# Experimental and Analytical Study of using Methanol with Bio diesel from Waste Cooking Oil–Diesel blend on a Diesel Engine

A PROJECT REPORT

**Submitted by**

K. Advait Krishna (Reg. No. FIT17ME077)
Nair Akshay Prasad(Reg. No. FIT17ME091)
Priyesh Raj(Reg. No. FIT17ME098)
Thomas Joe(Reg. No. FIT17ME121)

**to**
the APJ Abdul Kalam Technological University
in partial fulfillment of the requirements for the award of the Degree

of

***Bachelor of Technology***

*in*

***Mechanical Engineering***

FOCUS ON EXCELLENCE

**Department of Mechanical Engineering**

Federal Institute of Science And Technology (FISAT)®
Angamaly, Ernakulam

JUNE 2021

## DECLARATION

We undersigned hereby declare that the project report **Experimental and analytical study of using Methanol with Bio diesel from Waste Cooking Oil– Diesel blend on a Diesel engine** , submitted for partial fulfillment of the requirements for the award of degree of Master of Technology of the APJ Abdul Kalam Technological University, Kerala is a bonafide work done by us under supervision of Dr.Sumanlal M R. This submission represents our ideas in our own words and where ideas or words of others have been included, We have adequately and accurately cited and referenced the original sources. We also declare that we have adhered to ethics of academic honesty and integrity and have not misrepresented or fabricated any data or idea or fact or source in my submission. We understand that any violation of the above will be a cause for disciplinary action by the institute and/or the University and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been obtained. This report has not been previously formed the basis for the award of any degree, diploma or similar title of any other University.

**Mookkanoor**:

**Date**:

**K. Advait Krishna**

**Nair Akshay Prasad**

**Thomas Joe**

**Priyesh Raj**

**DEPARTMENT OF MECHANICAL ENGINEERING**

**Federal Institute of Science And Technology (FISAT)®**
Mookkannoor(P.O), Angamaly-683577

FOCUS ON EXCELLENCE

# CERTIFICATE

This is to certify that the report entitled "**Experimental and Analytical Study of using Methanol with Bio diesel from Waste Cooking Oil–Diesel blend on a Diesel Engine**" submitted by "**K. Advait Krishna, Nair Akshay Prasad, Priyesh Raj, Thomas Joe**" to the APJ Abdul Kalam Technological University in partial fulfillment of the requirements for the award of the Degree of Bachelor of Technology in (Mechanical Engineering) is a bonafide record of the project work carried out by him/her under my/our guidance and supervision. This report in any form has not been submitted to any other University or Institute for any purpose.

**Internal Supervisor**
**Dr. Sumanlal M R**
**Assistant Professor**
**Department of Mechanical Engineering**

**Project Coordinator**
**Assistant Professor**
**Department of Mechanical Engineering**

**Head Of The Department**
**Dr. Sumanlal M R**
**Professor**

# Contents

ACKNOWLEDGEMENT

ABSTRACT

LIST OF FIGURES

LIST OF TABLES

ABBREVATIONS

NOTATION

**1 INTRODUCTION** **1**

**2 LITERATURE SURVEY** **4**

**3 METHODOLOGY** **8**

**4 THEORETICAL ANALYSIS** **9**
4.1 SIMULATION PARAMETERS . . . . . . . . . . . . . . . . . . . . . . 9
4.2 SIMULATION RESULTS . . . . . . . . . . . . . . . . . . . . . . . . 11
4.2.1 MINERAL DIESEL . . . . . . . . . . . . . . . . . . . . . . 11
4.2.2 D80:B15:M5 . . . . . . . . . . . . . . . . . . . . . . . . . 12
4.2.3 D75:B15:M10 . . . . . . . . . . . . . . . . . . . . . . . . 13
4.2.4 D75:B20:M5 . . . . . . . . . . . . . . . . . . . . . . . . . 14
4.2.5 D70:B20:M10 . . . . . . . . . . . . . . . . . . . . . . . . 15

**5 EXPERIMENTAL PROCEDURE** **17**
5.1 EXPERIMENTAL SETUP . . . . . . . . . . . . . . . . . . . . . . . 17
5.2 PROCEDURE . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 19
5.3 THERMO-PHYSICAL PROPERTIES . . . . . . . . . . . . . . . . . 20

**6 RESULTS AND DISCUSSION** **21**
6.1 EMISSIONS . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 21
6.1.1 Carbon dioxide emission . . . . . . . . . . . . . . . . . . . 21
6.1.2 Carbon Monoxide . . . . . . . . . . . . . . . . . . . . . . 25
6.1.3 Nitrogen oxide emissions . . . . . . . . . . . . . . . . . . 28
6.1.4 Hydrocarbon emissions . . . . . . . . . . . . . . . . . . . 32
6.2 PERFORMANCE PARAMETERS . . . . . . . . . . . . . . . . . . . 35
6.2.1 Brake Thermal Efficiency . . . . . . . . . . . . . . . . . . 35
6.2.2 Brake specific fuel consumption: . . . . . . . . . . . . . . . 38

**7 CONCLUSION** **42**

**8 Scope for Further work** **43**

**9 Individual project contribution** **44**

**REFERENCES** **45**

# ACKNOWLEDGMENT

At this pleasing moment of having successfully completed our project, We wish to convey our sincere thanks and gratitude to the management of our college who provided all the facilities to us. We hereby express our deep sense of gratitude to our guide Dr.Sumanlal M R , Associate Professor Department of Mechanical Engineering, Federal institute of Science and Technology for the valuable guidance and suggestions offered during the course of this project and also in preparing this report. We would like to extend our thanks to Dr. Sumanlal M R, Head of the Department of Mechanical Engineering, Federal Institute of Science and Technology. Along with them we also extend our gratitude towards our principal Dr. George Issac, Federal Institute of Science and Technology who provided necessary arrangements for the work to be completed. I would like to express my thanks to my team members, for their support and wholehearted involvement in this project. We would like to express our thanks to my project coordinators, Mr. Harish T M, Mr. Nithin H, Mrs. Devi Parvathy for their encouragement and guidance for the preparation of this report. Finally, we take this opportunity for expressing our sincere gratitude to all our friends for their wholehearted co-operation. Last but not the least we would like to thank all those people whom we have not mentioned here, but who's helping hands have been great support to us.

K. Advait Krishna

Nair Akshay Prasad

Priyesh Raj

Thomas Joe

# ABSTRACT

In this current work, a comprehensive study for the possibility of using Diesel-Biodiesel-Methanol blend as an alternative for the mineral Diesel fuel was conducted. The test was conducted on a CRDI VCR 4stroke, single cylinder, water cooled engine at constant speed of 1500 rpm and five engine loads at different Exhaust Gas Recirculation (EGR) and Injection pressure (IOP) values. The Diesel-Biodiesel-Methanol were taken in blend ratios of 80:15:5,75:15:10, 75:20:5 and 70:20:10 respectively.Four runs were initiated for every fuel in which IOP and EGR values were changed. The emission and performance characteristics of each fuel were tabulated and graphically plotted. Overall, the results showed that the diesel-biodiesel-methanol blends showed an increase in BSFC and Brake thermal efficiency. CO emission of blends was seen to be comparatively lower than mineral diesel. CO2 and HC emission was observed to be increasing for blends when compared with diesel. While NOx emission had a decrease in value compared to diesel. Influence of EGR was found to be significant for the reduction of NOx emission. But it was found out that higher value of EGR to 12% increased CO emissions and decreasing the value of CO2 emissions.

# List of Tables

4.1 Fuel properties . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 16

5.1 Specifications of Engine . . . . . . . . . . . . . . . . . . . . . . . . . . 19

# List of Figures


3.1 Methadology Adopted . . . . . . . . . . 8

4.1 3D cylinder model . . . . . . . . . . 9
4.2 Computational domain for CFD analysis . . . . . . . . . . 10
4.3 Computational domain in mesh . . . . . . . . . . 10
4.4 Mass fraction contour of diesel . . . . . . . . . . 11
4.5 Temperature contour of diesel . . . . . . . . . . 11
4.6 Mass fraction contour of B15M5 . . . . . . . . . . 12
4.7 Temperature fraction contour of B15:M5 . . . . . . . . . . 12
4.8 Mass fraction contour of B15M10 . . . . . . . . . . 13
4.9 Temperature fraction contour of B15M10 . . . . . . . . . . 13
4.10 Mass fraction contour of B20M5 . . . . . . . . . . 14
4.11 Temperature fraction contour of B20M5 . . . . . . . . . . 14
4.12 Mass fraction contour of B20M10 . . . . . . . . . . 15
4.13 Temperature fraction contour of B20M10 . . . . . . . . . . 15

5.1 Schematic Diagram of Experimental Setup . . . . . . . . . . 18
5.2 Thermo-physical properties table . . . . . . . . . . 20

6.1 CO2 Emission at IOP 400 and EGR 0 . . . . . . . . . . 22
6.2 CO2 Emission at IOP 600 and EGR 0 . . . . . . . . . . 22
6.3 CO2 Emission at IOP 600 and EGR 6 . . . . . . . . . . 23
6.4 CO2 Emission at IOP 600 and EGR 12 . . . . . . . . . . 23
6.5 CO2 Emission of four runs at 75% load . . . . . . . . . . 24
6.6 CO Emission at IOP 400 and EGR 0 . . . . . . . . . . 25
6.7 CO Emission at IOP 600 and EGR 0 . . . . . . . . . . 26
6.8 CO Emission at IOP 600 and EGR 6 . . . . . . . . . . 26
6.9 CO Emission at IOP 600 and EGR 12 . . . . . . . . . . 27
6.10 CO Emission of four runs at 75% load . . . . . . . . . . 28
6.11 NOx Emissions at IOP 400 EGR 0 . . . . . . . . . . 29
6.12 NOx Emissions at IOP 600 EGR 0 . . . . . . . . . . 29
6.13 NOx Emissions at IOP 600 EGR 6 . . . . . . . . . . 30
6.14 NOx Emissions at IOP 600 EGR 12 . . . . . . . . . . 30
6.15 NOx Emissions of four runs at 75% load . . . . . . . . . . 31
6.16 HC Emission at IOP 400 EGR 0 . . . . . . . . . . 32
6.17 HC Emission at IOP 600 EGR 0 . . . . . . . . . . 33
6.18 HC Emission at IOP 600 EGR 6 . . . . . . . . . . 33
6.19 HC Emission at IOP 600 EGR 12 . . . . . . . . . . 34
6.20 HC Emission of four runs at 75% load . . . . . . . . . . 34
6.21 Brake Thermal Efficiency at IOP 400 EGR 0 . . . . . . . . . . 35
6.22 Brake Thermal Efficiency at IOP 600 EGR 0 . . . . . . . . . . 36
6.23 Brake Thermal Efficiency at IOP 600 EGR 6 . . . . . . . . . . 36
6.24 Brake Thermal Efficiency at IOP 600 EGR 12 . . . . . . . . . . 37
6.25 Brake Thermal Efficiency of four runs at 75%load . . . . . . . . . . 37

6.26 Brake Specific Fuel Consumption at IOP 400 and EGR 0 . . . . . . 38
6.27 Brake Specific Fuel Consumption at IOP 600 and EGR 0 . . . . . . 39
6.28 Brake Specific Fuel Consumption at IOP 600 and EGR 6 . . . . . . 39
6.29 Brake Specific Fuel Consumption at IOP 600 and EGR 12 . . . . . 40
6.30 Brake Specific Fuel Consumption at four runs at 75% load . . . . . 40

# ABBREVIATIONS

IOP – Injection pressure

EGR – Exhaust gas recirculation

PN - Particulate Number

ECU- Electronic control unit

WCO -Waste Cooking Oil

ASTM-American Society for Testing and Materials

CN - Cetane number

FFA - Free fatty acid

# NOTATIONS

$O_2$ - Oxygen

CO – Carbon monoxide

$CO_2$ – Carbon dioxide

$NO_x$ – Nitrogen oxides

HC- Hydrocarbons

D - Diesel

M- Methanol

# Chapter 1

# INTRODUCTION

In light of the recent events such as decreasing fossil fuel resources, hiking crude oil price and pollution has made many researchers check the viability of biodiesel as potential alternative fuels. Methanol (CH3OH) is an alcohol that was originally produced by the destructive distillation of wood. In recent decades, methanol has been produced in large quantities from natural gas using reformation gas process.Now when coming to bio diesel from waste cooking oil which produced by recycling Waste Cooking Oil and methanol in the presence of calcium oxide (CaO) nano-catalyst offers several benefits such as economic, environmental and waste management. Biodiesel production from waste cooking oil provides an alternative energy means of producing liquid fuels from biomass for various uses.

Methanol (M) is an alcohol that contains 30% more oxygen (O2) than fossil diesel fuel.A higher amount of O2 in a combustion process reduces emission rates of incomplete combustion products.According to various scientific research results the emission of incomplete combustion products (carbon monoxide and hydrocarbons), engine cold start, as well as cold exploitation and engine efficiency could be improved using Methanol as an additive for fossil diesel fuel (D) and biodiesel blends.However, the use of Methanol in a diesel engine can cause negative consequences. Increased fuel consumption and rates of nitrogen oxides emission.Scientific literature is full of analysis of ecological and energy parameter characteristics while diesel engine running on fuel blends containing Methanol. Only few of scientific sources provide results of pressure and heat release rates in a wide engine load and speed ranges. Methanol is characterized by low cetane number (CN), which is less than 5 units and prolongs the ignition delay of air–fuel mixture , at the same time increase the peak values of in-cylinder pressure rise and heat release characteristics.

Biodiesel is biodegradable and nontoxic alternative fuel for diesel engine which has become more attractive to replace diesel fuel. In this study, vegetable oil was identified as potential sources for biodiesel production. The production of biodiesel from different non-edible oilseed crops has been extensively investigated for the past few years. Thus, the aim of this study is to critically review on the characteristic of the potential biodiesel and biodiesel diesel blends fuel properties. The aspects of this study cover the biodiesel production and fuel properties of biodiesel and biodiesel blends. Besides, some studies have shown that there is a direct correlation between fatty acid composition and biodiesel properties. The fuel properties of biodiesel blends fuel were very close to diesel fuels and satisfied ASTM 6751 and EN 14214 standards. As a final note, further study on the utilization of biodiesel blends needs to be carried out in order to ensure optimization in engine operation. Waste cooking oil (WCO) is considered the most promising biodiesel feedstock despite its drawbacks, such as its high free fatty acid (FFA) and water contents. This review paper provides a comprehensive overview of the pre-treatment and the usage of WCO for the production of biodiesel using several methods, different types of reactors, and various types and amounts of alcohol and catalysts. The most common process in the production of biodiesel is transesterification, and using a methanol–ethanol mixture will combine the advantages of both alcohols in biodiesel production. In addition, this paper highlights the purification and analysis of the produced biodiesel, operating parameters that highly affect the biodiesel yield, and several economic studies. This review suggests that WCO is a promising feedstock in biodiesel production.ooking oil sources differ across the globe. Their base materials are plant-based lipids, such as corn oil, margarine, coconut oil, palm oil, olive oil, soybean oil, grape seed oil and canola oil, or animal-based lipids, such as butter, ghee, kermanshahi oil and fish oil.

In Malaysia, the most common cooking oil is made from oil palm because of its low cost relative to other sources, such as coconut, corn or soybean plants. Biodiesel is produced by the transesterification of these lipids. Previous studies have shown that biodiesel can be produced from various types of vegetable oil, such as sunflower oil, palm oil and soybean oil . However, the use of a food source (edible oil) to produce biodiesel at the expense of the millions of people facing hunger and starvation around the world has received harsh criticism from several non-governmental organisations (NGOs) worldwide due to the resultant increase in the demand for vegetable or edible oil and unnecessary clearing of forests for plantation. Deforestation will disturb animal and plant ecosystems. The use of WCO as a biodiesel feedstock could reduce such problems as water pollution and blockages in water drainage systems, which require extra work to clean. However, there is also a growing concern regarding the environmental impact of an increase in the production of WCO in homes and restaurants . WCO can be freely collected from restaurants and houses using a special "recycle bin" placed in each restaurant or house, which may require public awareness campaigns preceding the collection process. In Malaysia, NGO volunteers conducted an awareness campaign on the environmental impact caused by the direct discharge of WCO into the drainage system. These volunteers inform the community that disposing of WCO via drainage or a landfill could cause water and soil pollution and disturb the aquatic ecosystem in addition to being a human health concern. They also alerted the community to the negative effects of using recycled WCO as cooking media in food preparation. The NGO will establish a collection centre and arrange for the community to appoint a representative to collect the WCO. The WCO will be collected monthly, and payment will be made to the community fund. Finally, the collected WCO will be sent to the diesel manufacturer and factory.

Although state-of-the-art biodiesel production from WCO is less profitable than the use of fossil fuels, research is still on-going to improve the yield and quality of the fuel. Again, because the more fossil fuels are used each year than are produced, WCO is an excellent alternative. Additionally, this practice could prevent the recycling of WCO for cooking, which is being performed by some companies. Cooking oil recycled from WCO is believed to cause cancer because of the toxic contents produced when the oil is oxidised. However, obtaining WCO in large amounts remains a concern. Future studies should compare the methods used by other countries: their pros and cons, implementation, and economic impact. In London, Uptown Oil supplies fresh cooking oil to selected Western restaurants and pubs with a current average return of approximately 60% of the fresh oil. Their supplier has been trained to maximise the quality of the obtained WCO to reduce the impurities and ease the transformation process to biodiesel. The company collects and processes the WCO and produces recycled biodiesel directly in their plant. The biodiesel is then sold on the premises, especially to London black taxis. A strong relationship with local authorities offers direct contact with public facilities and institutions, such as hospitals, airports, schools, and catering services. Uptown also provides an eco-friendly window sticker to restaurants that supply the WCO in recognition of their co-operation.

Alcohols on the other hand, are other forms of renewable biofuels that have been studied extensively in the form of additives rather than complete replacements to diesel . Nevertheless, compared to diesel, alcohols are characterized by low cetane number and higher latent heat of vaporization preventing them from replacing the diesel entirely. Another drawback of alcohols is the incomplete miscibility to diesel leading to relatively heterogeneous mixtures rather than uniformly homogeneous blends resulting from diesel/biodiesel blending. Thus, one of the methodologies proposed to overcome the above problems is the use of tri-mixtures of diesel-biodiesel-alcohol blends rather than binary mixtures . In this method, the biodiesel will act as an emulsifying agent between the diesel and alcohol leading to a more homogeneous and relatively stable blend . Consequently, this type of blends has also been investigated extensively to comprehend the effect of different concentrations of the three components on the performance and exhaust emissions of the compression ignition engines.

Hence the objective of project is to incorporate Methanol and Waste cooking oil-Biodiesel with pure diesel in order to form blends and experiment the viability as alternative fuel..A comparative experimental study between the blends and pure diesel on the same engine at different loads at different engine parameters inorder to find pros and cons in using a blend of Diesel-Biodiesel-Methanol.For this the emission properties of these blends and also its effects in performance parameters are to investigated and compared with pure disel.

# Chapter 2

# LITERATURE SURVEY

**L-J Wang, R-Z Songet.al (2007) [2]** reviewed Combustion characteristics of diesel and dual fuel (methanol- diesel) for CI engine. Also, the cylinder pressure was sampled. Based on the data, the heat release rates of the dual-fuel engine were analysed. The effects of methanol mass fraction and pilot diesel injection timing on ignition were studied so as to understand the variation in ignition delay and the detailed combustion characteristics via change in the methanol mass fraction under different operating conditions.

Also, the basic principle of dual-fuel operation was reviewed. Methanol is delivered during the induction process (by port fuel injection in this study). It is premixed with air and forms homogeneous mixture in the cylinder. It will be ignited by pilot diesel, which is directly injected into the cylinder prior to the end of the compression stroke. Once auto ignition of the pilot diesel has occurred, the combustion of the premixed methanol and diesel and diffused combustion of diesel will take place simultaneously.If the A/F of the methanol is within flammability, the bulk of the surrounding methanol–air mixture will be burned in flame propagation. Therefore, methanol–diesel dual-fuel engine combustion has the combined combustion characteristics of CI engines and SI engines.

It was found that the faster heat release rate leads to a shorter combustion duration. The curve centre of the heat release rate tends to move towards TDC under high-load conditions, while it is postponed under low-load operations owing to the longer ignition delay. Thus, methanol–diesel dual-fuel operations are suitable for higher methanol mass fraction under high-load conditions. As a result,fuel economy will be improved. Also, it was found that with increase in methanol mass fraction, both CO and HC increase, but smoke and NOx can decrease simultaneously under all the operating conditions. The traditional NOx smoke trade-off phenomena disappear in dual-fuel engine operation.

**Dinesh Kumar Soni and Rajesh Gupta(2013) [5]** The present investigation deal with a two-stage strategy for methanol-diesel blend to achieve higher level of emission reduction to meet more stringent emission norms. In the first stage, an optimum blend of diesel methanol fuel has been determined using numerical simulation to give maximum possible NOx and soot reduction. In the next stage, numerical simulation has been performed by three different methods of emission reduction namely through variation of swirl ratio, variation in quantity of recirculation of exhaust gases in Exhaust Gas Recirculation (EGR) technique and finally by means of adding water in various proportions to the same optimum diesel methanol blended fuel to obtain further reduction of emission. The numerical simulation has been performed on a single cylinder Kirloskar diesel engine (model TV1) using commercially available CFD software AVL FIRE. Simulation starting with the optimum diesel–methanol blend as the base fuel, effects of swirl ratio; 1.0,1.3,1.6 and 2, percentage EGR varied between 10% and 20% and addition of water to the base fuel in the ratio of 5%, 10% and 15% by volume on emission are analyzed. Results indicate that water blend method tends to reduce NOx emission by 95% and soot by 14% with respect to emissions of base fuel. It was deduced that methanol proportion in the blending view of emissions reduction. As the percentage of methanol increases in diesel from 10% to 30%, significant reduction has achieved 65%, 68% and 56% in NO, CO and HC emission respectively with respect to diesel alone. Therefore, D+M30 blend may be considered as optimum blend in terms of emission reduction. Soot mass fraction may be noted to be an exception at this stage. The water addition method reduces NO emission up to 95%, which is lower than initial swirl method (2.5%) and EGR method (36%). This much amount of reduction in NO emission (95%) is achieved by using 15% water with D+M30 blend. The Soot mass fraction is reduced up to 14% in water addition method, whereas it increased up to 118% by using initial swirl method. It was found that, EGR method (20% EGR) gives same result of soot formation as D+M30 blend.To obtain an optimum fuel, diesel was blended with methanol in three different proportions: D+M10, D+M20 and D +M30 and simulation was carried out. The base fuel will then be chosen based on the predicted emission characteristics of three blends of diesel–methanol. Once the diesel–methanol blend which gives optimum values of emission is chosen, it can be used as the base fuel for next stage of investigation. In this stage, simulation will be conducted using three techniques of emission–reduction. The first method in which swirl-ratio is varied as 1, 1.3, 1.6 and 2 has the engine speed constant at 1500 rpm.

**Chao Chen, Anren Yaoet.al (2018)** [**3**] This review focused on understanding the particulate matter(PM) characteristics of diesel/methanol dual fuel modeat different loads, especially high loads. Therefore, the effect of start of injection (SOI) and intake temperature on PM under diesel/methanol dual fuel mode was studied at high loads. Meanwhile, the effect of SOI on PM was carried out at low and medium loads. In the current study,PM characteristics are primarily exhibited by the characteristics of soot and particulate number(PN). Finally, the correlation between soot and smoke opacity was explored on diesel/methanol dual fuel mode. On the basis of better understanding of those impacts, it was desired to provide some suggestions and guidelines on how to further reduce PM emissions with in the full operating range of the diesel/methanol dual fuel engine.

It was found from the study that at high loads, the effect of MSP on soot and PN emissions depends on intake temperatures. The high intake temperature induces the auto-ignition of methanol which increases soot and PN emissions.It reveals that the management of intake temperature is essential on diesel/methanol dual fuel mode.There is an applicable scope of MSP that can effectively reduce soot and PN emissions. The increase of MSP has a significant effect on the decrease of soot and PN emissions as MSP is larger than 20%. At low and medium loads, the effect of MSP on soot and PN emissions is dependent on the SOI. The effect of MSP on the decrease of PM enhances as SOI is away from the TDC. It means that delaying SOI at TDC can simultaneously decrease NOx and PM emissions on diesel/methanol dual fuel mode. The correlation between soot and smoke opacity is not found on diesel/methanol dual fuel mode. Smoke opacity is collectively influenced by elemental carbon, condensed HC and NO2 on diesel/methanol dual fuel mode.The addition of exhaust gas recirculation(EGR) or diesel oxidation catalyst (DOC) under diesel/methanol dual fuel mode results in the correlation between soot and smoke opacity. Smoke opacity is also mainly affected by elemental carbon because the usage of EGR and DOC significantly reduces HC and NO2 emissions on dual fuel mode The diesel methanol dual fuel (DMDF) technology has been used in diesel engines to reduce the nitrogen oxides (NOX) and particulate matter (PM) emissions in past years. A combination of a diesel oxidation catalyst (DOC) and a diesel particulate filter (DPF) is applied on DMDF engines to meet severer emission standards in this study.

**Sebastian Verhelst, James WG Turner(2019)** Transportation of people and goods largely relies on the use of fossil hydrocarbons, contributing to global warming and problems with local air quality. There are a number of alternatives to fossil fuels that can avoid a net carbon emission and can also decrease pollutant emissions. However, many have significant difficulty in competing with fossil fuels due to either limited availability, limited energy density, high cost, or a combination of these. Methanol (CH3OH) is one of these alternatives, which was demonstrated in large fleet trials during the 1980s and 1990s, and is currently again being introduced in various places and applications. It can be produced from fossil fuels, but also from biomass and from renewable energy sources in carbon capture and utilization schemes. It can be used in pure form or as a blend component, in internal combustion engines (ICEs) or in direct methanol fuel cells (DMFCs). These features added to the fact it is a liquid fuel, making it an efficient way of storing and distributing energy, make it stand out as one of the most attractive scalable alternatives. This review focuses on the use of methanol as a pure fuel or blend component for ICEs. First, we introduce methanol historically, briefly introduce the various methods for its production, and summarize health and safety of using methanol as a fuel. Then, we focus on its use as a fuel for ICEs. The current data on the physical and chemical properties relevant for ICEs are reviewed, highlighting the differences with fuels such as ethanol and gasoline. These are then related to the research reported on the behaviour of methanol and methanol blends in spark ignition and compression ignition engines. Many of the properties of methanol that are significantly different from those of for example gasoline (such as its high heat of vaporization) lead to advantages as well as challenges. Both are extensively discussed. Methanol's performance, in terms of power output, peak and part load efficiency, and emissions formation is summarized, for so-called flex-fuel engines as well as for dedicated engines. We also briefly touch upon engine hardware changes and material compatibility. Methanol fuel reforming using engine waste heat is discussed, as a potential route towards further increases in efficiency and decreases in emissions. Next to the experimental work, research efforts into modelling the behaviour of methanol as a fuel are also reviewed, including mixture formation, normal and abnormal combustion. Methanol's properties such as high latent heat, fast burning velocity, high knock-resistance and no carbon to-carbon bonds are shown to leverage engine technology developments such as increased compression ratios, downsizing and dilution; enabling much increased engine efficiencies. Finally, we point out the current gaps in knowledge to indicate which areas future research should be directed at.

# Chapter 3

# METHODOLOGY

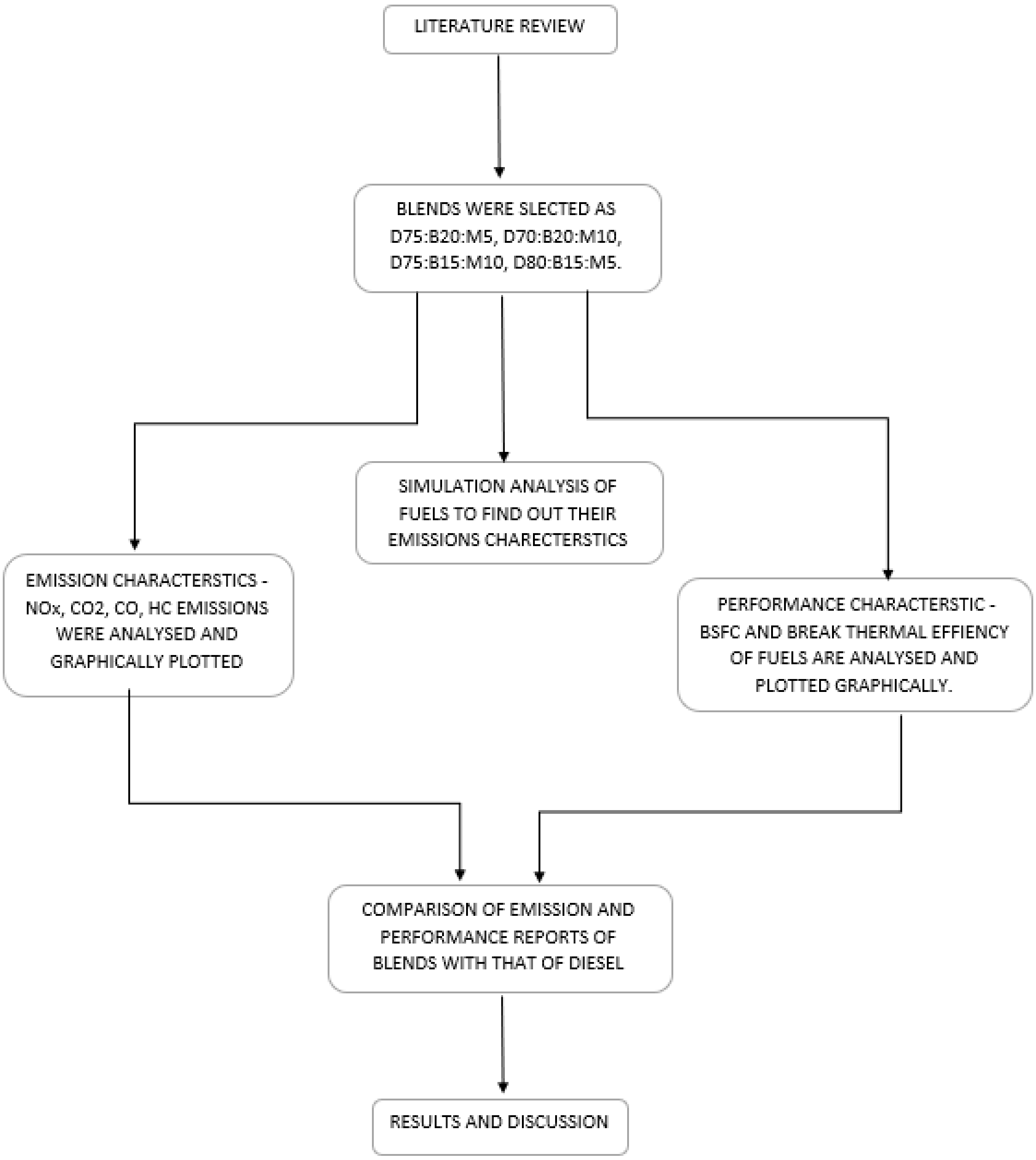


Figure 3.1: Methadology Adopted

# Chapter 4

# THEORETICAL ANALYSIS

## 4.1 SIMULATION PARAMETERS

The simulation was carried out using solver ANSYS FLUENT. The cylinder model was constructed in Ansys CAD considering the dimension of cylinder of the CRDI Test engine consisting of one nozzle for fuel and two nozzles for air inlet as shown below in Figure 1. The computational domain which is represented as 2D cross section of cylinder model is shown in the figure 4.1:

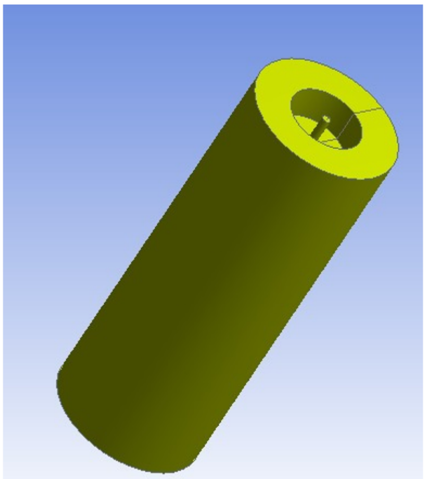

Figure 4.1: 3D cylinder model

The diameter of the cylinder model was taken equal to the bore diameter of the Test Engine, which is 87.5 mm. The Fuel nozzle diameter is 5mm and air nozzles are 20 mm each. Inlet conditions are used for the nozzles and at the right end, pressure boundary condition is used.

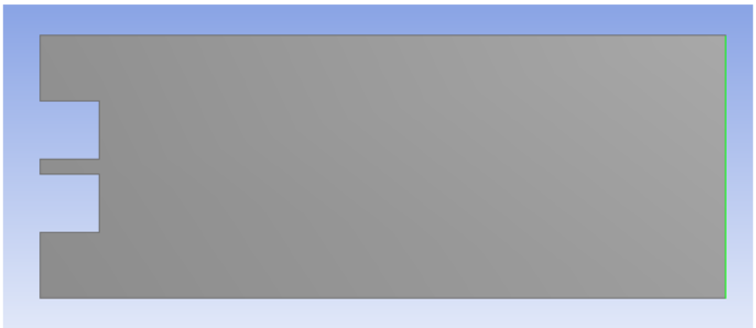

Figure 4.2: Computational domain for CFD analysis

**Meshing -** The mesh consisted of about 1 lakh elements. Figures 4.3 shows it

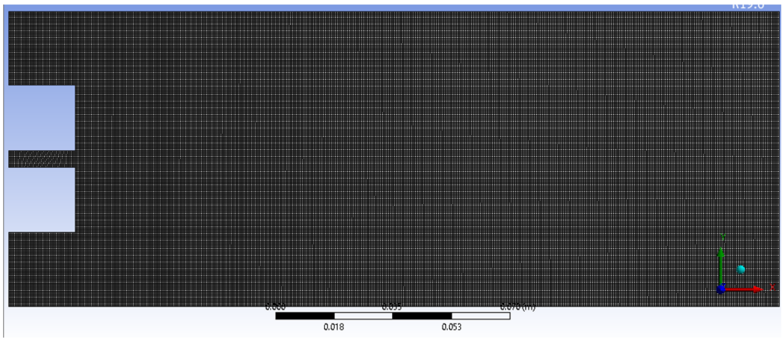

Figure 4.3: Computational domain in mesh

The mesh consists of mostly hexamesh type elements. The mesh was found to be of high quality based on metrics like skewness and orthogonality. The best skewness value is 0 and worst is 1. This mesh had average skewness of 0.00067. orthogonal quality of the mesh was 0.9999 ( best is 1 and worst close to 0)

For the simulation physics, navier stokes equation together with energy conservation equation was used. Since combustion would involve turbulence, k-epsilon model of turbulence was used. For modelling combustion, a non premixed combustion model was used. In this method, the fuel and air enters in separate streams.The approach is good because atomic elements are conserved in chemical reactions. In turn, the mixture fraction is a conserved scalar quantity, and therefore its governing transport equation does not have a source term. Combustion is simplified to a mixing problem. Air to fuel ratio of 14.5:1 was used.

## 4.2 SIMULATION RESULTS

### 4.2.1 MINERAL DIESEL

The mass fraction and Temperature fraction contour of diesel were obtained.

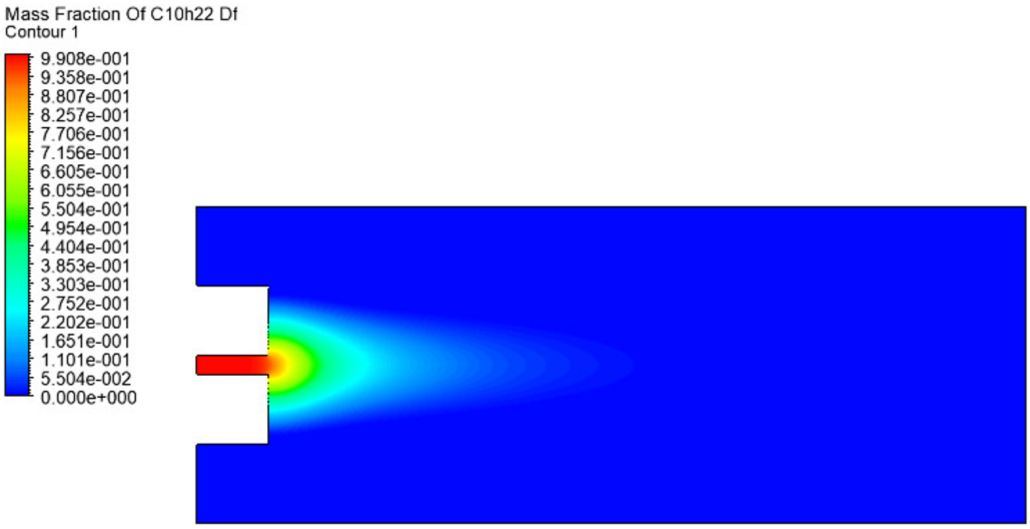


Figure 4.4: Mass fraction contour of diesel

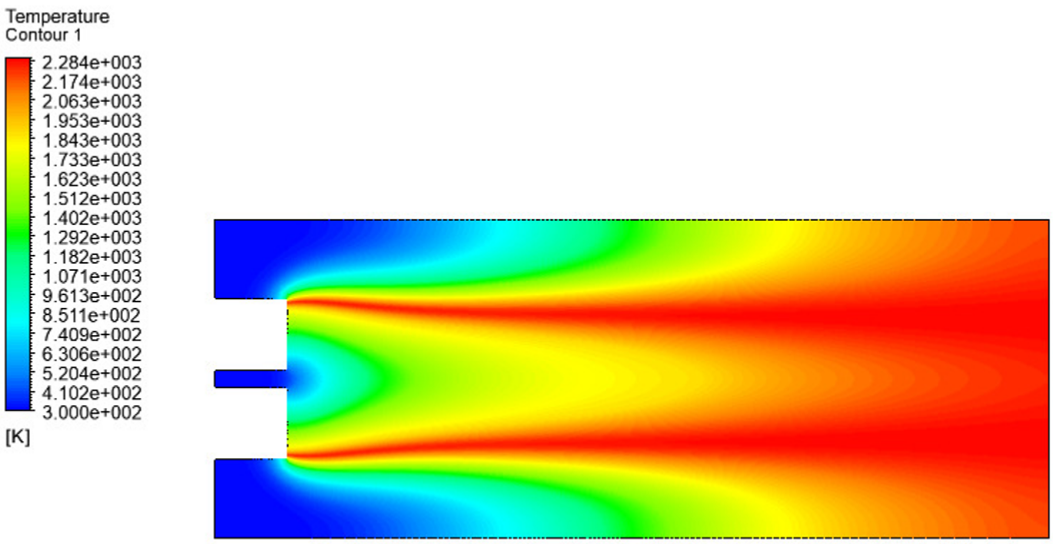


Figure 4.5: Temperature contour of diesel

### 4.2.2 D80:B15:M5

The mass fraction and temperature fraction contour of diesel were obtained for this blend

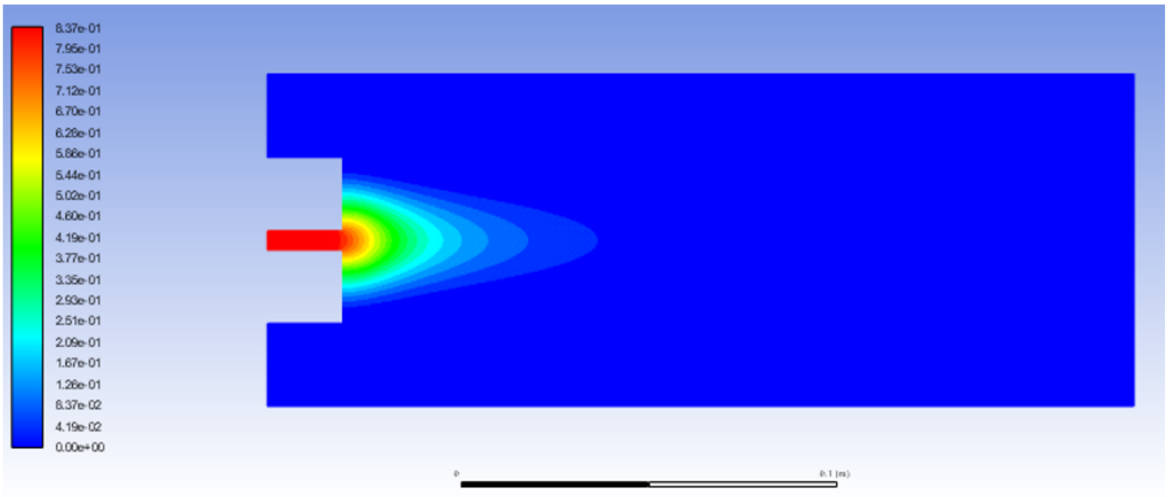


Figure 4.6: Mass fraction contour of B15M5

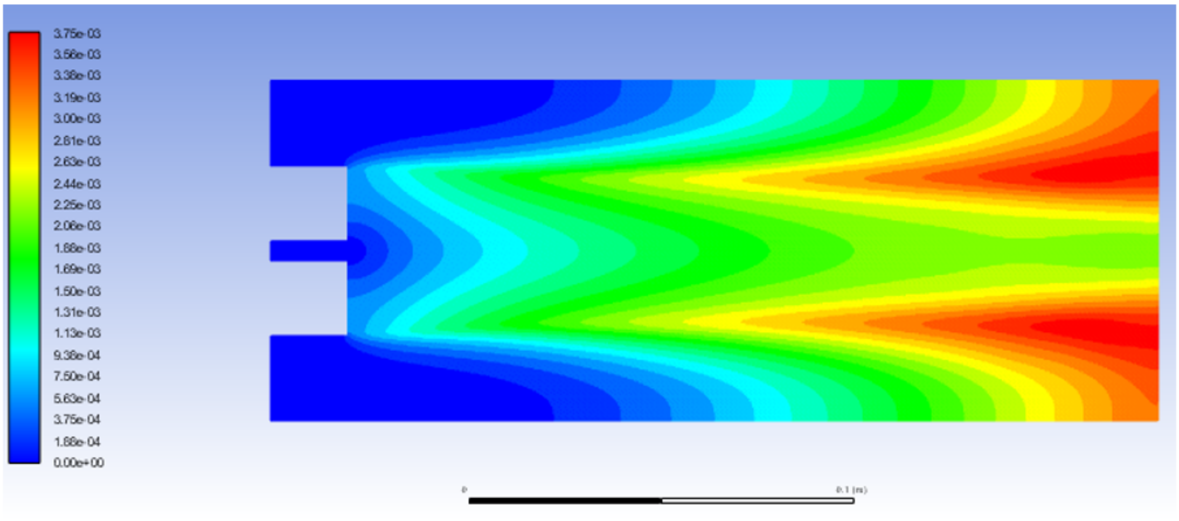


Figure 4.7: Temperature fraction contour of B15:M5

### 4.2.3 D75:B15:M10

The mass fraction and temperature fraction contour of diesel were obtained for this blend

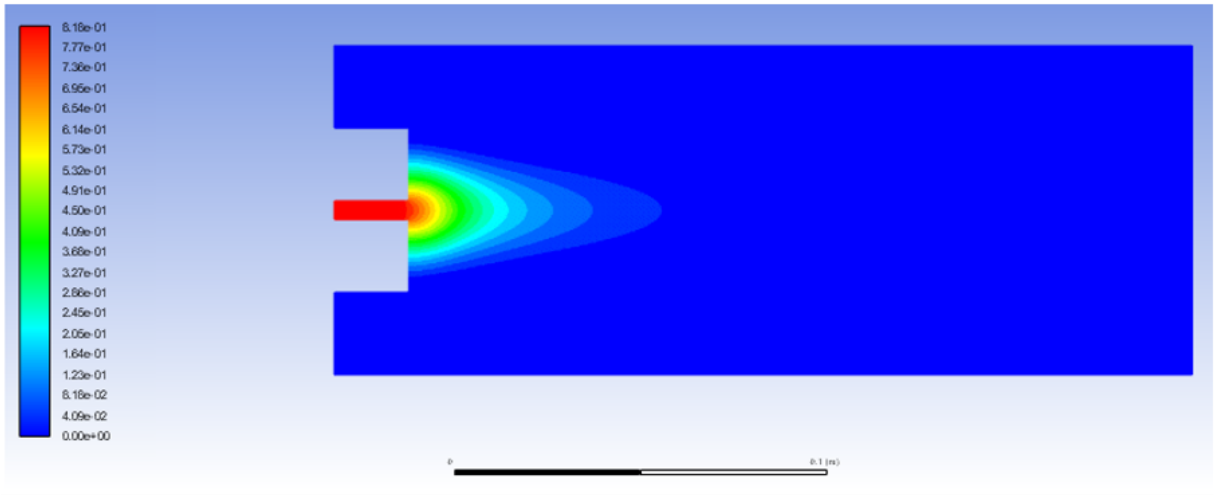


Figure 4.8: Mass fraction contour of B15M10

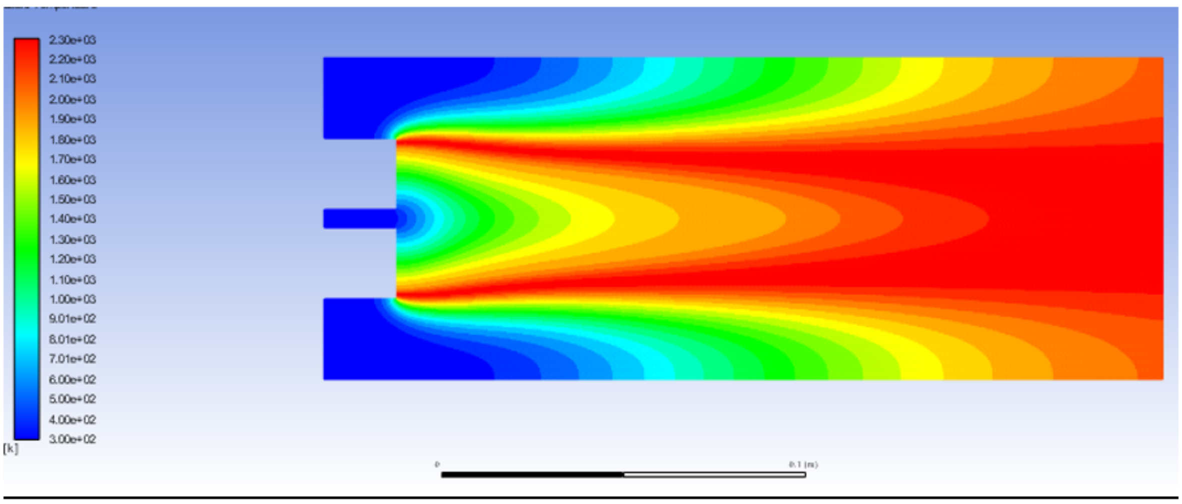


Figure 4.9: Temperature fraction contour of B15M10

## 4.2.4 D75:B20:M5

The mass fraction and temperature fraction contour of diesel were obtained for this blend

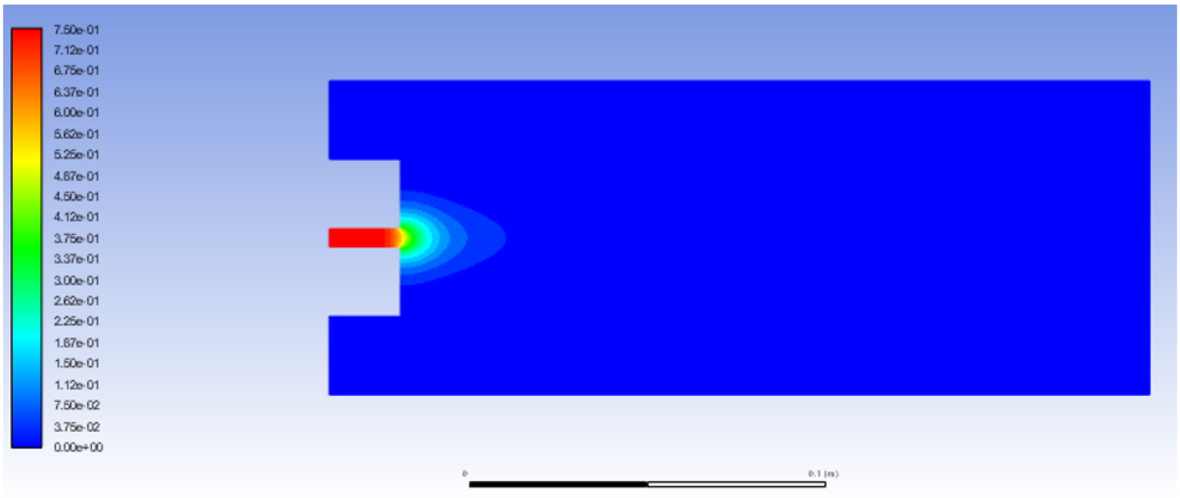


Figure 4.10: Mass fraction contour of B20M5

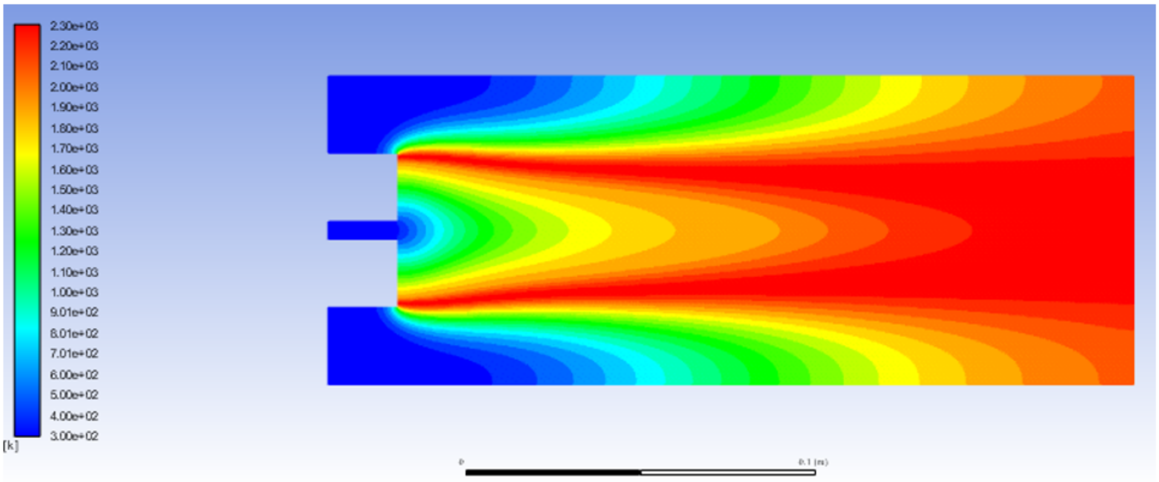


Figure 4.11: Temperature fraction contour of B20M5

## 4.2.5 D70:B20:M10

The mass fraction and temperature fraction contour of diesel were obtained for this blend

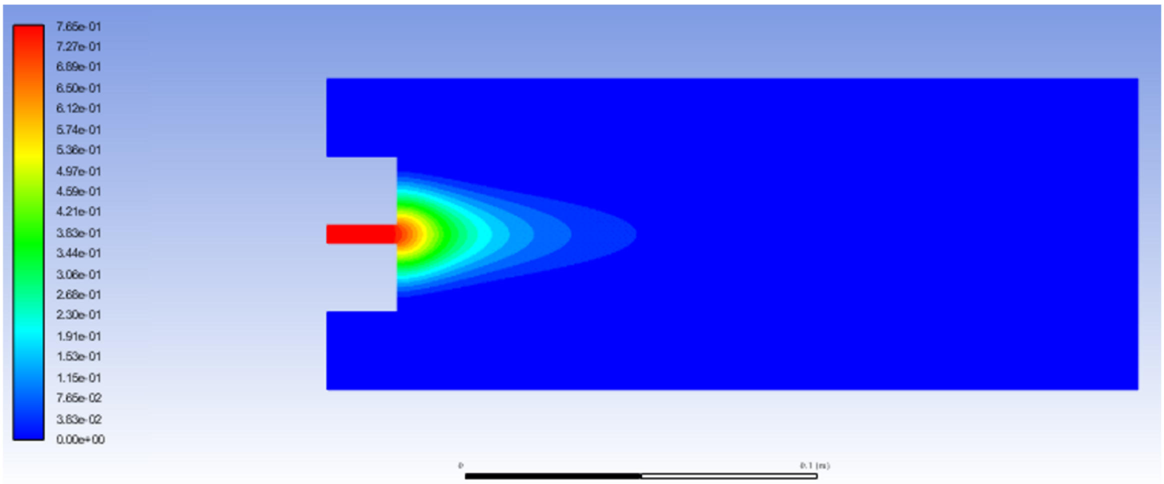


Figure 4.12: Mass fraction contour of B20M10

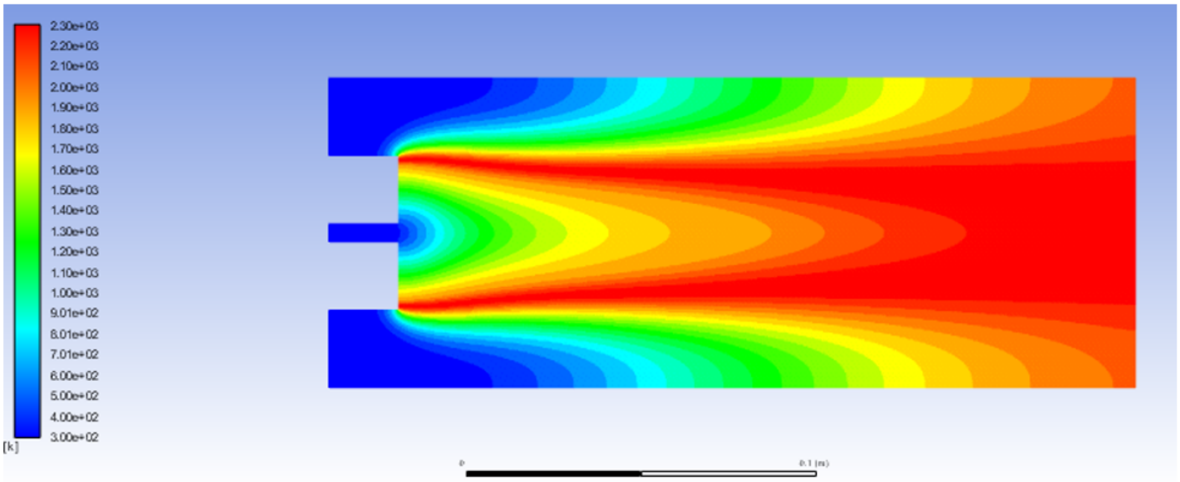


Figure 4.13: Temperature fraction contour of B20M10

CFD method was mainly used to numerically analyze the temperature of emission of fuels at outlet and the inner walls of cylinder. Also quantitative analysis of CO,CO2 and NOx was done and was compared. The summary of values obtained through CFD simulation is shown in the table.

| FUEL NAME | AREA Wt AVG OUTLET(K) | AREA Wt AVG WALLS(K) | AREA Wt AVG NOx | AREA Wt AVG CO2 | AREA Wt AVG CO |
|---|---|---|---|---|---|
| DIESEL | 2250.3391 | 1131.6887 | 0.0032006297 | 0.039549939 | 0.038314451 |
| B15M5 | 2175.7273 | 1031.3302 | 0.003096085 | 0.10055289 | 0.033209845 |
| B15M10 | 2170.1831 | 1028.2023 | 0.0030923209 | 0.10073379 | 0.0324747 |
| B20M5 | 2175.5332 | 1030.6769 | 0.0030993992 | 0.10431647 | 0.032897152 |
| B20M10 | 2169.5996 | 1027.4596 | 0.0030994352 | 0.10097644 | 0.032404736 |

Table 4.1: Fuel properties

**Outlet Temperature**

When the average outlet temperature of the emission of the blended fuels was compared to that of the diesel it was found that, B15M5 showed 3.31% decrease, B15M10 showed 3.56% decrease, B20M5 showed 3.324%, B20M10 showed 3.58% decrease.

**Temperature at walls**

When the temperature at inner walls of the blended fuels were compared to that of diesel, it was found that B15M5 showed 8.86% decrease, B15M10 showed 9.14% decrease, B20M5 showed 8.92% decrease, B20M10 showed 9.21% decrease.

**NOx emission**

When the Average rated NOx emission of blended fuels were compared to that of diesel fuel, it was seen that B15M5 showed 3.266% decrease, B15M10 showed 3.38% decrease, B20M5 showed 3.16% decrease, B20M10 showed 3.16% decrease.

**CO2 emission**

When the average rated CO2 emission of blended fuels were compared to that of diesel fuel, it was found out that B15M5 showed 154% increase, B15M10 showed 154.7% increase, B20M5 showed 163.75% increase, B20M10 showed 155.31% increase.

**CO emission**

When the average rated CO emission of blended fuels were compared to that of diesel it was seen that B15M5 showed 13.32% decrease, B15M10 showed 15.24% decrease, B20M5 showed 14.13% decrease and B20M10 showed 14.15% decrease.

# Chapter 5

# EXPERIMENTAL PROCEDURE

## 5.1 EXPERIMENTAL SETUP

The experiment was carried out in a setup consisting of single cylinder, four stroke, CRDI VCR engine connected to eddy current type dynamometer for loading.Compression ratio can be varied without stopping the engine and without altering the combustion chamber geometry by specially designed tilting cylinder block arrangement. In CRDI VCR fuel injection time, fuel injection angle, ignition angle can be programmed with open ECU at each operating point based on RPM and mass air pressure. It helps in optimizing engine performance throughout its operating range. Air temp, coolant temp, mass air pressure, temperature and trigger sensor are connected to Open ECU which control fuel flow, fuel injector and fuel pump. Set up is provided with necessary instruments for combustion pressure and crank-angle measurements. These signals are interfaced with computer for pressure crank-angle diagrams. Instruments are provided to interface airflow, fuel flow, temperatures and load measurements. The set up has stand-alone panel box consisting of air box, two fuel tanks for duel fuel test, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and hardware interface. Rotameters are provided for engine cooling water and calorimeter water flow measurement. A battery, starter and battery charger is provided for engine electric start arrangement. The setup enables study of VCR engine performance for brake power, indicated power, frictional power, BMEP, IMEP, brake thermal efficiency, indicated thermal efficiency, Mechanical efficiency, volumetric efficiency, specific fuel consumption, A/F ratio, heat balance and combustion analysis.Lab view based Engine Performance Analysis software package "Enginesoft" is provided for online engine performance evaluation. The readings were recorded as Excel file format. Nira i7r software package is provided for programming open ECU of the engine.For the EGR system of the engine, an SS pipeline was installed with a water cooling system to partially cool the recirculated gas before reaching the cylinder again. The rate of EGR was controlled by ECU for each run of the experiment. The Injection valves of the engine were built with solenoid driven sensors to control the Injection pressure value by ECU.Kubler Germany Crank angle sensor was used with resolution of 1 Deg and Speed 5500 RPM with TDC pulse to plot pressure-crank angle graph for the engine cycle. VPG Sensotronics strain gauge sensor (with load cell, range 0-50 Kg) was used to measure and record applied loads on the engine. Yokogawa Japan, DP transmitter with range 0-500 mm WC was used to record fuel flow rate.The data was recorded for 25 engine cycles so that the average result could be calculated. Radix made RTD type, made of PT100 and type K thermocouple was used to measure temperature of the engine cylinders as well as exhaust manifolds.ABUSTEK made, two wire type transmitters with input of "RTD PT100"with Range 0–100 Deg C,and Output 4–20 mA along with two wire type input thermocouple was used to transmit data from temperature sensor to ECU. AVL DIGAS 444N gas analyzer with detection limit 0.02 mg/m$\hat{3}$ and measurement range 10 FSN was used for emission analysis and quantitative measurement of CO, HC, CO2 and NOx emissions.Figure 1 shows the schematic diagram of the experimental setup.

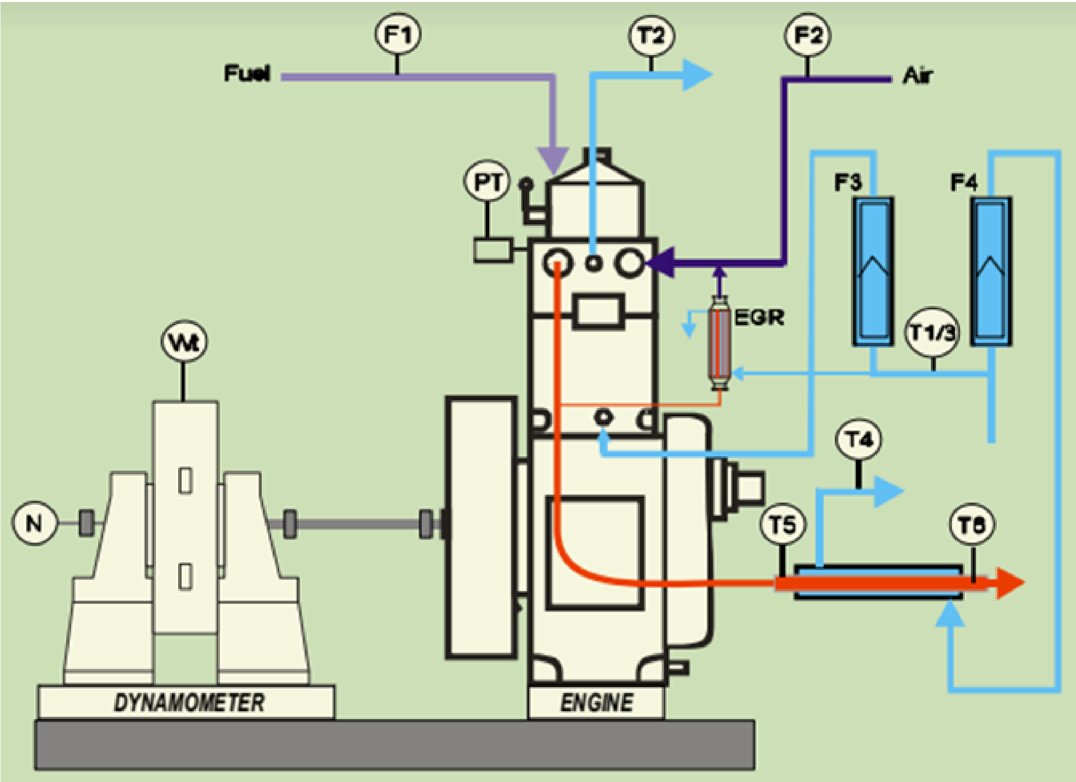


Figure 5.1: Schematic Diagram of Experimental Setup

### IMPORTANT ECU LINES

1. F1 – Fuel consumption line (kg/hr)
2. F2 – Air consumption line (kg/hr)
3. F4 – Calorimeter water flow (kg/hr)
4. T3 – Cylinder temperature line (K)
5. T3 – Calorimeter water inlet temp.(K)
6. T4 – Calorimeter water outlet temp.(K)
7. T5 – Exhaust gas to calorimeter inlet temp.(K)
8. T6 – Exhaust gas from Calorimeter outlet temp.(K)

| Engine Specification | Details |
|---|---|
| Product name | Kirloskar made VCR CRDI Computerized Test Engine |
| Engine type | 4 stroke, single cylinder |
| Cylinder bore x Piston stroke(mm) | 87.55 x 110 |
| Bore/Stroke ratio | 0.795 |
| Compression ratio taken | 18 |
| Maximum power | 3.5 kW |
| Speed | 1500 rpm |
| Cooling system type | Water cooled |

Table 5.1: Specifications of Engine

## 5.2 PROCEDURE

For the test the ordinary mineral diesel fuel was obtained.The bio-diesel used for the experiment was derived from waste cooking oil and was trans esterified to form waste cooking oil biodiesel.Mineral diesel, waste cooking oil biodiesel and methanol were blended at the lab itself into 4 different fuels with ratios D80:B15:M5, D75:B15:M10, D75:M20:M5 and D70:B20:M10. Table 2 shown below summarizes the fuel properties of diesel and all four blended fuels.Each blend fuel along with mineral diesel, which was taken as baseline fuel was tested at loads 0, 3, 6, 9, 12 kg (0%, 25%, 50%, 75%, and 100%) separately. Each load was tested with 4 Runs where first two runs were tested at 0% EGR rate and IOP was taken as 400 bar IOP for Run 1 and 600 bar IOP for Run 2. These two Runs were conducted to find BIOP in terms of cylinder pressure. For Run 3 and Run 4, BIOP was kept constant and EGR rate was taken as 6% for Run 3 and 12% for Run 4. Hence Run 1 means (400 bar, 0% EGR), Run 2 means (600 bar, 0% EGR), Run 3 means (BIOP, 6% EGR) and Run 4 means (BIOP and 12% EGR). Brake thermal efficiency and BSFC values were tabulated and graphs were plotted for performance analysis. For emission analysis, CO,CO2,NOx,HC values were tabulated and graphs were plotted against load at various runs.

# 5.3 THERMO-PHYSICAL PROPERTIES

| Sample/ Properties | Acid Value | Free Fatty Acid | Specific Gravity | Density | LCV Calorific Value | HCV Calorific Value | Flash Point | Fire Point | Kinematic Viscoisty @40°C | Dynamic Viscosity @40°C |
|---|---|---|---|---|---|---|---|---|---|---|
| Unit | $\frac{\text{mg of KOH}}{\text{gm of oil}}$ | % | -- | $\frac{kg}{m^3}$ | $\frac{Calorie}{gm-0_C}$ | $\frac{Calorie}{gm-0_C}$ | °C | °C | cSt | cP |
| ASTM Standard | D6751 | -- | D287 | D287 | D 4809 | D 4809 | D93-58T | D93-58T | D445 | D445 |
| StDl | 0.6 | 0.3 | 0.830 | 830 | 10,236 | 10822 | 53 | 56 | 2.09 | 1.73 |
| D80B15M5 | - | - | 0.834 | 834 | 9690 | 10276 | 76 | 85 | 3.30 | 2.75 |
| D75B15M10 | - | - | 0.832 | 832 | 9523 | 10110 | 75 | 83 | 3.23 | 2.70 |
| D75B20M5 | - | - | 0.836 | 836 | 9645 | 10231 | 83 | 93 | 3.48 | 2.92 |
| D70B20M10 | - | - | 0.834 | 834 | 9476 | 10062 | 82 | 90 | 3.42 | 2.86 |

Figure 5.2: Thermo-physical properties table

# Chapter 6

# RESULTS AND DISCUSSION

A series of tests were undertaken to investigate the emission and performance characteristics of diesel and biodiesel-methanol-diesel blends in a CRDI VCR, single cylinder engine with constant engine speed as 1500 rpm and five engine loads at different Exhaust Gas recirculation (EGR) and Injection pressure(IOP) values. Four runs were initiated for every fuel in which Run1 had IOP at 400 bars and EGR at 0%, Run2 had IOP at 600 bars and EGR at 0%, Run3 had IOP at 600 bar and EGR at 6% and Run 4 had IOP 600 and EGR 12%. The emission and performance characteristics for Diesel, B15M5, B15M10, B20M5 and B20M10 were found and these values were tabulated and graphically plotted.

## 6.1 EMISSIONS

### 6.1.1 Carbon dioxide emission

The Carbon dioxide emissions for all fuels were found out experimentally and the emission values were tabulated and graphically plotted. The carbon dioxide emissions for all fuels were found out at four different runs. Here Run1-IOP at 400 bar and EGR as 0%, Run2- IOP at 600 bar and EGR 0%, Run3- IOP at 600 bar and EGR as 6% and Run4- IOP at 600 bar and EGR as 12%. The emission results of every fuels at different runs and varying loads were found out.

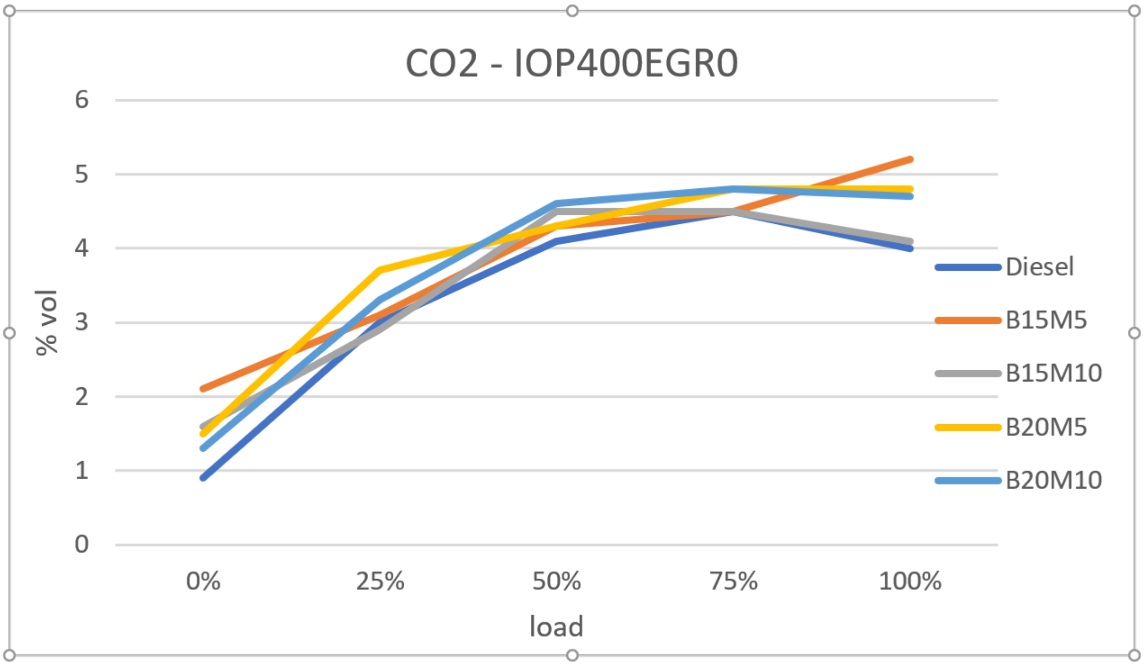


Figure 6.1: CO2 Emission at IOP 400 and EGR 0

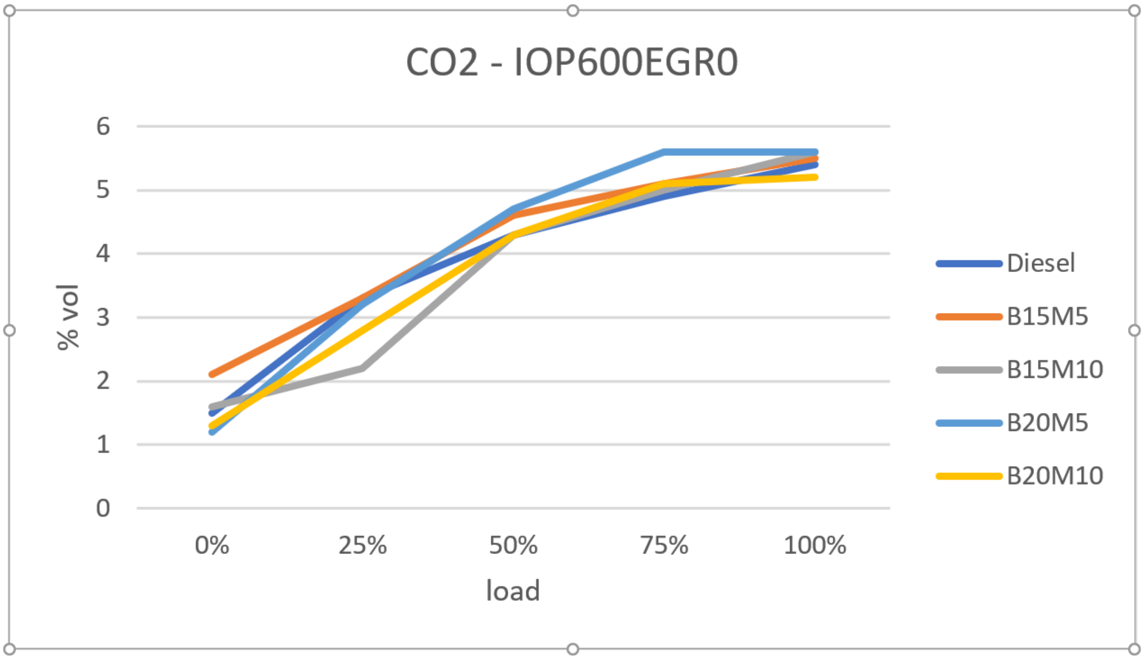


Figure 6.2: CO2 Emission at IOP 600 and EGR 0

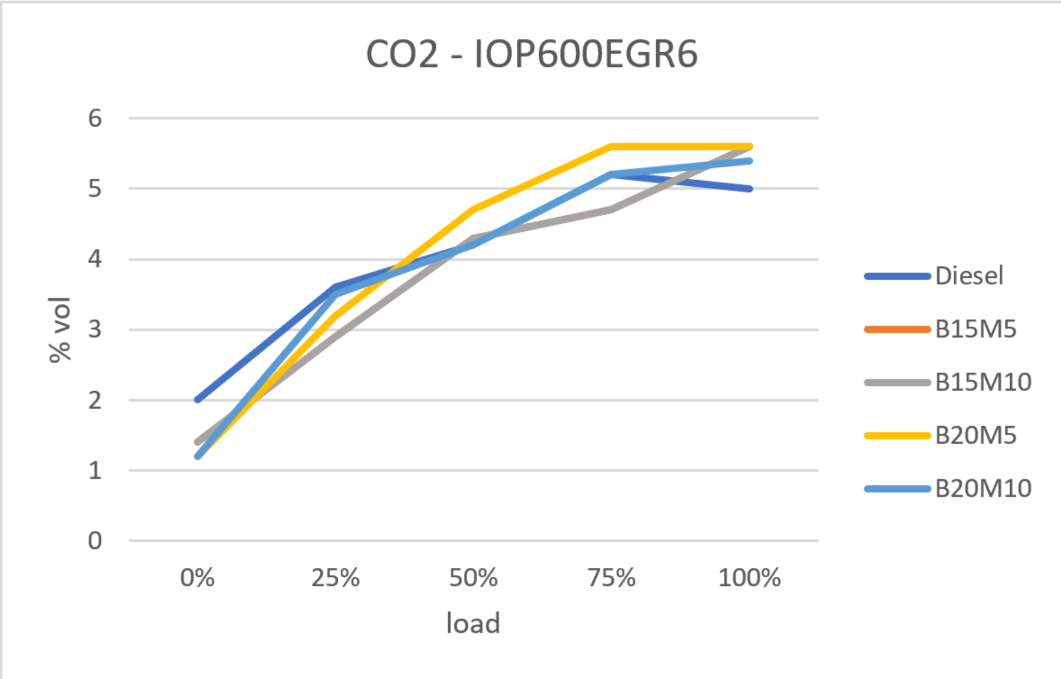


Figure 6.3: CO2 Emission at IOP 600 and EGR 6

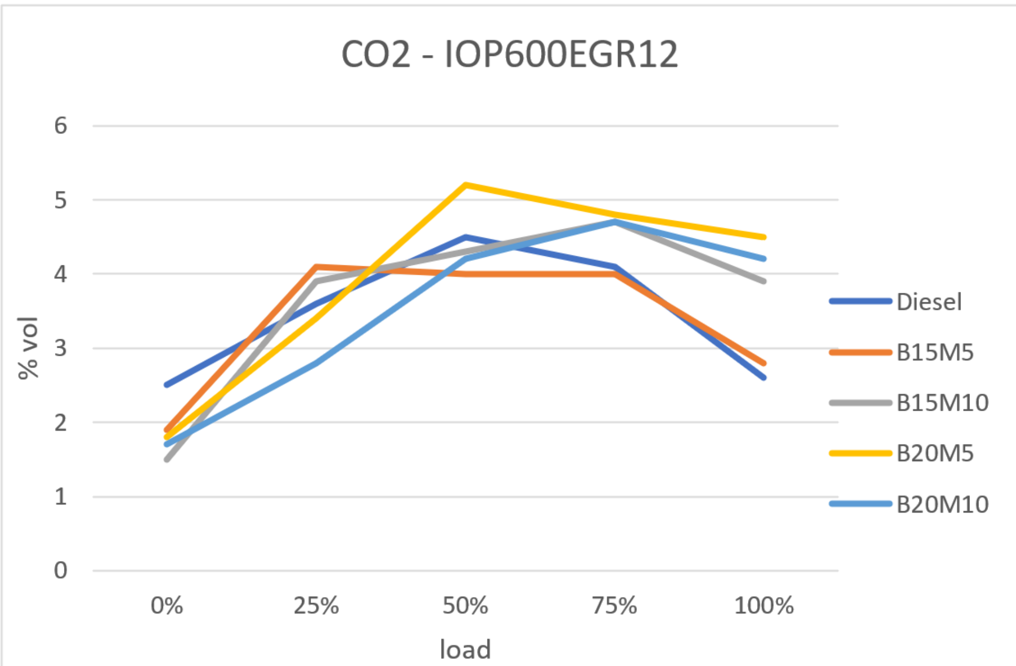


Figure 6.4: CO2 Emission at IOP 600 and EGR 12

An increase in carbon dioxide emission is seen when it moves from lower load to higher load, although this trend is not followed in case of Run4. Also it is seen that there is a nominal increase in CO2emission in the different blends when compared to that of mineral diesel. The Carbon dioxide emission of all fuels at different runs were compared at 75% load and the percentage deviation among the different blends to that of baseline fuel diesel were found out.

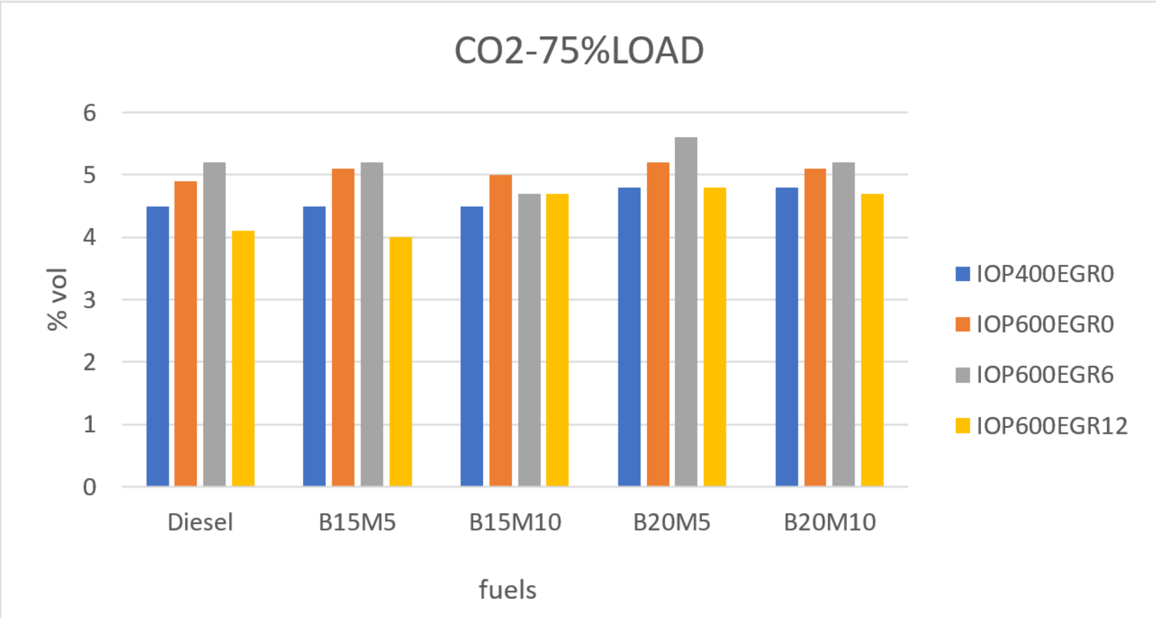


Figure 6.5: CO2 Emission of four runs at 75% load

From Carbon dioxide emission graph it was observed that the emissions in the blend fuels generally showed a slight increase when compared to mineral diesel. At 75% load Carbon dioxide emission in blends were compared with base line fuel ie, mineral diesel. It is seen that at Run1 both B15M5 and B15M10 showed no change in emission; but blends B20M5 and B20M10 showed 7.6% increase in Carbon dioxide emission. At Run 2 it is seen that B15M5 showed 4.08% increase, B15M10 showed 2.04% increase , B20M5 showed 6.1% increase and B20M10 showed 4.08% increase in carbon dioxide emission. At Run3 it is seen that both B15M5 and B20M10 showed no change but B15M10 showed 9.6% decrease and B20M5 showed 7.7% increase in carbon dioxide emissions. When comparing Run4 it was seen that B15M5 showed 2% decrease , B15M10 and B20M5 showed 14.6% increase and B15M5 showed 17.07% increase in Carbon dioxide emissions. In every fuel when the IOP value was increased from 400 to 600 bars keeping EGR at 0% it is seen that there is a significant increase in Carbon dioxide emission indicating improved internal combustion resulting in higher oxidation of carbon that forms more Carbon dioxide. In every fuel when the IOP value was kept at 600 bars and EGR value was increased from 6% to 12%, a decrease in carbon dioxide emission is seen. This is because when EGR value is increased there is a simultaneous decrease in oxygen content during combustion which results in incomplete burning of fuel hence reducing carbon dioxide content and increasing carbon monoxide content.

### 6.1.2 Carbon Monoxide

The Carbon monoxide emissions for all fuels were found out experimentally and the emission values were tabulated and graphically plotted. The carbon monoxide emissions for all fuels were found out at four different runs. Here Run1-IOP at 400 bar and EGR as 0%, Run2- IOP at 600 bar and EGR 0%, Run3- IOP at 600 bar and EGR as 6% and Run4- IOP at 600 bar and EGR as 12%.The emission results of every fuels at different runs and varying loads were found out.

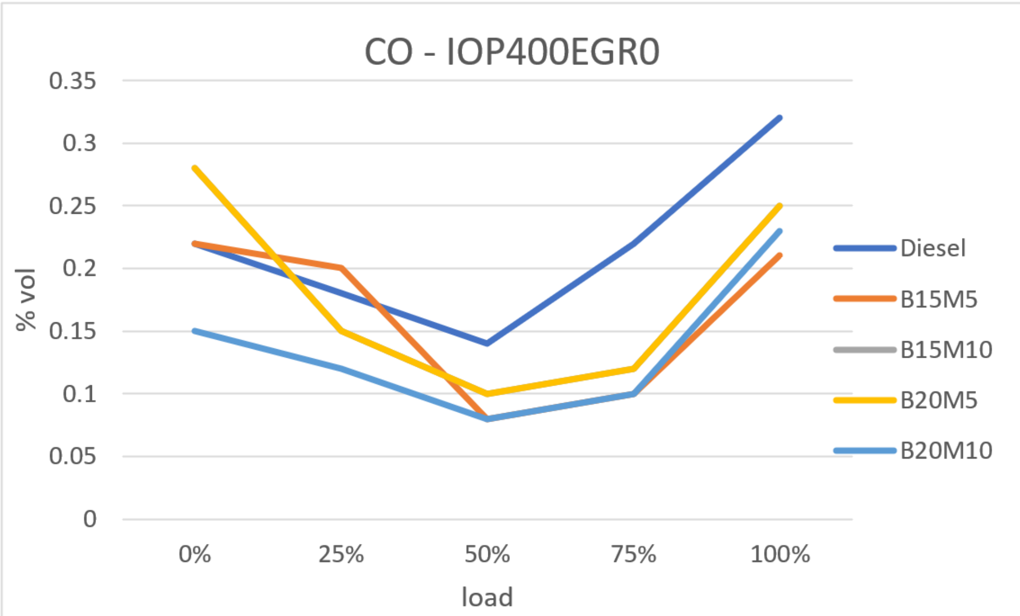


Figure 6.6: CO Emission at IOP 400 and EGR 0

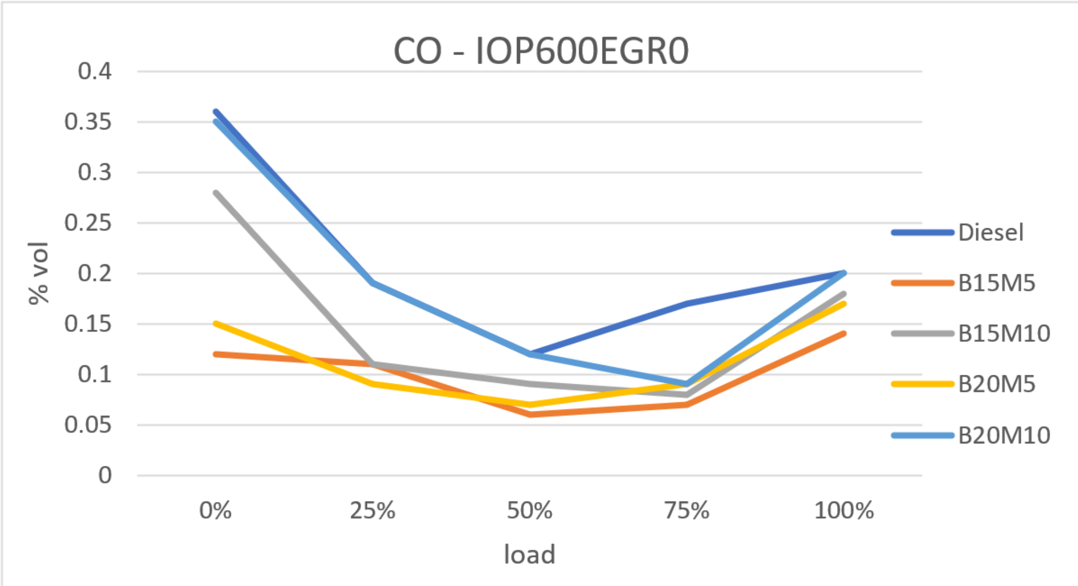


Figure 6.7: CO Emission at IOP 600 and EGR 0

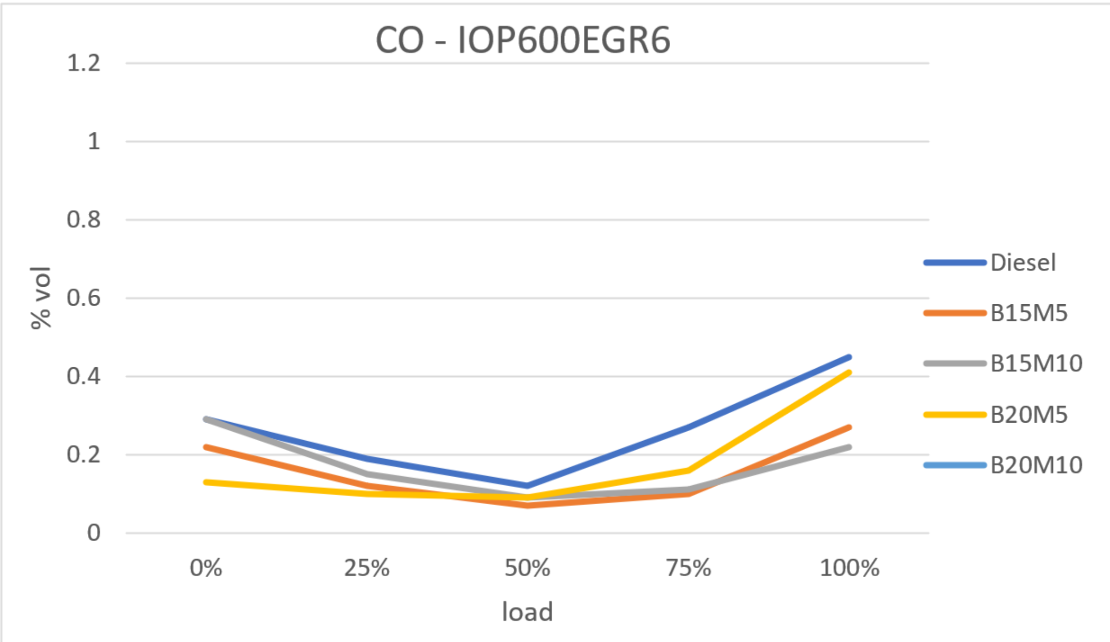


Figure 6.8: CO Emission at IOP 600 and EGR 6

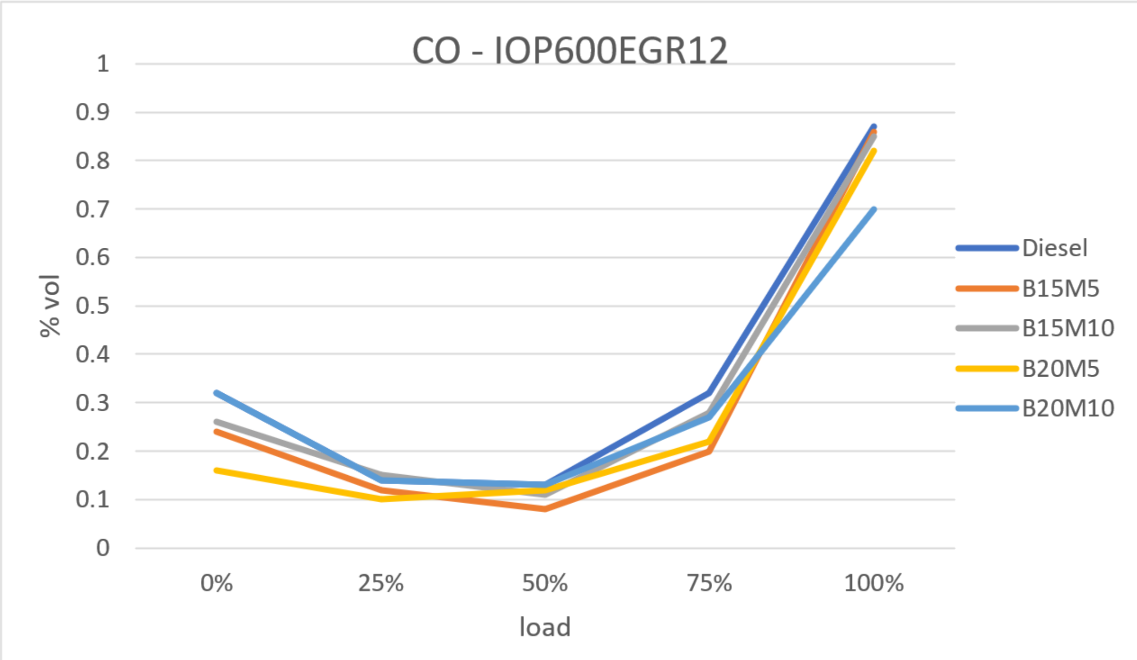


Figure 6.9: CO Emission at IOP 600 and EGR 12

At every Run it is visible from the graphs that the Carbon monoxide emission in blends has reduced when compared to baseline fuel that is mineral diesel. This is due to the simultaneous increase in carbon dioxide emission which is because of the complete combustion of fuel in case of blends. In case of Run 1 it is observed that there is a decrease in carbon monoxide emission in every fuel at lower loads, where as when the load increases a spike in carbon monoxide was observed. Similarly in case of Run2 there is decrease in carbon monoxide emission at lower loads and a small spike at higher loads. In Run3 the deviation in emission of carbon monoxide is almost similar at both higher and lower loads. In Run4 a big spike in carbon monoxide emission was observed at higher loads.

Carbon monoxide emissions for blends at 75% load were taken and they were compared to carbon monoxide emission of baseline fuel (diesel) at same load.

When the carbon monoxide graphs were observed it was seen that emissions for the blends were comparatively lesser than that of baseline fuel. For each fuel it was seen that maximum emission occurred when EGR was at 12% rate (Run 4) and least values were generally obtained when IOP was 600 bar and 0% EGR. Readings showed a significant influence of EGR on CO emission. When comparing Run 1 and Run 2 where IOP was increased from 400 bar to 600 bar the emissions generally showed a decrease in value.This is due to better internal combustion of the blend fuel at higher injection pressure due to lower droplet size of fuel resulting in higher vaporization of fuel. Hence higher oxidation of Carbon takes place resulting in lesser creation of CO. When comparing CO emissions in blends with that of diesel it was seen that in Run 1 of B15M5 shows 54.54% less CO emission than mineral diesel, Run1of B15M10 shows 45.45% less CO emission than that of mineral diesel, Run1 of B20M5 shows 54.54% less CO emission than that of mineral diesel and Run 1 of B20M5 shows 40.9% less CO emission than that of mineral diesel. When comparing CO emissions in blends with that of diesel

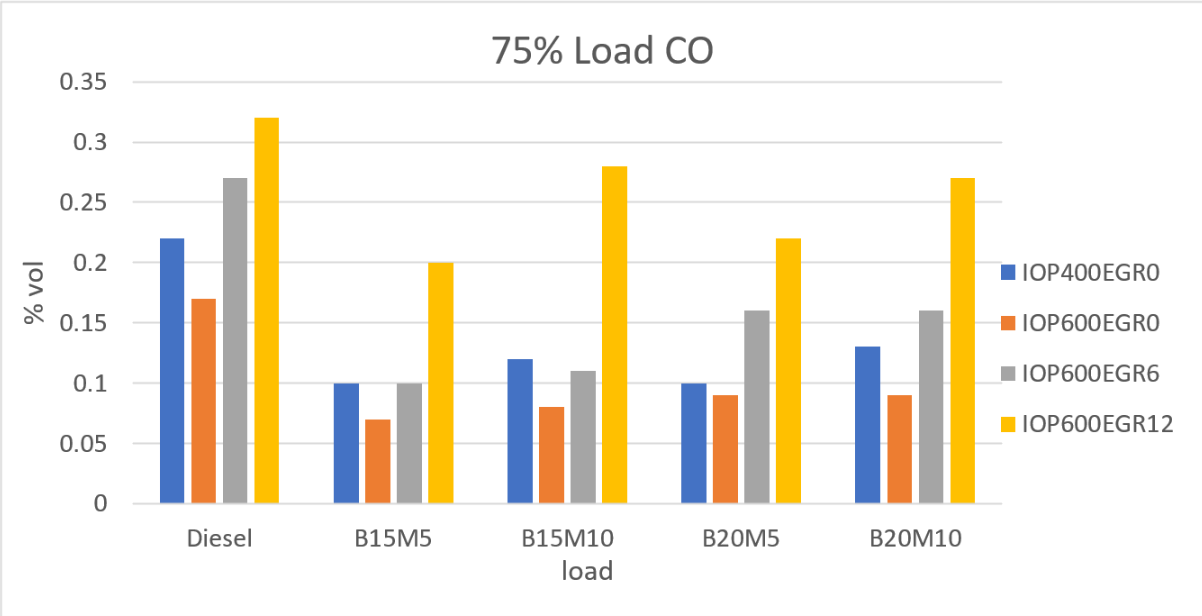


Figure 6.10: CO Emission of four runs at 75% load

it was seen that Run 2 of B15M5 shows 58.82% less CO emission than that of mineral diesel, Run2 B15M10 shows 52.94% less CO emission than that of mineral diesel, Run2 of B20M5 and B20M10 shows 47.05% less CO emission than that of mineral diesel. When comparing CO emissions in blends with that of diesel it was seen that Run 3 of B15M5 shows 62.96% less CO emission than that of mineral diesel, Run3 of B15M10 shows 59.25% less CO emission than that of mineral diesel, Run3of B20M5 and B20M10 shows 40.74% less emission of CO emission than that of mineral diesel. When comparing CO emissions in blends with that of diesel it was seen that Run 4 of B15M5 shows 37.5% less CO emission than that of mineral diesel, Run4 of B15M10 shows 12.5% less CO emission than that of mineral diesel, Run4 of B20M5 shows 31.25% less CO emission than that of mineral diesel and B20M10 shows 13.51% less CO emission than that of mineral diesel.

### 6.1.3 Nitrogen oxide emissions

The Nitrogen oxide emissions for all fuels were found out experimentally and the emission values were tabulated and graphically plotted. The Nitrogen oxide emissions for all fuels were found out at four different runs. Here Run1-IOP at 400 bar and EGR as 0%, Run2- IOP at 600 bar and EGR 0%, Run3- IOP at 600 bar and EGR as 6% and Run4- IOP at 600 bar and EGR as 12%. The emission results of every fuel at different runs and varying loads were found out.

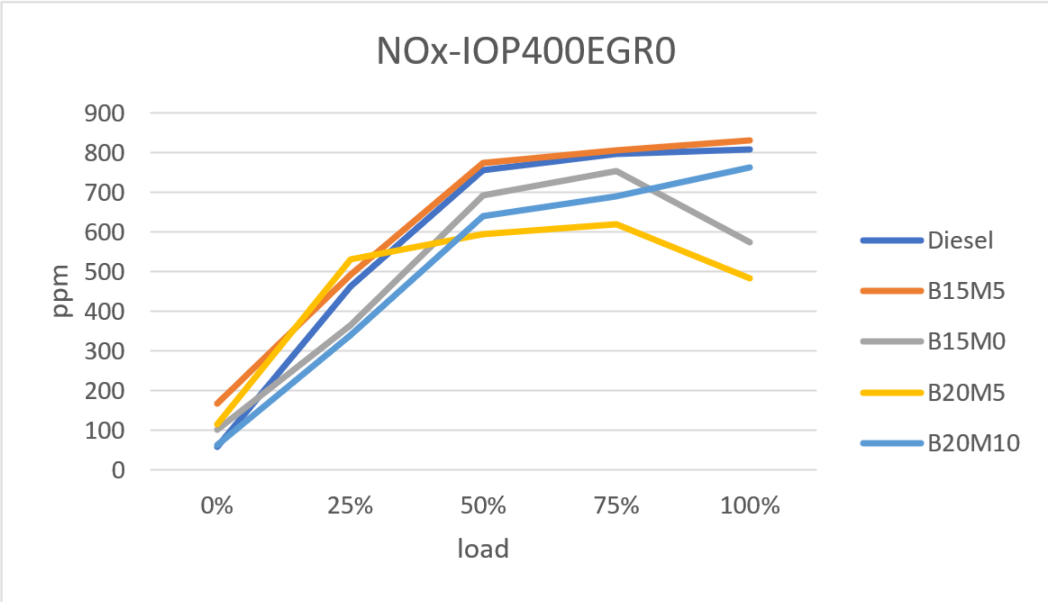


Figure 6.11: NOx Emissions at IOP 400 EGR 0

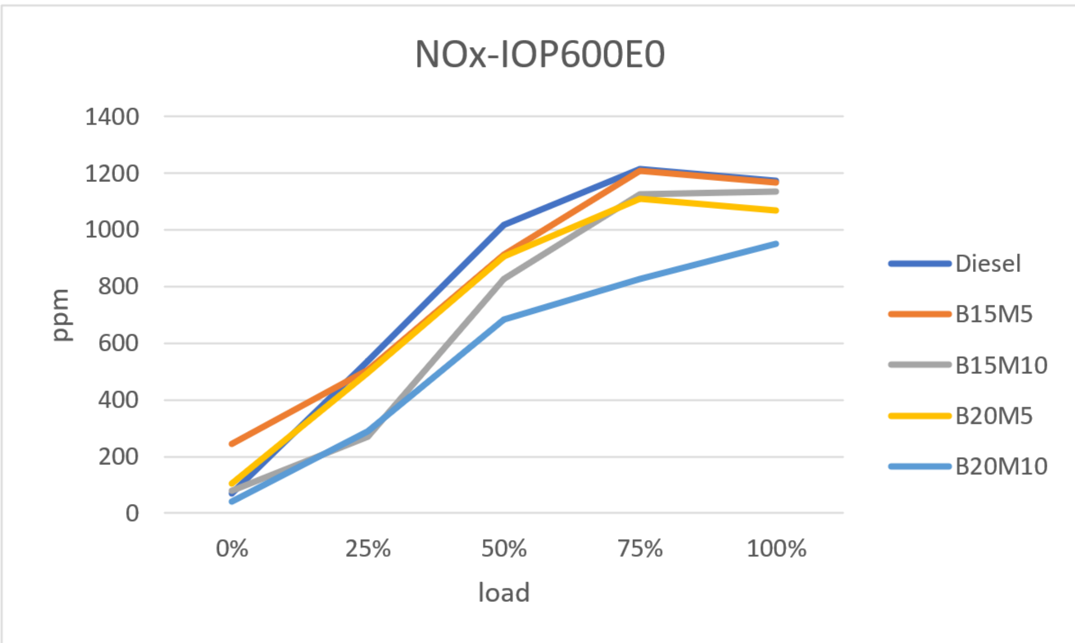


Figure 6.12: NOx Emissions at IOP 600 EGR 0

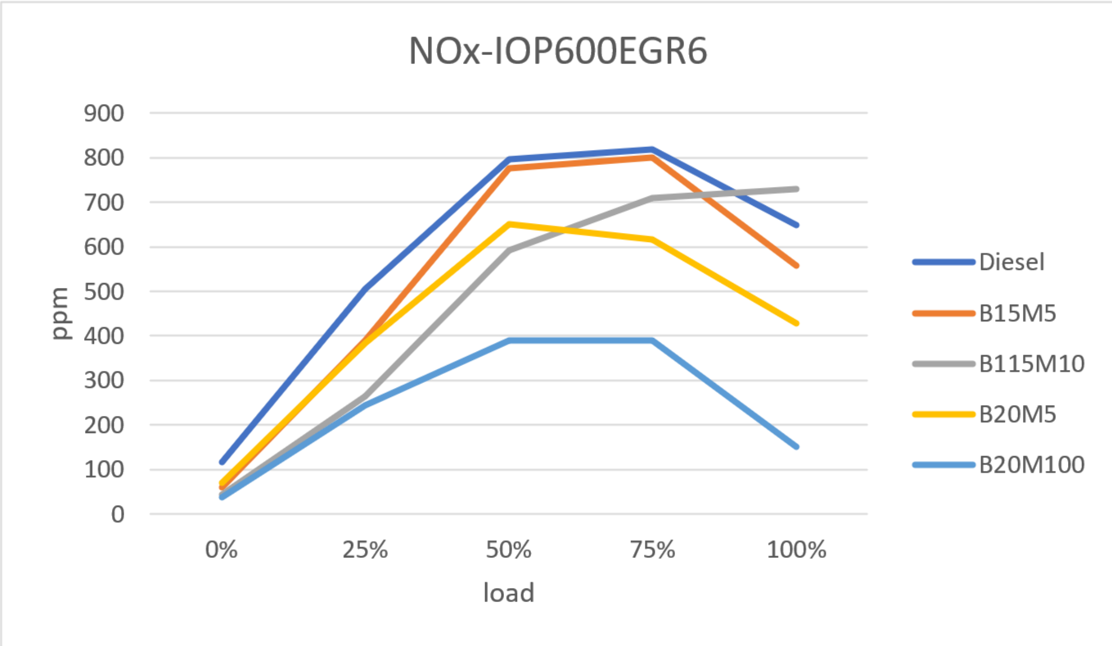


Figure 6.13: NOx Emissions at IOP 600 EGR 6

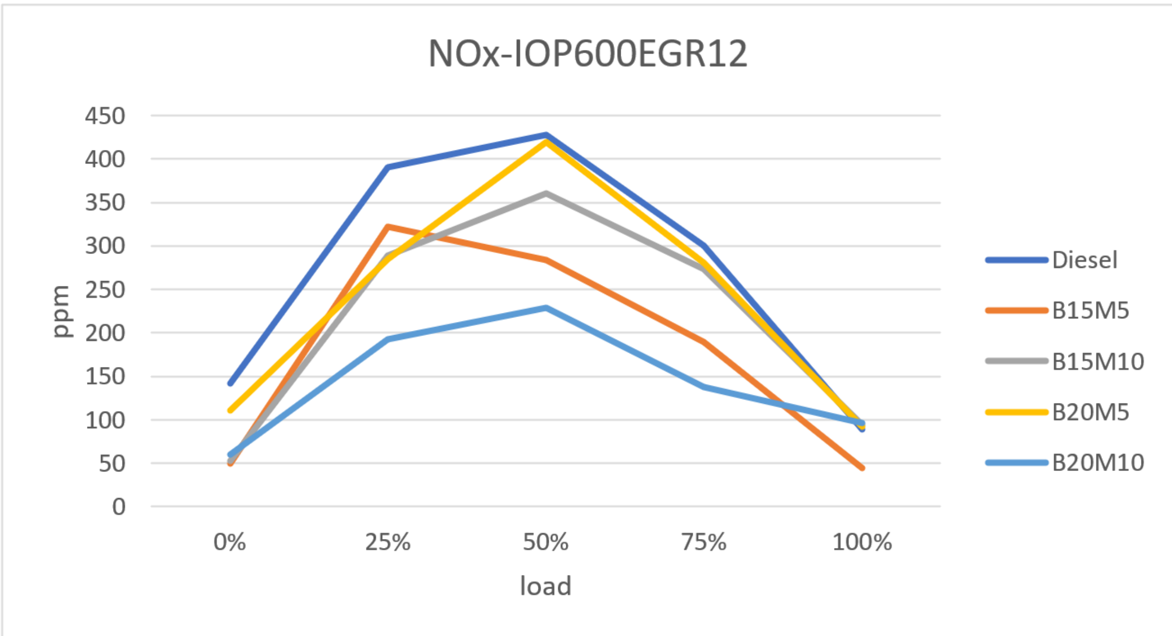


Figure 6.14: NOx Emissions at IOP 600 EGR 12

In case of all the fuels at Run 1 an increase in NOx emission is seen when we move from lower load to higher load. At Run 2 there is an increase in IOP value to 600 bars, which means more Nitrogen-oxygen interaction will take place due to increase in combustion rate there by increasing NOx emission. When we move onto Run3 it is seen that there is a significant drop in NOx emission of all fuels, which is due to less Nitrogen-Oxygen interaction due to decreased oxygen content while combustion takes place. Furthermore, at Run4 it is seen that there is NOx emission decreases sharply again when the EGR value is increased. NOx emissions of blends were compared to that of mineral diesel at 75% load and their relationships were found out.

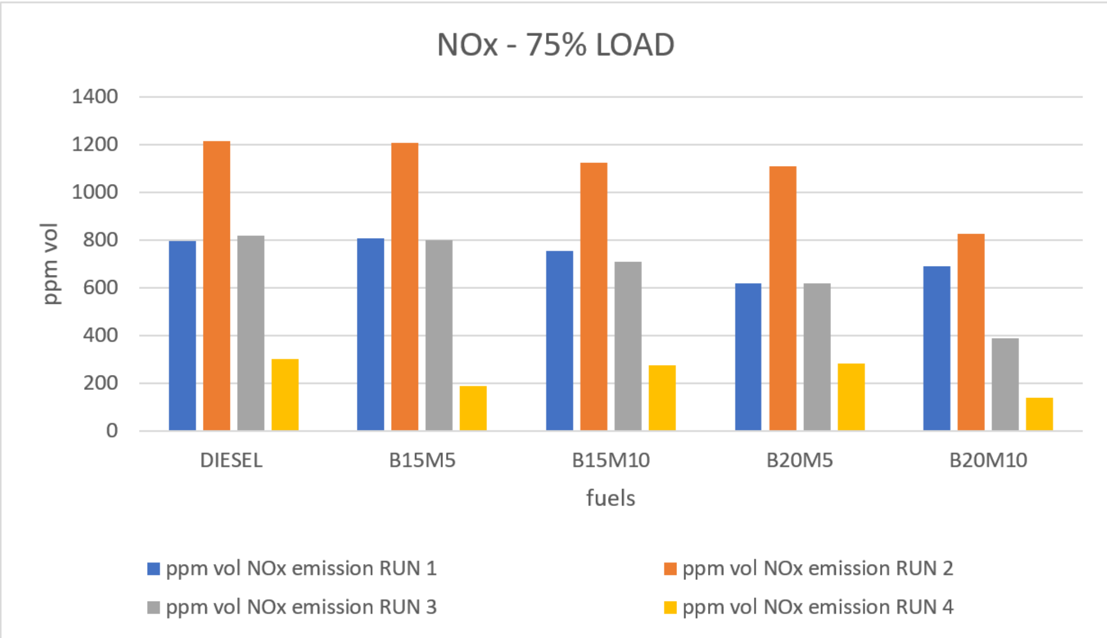


Figure 6.15: NOx Emissions of four runs at 75% load

Upon comparing the NOx emissions of blends with that of mineral diesel it is seen that the emissions in blends were significantly less. It was seen that all fuels show a significant increase in NOx emission when IOP was increased from 400 bars to 600 bars.Also, significant reduction of NOx emission was observed with the increase in EGR rate. Upon comparing all Runs of blend fuels with that of mineral diesel a decrease in NOx emission is observed. On comparing Run1 of all the fuels it is observed that B15M5 had no change in NOx emission, whereas B15M10 showed 5.6% lower emission, B20M5 showed 22.3% lower emission and B20M10 showed 13.35% lower NOX emission when compared to diesel. On comparing Run 2 of all blends with that of mineral diesel it is observed that B15M5 showed negligible difference, B15M10 showed 7.32% lower emission, B20M5 showed 8.64% lower emission, B20M10 showed 31.85% lower emission of N0xwhen compared to mineral diesel. On comparing Run 3 of all blends with that of mineral diesel, it is observed that B15M5 shows 2.3% lower emission, B15M10 shows 13.30% lower emission, B20M5 shows 24.66% lower and B20M10 shows 52.99% lower NOx emission when compared emissions in mineral diesel. On comparing Run 4 of all blends with that of mineral diesel it is observed that B15M5 shows 36.66% lower emission, B15M10 shows 8.66% lower emission, B20M5 shows 0.355% lower emission and B20M10 shows 47.33% lower NOx emission when compared to mineral diesel.

### 6.1.4 Hydrocarbon emissions

The hydrocarbon emissions for all fuels were found out experimentally and the emission values were tabulated and graphically plotted. The hydrocarbon emissions for all fuels were found out at four different runs. Here Run1 had IOP at 400 bar and EGR as 0%, Run2 had IOP at 600 bar and EGR 0%, Run3 had IOP at 600 bar and EGR as 6% and Run4 had IOP at 600 bar and EGR as 12%. The emission results of every fuel at different runs and varying loads were found out.

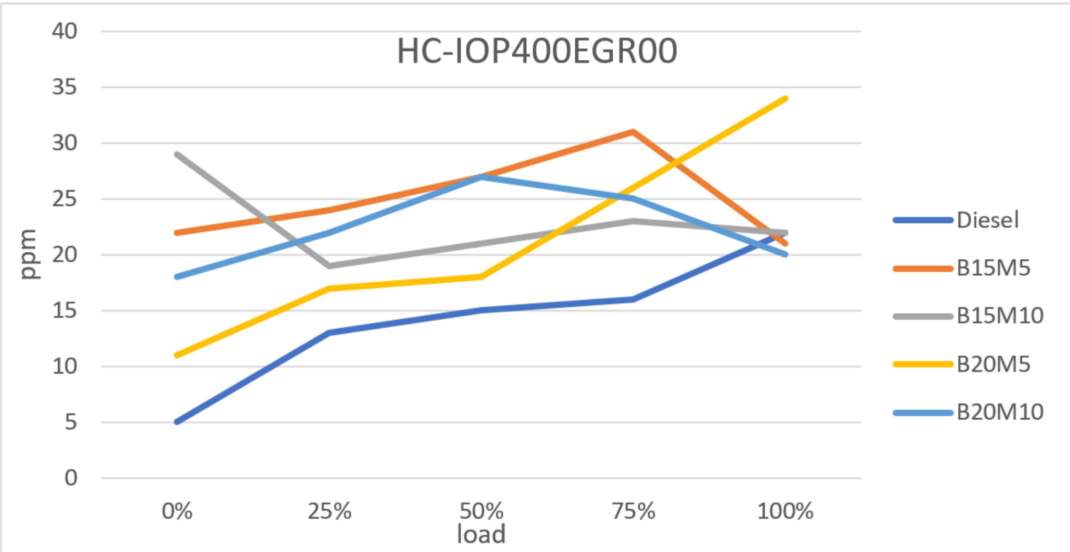


Figure 6.16: HC Emission at IOP 400 EGR 0

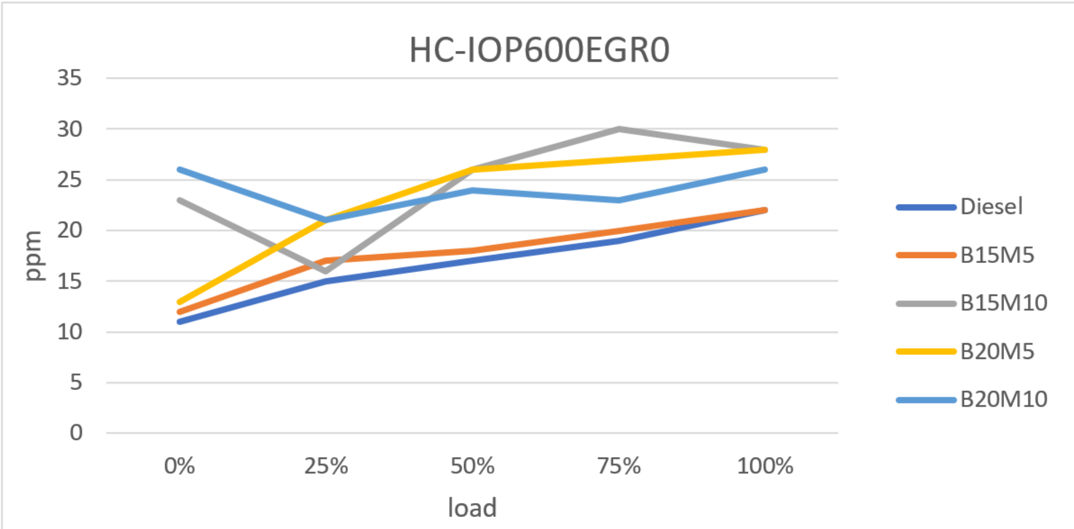


Figure 6.17: HC Emission at IOP 600 EGR 0

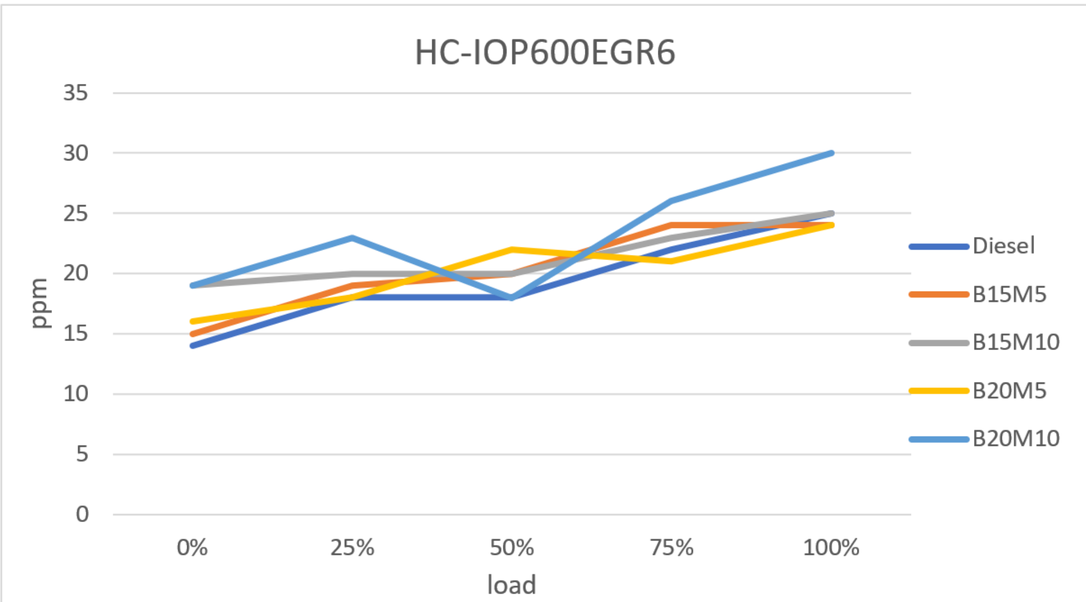


Figure 6.18: HC Emission at IOP 600 EGR 6

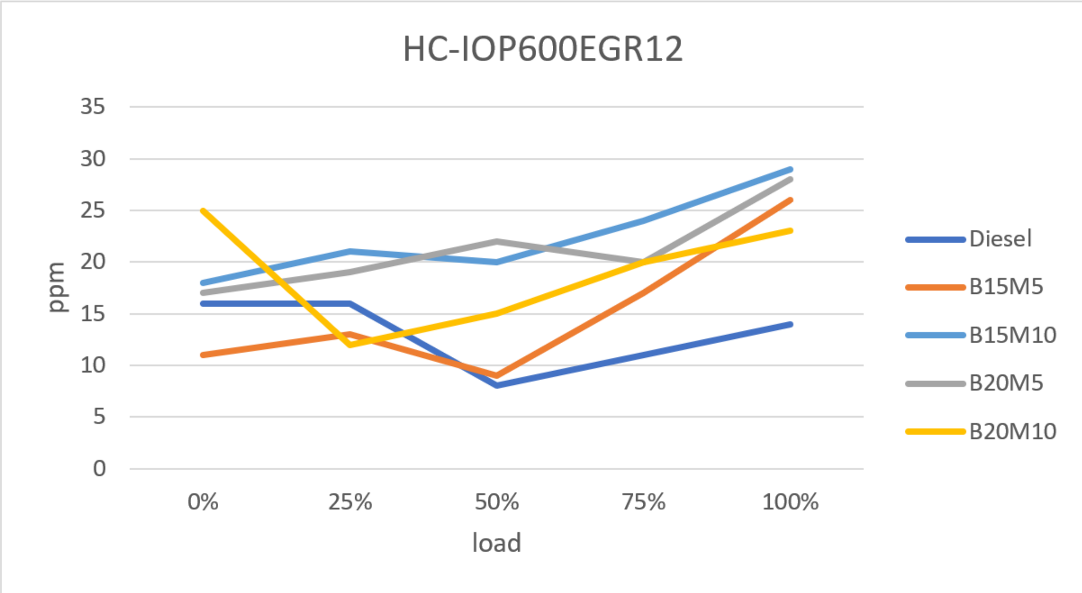


Figure 6.19: HC Emission at IOP 600 EGR 12

From the graphs of HC emission in all the fuel that were run at different IOP and EGR values, an increasing trend in HC emission was seen in the case of blends when compared to mineral diesel. The increase in HC emission in blends when compared to diesel could be explained by the negative influence of alcohol cooling effect, that is a part of the energy was lost due to the higher latent heat of evaporation. With decrease of the combustion temperature in the cylinder the concentration of HC raised.In all the fuels hydrocarbon emission did not show any drastic difference at different loads.

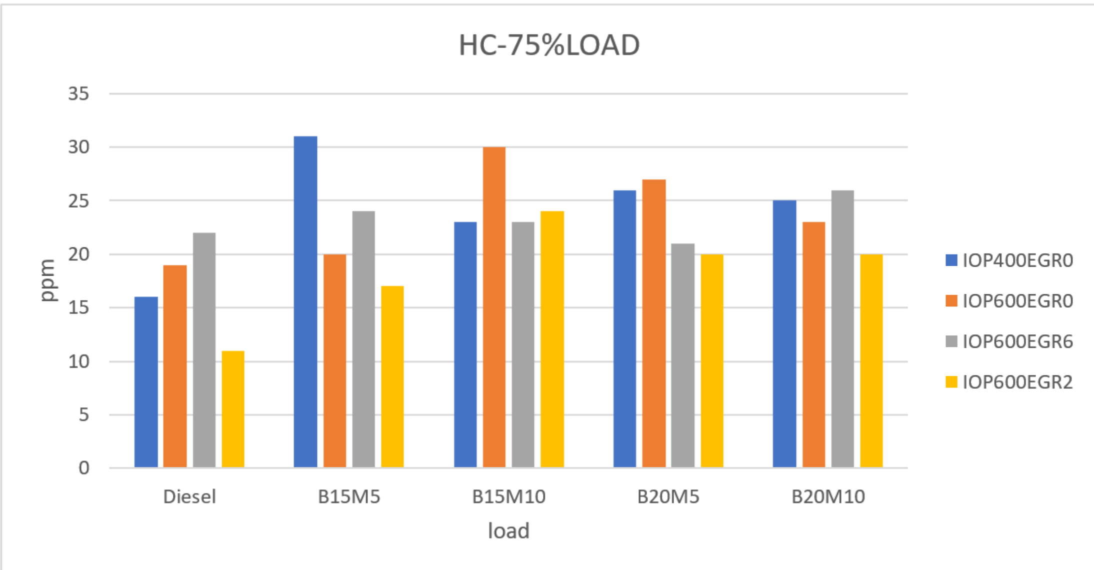


Figure 6.20: HC Emission of four runs at 75% load

From the HC emission comparison at 75% load it is seen that all runs have seen a significant increase in emission in case of blends when compared to mineral diesel.The increase in HC emission in blends when compared to diesel could be explained by the negative influence of alcohol cooling effect, that is a part of the energy was lost due to the higher latent heat of evaporation. With decrease of the combustion temperature in the cylinder the concentration of HC raised. At 75% load when Run1 of blends were compared with mineral diesel, B15M5 showed 93.75% increase, B15M10 showed 43.75% increase, B20M5 showed 62.5% increase, B20M10 showed 56.25% increase. At Run 2, B15M5 showed 5.26% increase, B15M10 showed 57.89% increase, B20M5 showed 42.1% increase, B20M10 showed 21.05% increase. At Run 3, B15M5 showed 9.09% increase, B15M5 showed 4.5% increase, B20M5 showed 4.5% decrease, B20M10 showed 18.18% increase. At run 4, B15M5 showed 54.54% increase, B15M10 showed 118% increase, B20M5 and B20M10 both showed 81.81% increase in Hydrocarbon emission.

## 6.2 PERFORMANCE PARAMETERS

### 6.2.1 Brake Thermal Efficiency

Brake thermal efficiency is the ratio of brake power to energy of the fuel. The brake thermal efficiency of the all the fuels were experimentally found out at different loads and the results were plotted in a graph.

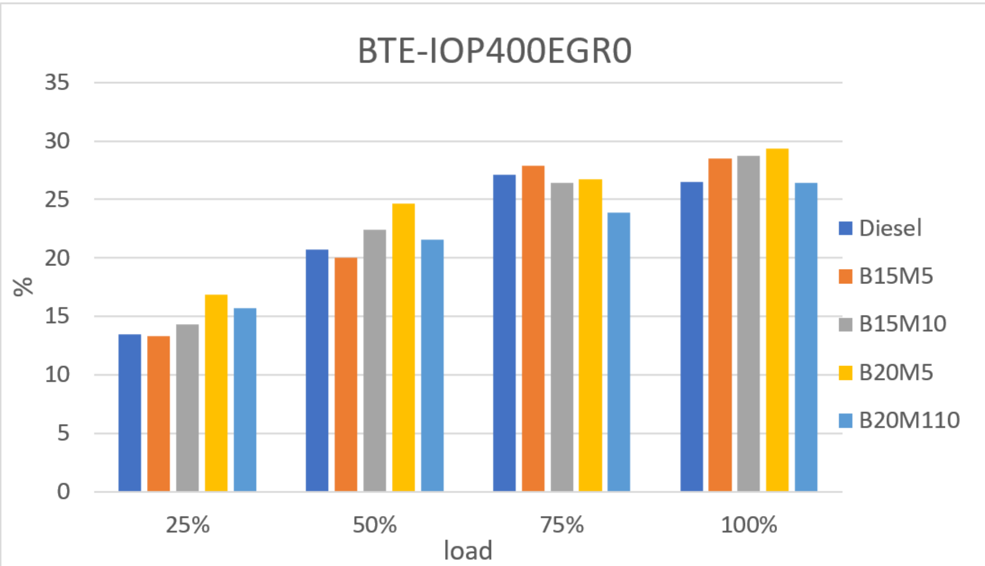


Figure 6.21: Brake Thermal Efficiency at IOP 400 EGR 0

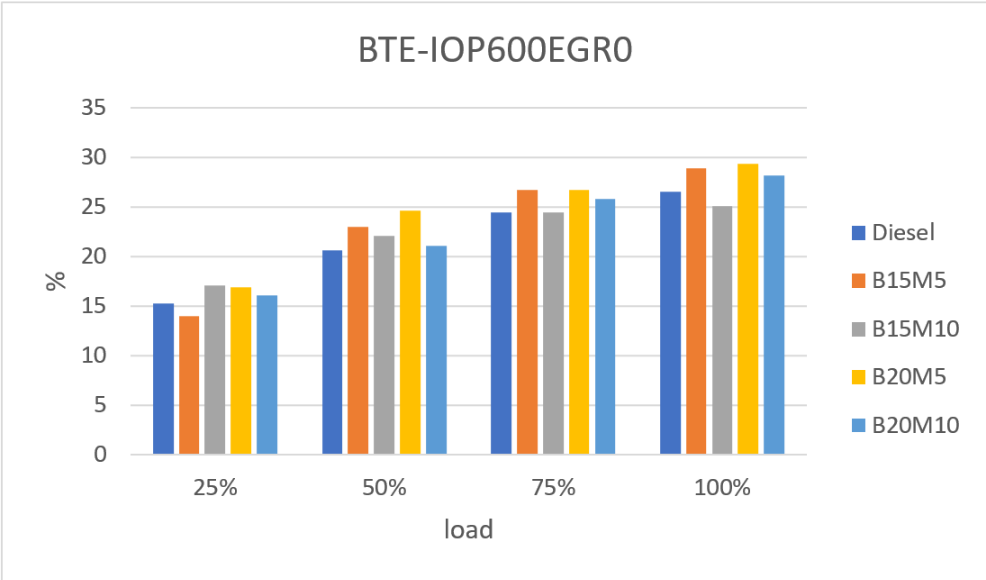


Figure 6.22: Brake Thermal Efficiency at IOP 600 EGR 0

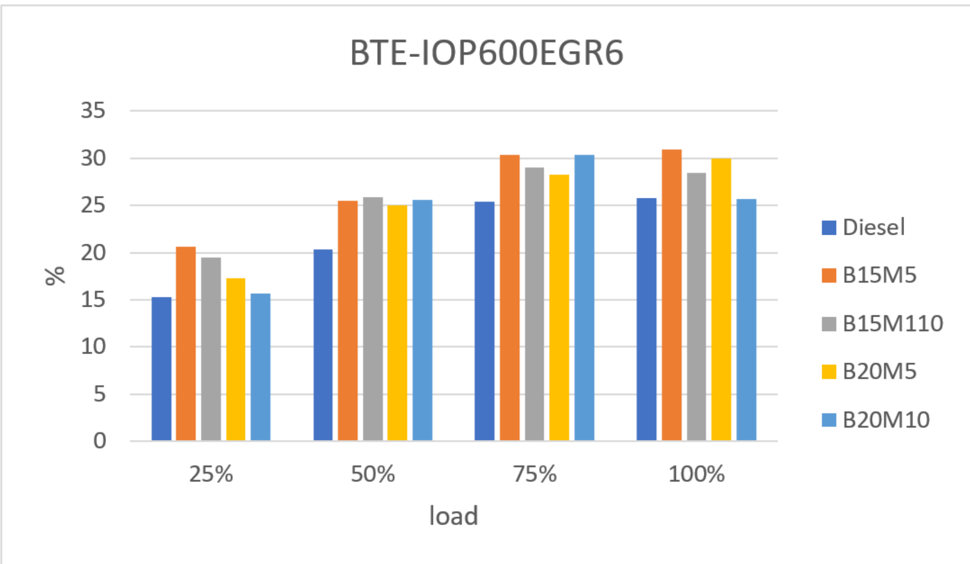


Figure 6.23: Brake Thermal Efficiency at IOP 600 EGR 6

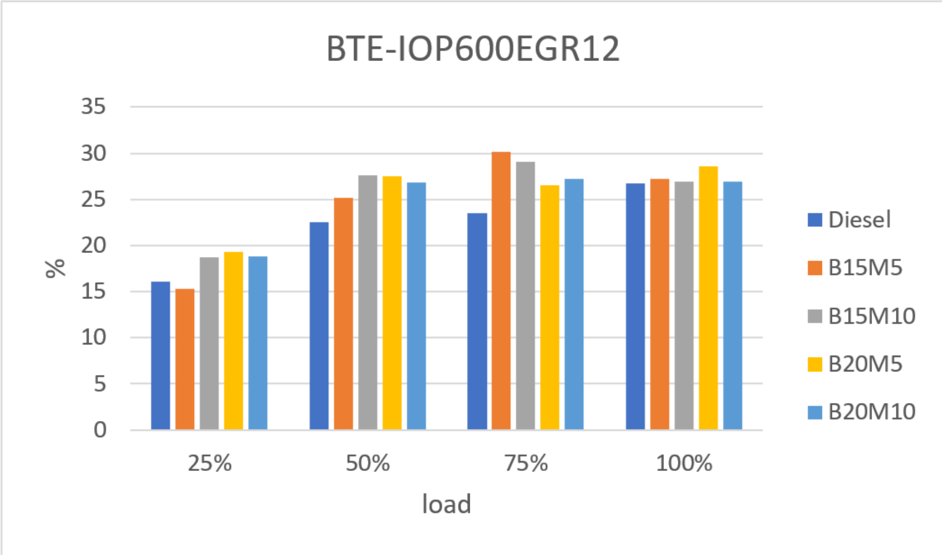


Figure 6.24: Brake Thermal Efficiency at IOP 600 EGR 12

From the graphs of brake thermal efficiency, it can be seen that their values show an increase at higher loads when compared to lower loads. This can be attributed to the reduction in heat loss and increase in power with the increase in load.The brake thermal efficiency of the blends are compared to that of mineral diesel at 75% load and changes were found out.

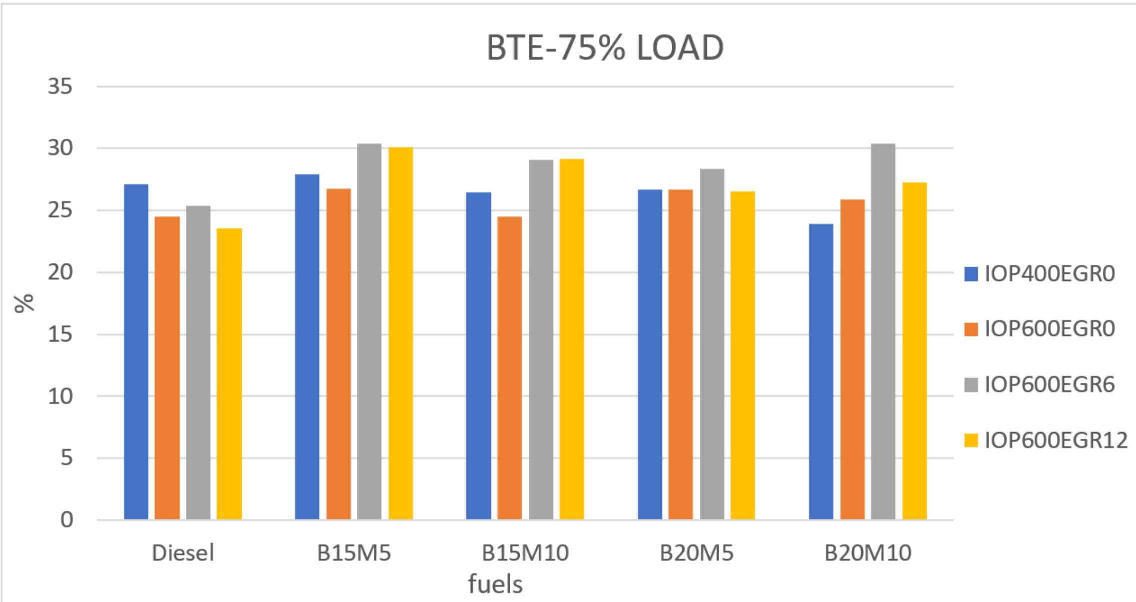


Figure 6.25: Brake Thermal Efficiency of four runs at 75%load

At Run 1 and 75% load upon observing the Brake thermal efficiency graphs and comparing the blends with that of mineral diesel it was seen that B15M5 showed 2.79% increase, B15M10 showed 2.36% decrease, B20M5 showed 1.43% decrease, B20M10 showed 11.81% decrease in its values of Brake Thermal Efficiency. At Run

2 and 75% load upon observing it was seen that, B15M5 showed 8.52% increase, B15M10 showed 0.05% increase, B20M5 showed 10.79% increase, B20M10 showed 5.64% increase in Brake Thermal Efficiency when compared to mineral diesel. At Run 3 and 75% load on observing it was seen that, B15M5 showed 35.62% increase, B15M10 showed 29.55% increase, B20M5 showed 26.38% increase, B20M10 showed 35.49% increase in Brake Thermal Efficiency when compared to mineral diesel. At Run 4 and 75% load on observing it was seen that, B15M5 showed 28.11% increase, B15M10 showed 23.86% increase, B20M5 showed 12.93% increase and B20M10 showed 15.86% increase in Brake Thermal Efficiency when compared to mineral diesel. The Brake thermal efficiency of were seen to increase in blends when compared to baseline fuel which is mineral diesel.

### 6.2.2 Brake specific fuel consumption:

The Brake specific fuel consumption of a fuel is the ratio of mass of fuel consumption and Brake power. The brake specific fuel consumption of all the fuels were found out and were plotted on graphs.

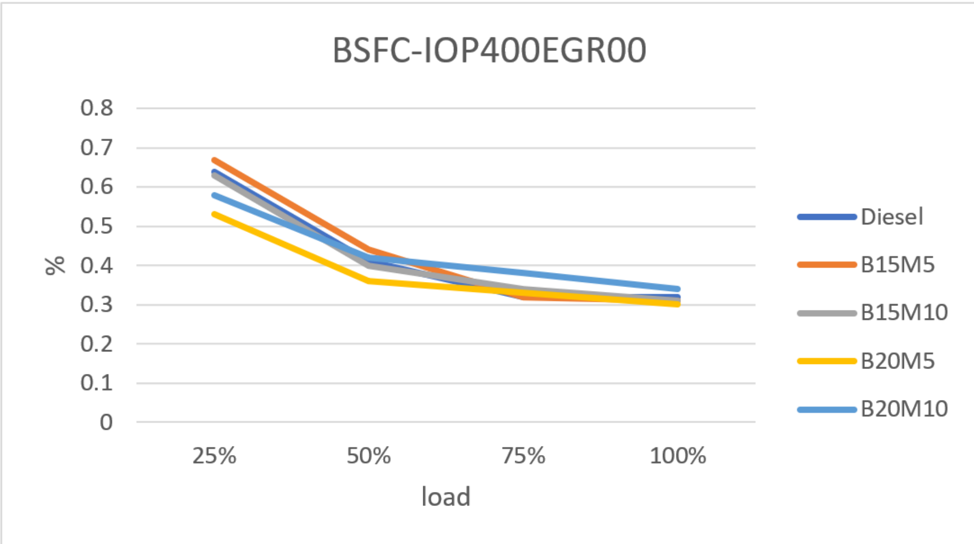


Figure 6.26: Brake Specific Fuel Consumption at IOP 400 and EGR 0

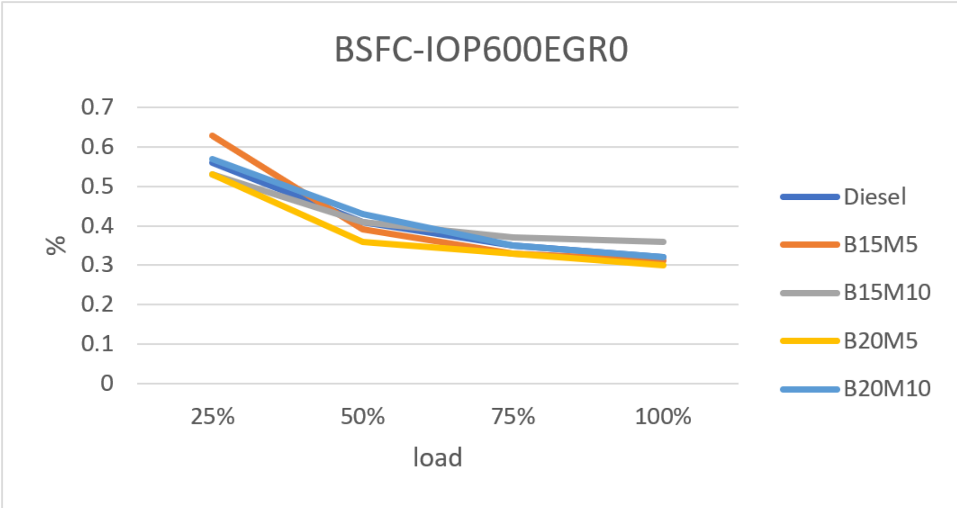


Figure 6.27: Brake Specific Fuel Consumption at IOP 600 and EGR 0

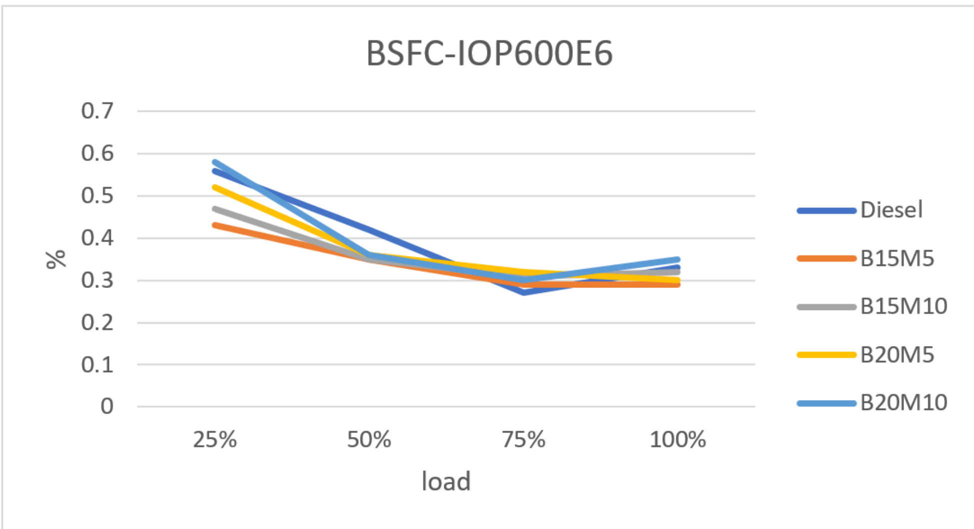


Figure 6.28: Brake Specific Fuel Consumption at IOP 600 and EGR 6

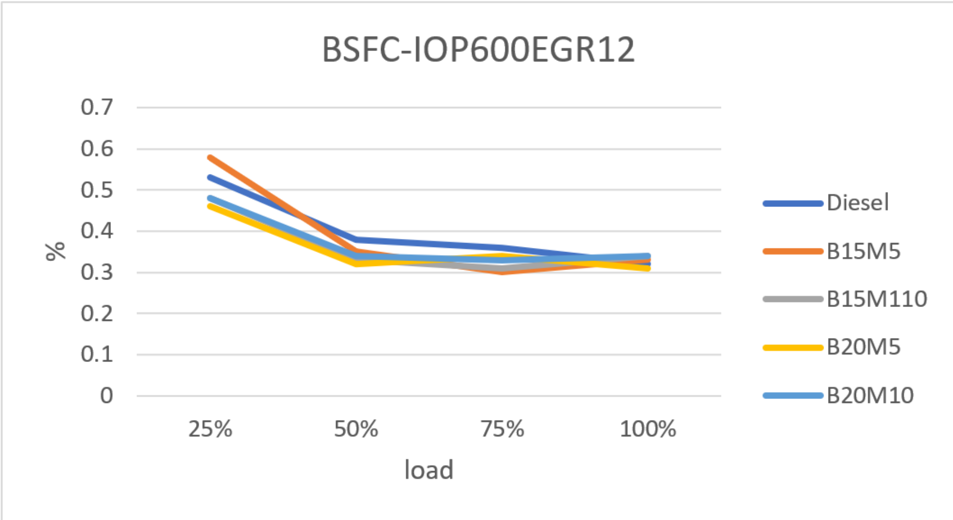


Figure 6.29: Brake Specific Fuel Consumption at IOP 600 and EGR 12

From the graphs it can be seen that the break specific fuel consumption for blends were generally lower than that of mineral diesel. The break specific fuel consumption of all the blends were compared to that of diesel at 75% load.

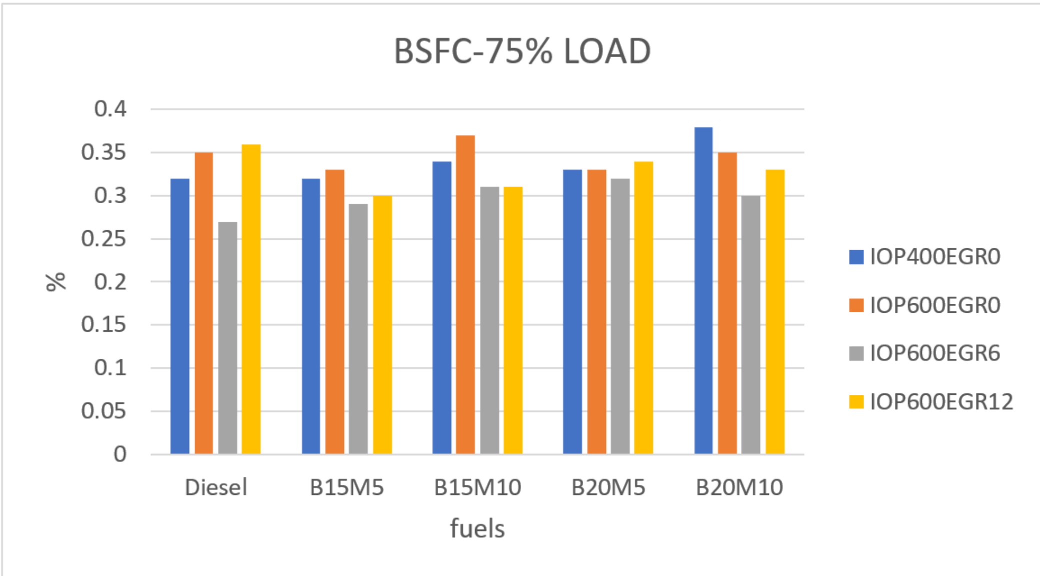


Figure 6.30: Brake Specific Fuel Consumption at four runs at 75% load

When BSFC graphs of blends were compared to that of mineral diesel it was observed at Run 1 B15M5 showed no change, B15M10 showed 6.2% increase, B20M5 showed 3.13% increase, B20M10 showed 18.75% increase. At run 2, B15M5 showed 5.7% decrease, B15M10 showed 5.7% increase, B20M5 showed 5.7% decrease and B20M10 showed no change. At run 3, B15M5 shows 7.4% increase, B15M10 shows 11.11% increase, B20M5 shows 18.51% increase, B20M10 shows 11.11% increase.

At run 4, B15M5 shows 16.66% decrease, B15M10 shows 13.88% decrease, B20M5 shows 5.5% decrease, B20M10 shows 8.3% decrease. So generally, a nominal increase in brake specific fuel consumption was seen.

# Chapter 7

# CONCLUSION

From the observed data the following conclusions were made.

- The carbon dioxide emission in all the fuels generally showed an increase in emission when the loads were increased. The emission of carbon dioxide was seen to increase upon increasing the Injection pressure(IOP), whereas upon increasing the Exhaust gas recirculation (EGR) rate, the carbon dioxide emission was seen to decrease. Comparison of carbon dioxide emission when done at 75% load generally showed an increase in case of blends than that of mineral diesel

- The carbon monoxide emission in blends were generally found to decrease when compared to mineral diesel at different loads. The emission in all fuels was seen to decrease with increase in injection of pressure (IOP), whereas upon increasing the exhaust gas recirculation (EGR) the emission was seen to increase. Comparison of carbon monoxide emission when done at 75% load was seen to decrease in blends when compared to mineral diesel.

- The NOx emission in blends were generally found to decrease when compared mineral diesel. The emission of all fuels were seen to increase when Injection of pressure was increased, where as when the EGR was increased it was seen that the NOx emission has significantly decreased in all fuels. When the emissions were compared at 75% load NOx emission seems to have decreased in blends when compared to mineral diesel.

- The HC emission in blends were generally found to increase when compared to mineral diesel. The comparison of their emissions were done at 75% load and it was seen that HC emission in blends showed a slight increase when compared to mineral diesel.

- The Brake thermal efficiency in blends were found to increase when compared to mineral diesel. Comparison of Brake thermal efficiency was done at 75% load and it was observed that Blends generally showed an increase when compared to mineral diesel

- The Break specific fuel consumption in blends were seen to have a nominal increase when compared to mineral diesel. When the comparison was done at 75% it was seen that blends showed increase in Brake specific fuel consumption when compared to mineral diesel.

# Chapter 8

# Scope for Further work

- Injection of pressure value in the engine could be varied further to get better results in emission. IOP when increased generally shows an increase in Carbon dioxide and decrease in carbon monoxide, so the IOP could be varied further to get better results.
- Exhaust gas recirculation (EGR) value could be varied further to control the emissions at a better rate. EGR addition generally showed a decrease in NOx emission, so this could be pursued upon and even better results of NOx emission can be obtained.
- Hydrocarbon and carbon monoxide emissions can be controlled by the use of an external device called Diesel oxidation catalyst (DOC). It's a device that can convert HC and CO into Carbon dioxide and water. This device could hence be used and emissions can be further decreased
- The blend ratios could be further adjusted by adding more Bio-diesel and their emission and performance characteristics can be studied.
- The blend ratio can be adjusted further in a way that shows increase in Methanol substitution percentage, and their emission and performance characteristics can be studied.

# Chapter 9

# Individual project contribution

The idea of "Experimental and analytical study of using methanol with bio-diesel from waste cooking oil-Diesel blend on a diesel engine" was a common interest among the members of the group. The idea was finalised after consulting with our Project guide followed by investigating the suitability and the methodology of the intended work. The work was then divided among the members.

- Literature review : journal paper references were interpreted to out the suitable proportion of blends that had to be tested. Various parameters used in reference papers were taken in our experiment to compare our results. Journal paper regarding methanol - diesel - biodiesel was referred by Nair Akshay Prasad and Thomas Joe. The blends established were finalized by Priyesh Raj and Advait krishna with guidance from Project guide.
- Simulation results were analysed by Priyesh Raj , Advait Krishna and Nair Akshay Prasad.
- Parameters for the experimental analysis was established by Advait krishna with guidance from project guide. The test matrix was made by Priyesh Raj.
- Experimental analysis was done in two steps. Emission analysis was done by Advait Krishna and performance analysis was done by Priyesh Raj, Nair Akshay Prasad and Thomas Joe. The graphs were plotted by Priyesh Raj and Advait Krishna and results were studied conclusions were made by Advait Krishna.
- Project presentation: The mustering contents and preparation of slides were done by Advait Krishna with the support of other members. Project report was made by Priyesh Raj and Advait Krishna.

# Bibliography


[1] Sebastian Verhelst, James WG Turner, “Methanol as fuel for internal combustion engines” *Progress for Energy and Combustion Science*,Volume 70, January 2019, Page 23-88

[2] L-J Wang, R-Z Song,”Study on combustion characteristics of a methanol–diesel dual-fuel compression ignition engine”*Automobile Engineering*,Volume 222, Issue 4, April 1, 2008, Pages 619-627

[3] Chao Chen, Anren Yao, “Study of the characteristics of PM and the correlation of soot and smoke opacity on the diesel methanol dual fuel engine” *Applied Thermal Engineering*, Volume 148, 5 February 2019, Pages 391-403

[4] Ambar Gaur, Shubam Mishra, “A review on Factor affecting biodiesel produced from waste cooking oil: An Indian perspective” *Materials today:Proceedings*,23 October 2020, Volume 1

[5] Domenico De Serio, Alex de Oliveira, “Effects of EGR rate on performance and emissions of a diesel power generator fuelled by B7” *J.Braz.Soc.Mech.Sci.Eng* ,(2017) 39:1919-1927

[6] Metin Gumus, Cenk Sayin, Mustafa Canakci, “impact of fuel injection pressure on the exhaust emissions of a direct injection diesel engine fuelled with biodiesel- diesel fuel blends” *M Gumus et al./ Fuel 95* (2012) 486-494

[7] W N Maawa, R Mamat, G Najafi, O Majeed Ali and A Aziz1, “impact of fuel injection pressure on the exhaust emissions of a direct injection diesel engine fuelled with biodiesel- diesel fuel blends” , M Gumus et al./ Fuel 95 (2012) 486-494

[8] Sam Ki Yoon, Jun Cong Ge and Nag Jung Choi, “ArticleInfluence of Fuel Injection Pressure on the Emissions Characteristics and Engine Performance in a CRDI Diesel Engine Fuelled with Palm Biodiesel Blends” *Energies* 2019, 12, 3837

[9] J. Z˘aglinskis , K. Lukács , Á. Bereczky , “Comparison of properties of a compression ignition engine operating on diesel–biodiesel blend with methanol additive” *Energies* 2019, 12, 3837

[10] ] Amer A. Mohammed, Muthana L. Abdulla and Ahmad Muneer El-Deen Faik , “The Impact of methanol addition to the Biodiesel- Diesel blends on the performance and exhaust emission of the CI engines”,IOP conf.series: journal of physics: Conf.series 1279(2019)012056

[11] ] Sebastian Verhelst , James WG Turner, Louis Sileghemb, Jeroen Vancoillie, “Methanol as a fuel for internal combustion engines”,S. Verhelst et al. *Progress in Energy and Combustion Science 70* (2019) 43–88