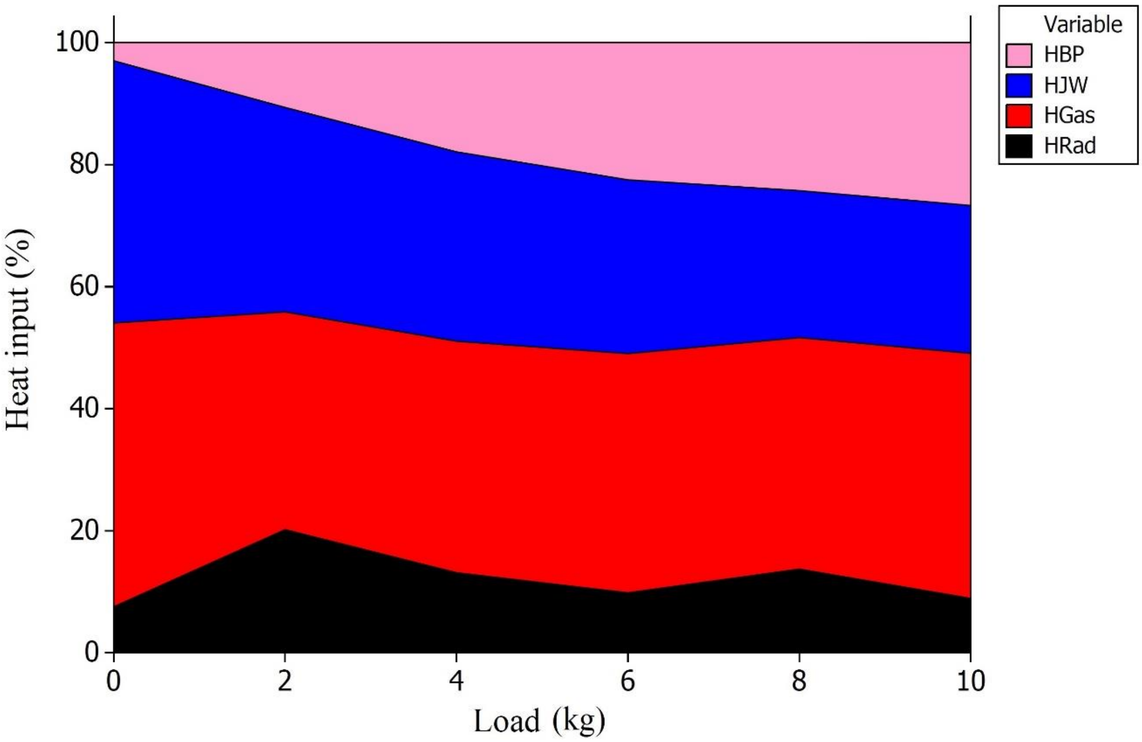
(e)

Heat balance for GSOME10%DEE10% blend fuel



(f)

Heat balance for GSOME15%DEE15% blend fuel



(g)

CHAPTER 5

CONCLUSIONS AND FUTURE SCOPE

5.1 Conclusions

The main objective of this study was to enhance the production of methyl ester from grape seed oil using transesterification process. The physicochemical properties, performance and emissions characteristics of grape seed oil methyl ester and grape seed oil methyl ester with diethyl ether as an additive were evaluated in this present study.

The main findings of this study were listed below:

- The maximum biodiesel and minimum viscosity were evaluated as 98.41% and 4.14 centistokes respectively with molar ratio 4:1, 0.5% KOH catalyst concentration and 60 minutes reaction time at a temperature of 60 °C
- The relative density of grape seed oil and grape seed oil methyl ester was found to be 922.17 and 880.2 kg/m^3 respectively at 15 °C.
- The free fatty acid content of grape seed oil and grape seed oil methyl ester was observed to be 0.6 and 0.18% respectively.
- The kinematic viscosity of grape seed oil and grape seed oil methyl ester was found to be 26.92 and 4.14 cSt respectively at 40 °C.
- It was found that the flash and fire point of grape seed oil methyl ester were 250.7 and 174 °C respectively.
- It was evaluated that the cloud and pour point of grape seed oil methyl ester were -5 and -6 °C respectively.
- The higher heating value of grape seed oil and grape seed oil methyl ester was found to be 37.7 and 39.52 MJ/kg respectively.
- From above graphical representation, it was found that GSOME20% showed the better performance among all blended fuel when compare to diesel fuel at compression ratio 18:1 under full load condition.
- The bake power and brake specific fuel consumption of VCR engine was found to be almost same for all blended fuel when compare to diesel fuel. The BP and BSFC increases with the increase in engine load.
- The mechanical efficiency of blend GSOME20% was found to be 31.50% which was higher than the diesel fuel i.e. 30.41% at compression ratio 18:1 under full load condition.

- The exhaust gas temperature was found to be 250.73 °C for blend GSOME20% which was lower than diesel fuel i.e. 260.13 °C under full load condition at compression ratio 18:1.
- The CO emission was found to be 483 ppm for GSOME20% blended fuel which was lower than diesel fuel i.e. 609 ppm at compression ratio 18:1 under full load condition.
- As per above discussion, the grape seed oil methyl ester with diethyl ether as an additive showed better performance at blend GSOME10%DEE10% among all other blended fuel at compression ratio 18:1.
- Increase in emissions of oxides of nitrogen was observed with engine load. The minimum NOx emissions i.e. 126 ppm was found at compression 18:1 with GSOME10%DEE10% fuel blend under no load to full load condition which was lower than diesel fuel i.e. 148 ppm.
- Increase in emissions of carbon monoxide was observed with engine load. The minimum CO emissions i.e. 460 ppm was found with GSOME10%DEE10% at compression 18:1 under no load to full load condition which was lower than diesel fuel i.e. 609 ppm.
- It was observed that hydrocarbon emissions increase with the increase in engine load. The unburned hydrocarbon emissions was found to be greater than diesel fuel for all fuel blends.

5.2 Future scope

To substitute the fossil fuels, different types of derived fuels such as methyl ester from vegetable oils and liquid fuels are produced. The following point should be considered before introducing the biofuel in India.

- There should be proper use of by-products prepared from biodiesel so that cost of biodiesel can be reduced.
- The unburned hydrocarbon emission was found to be greater than diesel fuel. So further research work should be done to reduce HC emissions.
- Economic analysis shall also be performed.
- Modification of engine should be done so that engine can run solely on biodiesel.
- There is limited research found on compatibility of metals used in engines when fuelled with biodiesel to avoid the unforeseen problems in future such as O-rings, sealing gasket etc. So further research can be done on this gap.

REFERENCES

1) Abdul Kalam APJ. Dynamics of rural development. In: 93rd Indian Science Congress Annual Report. 2005; 2006: 34-40.
2) Abedin, M.J., Masjuki, H.H., Kalam, M.A., Sanjid, A., Rahman, S.A. and Fattah, I.R., 2014. Performance, emissions, and heat losses of palm and jatropha biodiesel blends in a diesel engine. *Industrial Crops and Products*, *59*, pp.96-104.
3) Acharya, S.K., Swain, R.K. and Mohanty, M.K., 2014. Emission Analysis of Using Preheated Karanja and Kusum Oil. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, *36*(12), pp.1358-1365.
4) A E Atabani, Irfan Anjum Badruddin, H H Masjuki, W.T. Chong, K. T. L. (2015) Pangium edule Reinw : A Promising Non-edible Oil Feedstock for Biodiesel Production. *Arabian Journal for Science and Engineering*, *40(2).*pp. 583–594. doi: 10.1007/s13369-014-1452-5.
5) Agarwal, A.K., 2007. Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines. *Progress in Energy and Combustion Science*, *33*(3), pp.233-271.
6) Ahmad, M., Rashid, S., Khan, M.A., Zafar, M., Sultana, S. and Gulzar, S., 2009. Optimization of base catalyzed transesterification of peanut oil biodiesel. *African Journal of Biotechnology*, *8*(3). pp.184-198.
7) Al Awad, A.S., Selim, M.Y., Zeibak, A.F. and Moussa, R., 2014. Jojoba ethyl ester production and properties of ethanol blends. *Fuel*, *124*, pp.73-75.
8) Akarte, R.R., 2004. An overview of energy and issues of future. In *First National Conference on Energy and Fuel Issues of Future, Pune: PIET* (pp. 150-160).
9) Aransiola, E.F., Ojumu, T.V., Oyekola, O.O., Madzimbamuto, T.F. and Ikhu-Omoregbe, D.I.O., 2014. A review of current technology for biodiesel production: State of the art. *Biomass and bioenergy, 61*, pp.276-297.
10) Aydın, H., 2016. Scrutinizing the combustion, performance and emissions of safflower biodiesel–kerosene fueled diesel engine used as power source for a generator. *Energy Conversion and Management*, *117*, pp.400-409.
11) Balaji, G. and Cheralathan, M., 2014. Experimental investigation to reduce emissions of CI (compression ignition) engine fuelled with methyl ester of cottonseed oil using antioxidant. *International Journal of Ambient Energy*, *35*(1), pp.13-19.
12) Bijalwan A, Sharma CM, Kediyal VK. Biodiesel revolution. Science Reporter. 2006; 14-7.

13) Bouaid, A., Martinez, M. and Aracil, J., 2009. Production of biodiesel from bioethanol and Brassica carinata oil: oxidation stability study. *Bioresource Technology*, *100*(7), pp.2234-2239.

14) Can, Ö., Öztürk, E. and Yücesu, H.S., 2017. Combustion and exhaust emissions of canola biodiesel blends in a single cylinder DI diesel engine. *Renewable Energy*, *109,* pp.73-82.

15) Chongkhong, S., Tongurai, C., Chetpattananondh, P. and Bunyakan, C., 2007. Biodiesel production by esterification of palm fatty acid distillate. *Biomass and Bioenergy, 31*(8), pp.563-568.

16) Demirbas, A., 2005. Biodiesel production from vegetable oils via catalytic and non-catalytic supercritical methanol transesterification methods. *Progress in Energy and Combustion Science*, *31*(5-6), pp.466-487.

17) Demirbas, M.F., 2008. Pyrolysis of vegetable oils and animal fats for the production of renewable fuels. *Energy Education Science and Technology*, *22*(1), pp.59-67.

18) Duz, M.Z., Saydut, A. and Ozturk, G., 2011. Alkali catalyzed transesterification of safflower seed oil assisted by microwave irradiation. *Fuel Processing Technology*, *92*(3), pp.308-313.

19) Fernández, C. M. *et al.* 2010 'Bioresource Technology Production of biodiesel from winery waste : Extraction , refining and transesterification of grape seed oil', *Bioresource Technology*. Elsevier Ltd, 101(18), pp. 7019–7024.

20) Gangil, S., Singh, R., Bhavate, P., Bhagat, D. and Modhera, B., 2016. Evaluation of engine performance and emission with methyl ester of Karanja oil. *Perspectives in Science*, *8,* pp.241-243.

21) Haldar, S.K., Ghosh, B.B. and Nag, A., 2009. Studies on the comparison of performance and emission characteristics of a diesel engine using three degummed non-edible vegetable oils. *Biomass and Bioenergy*, *33*(8), pp.1013-1018.

22) Ilkılıç, C., Aydın, S., Behcet, R. and Aydin, H., 2011. Biodiesel from safflower oil and its application in a diesel engine. *Fuel processing technology*, *92*(3), pp.356-362.

23) Jain, S. and Sharma, M.P., 2010. Prospects of biodiesel from Jatropha in India: a review. *Renewable and Sustainable Energy Reviews*, *14*(2), pp.763-771.

24) Janaun, J. and Ellis, N., 2010. Perspectives on biodiesel as a sustainable fuel. *Renewable and Sustainable Energy Reviews*, *14*(4), pp.1312-1320.

25) Jayaprabakar, J., Anish, M., Beemkumar, N., Mathew, A. and Alex George, A., 2017. Effect of diethyl ether blended with neem oil methyl esters in CI engine. *International Journal of Ambient Energy*, 44(10) pp.1-3.

26) Kakati, J., Gogoi, T. K. and Pakshirajan, K. 2017 'Production of biodiesel from Amari (Amoora Wallichii King) tree seeds using optimum process parameters and its characterization', *Energy Conversion and Management*. Elsevier Ltd, 135, pp. 281–290. doi: 10.1016/j.enconman.2016.12.087.

27) Kumari, V., Shah, S. and Gupta, M.N., 2007. Preparation of biodiesel by lipase-catalyzed transesterification of high free fatty acid containing oil from Madhuca indica. *Energy & Fuels*, *21*(1), pp.368-372.

28) Lu, H., Liu, Y., Zhou, H., Yang, Y., Chen, M. and Liang, B., 2009. Production of biodiesel from Jatropha curcas L. oil. *Computers & Chemical Engineering*, *33*(5), pp.1091-1096.

29) Ma, F. and Hanna, M.A., 1999. Biodiesel production: a review. *Bioresource Technology*, *70*(1), pp.1-15.

30) Meher, L.C., Dharmagadda, V.S. and Naik, S.N., 2006. Optimization of alkali-catalyzed transesterification of Pongamia pinnata oil for production of biodiesel. *Bioresource Technology*, *97*(12), pp.1392-1397.

31) Murugesan, A. and Avinash, A. (2017) 'Environmental Effects Optimization of biodiesel production from raw and purified bio-oil', *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*. Taylor & Francis, 39(10), pp. 1–7.

32) Muthukumaran, C. *et al.* 2017 'Process optimization and kinetic modeling of biodiesel production using non-edible Madhuca indica oil', *Fuel*. Elsevier Ltd, 195, pp. 217–225.

33) Nayak, S.K. and Pattanaik, B.P., 2014. Experimental investigation on performance and emission characteristics of a diesel engine fuelled with mahua biodiesel using additive. *Energy Procedia*, *54*, pp.569-579.

34) Perumal, G., Rengasamy, T. and Dharmendira Kumar, M., 2017. Production of biodiesel by transesterification of Senna occidentalis nonedible oil. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, *39*(17), pp.1855-1861.

35) Phan, A.N. and Phan, T.M., 2008. Biodiesel production from waste cooking oils. *Fuel*, *87*(18), pp.3490-3496.

36) Rajan, K., Prabhahar, M. and Senthilkumar, K.R., 2016. Experimental studies on the performance, emission and combustion characteristics of a biodiesel-fuelled (Pongamia methyl ester) diesel engine with diethyl ether as an oxygenated fuel additive. *International Journal of Ambient Energy*, *37*(5), pp.439-445.

37) Ramadhas, A.S., Muraleedharan, C. and Jayaraj, S., 2005. Performance and emission evaluation of a diesel engine fueled with methyl esters of rubber seed oil. *Renewable Energy*, *30*(12), pp.1789-1800.

38) Rashid, U., Anwar, F., Moser, B.R. and Knothe, G., 2008. Moringa oleifera oil: a possible source of biodiesel. *Bioresource Technology*, *99*(17), pp.8175-8179.

39) Saydut, A., Erdogan, S., Kafadar, A.B., Kaya, C., Aydin, F. and Hamamci, C., 2016. Process optimization for production of biodiesel from hazelnut oil, sunflower oil and their hybrid feedstock. *Fuel*, *183*, pp.512-517.

40) Schwab, A.W., Dykstra, G.J., Selke, E., Sorenson, S.C. and Pryde, E.H., 1988. Diesel fuel from thermal decomposition of soybean oil. *Journal of the American Oil Chemists' Society*, *65*(11), pp.1781-1786.

41) Shah, S., Sharma, S. and Gupta, M.N., 2004. Biodiesel preparation by lipase-catalyzed transesterification of Jatropha oil. *Energy & Fuels*, *18*(1), pp.154-159.

42) Sinha, S., Agarwal, A.K. and Garg, S., 2008. Biodiesel development from rice bran oil: Transesterification process optimization and fuel characterization. *Energy Conversion and Management*, *49*(5), pp.1248-1257.

43) S.Karthikeyan, A. P. & A. E. 2015 'An Environmental Effect of Vitis vinifera (Grape Seed Oil) Biofuel Blends in Marine Engine', 44(June), pp. 886–891.

44) Sonntag, N.O.V., 1979. Fat splitting. *Journal of the American Oil Chemists' Society*, *56*(11), pp.729A-732A.

45) Subba IV. General President Indian science congress association. In: Presidential Address. 93rd Indian Science Congress Annual Report. 2005; 2006.

46) Ullah, F., Nosheen, A., Hussain, I. and Banon, A., 2009. Base catalyzed transesterification of wild apricot kernel oil for biodiesel production. *African Journal of Biotechnology*, *8*(14).pp.133-173.

PUBLICATIONS

Paper communicated

- Singh Gurpinder, S.K. Mohapatra, S. S. Ragit (2018). Optimization of Biodiesel Production from Grape Seed oil Using Taguchi's Orthogonal Array. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects. (published)*
- Gurpinder Singh, Saroj Kumar Mohapatra & S. S. Ragit (2018). Performance Analysis and Emission Characteristics of Diesel Engine Fueled with Blends of Waste Grape Seed Oil Biodiesel. *International Journal of Green Energy. (under review)*