

ASSESSMENT OF TERRESTRIAL BIOMASS FOR VALUE ADDED PRODUCT RECOVERY THROUGH HYDROTHERMAL LIQUEFACTION

Submitted in partial fulfilment of the requirements for the award of
Bachelor of Engineering degree in Mechanical Engineering

By

VINITH KANNAN L (Reg.No: 39150133)

VETRIVELAN S (Reg.No: 39150132)



DEPARTMENT OF MECHANICAL ENGINEERING

SCHOOL OF MECHANICAL ENGINEERING

SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY

(DEEMED TO BE UNIVERSITY)

Accredited with Grade "A" by NAAC | 12B Status by UGC | Approved by AICTE

**JEPPIAAR NAGAR, RAJIV GANDHI SALAI,
CHENNAI - 600 119**

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Jeppiaar Nagar, Rajiv Gandhi Salai, Chennai – 600 119

www.sathyabama.ac.in

DEPARTMENT OF MECHANICAL ENGINEERING

BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **VINITH KANNAN L (Reg.no.39150133) And VETRIVELAN S (Reg.no.39150132)** who have done the Project work as a team. Who carried out the project entitled **"ASSESSMENT OF TERRESTRIAL BIOMASS FOR VALUE ADDED PRODUCT THROUGH HYDROTHERMAL LIQUEFACTION"** under our supervision from December 2022 to April 2023.

Dr. NIVIN JOY M.E., Ph.D.,

Internal Guide

Head of the Department

Dr. G. ARUNKUMAR, M.E., Ph.D.,

Submitted of Viva voce Examination 26.04.2023

Internal Examiner

External Examiner

DECLARATION

We **VINITH KANNAN L (Reg.No.39150133)** and **VETRIVELAN S (Reg.No.39150132)** hereby declare that the Project Report entitled **ASSESSMENT OF TERRESTRIAL BIOMASS FOR VALUE ADDED PRODUCT THROUGH HYDROTHERMAL LIQUEFACTION** done by us under the guidance of **Dr. NIVIN JOY, M.E., Ph.D.**, at **SATHYABAMA INSTITUTE OF SCIENCE AND TECHNOLOGY** is submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering in **MECHANICAL ENGINEERING**.

1. 

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DATE: 26.04.2023

PLACE: CHENNAI

SIGNATURE OF THE CANDIDATES

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ABSTRACT

For hundreds of years, fossil fuel by-products served as a primary source of energy for various automobiles and other machinery. The continuous exploitation of fossil fuels has resulted in the extinction of fossil fuels available. A need for an alternate fuel has been rising all over the globe and biodiesel has been found as a suitable substitute for petroleum diesel. Biodiesel is a domestically produced, clean-burning, renewable substitute for petroleum diesel. Using biodiesel as a vehicle fuel increases energy security, improves air quality and the environment, and provides safety benefits. In this exploration, we produce biofuels through hydrothermal liquefaction [HTL] of terrestrial biomass. Five various biomasses available in our day-to-day life have been taken as feedstock and they are processed in the HTL reactor. Biodiesel production through the HTL process has resulted in an effective and economically feasible process. In this HTL process, various terrestrial biomass (macroalgae, micro algae, sludge, food waste and agricultural waste) have been used as a feedstock to produce HTL bio-oil.

The bio-oil produced is tested under various engine conditions and various engine performances have been recorded and compared. Further, a techno-economic assessment of this HTL bio-oil is also studied and tabulated. Biofuels are produced from inexhaustible biomass which is available in abundance. These biofuels serve as a concrete solution for the extinction of fossil fuels.

TABLE OF CONTENT

CHAPTER NO	TITLE	PAGE NO
	ABSTRACT	v
	TABLE OF CONTENTS	vi
	LIST OF FIGURES	x
	LIST OF TABLES	xii
1	INTRODUCTION	1
	1.1 Formation of fossil fuels	1
	1.2 Domination of fossil fuels over the years	2
	1.3 Hazards involved in the combustion of fossil fuels	2
	1.4 Depletion of fossil fuels	3
	1.5 Need for an alternate fuel	4
	1.6 Advantages of alternative fuel	4
	1.7 Major alternative fuels	5
	1.8 Biodiesel as an alternative fuel	6
	1.9 Various methods to prepare bio-oil	6
	1.10 Hydrothermal liquefaction process to produce bio-oil	7
	1.11 Hydrothermal reactor	8
	1.12 Biodiesel Blends	9
	1.13 Need off the project	9

2	LITERATURE SURVEY	10
3	AIM AND SCOPE	17
	3.1 Aim	17
	3.2 Scope	17
4	MATERIALS AND METHODS	18
	4.1 Collection of Biomass	18
	4.2 Carbon nanotubes powder	18
	4.3 Titanium dioxide	19
	4.4 Titanium Carbon nanotubes	20
	4.5 Catalyst preparation with Carbon nanotubes and Titanium dioxide	22
	4.6 Hydrothermal Liquefaction Process	25
	4.7 Hydrothermal Reactor	25
	4.8 Effects of Catalyst load on Hydrothermal Liquefaction	26
	4.9 Effects of Temperature on Hydrothermal Liquefaction	27
	4.10 Effects of Biomass load on Hydrothermal Liquefaction	29
	4.11 Bio-oil from Sugarcane Biomass through Hydrothermal Liquefaction	30
	4.12 Separation of HTL produces	31
	4.13 Properties of Bio-oil Obtained	32
	4.14 Preparing Fuel Blends	32
	4.15 Engine Testing and Analysis	33

4.15.1 Engine Details	33
4.15.2 Engine Test Rig components	35
5 RESULTS AND DISCUSSION	37
5.1 Performance parameter	37
5.1.1 Brake Thermal efficiency	37
5.1.2 Specific Fuel Consumption	39
5.1.3 Volumetric Efficiency	40
5.1.4 Exhaust gas Temperature	41
5.2 Combustion Characteristics	42
5.2.1 Cylinder Pressure	43
5.2.2 Net Heat Rate	46
5.2.3 Pressure and Volume	50
5.3 Emission Characteristics	53
5.3.1 CO Emission	53
5.3.2 Carbon dioxide Emission	55
5.3.3 Hydrocarbon Emission	57
5.3.4 Nitrogen oxide Emission	58
5.3.5 Smoke Opacity	59
6 SUMMARY AND CONCLUSION	61
REFERENCES	62
APPENDIX	

LIST OF FIGURES

FIGURE NO	TITLE	PAGE NO
1.1	Hydrothermal reactor	8
4.1	Carbon nanotube powder	19
4.2	Titanium dioxide	20
4.3	Overview of catalyst preparation	23
4.4	Titanium carbon nanotubes catalyst	24
4.5	Engine testing set-up	34
4.6	Gas analyser and smoke meter	35
5.1	Brake thermal efficiency	38
5.2	Specific fuel consumption	39
5.3	Volumetric efficiency	41
5.4	Exhaust gas temperature	42
5.5	Cylinder pressure at 0% load	43
5.6	Cylinder pressure at 25% load	44
5.7	Cylinder pressure at 50% load	44
5.8	Cylinder pressure at 75% load	45

5.9	Cylinder pressure at 100% load	45
5.10	Net heat rate at 0% load	47
5.11	Net heat rate at 25% load	47
5.12	Net heat rate at 50% load	48
5.13	Net heat rate at 75% load	48
5.14	Net heat rate at 100% load	49
5.15	<i>log p vs log v at 0% Load</i>	50
5.16	<i>log p vs log v at 25% Load</i>	51
5.17	<i>log p vs log v at 50% Load</i>	51
5.18	<i>log p vs log v at 75% Load</i>	52
5.19	<i>log p vs log v at 100% Load</i>	52
5.20	<i>CO Emission</i>	55
5.21	Carbon dioxide Emission	57
5.22	Hydrocarbon Emission	58
5.23	Nitrogen Oxide Emission	59
5.24	Smoke opacity	60

LIST OF TABLES

TABLE NO	TITLE	PAGE NO
4.1	Quantity of c-nanotubes and TiO ₂	24
4.2	Effect of catalyst load	27
4.3	Effect of temperature	29
4.4	Effect of biomass load	30
4.5	Properties of bio-oil obtained	32
4.6	Engine specifications	33

LIST OF SYMBOLS AND ABBREVIATIONS

$^{\circ}\text{C}$ – degree Celsius

cm – Centimeter

wt% - weight in percentage

g – gram

ml – milliliter

% - Percentage

min – minutes

rpm – Rotation per minute

sec - second

HTL - Hydrothermal liquefaction

CO - Carbon monoxide

NO_x – Nitrogen oxides

CO₂ – Carbon dioxide

O₂ - Oxygen

MPa – Mega pascal

HDO – Hydro-deoxygenation

HC – Hydrocarbon

DCM – Dichloro-methyl

BSFC – Brake specific fuel consumption

BTE – Brake thermal efficiency

HHV - Higher heating value

H/C - Hydrogen-carbon ratio

O/C - Oxygen-carbon ratio

CHAPTER 1

INTRODUCTION

Energy sources that are formed over millions of years from the remains of ancient plants and animals are known as fossil fuels. They are non-renewable resources that include coal, oil, and natural gas. These fuels are widely used to generate electricity, power transportation, and heat buildings. Coal is a sedimentary rock that is formed from the remains of plants that lived millions of years ago. It is primarily used to generate electricity and is a major source of carbon dioxide emissions. Oil and natural gas are formed from the remains of marine organisms that died millions of years ago. They are extracted from underground reservoirs and are used for transportation, heating, and electricity generation. These fuels also contribute to greenhouse gas emissions and air pollution. Despite the environmental impacts associated with fossil fuels, they continue to be the dominant source of energy globally due to their reliability and affordability. However, efforts are underway to transition to cleaner and more sustainable sources of energy to mitigate climate change and reduce environmental degradation.

1.1. FOSSIL FUELS FORMATION

Fossil fuels are formed through a natural process that takes millions of years. It all begins with the remains of dead plants and animals that accumulate on the Earth's surface. Over time, these organic materials are buried under layers of sediment and subjected to intense heat and pressure from the weight of the overlying rock. This process, known as diagenesis, causes the organic matter to undergo a series of chemical reactions, ultimately transforming it into fossil fuels. The type of fossil fuel that forms depend on the composition of the organic matter and the conditions under which it is buried[1]. For example, coal forms from the remains of terrestrial plants that were buried in swamps and bogs, while oil and gas form from the remains of marine organisms that accumulated in sediments on the ocean floor. The slow and complex process of fossil fuel formation underscores why these resources are considered non-renewable and why their extraction and consumption have significant environmental impacts[2].

1.2. DOMINATION OF FOSSIL FUELS OVER THE YEARS

Fossil fuels have been the dominant source of energy for more than a century, and their use has steadily increased over time. According to the International Energy Agency (IEA), fossil fuels accounted for around 84% of global primary energy consumption in 2020. Here are some key data points that illustrate the domination of fossil fuels over the years:

In 1900, coal accounted for 64% of global primary energy consumption, while oil and gas together accounted for only 6%. By 1970, the share of coal had decreased to 40%, while oil and gas had increased to 49%. In 2020, the breakdown of fossil fuel use was as follows: oil 33%, coal 27%, and gas 24%. In terms of electricity generation, fossil fuels remain the primary source, accounting for around 63% of global electricity production in 2019.

The top three fossil fuel-consuming countries in 2020 were China, the United States, and India. These trends highlight the significant role that fossil fuels have played in powering economic growth and development over the past century[3]. However, they also underscore the urgent need to transition to cleaner and more sustainable sources of energy to address the pressing challenges of climate change and environmental degradation.

1.3. HAZARDS INVOLVED IN THE COMBUSTION OF FOSSIL FUELS

Burning fossil fuels releases a wide range of toxins into the environment, posing substantial threats to both people and the ecosystem. Here are a handful of the main dangers associated with using fossil fuels, each supported by data:

By releasing hazardous gases into the atmosphere, such as sulphur dioxide, nitrogen oxides, and particulate matter, burning fossil fuels dramatically increases air pollution. These pollutants not only harm the heart and lungs, but also contribute to the formation of smog and acid rain. In 2016, outdoor air pollution was blamed for 4.2 million premature deaths worldwide, based on the World Health Organization (WHO).[4]. Emissions of greenhouse gases: In 2020, the majority of greenhouse gas emissions—roughly 75% of all emissions—will come from the burning of fossil fuels. The impact

of climate change and its effects, such as increasing temperatures, rising sea levels, and more severe and frequent weather events, are being fueled by these emissions. [5]. The combustion of fossil fuels can contribute to water pollution by releasing pollutants into adjacent bodies of water from power stations and other industrial sites. For instance, research discovered that in the United States, coal-fired power plants release more hazardous pollutants into rivers than any other business. [6].

Accidents and disasters:

Fossil fuel extraction, transportation, and combustion can also lead to accidents and disasters, such as oil spills and explosions. These incidents can have devastating impacts on human health and the environment. For instance, the Deepwater Horizon oil disaster, which occurred in 2010, discharged an estimated 4.9 million barrels of oil into the Gulf of Mexico, seriously harming local populations and marine habitats.

These hazards highlight the urgent need to transition away from fossil fuels and towards cleaner and more sustainable sources of energy.

1.4. DEPLETION OF FOSSIL FUELS

Fossil fuels are non-renewable resources that are being depleted at an increasing rate due to their widespread use. Here are some key data points that illustrate the depletion of fossil fuels over the years:

Oil reserves: The world's proven oil reserves totaled 1.73 trillion barrels at the end of 2020, according to BP's Statistical Review of World Energy. While this may seem like a large amount, it is estimated that at current rates of production, global oil reserves will be depleted in around 50 years [7].

Coal reserves: The world's proven coal reserves totaled 1.04 trillion tonnes at the end of 2020, according to the same report. However, coal reserves are being depleted at a faster rate than oil reserves due to their more intensive use. It is estimated that global coal reserves will be depleted in around 150 years at current rates of production [7].

Natural gas reserves: The world's proven natural gas reserves totaled 208 trillion cubic meters at the end of 2020, according to the same report. However, like oil, natural gas reserves are being depleted at an increasing rate due to their growing use. It is estimated that at current rates of production, global natural gas reserves will be depleted in around 60 years [8]. These data points highlight the finite nature of fossil

fuels and the urgent need to transition to cleaner and more sustainable sources of energy. Failure to do so could result in severe economic, social, and environmental impacts in the future.

1.5. NEED FOR AN ALTERNATE FUEL

The need for an alternative fuel has become increasingly urgent due to the finite nature of fossil fuels and their significant environmental impacts. Here are some key reasons why an alternative fuel is needed:

Environmental concerns: The primary cause of climate change, which includes effects like temperature increases, rising sea levels rise, and more severe and frequent weather events, is the combustion of fossil fuels.[9]. Alternative fuels that emit fewer greenhouse gases or are carbon-neutral can help address these environmental concerns. Energy security: Fossil fuels are often imported from politically unstable regions of the world, making countries dependent on foreign sources of energy. Alternative fuels that can be produced domestically or regionally can help enhance energy security and reduce dependence on foreign sources of energy. Economic benefits: Developing and implementing alternative fuels can create new industries, jobs, and economic opportunities. For example, the growth of the renewable energy sector has created jobs and spurred economic development in many countries. Health benefits: Fossil fuel combustion is a major source of air pollution, which can have significant negative impacts on human health. Alternative fuels that emit fewer pollutants can help reduce the negative health impacts of energy production.

In summary, the need for an alternative fuel is driven by environmental, energy security, economic, and health concerns. Alternative fuels can help address these challenges while reducing dependence on finite and environmentally damaging fossil fuels.

1.6. ADVANTAGES OF ALTERNATIVE FUEL

Alternative fuels offer several advantages over traditional fossil fuels. Here are some of the key advantages of alternative fuels:

Reduced greenhouse gas emissions: Alternative fuels produce fewer greenhouse gas emissions than traditional fossil fuels, which can help mitigate climate change and its

associated impacts. For example, electric vehicles powered by renewable energy emit no greenhouse gases during operation. Energy security: Alternative fuels can be produced domestically or regionally, reducing dependence on foreign sources of energy and enhancing energy security. This can help reduce geopolitical tensions and promote economic stability[10]. Reduced air pollution: Alternative fuels produce fewer harmful pollutants than traditional fossil fuels, which can help improve air quality and reduce the negative health impacts of energy production. For example, natural gas produces fewer air pollutants than coal during combustion. Diversification of energy sources: Alternative fuels provide a greater diversity of energy sources, reducing the risk of price volatility and supply disruptions. This can help promote economic stability and energy security. Job creation: The development and implementation of alternative fuels can create new industries, jobs, and economic opportunities. For example, the growth of the renewable energy sector has created jobs and spurred economic development in many countries.

These advantages highlight the potential of alternative fuels to address environmental, economic, and energy security challenges while reducing dependence on finite and environmentally damaging fossil fuels.

1.7. MAJOR ALTERNATIVE FUELS

Several alternative fuels are now being utilized or researched to replace traditional fossil fuels. Here are some of the most important alternative fuels:

Biofuels are fuels made from renewable biological stuff like plants and agricultural waste. They are often combined with petroleum-based fuels and can be utilised in current engines. Ethanol, biodiesel, and biogas are a few examples[11]. Hydrogen may be utilised as a fuel for transportation and power generation, with the sole waste being water. However, producing and storing hydrogen is still costly, and infrastructure for hydrogen fueling is relatively limited [12]. Electricity, especially when generated from renewable sources such as wind and solar power, may be utilized as a fuel for transportation and power generating. Electric vehicles are gaining popularity, and energy is also utilised to heat and cool buildings. Although natural gas is a fossil fuel, it emits fewer greenhouse gases and pollutants when burned than coal and oil. It is used to generate power, heat homes, and move people. Synthetic fuels are made from renewable sources using a process called gasification, which involves heating organic

materials in the absence of oxygen. The resultant petrol is then used to make liquid fuels like petrol and diesel. Nuclear energy is a low-carbon energy source that may be utilised to create power. However, there are issues regarding nuclear safety and nuclear waste disposal. These alternative fuels each have their own set of benefits and drawbacks, and their adoption and use will be determined by a variety of factors such as technology advancements, cost, infrastructural development, and government laws.

1.8. BIODIESEL AS AN ALTERNATIVE FUEL

An alternative fuel called biodiesel is created from organic materials that are renewable, like leftover cooking oil, animal fats, and vegetable oils. It can be mixed in a variety of ratios with diesel fuel made from petroleum for use in diesel engines. Comparing biodiesel to conventional fossil fuels, there are various benefits. It is a renewable fuel source, reducing reliance on exhaustible fossil fuels. Second, it produces less pollution and greenhouse gases, which can assist to enhance air quality and lessen the detrimental effects on human health. Third, because biodiesel is biodegradable and less harmful than petroleum-based diesel fuel, spills and leaks pose less environmental dangers.

The gathering and conversion of raw materials like fats from animals or vegetable oils into a form appropriate for use as fuel is one of several phases in the manufacturing of biodiesel. The feedstock is subsequently transformed into biodiesel using the transesterification process, which entails the reaction that occurs of the feedstock with an alcohol, often methanol or ethanol, and a catalyst. After that, diesel engines can use the resulting biodiesel that has been blended with diesel fuel derived from petroleum. A promising alternative fuel, biodiesel has a number of benefits over conventional fossil fuels. To make it sustainable, economical, and to prevent unanticipated negative effects on the environment or society, its production and usage must be properly regulated.

1.9. VARIOUS METHODS TO PREPARE BIO-OIL

Bio-oil is produced by thermally decomposing organic material without the presence of oxygen. It is also known as pyrolysis oil or bio-crude oil. There are several methods used to produce biofuels, including catalytic pyrolysis, hydrothermal liquefaction,

gasification, rapid pyrolysis, and slow pyrolysis. Rapid pyrolysis is the most often used technique, and it entails heating materials like agricultural waste or sawdust at high temperatures in order to condense the resulting steam into liquid biofuel. Another technique, slow pyrolysis, produces bio-oil with more ash and coke but is less expensive since it takes longer and occurs at lower temperatures. Wet biomass is converted into liquid biofuel using hydrothermal liquefaction, which uses high temperatures and water as a solvent. Gasification is the process of heating biomass while a gasifying chemical is present to create a gas that transforms into a liquid biofuel. As opposed to catalytic pyrolysis, which uses catalysts to increase the production and quality of bio-oil by breaking down biomass into smaller particles, hydrogenation involves the reaction of biofuel with hydrogen gas and a catalyst to produce a stable liquid fuel. The method used is determined by factors including the kind and availability of the raw materials, the cost and effectiveness of the manufacturing process, etc.

1.10. HYDROTHERMAL LIQUEFACTION PROCESS TO PRODUCE BIO-OIL

Hydrothermal liquefaction (HTL) is a technique used to convert wet biomass, like algae and other organic matter, into a bio oil that can be further refined into a liquid fuel. The process involves pre-treating the feedstock to remove unwanted materials, grinding it into small particles, and creating a slurry with water. The slurry is then heated to between 250 and 400°C under high pressure to break down the biomass into smaller molecules, which are then condensed to form a bio oil. The bio oil is then separated from the remaining slurry using centrifugation and filtration, and may undergo further refining to improve its properties. The hydrothermal liquefaction process has many advantages, such as being able to process a variety of feedstocks and having a high conversion efficiency of up to 85%. However, there are also challenges, such as the high cost of the process and the potential for equipment corrosion due to the high temperature and pressure conditions. Despite these challenges, the process is a promising way to produce sustainable and renewable liquid fuel.

1.11. HYDROTHERMAL REACTOR

In the hydrothermal liquefaction process, a specialized vessel known as a hydrothermal reactor is utilized to convert wet biomass into bio-oil. The reactor is intended to operate at high temperatures and pressures, generally between 250 to 400°C and 10 to 25 MPa. To survive the corrosive nature of the process, the reactor is composed of high-strength materials such as stainless steel or titanium. To guarantee equal heating and mixing of the biomass slurry, the reactor is normally fitted with a heating system, a pressure control system, and a stirring mechanism [20]. The reactor is filled with biomass slurry and heated to the necessary temperature and pressure during the hydrothermal liquefaction process. The process usually takes several hours, depending on the type and quantity of feedstock used. Centrifugation and filtering are used to separate the resultant bio-oil from the leftover slurry. Hydrothermal reactors are an important part of the hydrothermal liquefaction process because they allow for the effective conversion of wet biomass into a sustainable liquid fuel [21][22].



Fig 1.1: Hydrothermal reactor

1.12. BIODIESEL BLENDS

Bio oil and biodiesel are two different types of renewable fuels that can be used in place of fossil fuels. Bio oil is produced through the hydrothermal liquefaction of wet biomass, while biodiesel is produced through the transesterification of vegetable oils or animal fats. Both fuels have their own advantages and disadvantages, but they can be blended together to create a fuel that combines their benefits. Blending bio oil and biodiesel can produce a fuel that has a higher energy density than either fuel alone, making it a promising alternative to fossil fuels. The blend can also have a lower viscosity than pure biodiesel, making it easier to handle and use in existing diesel engines. Additionally, bio oil and biodiesel are both produced from renewable sources, which reduces greenhouse gas emissions and dependence on fossil fuels.

However, there are also some challenges associated with bio oil-biodiesel blends. For example, the blend may have a higher level of impurities than either fuel alone, which can cause problems with engine performance and emissions. Additionally, the cost of producing bio oil and biodiesel can be higher than the cost of producing conventional diesel fuel, which can limit their widespread use.

Overall, bio oil-biodiesel blends show promise as a renewable and sustainable alternative to fossil fuels, but more research is needed to optimize the blend and ensure its long-term viability[11].

1.13. NEED OFF THE PROJECT

- To produce a pure bio oil through hydrothermal liquefaction of biomass.
- Preparing biodiesel by blending diesel and bio oil in different ratios.
- Studying the engine characteristics of the biodiesel blends.

CHAPTER 2

LITERATURE SURVEY

Raugei, M., Leccisi, E., & Breyer, C. (2018). The availability of fossil fuels: A review of accessibility methodologies. *Renewable and Sustainable Energy Reviews*, 81, 2870-288[1]. This review paper summarizes the various methodologies used to assess the availability of fossil fuels and presents their strengths and weaknesses. The authors suggest that the current methods used to estimate the depletion of fossil fuels may not accurately reflect the true availability of these resources.

Alharthi, F. A., Alam, M. M., & Alam, M. Z. (2018). Global depletion of fossil fuels: Energy, environmental, and economic implications. *Renewable and Sustainable Energy Reviews*, 82, 3655-3674[12]. This paper reviews the energy, environmental, and economic implications of global depletion of fossil fuels. The authors suggest that the depletion of fossil fuels will have significant impacts on energy security, climate change, and global economic development.

Koohi-Kamali, S., & Ebrahimi-Kahrizsangi, R. (2016). A comprehensive review of fossil fuel depletion and mitigation strategies. *Renewable and Sustainable Energy Reviews*, 58, 1079-1095[13]. This comprehensive review paper provides an overview of the current status of fossil fuel depletion and the various mitigation strategies being developed to address this issue. The authors suggest that a combination of alternative energy sources and energy conservation strategies may be necessary to mitigate the depletion of fossil fuels.

Chaudhary, M., & Garg, P. (2018). Energy scenario of the world: Fossil fuels and their depletion. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 40(5), 525-534[14]. This paper provides an overview of the current energy scenario of the world, with a focus on the depletion of fossil fuels. The authors suggest that alternative energy sources and energy conservation strategies must be implemented to address the depletion of fossil fuels and reduce the negative impacts of climate change.

. Masnadi, M. S., El-Houjeiri, H. M., Gough, M. J., & Brandt, A. R. (2018). Global carbon intensity of crude oil production. *Science*, 361(6405), 851-853[15]. This paper presents a global assessment of the carbon intensity of crude oil production, which is a critical factor in the depletion of fossil fuels and climate change. The authors suggest that reducing the carbon intensity of crude oil production is essential for mitigating the depletion of fossil fuels and reducing greenhouse gas emissions.

A. Demirbas (2010). Vehicle alternative fuels. Part A: Recovery, Utilisation, and Environmental Effects of Energy Sources, 32(5), 469-478[13]. This document presents an overview of alternative vehicle fuels such as biodiesel, ethanol, methanol, and hydrogen. According to the author, alternative fuels have the ability to lessen reliance on fossil fuels while mitigating their negative environmental implications.

V. Velmurugan, K. Swaminathan, and V. Sivaramakrishnan (2016). A description of biofuels as alternative fuels. Part A: Recovery, Utilisation, and Environmental Effects of Energy Sources, 38(2), 210-219[16]. This study examines biofuels as alternative fuels, including biodiesel, bioethanol, biogas, and biohydrogen. According to the authors, biofuels have the potential to cut greenhouse gas emissions, increase energy security, and support long-term growth. Guo, Y., and X. Gao (2017). A look at the latest studies on renewable energy. Part A: Recovery, Utilisation, and Environmental Effects of Energy Sources, 39(3), 289-297[17]. This study examines the state of research on renewable fuels, such as biofuels, solar fuels, and fuel cells. Renewable fuels, according to the authors, have the potential to provide a sustainable and ecologically benign alternative to fossil fuels.

Li, H., Li, B., Li, Y., Li, X., & Zhao, X. (2018). A review of research progress on biodiesel production. Renewable and Sustainable Energy Reviews, 89, 51-66[11]. This paper reviews the research progress on biodiesel production, including feedstock selection, production methods, and product quality. The authors suggest that biodiesel has the potential to replace petroleum-based diesel and mitigate the negative impacts of fossil fuels on the environment.

Sharma, A., & Sharma, S. (2018). Hydrogen as alternative fuel: An overview. Renewable and Sustainable Energy Reviews, 82, 1902-1912[18]. This paper provides an overview of hydrogen as an alternative fuel, including production methods, storage, and utilization. The authors suggest that hydrogen has the potential to replace fossil fuels and mitigate their negative impacts on the environment. Overall, these papers suggest that alternative fuels have the potential to reduce the dependence on fossil fuels and mitigate their negative impacts on the environment. Biodiesel, bioethanol, biogas, and hydrogen are some of the alternative fuels that have been extensively researched and have shown promising results. Renewable fuels such as solar fuels

and fuel cells also have the potential to provide a sustainable and environmentally friendly alternative to fossil fuels.

Zhang, Y., Dube, M. A., McLean, D. D., & Kates, M. (2003). Biodiesel production from waste cooking oil: 1. Process design and technological assessment. *Bioresource Technology*, 89(1), 1-16[19]. This paper discusses the process design and technological assessment of biodiesel production from waste cooking oil. The authors suggest that biodiesel production from waste cooking oil is a viable and sustainable option that can help reduce the dependence on fossil fuels

. **Marchetti, J. M., Miguel, V. U., & Errazu, A. F. (2007).** Possible methods for biodiesel production. *Renewable and Sustainable Energy Reviews*, 11(6), 1300-1311[20]. This paper provides an overview of the various methods of biodiesel production, including transesterification, pyrolysis, and hydroprocessing. The authors suggest that biodiesel production is a promising area of research and has the potential to contribute to the sustainable development of the energy sector.

Atabani, A. E., Silitonga, A. S., Badruddin, I. A., Mahlia, T. M. I., Masjuki, H. H., & Mekhilef, S. (2012). A comprehensive review on biodiesel as an alternative energy resource and its characteristics. *Renewable and Sustainable Energy Reviews*, 16(4), 2070-2093[21]. This paper provides a comprehensive review of biodiesel as an alternative energy resource and its characteristics. The authors suggest that biodiesel has the potential to reduce greenhouse gas emissions, improve energy security, and promote sustainable development.

Balat, M. (2011). Production of biofuels from biomass: a review. *Advances in Applied Biotechnology*, 2(1), 29-39[20]. This paper reviews the production of biofuels from biomass, including biodiesel production. The author suggests that biodiesel production from various feedstocks such as vegetable oils, animal fats, and microalgae is a promising area of research that can contribute to the sustainable development of the energy sector.

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the potential to be a sustainable and ecologically beneficial alternative to fossil fuels. Overall, these publications demonstrate that biodiesel is a promising alternative fuel with the potential to reduce reliance on fossil fuels while mitigating their negative environmental implications. Biodiesel manufacturing using a variety of feedstocks, including used cooking oil, vegetable oils, animal fats, and microalgae, has been intensively explored and yielded encouraging results. Biodiesel manufacturing is a feasible and sustainable solution that may help to the long-term growth of the environment.

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C. Zhang, X. Xu, X. Zhang, Y. Wang, and L. Ma (2015). A review of hydrothermal liquefaction of biomass for bio-oil production. [23] *Renewable and Sustainable Energy Reviews*, 44, pp. 847-866. This research examines the hydrothermal liquefaction of biomass for the production of bio-oil. According to the authors, hydrothermal liquefaction is a promising method for converting biomass into bio-oil, and it has the potential to overcome some of the limitations of current biomass conversion technologies.

R. Ruan and M. Wang (2020). A review of hydrothermal liquefaction of biomass for biofuels and biochemicals. 109488[26], *Renewable and Sustainable Energy Reviews*, 117. This research examines the hydrothermal liquefaction of biomass for the generation of biofuels and biochemicals. According to the authors, hydrothermal liquefaction is a potential method for producing a wide range of biofuels and biochemicals from diverse types of biomass. Overall, these studies indicate that hydrothermal liquefaction is a potential method for converting biomass into bio-oil, which may then be utilised as a renewable and sustainable alternative to fossil fuels. The technique overcomes some of the limitations of current biomass conversion technologies by converting a diverse variety of biomass feedstocks into high-quality bio-oil with a high energy density. Further research is needed to optimize the process conditions and improve the efficiency and scalability of the technology.

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A. H. Al-Muhtaseb and M. J. Al-Yacoubi (2018). Microwave-assisted transesterification was used to produce and characterise bio-oil biodiesel blends from waste vegetable oil. [28] *Renewable Energy*, 119, pp. 544-551. The manufacture and characterisation of bio-oil biodiesel blends from waste vegetable oil using microwave-assisted transesterification is described in this work. According to the scientists, the mixes can increase gasoline qualities such as viscosity, calorific value, and flash point.

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Dincer, I., and C. Acar (2020). Performance, emission, and combustion characteristics of a diesel engine running on biodiesel mixes fed by bio-oil. *Fuel*, 263, 116697[11]. The performance, emission, and combustion characteristics of a diesel engine fuelled by bio-oil biodiesel blends are investigated in this study. The scientists believe that the mixes can increase engine performance and lower emissions while preserving a comparable combustion behaviour to diesel fuel. Overall, these studies imply that combining bio-oil and biodiesel can enhance fuel characteristics, lower emissions, and improve engine efficiency. More study is required to optimise the blending ratio, increase blended fuel stability, and explore the long-term impacts of mixed fuel on the engine and environment.

Cheng, W., & Zhao, X. (2017). Effects of different biodiesel blends on engine performance and emissions in low temperature combustion. *Renewable Energy*, 105, 53-61[30]. This study examines the effects of different biodiesel blends on engine performance and emissions in low-temperature combustion. The authors suggest that

the addition of biodiesel to diesel fuel can reduce the emissions of nitrogen oxides (NO_x) and particulate matter (PM), while maintaining a similar engine performance as diesel fuel. **Kalghatgi, G. T. (2016).** Biodiesel combustion, emissions and emissions reduction. *Fuel Processing Technology*, 145, 111-131[31]. This review article summarizes the current knowledge on biodiesel combustion, emissions, and emissions reduction. The author suggests that biodiesel can reduce the emissions of carbon monoxide (CO), hydrocarbons (HC), and PM, while increasing the emissions of NO_x. The emissions reduction techniques, such as exhaust gas recirculation (EGR), injection timing, and fuel additives, can mitigate the emissions of NO_x.

Nadeem, M., Shahadat, M., Hussain, M., & Ahmad, M. (2018). A review on performance and emission characteristics of biodiesel fuelled diesel engines. *Journal of Cleaner Production*, 180, 144-158[32].

This review article provides information on the performance and characteristics of biodiesel fuelled diesel engines. The authors suggest that biodiesel can improve engine performance and increase NO_x emissions while reducing CO, HC and PM emissions. Small particles and nitrogen oxide emissions can be further reduced using exhaust aftertreatment such as a diesel particulate filter (DPF) and optional catalytic reduction (SCR). Collectively, these studies show that biodiesel blends can improve engine performance and increase NO_x emissions while reducing CO, HC and PM emissions. Adding ethanol to biodiesel-diesel blends can improve engine performance and reduce emissions. Reduction technologies such as EGR, injection timing and exhaust conditioning can reduce NO_x and PM emissions. More research is needed to improve blending, to examine the long-term effects of fuel blends on the engine and the environment, and to develop biodiesel blending emission reduction technologies.

CHAPTER 3

AIM AND SCOPE

3.1 AIM

- Investigation is led on hydrothermal liquefaction of algae, sludge, food waste and rice straw due to the efficiency of the process and good yield of bio oil.

- To prepare clean bio oil from day to day life biomass feedstocks.
- To perform engine test of the produced bio oils and study the engine characteristics of each bio oil.
- Optimizing the result and analysis of the test.

3.2 SCOPE

As India's primary energy demand will double by 2040, the use of alternative fuels such as biodiesel will surely increase. This fuel also helps reduce environmental impact, as the final product is 95% carbon-free. Biofuel produced by hydrothermal liquefaction of biomass is seen as an alternative fuel to fossil fuels. They also produce less pollution and are less corrosive in nature. The hydrothermal liquefaction process solves the need for fossil fuels by providing a stable solution.

CHAPTER 4

MATERIALS AND METHODS

The process of our project involves the following steps.

- Collection of biomass
- Catalyst preparation
- Hydrothermal liquefaction of biomass

- Collection of bio oil
- Bio-oil-diesel blends
- Engine testing of bio diesel blends

4.1. COLLECTION OF BIOMASS

The local sugarcane juice store provided the feedstock for our project. The collected sugarcane waste has been reduced to small bits and combined with water to create a slurry, which is subsequently processed in the hydrothermal liquefaction reactor.

4.2. CARBON NANOTUBES POWDER

Carbon nanotubes powder is a type of nanomaterial consisting of tiny cylindrical tubes made of carbon atoms. These nanotubes are incredibly small, with diameters as small as a few nanometers and lengths up to several millimeters. Carbon nanotubes are known for their unique mechanical, electrical, and thermal properties, making them useful in a wide range of applications. They are stronger than steel but are lightweight and flexible, which makes them ideal for use in materials that require high strength and low weight. They also have excellent electrical conductivity and can be used in electronic devices, such as transistors and sensors. Carbon nanotube powders can be produced by various methods such as chemical vapor deposition, arc discharge, and laser cutting. The resulting powder can be used as a raw material for the production of carbon nanotube products. One of the most important problems in the production of carbon nanotube powder is to control its properties such as size, shape and purity. The properties of the powder are related to the properties of the final product, so these properties must be carefully controlled. Overall, carbon nanotube powder is a promising nanomaterial with many applications in industries such as electronics, energy storage and biomedicine. As research continues to explore the properties and capabilities of these materials, we will see further expansion in this area.



Fig 4.1: Carbon nanotube powder

4.3. TITANIUM DIOXIDE

Titanium dioxide (TiO_2), a naturally occurring titanium oxide, is one of the most widely used materials in the world. It is an odorless and tasteless white powder widely used in many industries due to its special properties. One of the most important properties of titanium dioxide is its ability to reflect and scatter light, making it such a versatile material as paints, coatings and plastics. It is also used as a UV blocker in sunscreen products and as a preservative in food and cosmetics. Titanium dioxide can be produced by a number of methods, including sulfate, chloride, and hydrothermal. The Kraft method is the most widely used method, where ilmenite (a titanium-containing mineral) reacts with sulfuric acid to produce titanium dioxide. In addition to its optical properties, titanium dioxide is also known for its chemical stability, making it resistant to corrosion and degradation. This property makes it useful in many industrial applications such as catalyst, ceramics and electronics manufacturing.

Overall, titanium dioxide is a versatile and versatile material with unique properties that allow it to be used in a variety of applications. However, security issues should be carefully considered and resolved while using it.

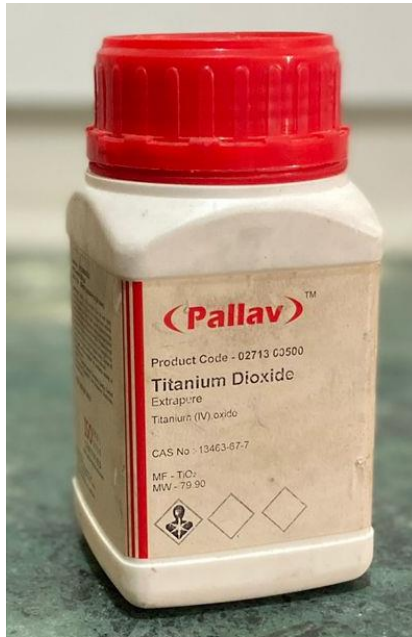


Fig 4.2: Titanium dioxide

4.4. TITANIUM CARBON NANOTUBES

Titanium carbon nanotubes are a type of hybrid material that combines the unique properties of both titanium and carbon nanotubes. These materials have been the subject of significant research interest in recent years due to their potential applications in various fields, including aerospace, electronics, and biomedicine. Carbon nanotubes are a type of nanomaterial made of carbon atoms arranged in a cylindrical shape. They are known for their excellent mechanical, electrical, and thermal properties, including high strength, flexibility, and electrical conductivity. However, they are often limited by their low chemical stability, which can lead to degradation and reduced performance over time. Titanium, on the other hand, is a metal known for its high chemical stability and resistance to corrosion. It is widely used in various applications, including aerospace and biomedical implants, due to its strength, bio compatibility, and low toxicity. By combining these two materials, researchers aim to create a new class of materials that have the best properties of both materials. Titanium carbon nanotubes can be synthesized through various methods, including chemical vapor deposition, electrochemical deposition, and hydrothermal synthesis. One of the most significant benefits of titanium carbon nanotubes is their high strength and stiffness. The titanium matrix provides excellent mechanical properties, while the carbon nanotubes provide additional reinforcement

and toughness. This combination of properties makes them ideal for use in structural applications that require high strength and durability, such as in aerospace and automotive components. In addition to their mechanical properties, titanium carbon nanotubes also exhibit excellent electrical conductivity, making them useful in electronic devices such as sensors and energy storage devices. They also have potential applications in the field of biomedicine, where their biocompatibility and low toxicity make them suitable for use in implants and drug delivery systems.

However, the development of titanium carbon nanotubes is still in the early stages, and several challenges need to be addressed before they can be used in commercial applications. One of the most significant challenges is achieving uniform dispersion of carbon nanotubes within the titanium matrix, which can affect the overall performance of the material. Researchers are exploring various methods to address this challenge, including surface modification of carbon nanotubes and optimization of the synthesis process.

Another challenge is the scalability of the production process. Current methods for synthesizing titanium carbon nanotubes are often expensive and time-consuming, making them unsuitable for large-scale production. Researchers are exploring various methods to improve the efficiency and cost-effectiveness of the synthesis process, including the use of novel precursors and alternative synthesis methods. Despite these challenges, the potential applications of titanium carbon nanotubes are vast, and research in this field is ongoing. As the synthesis and characterization techniques continue to improve, we can expect to see even more exciting developments in this area in the future.

4.5. CATALYST PREPARATION WITH CARBON NANOTUBES AND TITANIUM DIOXIDE.

- We have prepared titanium-carbon nanotube catalyst in six different ratios by keeping the carbon nanotubes constant and varying the amount of titanium dioxide used.
- Titanium dioxide dissolved completely in 1N.H₂SO₄ solution, the preparation of 1N.H₂SO₄ includes dissolving 9.2 ml of H₂SO₄(conc) in 100 ml of distilled water.
- The required amount of titanium dioxide was mixed with 35ml of 1N.H₂SO₄ soln and stirred well with the help of magnetic stirrer.
- 50mg\100mg of carbon nanotubes was dissolved in 35ml of ethanol and stirred well with the help of magnetic stirrer.
- Then both the solutions were mixed together and stirred well with magnetic stirrer.
- The stirred solution is then transferred into small HTL reactor and kept in hot air oven at 150 degree Celsius for 6 hours and then cooled overnight.
- The next morning a solid composite has been formed inside the reactor which is collected and centrifuged 3 times with distilled water and one time with ethanol and then the solid composite is collected and dried in oven and crushed into fine powder and transferred to an air tight container.



Carbon nanotubes
in ethanol



Titanium dioxide
In 1N.H2SO4



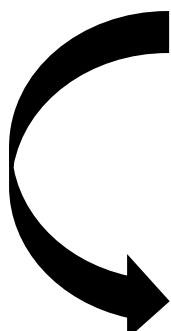
Mini Hydrothermal
reactor



Centrifugation of solid
composite



Drying of the centrifuged solid
composite



Grinding of the solid composite



Final solid composite

Fig 4.3: Overview of catalyst preparation

Table 4.1: Quantity of c-nanotubes and TiO₂

Amount of carbon nanotubes mixed with ethanol(mg)	Amount of titanium dioxide mixed with 1N.H ₂ SO ₄ soln (g)
50	0.72
50	1.42
50	2.15
100	0.72
100	1.42
100	2.14

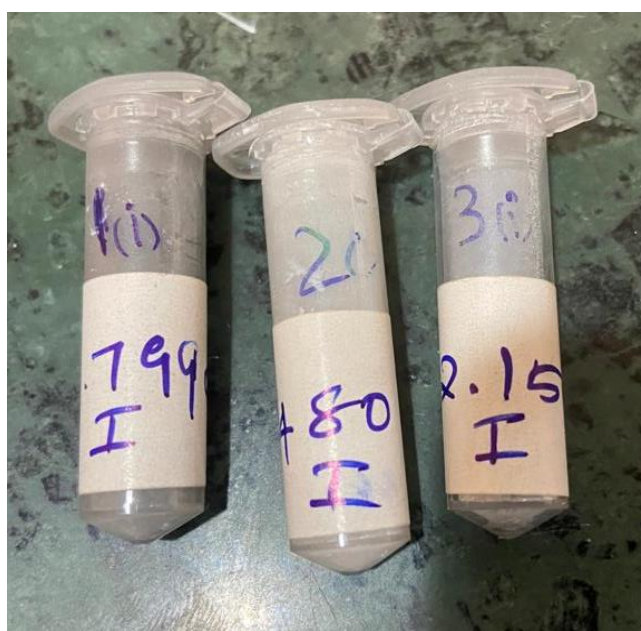


Fig 4.4: Titanium carbon nanotubes catalyst

4.6. HYDROTHERMAL LIQUEFACTION PROCESS

Hydrothermal liquefaction (HTL) is a process that involves converting biomass into liquid biofuel through the application of high pressure and heat in a confined space. This process offers several advantages over other methods of biomass conversion, such as pyrolysis and gasification, as it operates at lower temperatures, reduces energy requirements, and produces liquid products that are suitable for mass production. The HTL process involves four main stages: pre-treatment, liquefaction, product separation, and product recovery. The type of biomass feedstock used, the particle size, reaction temperature, reaction time, pressure, and catalysts can all affect the efficiency, yield, and quality of the final product. For example, feedstock with a higher lipid content, such as algae, may be more suitable for producing biofuels. A smaller particle size can increase the contact area between the biomass and the solvent, improving the process's efficiency. Higher temperatures can increase the rate of chemical reactions, but also increase thermal degradation. Longer reaction times can increase the conversion of biomass to liquid products but can also produce unwanted by-products. Higher pressure can increase the solubility of biomass in the solvent but require more energy to maintain. The addition of catalysts can improve the yield and quality of the final product, but their cost and availability may limit the commercialization of the HTL process. Optimizing these factors is critical for the commercialization and widespread adoption of the HTL process as a sustainable method for producing biofuels and other high-value products.

4.7. HYDROTHERMAL REACTOR

A hydrothermal reactor is a type of vessel designed for conducting chemical reactions in the presence of water under high pressure and temperature conditions. The reactor typically comprises a reaction vessel made of materials that resist corrosion, such as stainless steel, and a heating system that can be a resistance heater or a microwave oven. The reaction vessel is sealed to prevent the escape of water or reactants under high pressure.

Hydrothermal synthesis is one of the processes carried out using the hydrothermal reactor, and it involves synthesizing various materials, such as nanomaterials, zeolites, and metal oxides under high temperature and pressure conditions. The reactor provides an ideal environment for the synthesis process, as the presence of water can serve as a reactant and a solvent.

The hydrothermal liquefaction process is another application of the hydrothermal

reactor, used to convert biomass into liquid biofuels and other valuable products. This process involves heating the biomass in the presence of water at high pressure and temperature, which breaks down the biomass into liquid form. The resulting liquid product is further refined to produce fuels or chemicals.

In addition to these applications, the hydrothermal reactor is also utilized in the study of hydrothermal vents and the ecosystems they support. Hydrothermal vents are geysers located underwater that emit hot water and minerals, and the hydrothermal reactor can simulate the conditions found at these vents, facilitating the study of the chemistry and biology of these unique ecosystems.

In summary, the hydrothermal reactor is a vessel used to conduct chemical reactions in the presence of water under high pressure and temperature conditions. Its applications include hydrothermal synthesis, hydrothermal liquefaction, and the study of hydrothermal vents and their associated ecosystems. The reactor's ability to provide an ideal environment for these processes is due to the high pressure and temperature conditions and the presence of water.

4.8. CATALYST LOAD EFFECT ON HYDROTHERMAL LIQUEFACTION

Catalysts are extensively employed in the hydrothermal liquefaction (HTL) process to increase the output and quality of liquid biofuels and other high-value biomass products. The influence of catalyst load on the HTL process has been widely investigated in recent years, and the results reveal that the catalyst load can have a substantial impact on the HTL process's efficiency and yield. The amount of catalyst added to the HTL reactor in relation to the amount of biomass is referred to as the catalyst load. Depending on the kind of catalyst and the specific HTL method, the catalyst load might range from a few percent to as much as 50% by weight. Increasing the catalyst load has been demonstrated in studies to enhance the efficiency and yield of the HTL process. The catalyst can help to break down complex organic compounds in biomass into simpler ones that can subsequently be turned into liquid biofuels and other high-value products. The catalyst can also shorten the reaction time and temperature necessary for the HTL process, lowering energy needs and costs. High catalyst load can further raise the cost of the process since catalysts are costly and difficult to dispose of. A number of experiments have been conducted in order to establish the best catalyst load for the HTL process. According to these investigations,

the ideal catalyst load varies depending on the kind of biomass, the type of catalyst, and the exact HTL technique employed. The ideal catalyst load has been determined to be between 5% and 20% by weight. Increasing the catalyst load, on the other hand, might have certain detrimental impacts on the HTL process. High catalyst load can result in the development of undesirable byproducts like as char and coke, which can impair end product yield and quality.

The below table show that, catalyst load varies and the temperature 300°C and biomass 90g reminds constant.

Unit - wt%

Solvent - 1 L

Table 4.2: Effect of Catalyst

Catalyst load	Biochar	Bio-oil	Aqueous phase	Gaseous phase
1	14.8	25.7	33.5	26
2	13.1	28.4	31.2	27.3
3	11.1	29.4	27.4	32.1
4	9.4	28.4	28.4	33.8
5	10.4	26.8	29.5	33.3

4.9. TEMPERATURE EFFECTS ON HYDROTHERMAL LIQUEFACTION

Temperature is a crucial factor that plays a vital role in the efficiency and yield of the hydrothermal liquefaction (HTL) process. HTL involves heating biomass in the presence of water at high temperatures and pressures, breaking down complex organic molecules into simpler molecules that can be converted into liquid biofuels and other high-value products. The temperature effects on the HTL process has been extensively researched, and it has been found that temperature has a significant impact on the efficiency and yield of the process. Studies have shown that increasing the temperature promotes the breakdown of complex organic molecules into simpler molecules, resulting in higher yields of liquid biofuels and other high-value products. The reaction rate increases as the temperature rises, leading to a reduction in reaction time and an overall improvement in the process's efficiency. However, there exists an optimal temperature range for the HTL process, beyond which the efficiency and yield

begin to decline. The optimal temperature range varies depending on the type of biomass used and the specific HTL process employed. Typically, the optimal temperature range for the HTL process is between 250°C and 350°C.

Temperatures above the optimal range can lead to the formation of unwanted by-products such as char and coke, reducing the yield and quality of the final product and causing fouling of the reactor and other process equipment. Additionally, higher temperatures increase the energy requirements and the cost of the process as they demand more energy to maintain. To commercialize and widely adopt the HTL process as a sustainable and viable method for producing biofuels and other high-value products, finding the optimal temperature range is critical. Therefore, it is essential to maintain a balance between temperature and efficiency to maximize the yield and quality of the final product while minimizing the formation of unwanted by-products.

The below table shows that, Temperature varies and the Catalyst and biomass 50g remains constant.

Unit - **wt%**

Solvent - **1 L**

Table 4.3: Effects of Temperature

Temperature	Biochar	Bio-oil	Aqueous phase	Gaseous phase
240	17	18.4	33.4	31.2
260	16.1	20.4	31.5	32
280	14.5	23.4	28.4	33.7
300	15	22.1	27.5	35.4
320	15.3	20.8	29.5	34.4

4.10. EFFECT OF BIOMASS LOAD ON HYDROTHERMAL LIQUEFACTION

The biomass load refers to the amount of biomass that is fed into the HTL reactor. The effect of biomass load on the HTL process is complex and can vary depending on several factors, including the type of biomass, the reactor design, and the operating conditions. However, in general, increasing the biomass load can lead to the following effects:

1. Increased product yields: One of the main benefits of increasing the biomass load is an increase in the product yields. This is because more biomass means more feedstock for the HTL process, which can result in higher bio-oil yields. However, it is important to note that there is a limit to how much biomass can be loaded into the reactor before the process becomes inefficient.
2. Increased viscosity: As the biomass load increases, the viscosity of the feedstock can also increase. This can make it more difficult for the feedstock to flow through the reactor and can require higher pressures and temperatures to achieve the desired reaction conditions.
3. Decreased heating rate: As the biomass load increases, it can take longer for the feedstock to reach the desired reaction temperature. This is because the heat transfer rate is reduced due to the increased mass of the biomass in the reactor.
4. Increased reactor size: Increasing the biomass load can also require a larger reactor size to accommodate the additional feedstock. This can increase the capital and operating costs of the HTL process.

The biomass load is an important parameter that can affect the efficiency of the HTL process. While increasing the biomass load can lead to higher product yields, it can also increase the viscosity of the feedstock, decrease the heating rate, and require a larger reactor size. Thus, the optimal biomass load for the HTL process will depend on several factors and will need to be determined on a case-by-case basis.

The below table shows that, Biomass load varies and the temperature 300 °C and catalyst remains constant.

Unit - wt%

Solvent - 1 L

Table 4.4: Effect of Biomass load

Biomass	Biochar	Bio-oil	Aqueous phase	Gaseous phase
40	19.4	16.4	31.2	33
50	18.1	17.5	30.2	34.2

60	16.4	19.8	32.5	31.3
70	15.1	21.3	29.4	34.2
80	13.5	24.1	27.5	34.9
90	14.5	26.7	29.5	29.3
100	16.7	24.5	30.2	28.6

4.11. BIO-OIL FROM SUGARCANE BIOMASS THROUGH HYDROTHERMAL LIQUEFACTION

Hydrothermal liquefaction (HTL) is a potential process for turning sugarcane biomass into bio-oil. The biomass is heated at high pressure and temperature with water, which breaks down the complex organic molecules into simpler ones that can be turned into bio-oil. Byproducts like as char and coke are also produced as solid and gaseous byproducts of the process. The kind of sugarcane biomass, operating conditions, and the presence of a catalyst all influence the quality and production of bio-oil generated by the HTL process. For example, using FeCl_3 as a catalyst may raise bio-oil production to 52.9% at 300°C for 60 minutes. Another study discovered that sugarcane waste produced bio-oil with a high energy density and low oxygen content. Bio-oil, on the other hand, has a high oxygen content and a low heating value, limiting its utility as a transportation fuel. Catalytic hydrotreating can improve its characteristics and make it viable as a transportation fuel. More study is needed to optimise the HTL process and enhance the qualities of sugarcane biomass-derived bio-oil as a sustainable alternative to existing fossil fuels.

Several procedures and parameters must be optimised to produce the maximum potential production and quality of bio-oil from sugarcane waste using hydrothermal liquefaction (HTL). A typical HTL process approach includes various steps and procedures that must be properly regulated. This includes selecting the best sugarcane waste, determining ideal operating variables such as temperature, pressure, and residence time, and using catalysts to improve the Process. Maximum bio-oil production and quality may be achieved from sugarcane waste using this technology via the HTL process. The powdered waste is put into a high-pressure reactor with a precise amount of water to begin the hydrothermal liquefaction (HTL) process of sugarcane waste. It is critical to evaluate the water-to-biomass ratio since

it has a major influence on the yield and quality of the bio-oil produced. For best HTL results, the water-to-biomass ratio should be between 2:1 and 5:1. After loading the powdered sugarcane waste into the high-pressure reactor with the set amount of water, the reactor is heated to a certain temperature and pressurised to a specific pressure range. Temperatures normally vary from 250°C to 350°C, while pressures typically range from 10 MPa to 25 MPa. The heating and pressurisation of the reactor are critical parameters that affect the ultimate yield and quality of the bio-oil generated by the hydrothermal liquefaction (HTL) process.

4.12. SEPARATION OF HTL PRODUCTS

The process of Hydrothermal Liquefaction (HTL) of sugarcane biomass generates bio-oil, aqueous phase, and solid residue (char), which need to be separated to obtain the bio-oil for further processing. Several methods, such as filtration, centrifugation, decantation, solvent extraction, and distillation, can be employed to separate the HTL products depending on their properties and the desired separation efficiency. Filtration is a commonly used method to separate solid residue from the aqueous phase and bio-oil, which involves selecting a suitable filter medium, pre-filtering the mixture of products, passing it through the filter medium, and washing the solid residue after filtration. The filtered bio-oil and aqueous phase can be separated by gravity or centrifugation. Efficient recovery of bio-oil is crucial for effective and efficient production of bio-oil from sugarcane biomass by HTL. Optimal selection of filter media and process parameters such as pressure, flow, and temperature can enhance the separation process and boost the quality and yield of bio-oil.

4.13. PROPERTIES OF BIO-OIL OBTAINED.

Unit- wt%

Table 4.5: Properties of bio-oil obtained

	C	H	N	S	O	HHV	H/C	O/C
Biomass	41.2	7.23	2.12	0.12	49.33	15.44464	2.105825	0.897998

Bio-oil	68.2	10.3	1.89	0.56	19.05	34.35958	1.812317	0.209494
Bio char	79.23	6.89	2.56	0.12	11.2	34.61946	1.043544	0.10602

4.14. PREPARING FUEL BLENDS

Bio-oil, also called pyrolysis oil, is a renewable fuel source that can be used in diesel engines. It is produced from biomass through HTL, a process that involves heating organic material in the absence of oxygen to produce a liquid oil. The properties of bio-oil, such as its viscosity and density, can vary depending on the feedstock and pyrolysis process used. Hence, it is essential to carefully select and test the bio-oil to ensure that it is compatible with the engine and meets the required fuel specifications. Using bio-oil in diesel engines can offer several benefits, such as reduced greenhouse gas emissions and reliance on fossil fuels. However, using biofuel as fuel for generators can present several challenges, including engine oil and chemical contamination. Therefore, special care must be taken when using bio-oil as a fuel in diesel engines. Engine and operation must be carefully evaluated for the safe and effective use of biofuel.

The kinematic viscosity of the Bio oil is 6.31 mm²/s, while its density is 868 kg/m³. These properties provide essential information regarding the Bio oil's flow behavior and physical characteristics. A lower kinematic viscosity suggests that the Bio oil has less resistance to flow and may flow more easily than fluids with higher viscosities. On the other hand, its density of 868 kg/m³ indicates that the Bio oil is relatively lightweight, which may have a lower viscosity compared to oils with higher densities. The knowledge of these properties is crucial for various applications of Bio oil, such as lubrication, as well as cosmetic or skincare products. Understanding the flow behavior and physical properties of the Bio oil can aid in selecting the appropriate application of the oil in different scenarios.

4.2. ENGINE TESTING AND ANALYSIS

An eddy current type dynamometer is used to load the single-cylinder, four-stroke diesel engine for engine study. For measuring crank angle and combustion pressure, the necessary tools are provided.

4.2.1 Engine Details

Table 4.2: Engine specifications

Engine Model	Kirloskar TV1
No of Cylinder	1
No of Strokes	4
Cubic Capacity (liter)	0.661
Rated Speed (rpm)	1500
Power	5.20KW
Power Rating	7 hp
Cylinder Bore(mm)	87.50
Stroke Length(mm)	110.00
Connecting rod length(mm)	234
Compression ratio	17.50
Pump	Type Monobloc
Cooling type	Water cooled
Over all dimensions	Width 2000*length2500*height1500mm.
Dynamometer	Eddy current type water cooled
Software	Engine Soft

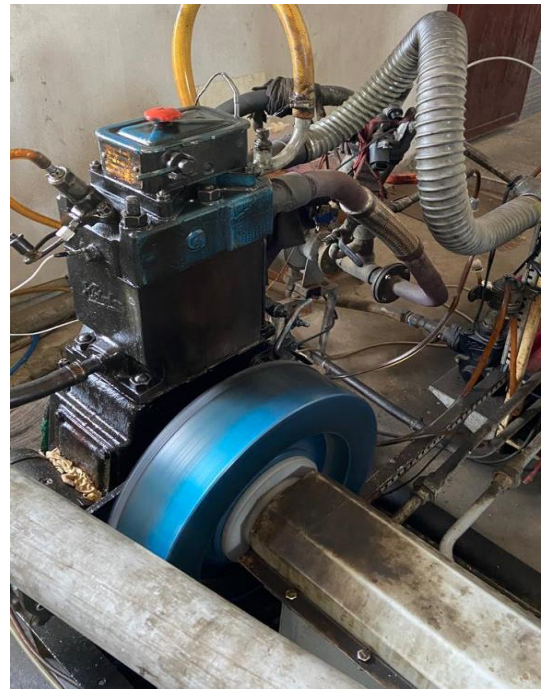


Fig 4.5: Engine testing setup

4.2.2 Engine Test Rig Components:

The Engine test rig is made up of a single-cylinder four-stroke diesel engine that is linked to the following components in the following order:

1. Eddy Current dynamometer (engine loading)
2. Panel box
3. AVL Smoke meter
4. Gas Analyzer
5. Fuel tank
6. Manometer
7. Fuel measuring unit
8. Digital speed indicator

9. Temperature Indicator



Fig 4.6: Gas analyzer and Smoke meter

Engine testing of bio oil as a fuel requires the use of specialized instruments such as a smoke meter and gas analyzer to measure the exhaust emissions and ensure compliance with emissions regulations. A smoke meter is used to measure the opacity of the exhaust emissions from an engine, which indicates the level of particulate matter emissions. The higher the opacity, the higher the level of particulate matter emissions. On the other hand, a gas analyzer is used to measure the concentration of different gases in the engine exhaust, such as carbon monoxide, nitrogen oxides, and hydrocarbons. This instrument provides a comprehensive analysis of the engine exhaust, allowing for the measurement of different pollutants and their concentrations. The smoke meter and gas analyzer work together to provide a comprehensive picture of the engine exhaust emissions, which is necessary for ensuring compliance with emissions regulations. The combustion of bio oil as a fuel can produce higher levels of particulate matter and other pollutants than conventional diesel fuel. Therefore, careful monitoring of the engine emissions is necessary to ensure that the bio oil fuel meets the required emissions standards. These instruments are essential for evaluating the performance of bio oil as a fuel and optimizing engine performance.

CHAPTER 5

RESULTS AND DISCUSSION

Engine testing is an important step in evaluating the performance of bio-oil as a fuel. After conducting engine tests, the results and discussion section should present the findings and discuss their implications. Graphs are used to illustrate and discuss the outcomes of the investigations. Brake thermal efficiency, specific fuel consumption, volumetric efficiency, and exhaust gas temperature are among the performance metrics. The combustion type of the engine is measured using cylinder pressure, Pressure volume graph and heat release rate. Carbon monoxide, unburned hydrocarbons, NOX, smoke opacity, and carbon dioxide are among the emission parameters.

5.1 PERFORMANCE PARAMETERS:

This section explains the performance aspects of blended fuel such as brake thermal efficiency, specific fuel consumption, volumetric efficiency, and exhaust gas temperature.

5.1.1 Brake thermal efficiency:

Brake thermal efficiency (BTE) is an essential performance indicator for evaluating the efficiency of internal combustion engines. It measures how efficiently the engine converts the fuel's chemical energy into useful mechanical work. It is calculated by dividing the engine's brake power output by the heat energy in the fuel consumed. A higher BTE means the engine can convert more of the fuel's energy into useful work, resulting in improved fuel economy and reduced emissions. In this regard, optimizing engine design and operation to improve BTE is a critical research area for developing more efficient and sustainable engines. Therefore, measuring and improving BTE is essential for enhancing the overall performance and environmental impact of engines.

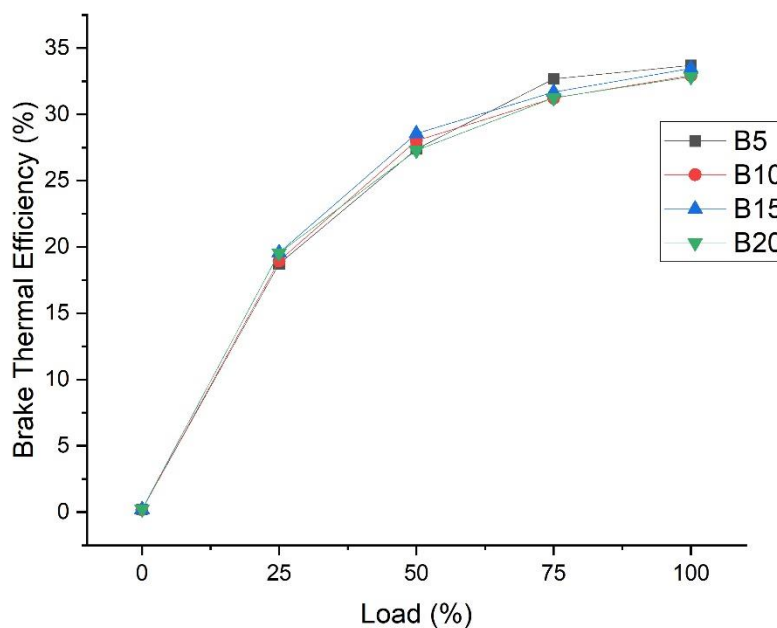


Fig 5.1: Brake thermal efficiency

An increase in BTE represents an improvement in engine efficiency, which translates into better fuel economy and reduced emissions. This makes increasing BTE a desirable outcome for engine manufacturers, researchers, and users alike.

Conversely, a decrease in BTE is an undesirable outcome as it indicates a reduction in engine efficiency. This can lead to reduced fuel economy, increased emissions, and lower power output. Several factors can cause a decrease in BTE, such as low-quality fuel, inefficient combustion, and mechanical losses in the engine. Therefore, improving BTE is a critical area of research to develop more efficient and sustainable engines.

Several studies have investigated the effect of various fuel properties on BTE. For instance, a study conducted by Zhang et al. (2021) found that increasing the cetane number of diesel fuel can improve BTE in a diesel engine. Similarly, Liu et al. (2020) found that blending bio-oil with diesel fuel can improve BTE due to the enhanced combustion characteristics of the blended fuel.

Other studies have focused on improving BTE by optimizing engine parameters such as compression ratio and fuel injection timing. For instance, a study by Wang et al. (2019) investigated the effect of injection timing and compression ratio on BTE in a diesel engine and found that adjusting these parameters can significantly improve BTE.

5.1.2 Specific fuel consumption

Specific fuel consumption (SFC) is a critical parameter for evaluating the fuel efficiency of internal combustion engines. SFC is defined as the amount of fuel consumed by the engine per unit time per unit power output. In other words, it represents the rate of fuel consumption of an engine for producing a given amount of power. SFC is an essential metric for engine design and optimization as it directly affects the engine's fuel economy and operating cost. A reduction in SFC can lead to improved fuel economy, reduced emissions, and lower operational costs. Therefore, engine manufacturers and researchers are continually seeking new technologies and strategies to reduce SFC and improve engine efficiency.

In summary, specific fuel consumption is a key parameter for evaluating the fuel efficiency of internal combustion engines. It represents the rate of fuel consumption of an engine for producing a given amount of power and is a critical metric for engine design and optimization.

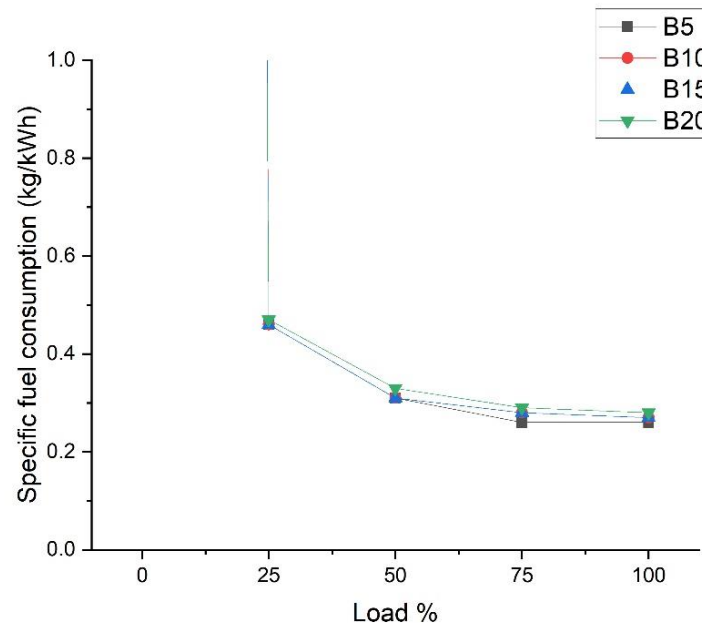


Fig 5.2: Specific fuel consumption

High SFC means that the engine consumes more fuel per unit time per unit power output. This indicates that the engine is less fuel-efficient and will consume more fuel to produce the same amount of power compared to an engine with a lower SFC. A high SFC leads to increased fuel costs, higher emissions, and reduced fuel economy. On the other hand, a low SFC indicates a more fuel-efficient engine that consumes less fuel to produce the same amount of power. This leads to lower fuel costs, reduced emissions, and improved fuel economy.

One study by Xie et al. (2020) focused on the effect of fuel properties on SFC and engine performance in a diesel engine. The researchers investigated the impact of different biodiesel blends on SFC and observed that higher biodiesel content led to lower SFC and improved engine efficiency. They also noted that the engine performance was influenced by fuel properties such as viscosity, density, and heating value.

Overall, these studies highlight the importance of optimizing engine operating conditions and fuel properties to reduce SFC and improve engine efficiency. By developing new strategies and technologies to improve SFC, it is possible to achieve better fuel economy, reduced emissions, and improved engine performance.

5.1.3 Volumetric efficiency

Volumetric efficiency is a measure of an engine's ability to fill its combustion chambers with air and fuel mixture during the intake stroke. It is expressed as a percentage and is calculated by dividing the actual volume of air and fuel mixture entering the combustion chamber by the theoretical maximum volume that the engine can hold. Volumetric efficiency is an essential parameter for engine designers and tuners as it provides a measure of the engine's ability to produce power. It is often used in engine tuning to optimize the engine's air and fuel delivery system for maximum performance.

An engine with a high volumetric efficiency can fill its combustion chamber more effectively, resulting in better combustion and improved engine performance. This is because a high volumetric efficiency allows more air and fuel mixture to be supplied to the engine, which in turn produces more power.

According to S. Yang and Z. Huang, one of the most effective techniques is forced induction, which involves using a supercharger or turbocharger to compress the incoming air and increase its mass flow rate. This technique can significantly enhance the volumetric efficiency of an engine.

Another method is variable valve timing (VVT), which allows for the adjustment of the valve lift and timing to optimize the airflow into and out of the cylinder. As noted by T. Hu, Z. Cui, and S. Cai, VVT can improve volumetric efficiency by up to 20%.

Furthermore, modifying the intake and exhaust systems can enhance volumetric efficiency. A larger diameter exhaust system, for example, can improve the flow of exhaust gases out of the engine, allowing more air to enter the cylinder during the intake stroke. A cold air intake system, on the other hand, can provide cooler and denser air to the engine, improving volumetric efficiency. These techniques are discussed by J. Van Basshuysen and F. Schäfer in their book, *Internal Combustion Engine Handbook*.

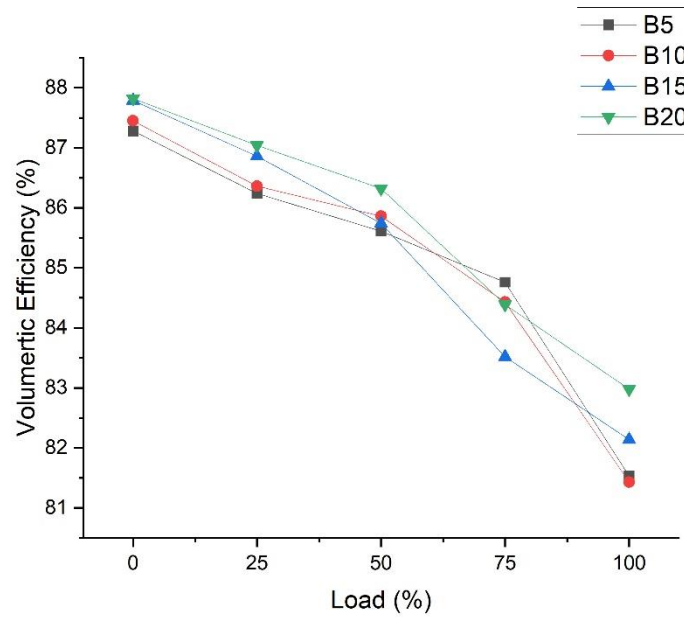


Fig 5.3: Volumetric Efficiency

5.1.4 Exhaust gas temperature

Exhaust gas temperature (EGT) refers to the temperature of the gases that are expelled from an internal combustion engine during the exhaust stroke. The EGT is a critical parameter in engine tuning and performance analysis, as it provides an indication of the engine's operating conditions and efficiency.

The temperature of the exhaust gas is affected by several factors, including the engine's fueling and ignition timing, engine load, and the quality of the fuel being used. When fuel is burned inside the engine cylinder, it produces heat, which raises the temperature of the exhaust gas. A higher engine load or more aggressive ignition timing can increase the temperature of the exhaust gas, while a richer fuel mixture can lower the EGT.

Monitoring the EGT is essential in high-performance engines, as excessively high exhaust gas temperatures can lead to engine damage, such as burned exhaust valves, cracked exhaust manifolds, and damaged turbochargers. A too-low EGT, on the other hand, can indicate incomplete combustion or insufficient fueling, which can result in a loss of engine power and increased fuel consumption.

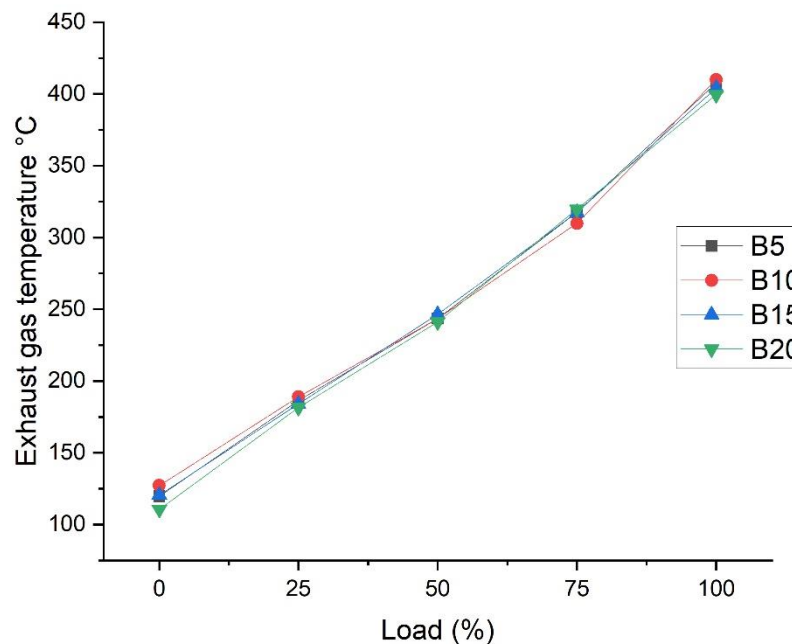


Fig 5.4: Exhaust gas temperature

5.2 COMBUSTION CHARACTERISTICS:

This section describes the combined properties of the mixture, such as heat release rate, cylinder pressure, and pressure-volume diagram. Graphs are also created and analyzed.

5.2.1 Cylinder pressure

Cylinder pressure in a diesel engine refers to the pressure generated within the combustion chamber during the combustion process. This pressure is the result of the collision of fuel and air mixing in the cylinder, which makes the pressure faster and stronger.

The cylinder pressure in a diesel engine is a critical parameter that can provide valuable information about the engine's performance and efficiency. This pressure is directly related to the amount of power that the engine can produce, and monitoring it can help identify issues such as faulty fuel injection or damaged components.

Diesel engines operate using a compression ignition process, which relies on high cylinder pressures to ignite the fuel-air mixture. As the piston compresses the mixture, the pressure and temperature within the cylinder rise, reaching a point where the fuel ignites spontaneously. The resulting combustion process generates a significant amount of pressure, which drives the piston downward, producing mechanical work.

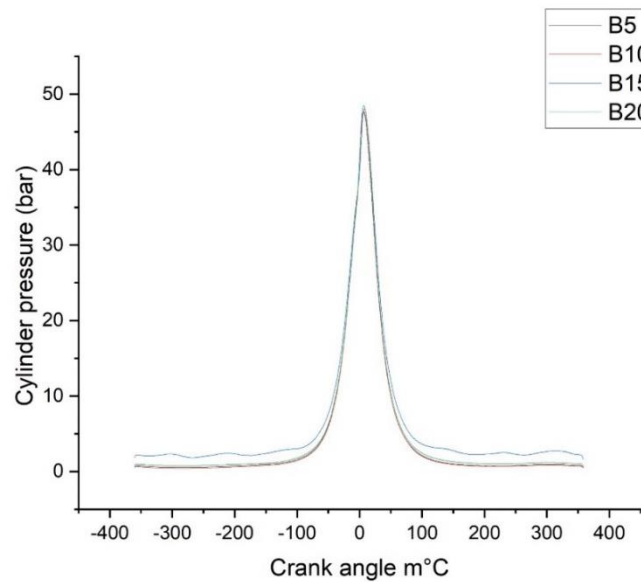


Fig 5.5: Cylinder Pressure at 0% Load

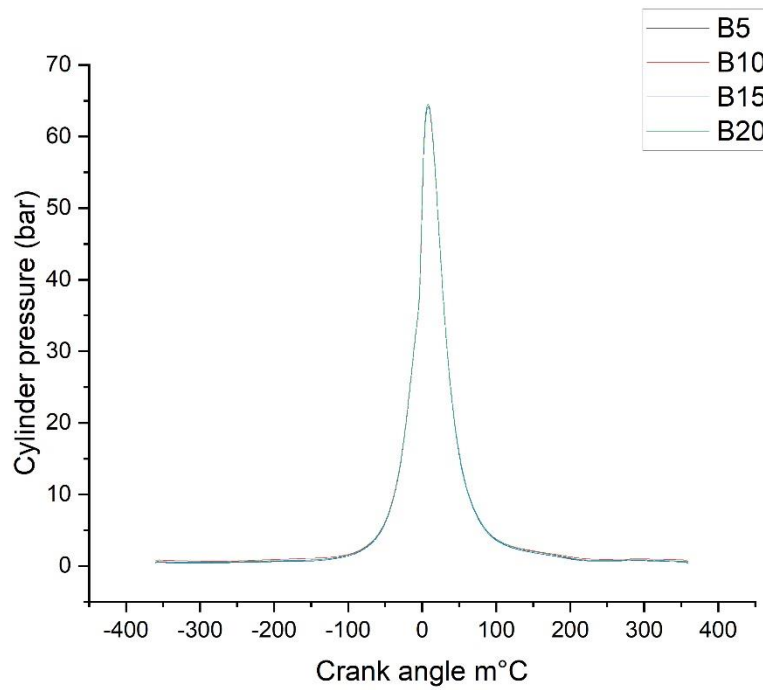


Fig 5.6: Cylinder Pressure at 25% Load

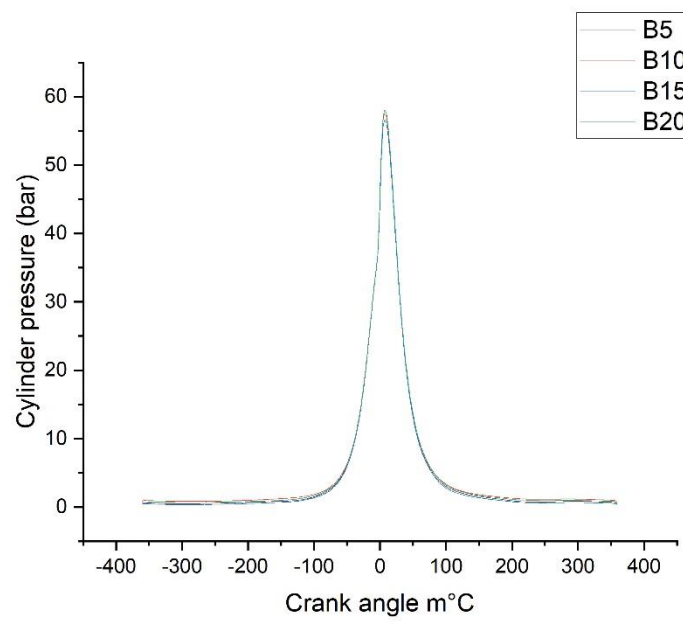


Fig 5.7: Cylinder Pressure at 50%% Load

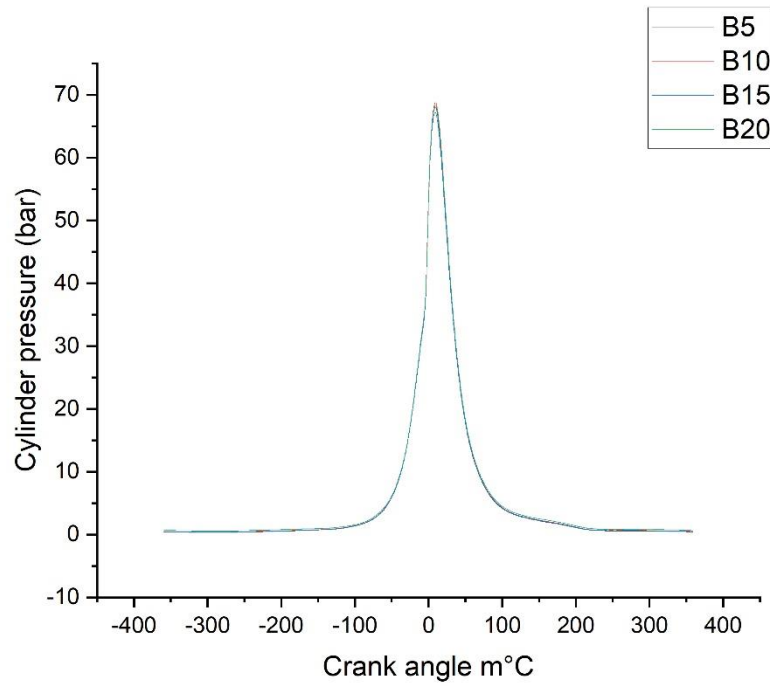


Fig 5.8: Cylinder Pressure at 75% at Load

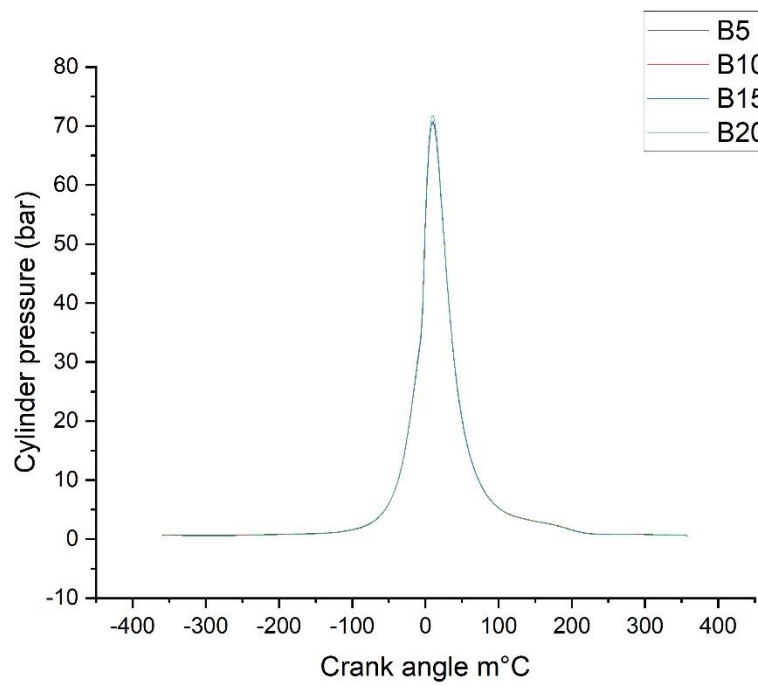


Fig 5.9: Cylinder Pressure at 100% Load

The graph is shown with the crank angle in the x-axis and the cylinder pressure in the y-axis for various loads, including 0%, 25%, 50%, 75%, and 100%. In all, 5 graphs are therefore concurrently drawn for each load.

S. Song and Y. Park discuss the importance of cylinder pressure measurement for the analysis and control of diesel engines.

P. Tunestål and B. Johansson investigated the effect of gas recirculation (EGR) on cylinder pressure and combustion in their article "Effect of EGR on Combustion in Diesel Engines". They used a combination of experiments and numbers to examine the effects of EGR on mixture timing, cylinder pressure and emissions.

5.2.2 Net Heat rate

Net Heat Rate (NHR) is an important performance parameter for diesel engines that describes the amount of energy required to produce a unit of power output. It is defined as the ratio of the fuel energy input to the engine to the power output of the engine, expressed in units of energy per unit of power.

Diesel fuel properties, such as the cetane number and energy content, can also affect the NHR of a diesel engine. Fuels with higher cetane numbers and energy contents can lead to lower NHR values by improving combustion efficiency and reducing the amount of fuel needed to produce a unit of power output. In summary, Net Heat Rate is an important performance parameter for diesel engines that describes the amount of energy required to produce a unit of power output. It is affected by several factors including engine design, operating conditions, and fuel properties, and can be improved through optimization of these factors.

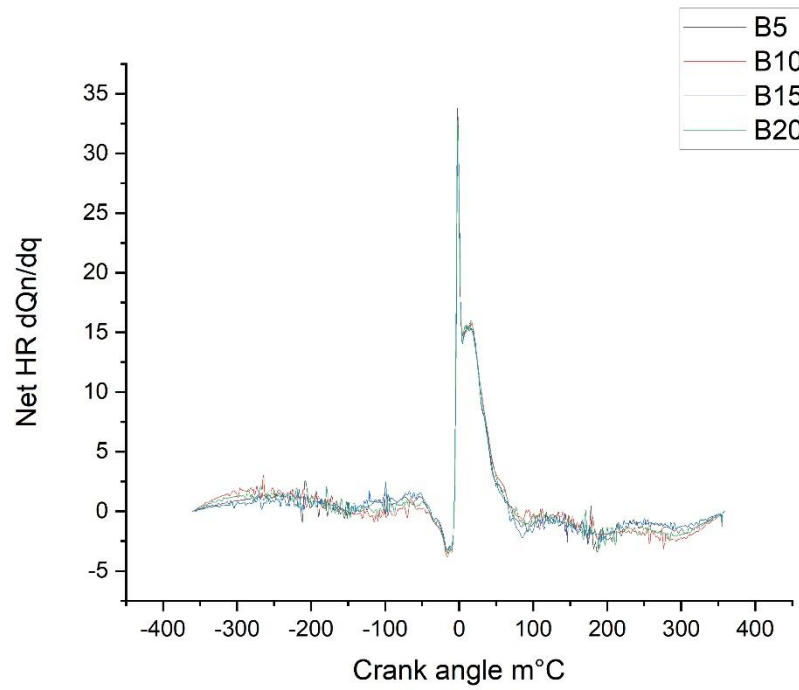


Fig 5.10: Net Heat rate at 0% Load

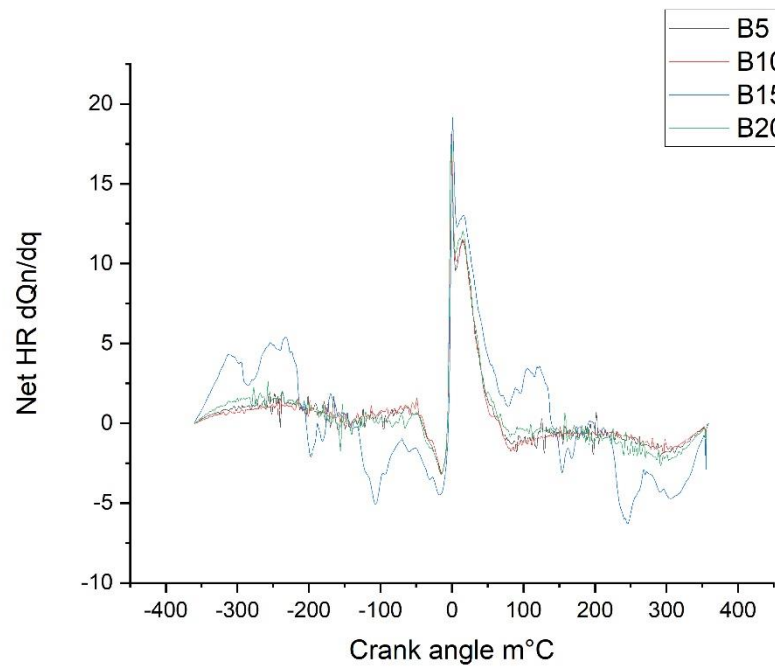


Fig 5.11: Net Heat rate at 25% Load

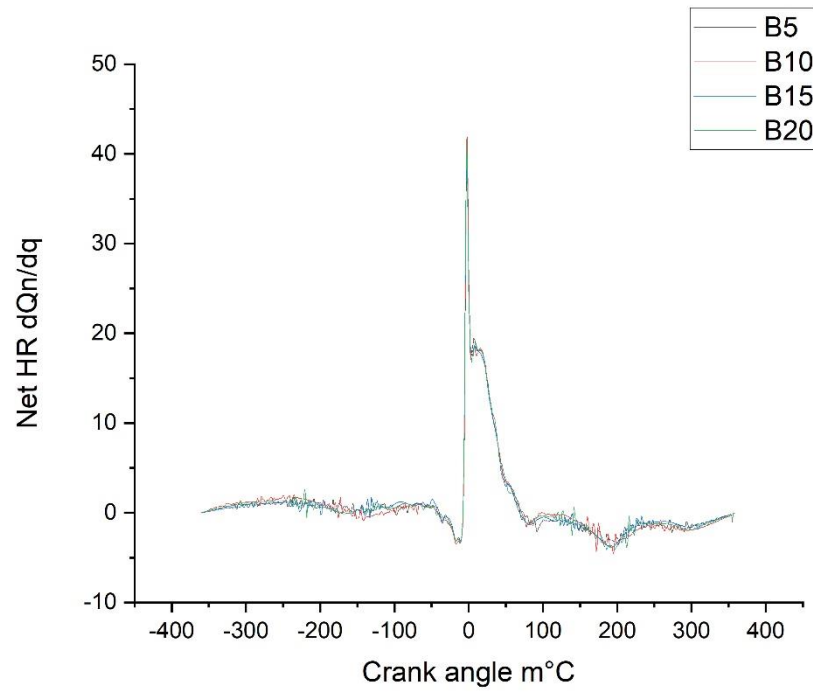


Fig 5.12: Net Heat rate at 50% Load

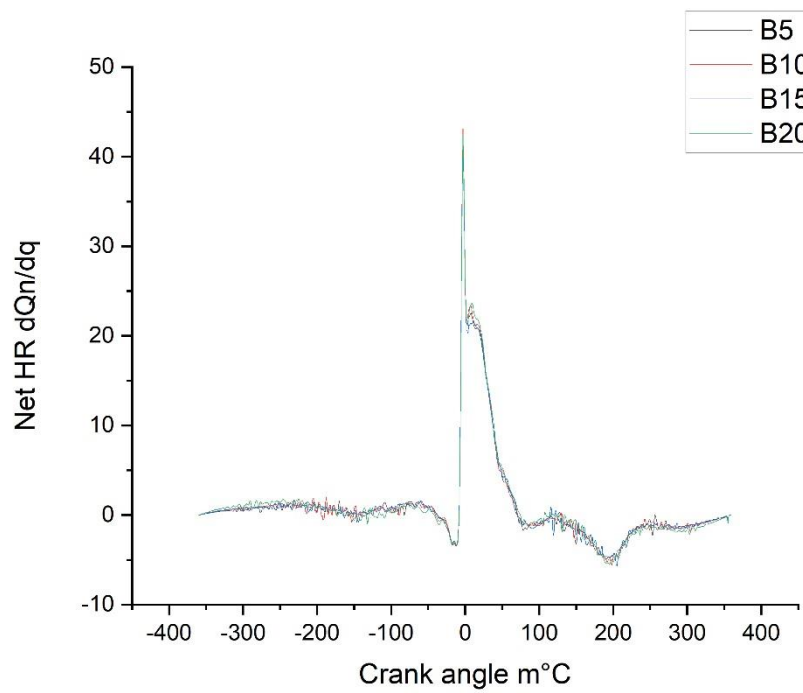


Fig 5.13: Net Heat rate at 75% Load

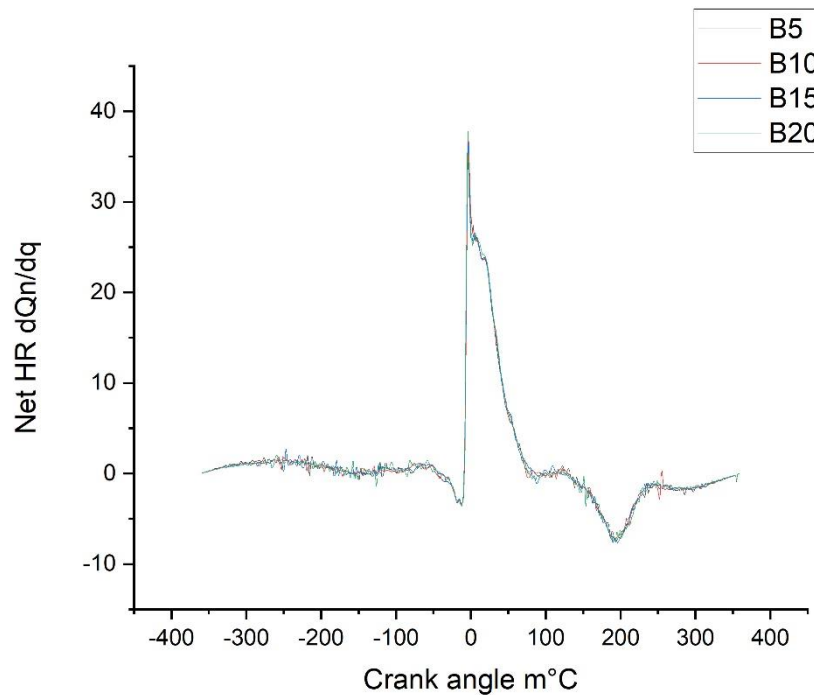


Fig 5.14: Net Heat rate at 100% Load

The NHR of a diesel engine is affected by many factors such as engine design, operation and fuel consumption. Engine design improvements, such as higher compression ratios and improved combustion chamber geometry, can reduce NHR values by optimizing the combustion process. Likewise, optimizing engine performance, such as adjusting fuel injection timing and ratio, can improve fuel efficiency and reduce NHR values.

In their paper "Influence of Injection Pressure and Timing on Net Heat Release Rate and Fuel Conversion Efficiency in a DI Diesel Engine," S. Saravanan and R. Velraj investigate the effects of injection pressure and timing on NHR and fuel conversion efficiency in a diesel engine. They use experimental methods to study the impact of these parameters on combustion characteristics, NHR, and fuel consumption.

P. Gupta, A. Agarwal, and A. K. Srivastava study the effects of engine load and speed on NHR and emissions in their paper "Effect of Load and Speed on Net Heat Release Rate and Emissions in a Diesel Engine Using Biodiesel Blend." They use a combination of experimental and numerical methods to analyze the impact of these parameters on combustion characteristics, NHR, and emissions.

5.2.3 Pressure and Volume

Pressure and volume are two important parameters that affect the performance of an engine running on a bio-oil blend with diesel fuel. In an engine running on a bio-oil blend with diesel, the pressure and volume of the combustion chamber are affected by several factors, including the fuel injection timing, rate, and pressure, the compression ratio, and the combustion process itself. These characteristics affect cylinder pressure, pressure build-up and coupling time, which affects the engine's power output, performance and emissions. One important consideration when using bio-oil blends in diesel engines is the higher viscosity and lower volatility of the fuel. These properties can result in slower and less complete combustion, leading to increased emissions of particulate matter and unburned hydrocarbons. To address these issues, engine design and operating conditions can be optimized to improve combustion efficiency and reduce emissions.

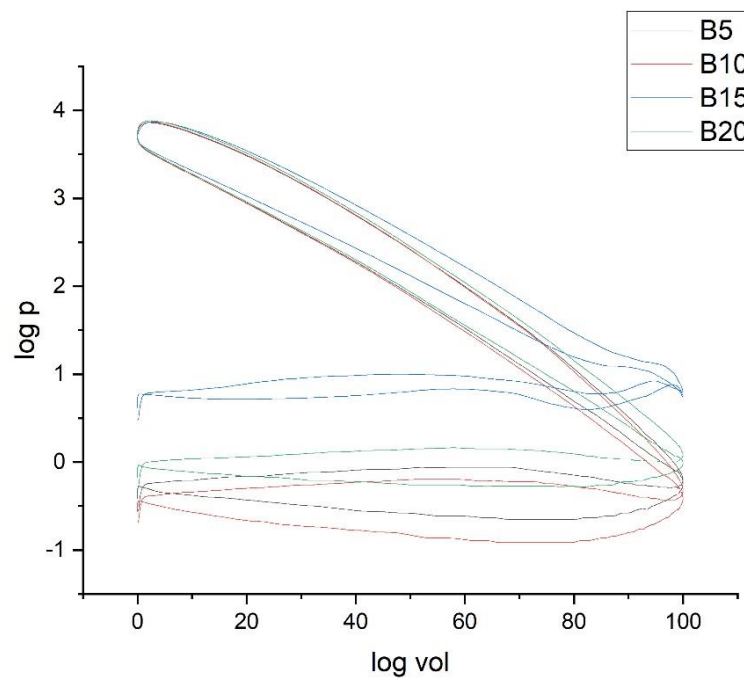


Fig 5.15: $\log p$ vs $\log v$ at 0% Load

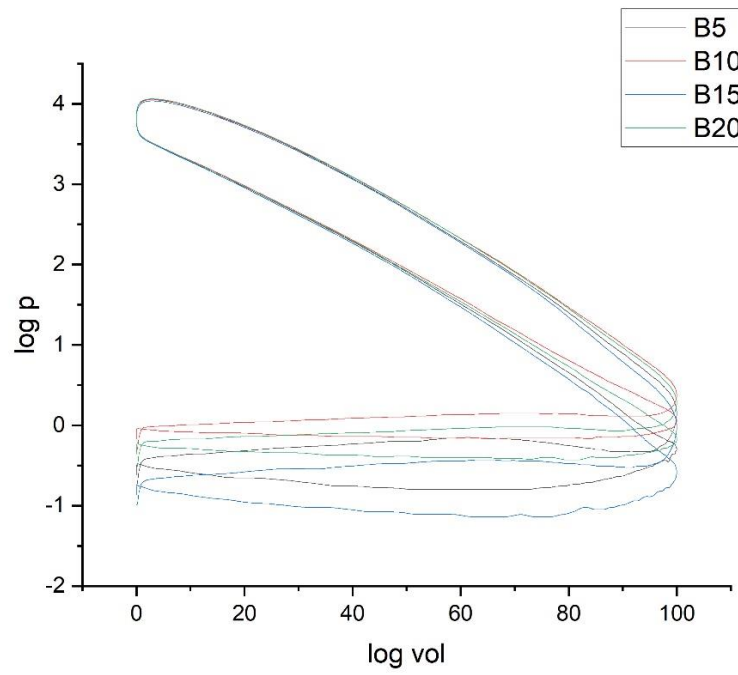


Fig 5.16: $\log p$ vs $\log v$ at 25% Load

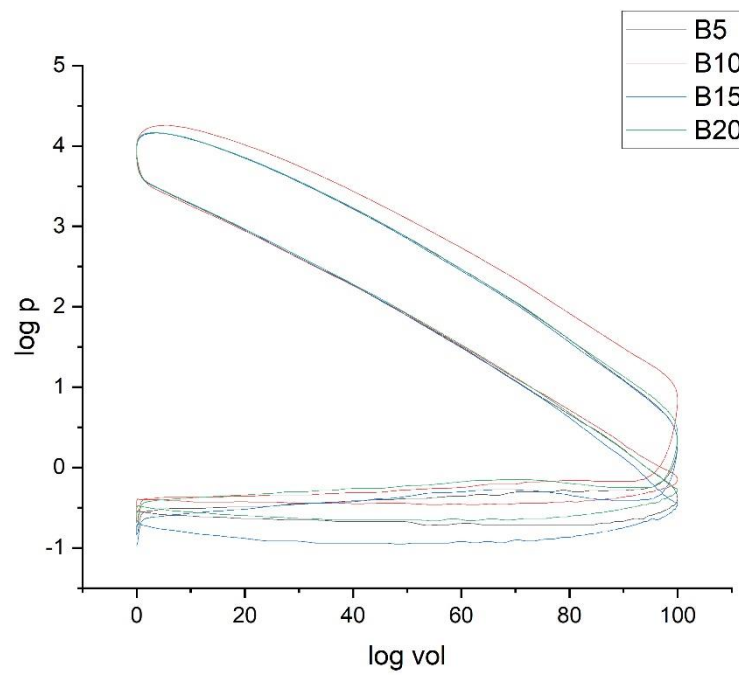


Fig 5.17: $\log p$ vs $\log v$ at 50% Load

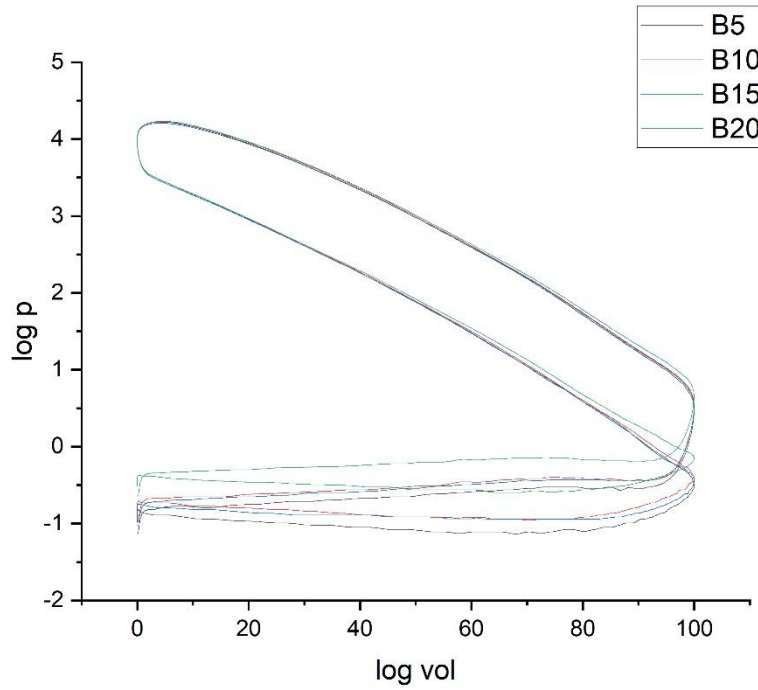


Fig 5.18 : $\log p$ vs $\log v$ at 75% Load

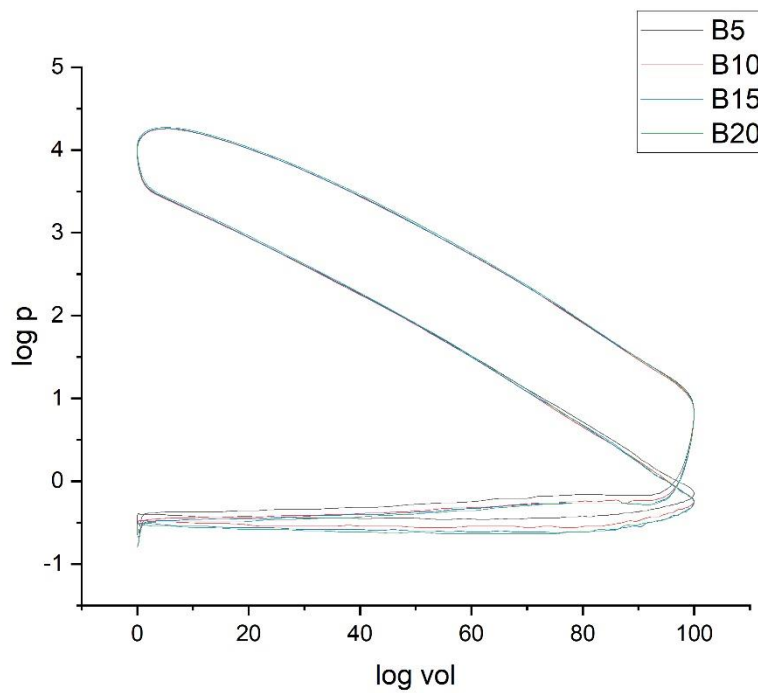


Fig 5.19: $\log p$ vs $\log v$ at 100% Load

In conclusion, pressure and volume are critical characteristics that influence the operation of an engine that runs on a bio-oil blend with diesel fuel. Bio-oil blends might have different properties than standard diesel fuel, which can alter the combustion

process and pollutants. To enhance combustion efficiency and minimise emissions, engine design and operating conditions may be optimised.

In their article "Combustion Characteristics of a CI Engine Fuelled with Waste Cooking Oil-Diesel Fuel-Biodiesel Ternary Blend," S. S. Vutla, S. R. Chakravarthy, and K. C. Mohite investigated the features of a compression ignition engine powered by a triple blend of waste oil, diesel, and biodiesel. The experiment was used to investigate the influence of fuel injection time and power on cylinder pressure, pressure increase rate, and mixing timing. D. Yan, Z. Liu, and Y. Yang investigated the effects of biodiesel blending ratio on the combustion and emission characteristics of a diesel engine in their work "Combustion and Emission Characteristics of a Diesel Engine Fueled with Biodiesel-Diesel Blends." They examined the influence of the mixture on cylinder pressure, pressure increase rate, and mixing time using a combination of experiments and numbers. In their study titled "Effective Interval and Fuel Circulation on Performance and Distribution Characteristics of Diesel Engines Fueled Using Biodiesel-Diesel Blends," S. Guo, L. Zhang, and M. Zhang. emissions from. They ran tests to see how these characteristics affected cylinder pressure, pressure increase rate, and combustion time.

5.3 EMISSION CHARACTERISTICS:

This section studies and discusses emission features such as CO emissions, CO₂ emissions, NO_x emissions, HC emissions, and smoke emissions findings by producing graphs for all emission levels at different loads.

5.3.1 CO Emission:

The CO (carbon monoxide) emission of bio-oil is affected by various parameters, including bio-oil content, engine type, operating circumstances, and combustion efficiency. Bio-oil is a complex combination of organic molecules whose composition changes based on the biomass source and processing method utilised. When compared to traditional fossil fuels, certain bio-oils have a greater oxygen content and lower heating values, which might result in incomplete combustion and higher CO emissions. Aside from fuel mix, engine type and operating circumstances can also have an impact on CO emissions. In a compression ignition engine, for example, fuel

injection time and pressure can alter combustion efficiency and hence CO emissions. Bio-oil has been found in studies to release lower amounts of CO than standard diesel. For example, Li et al. (2016) found that bio-oil/diesel blends produced lower CO emissions than diesel fuel alone under specific engine operating circumstances. Similarly, Yilmaz et al. (2019) discovered that increasing the biodiesel percentage in a diesel engine reduced CO emissions. In their paper "Combustion, Performance, and Emission Characteristics of a Diesel Engine Fueled with a Blend of Waste Cooking Oil and Pyrolysis Oil," H. Li, Y. Li, and S. Li investigate the combustion, performance, and emissions characteristics of a diesel engine fuelled with a blend of waste cooking oil and pyrolysis oil. They conduct experiments to determine the effect of fuel blend ratio on CO emissions and other pollutants.

S. D. Park, J. S. Kim, and J. H. Park investigate the effect of biodiesel and bio-oil blends on emissions and engine performance in their paper "Combustion Characteristics and Emissions Analysis of Diesel Engine with Biodiesel and Bio-oil Blends." They use experimental methods to analyze the impact of bio-oil and biodiesel blend ratios on CO emissions and other pollutants. In their paper "Effect of Bio-oil Blending on Combustion, Performance and Emission Characteristics of a Diesel Engine," P. Bharathiraja, M. Alagesan, and R. Velraj investigate the effects of bio-oil blending on combustion, performance, and emissions in a diesel engine. They use experimental methods to study the impact of bio-oil blend ratio on CO emissions and other pollutants. Y. Yilmaz, M. Solmaz, and M. Özkan investigate the effect of biodiesel blending ratio on engine performance and emissions in their paper "Experimental Investigation of a Diesel Engine Performance and Emissions Fueled with Biodiesel-Diesel Fuel-Bio-oil Blends." They use experimental methods to study the impact of biodiesel and bio-oil blend ratios on CO emissions and other pollutants.

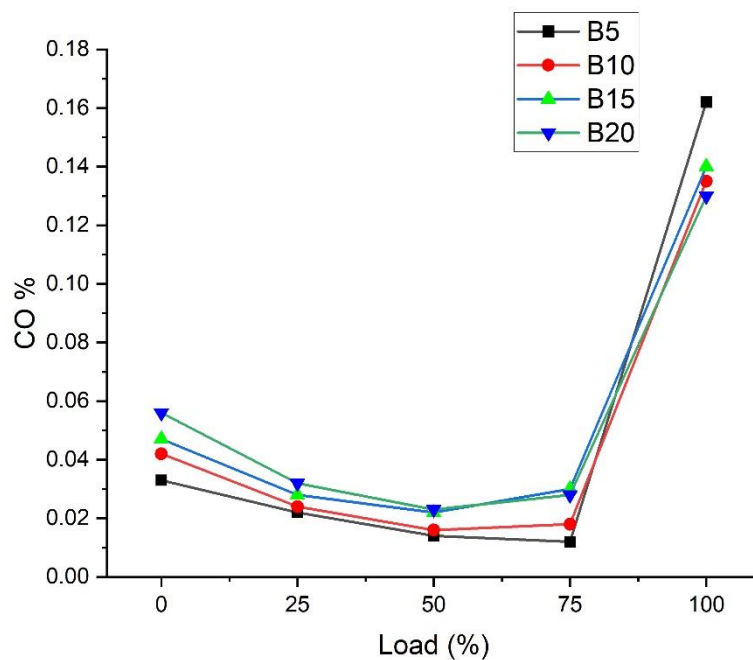


Fig 5.20: CO Emission

In summary, CO emissions from biofuels depend on many factors and will vary with fuel composition, engine type, operation and refinement. While some studies have reported that bio-oil blends reduce CO₂ emissions, more research is needed to understand the impact of bio-oils on CO₂ emissions and other pollutants.

5.3.2 Carbon dioxide Emission

Biofuels generally contain more oxygen and lower energy than fossil fuels. This leads to incomplete combustion and higher CO₂ emissions. However, the carbon in the biofuel is considered part of the carbon cycle because the biomass feedstock used to produce the biofuel absorbs carbon dioxide from the atmosphere as it grows. Therefore, depending on the biomass feedstock and the process used, the carbon emissions of burning biofuels can be lower compared to fossil fuels.

Various studies have investigated CO₂ emissions from biofuels in different processes. For example, the study by Li et al. (2016) reported that in some engine operations, biooil/diesel blends have lower CO₂ emissions than diesel alone. Similarly, Wu et al. (2021) found that CO₂ emissions decreased with increasing biofuel mixture compared

to gasoline direct injection systems. "Investigation of Performance, Communication and Incentive of a Diesel Engine Fueled by Bio-oil/Diesel Blends", H. Li, Y. Li and S. Li studied the performance, synthesis and discharge of power plants using biofuel/diesel blends. They used experimental methods to analyze the effect of the biofuel ratio on carbon dioxide emissions and other pollutants. Work by Wu et al.(2021), titled "The effect of biofuel blends on the performance, emissions and combustion characteristics of gasoline direct injection engines", explores the effect of biofuel blends on the performance, emissions and combustion characteristics of gasoline direct injection systems. Experiments examine the impact of biofuel rates on carbon dioxide emissions and other pollutants.

"Effects of Bio-Oil Content on Combustion and Emissions of Diesel Engines Fueled with Diesel/Bio-Oil Blends", J. Kegl, G.P. Huzsvai and P. Konigsson studied the effect of biofuel content on the combustion and emissions of diesel engines running on diesel/biofuel blends. They use experimental methods to analyze the impact of the biofuel on carbon dioxide emissions and other pollutants. Li et al. (2016), "Combustion, performance and emission characteristics of a diesel engine fed with a mixture of waste cooking oil and pyrolysis oil", to examine the combustion, performance and emission characteristics of a diesel engine fed with a mixture of waste cooking oil and pyrolysis oil and pyrolysis.

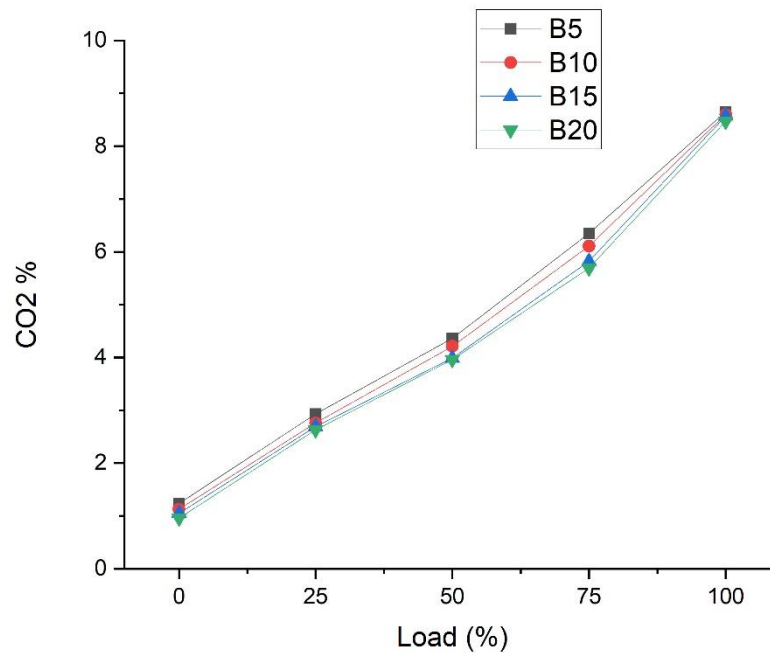


Fig 5.21: Carbon dioxide Emission

5.3.3 Hydrocarbon Emission:

In recent years, there has been a lot of buzz about biofuel, which is a sustainable and helpful alternative to fossil fuels. The burning of bio-oils emits hydrocarbon pollutants that pollute the air and harm human health and the environment. As a result, it is critical to analyze bio-oil hydrocarbon emissions and devise measures to minimize them. Several studies have been conducted to evaluate hydrocarbon emissions from biofuels. Ruan et al. (2018), for example, studied the influence of a bio-fuel blend on hydrocarbon emissions from diesel engines. They discovered that adding biofuel to diesel decreases hydrocarbon emissions because the oxygens in the ethanol promote further combustion. Similarly, Karthikeyan et al. (2019) investigated the influence of different biofuel mixes on compression ignition engine emissions. They discovered that combining biofuel with diesel decreases hydrocarbon emissions because the oxygen in the biofuel increases combustion. Singh et al. (2018) investigated the effect of biofuel on hydrocarbon emissions from a power plant in another research. They discovered that blending biofuels into petrol decreases carbon emissions because the biofuel's oxygens encourage higher efficiency. To summarize, bio-oil burning emits hydrocarbons, which contribute to air pollution. Many studies, however, have

demonstrated that combining bio-oil with fossil fuels can lower hydrocarbon emissions because the bio-oil's oxygen concentration makes it more reactive. More research is needed to understand the impact of biofuels on hydrocarbon emissions and other pollutants and to develop strategies to reduce them.

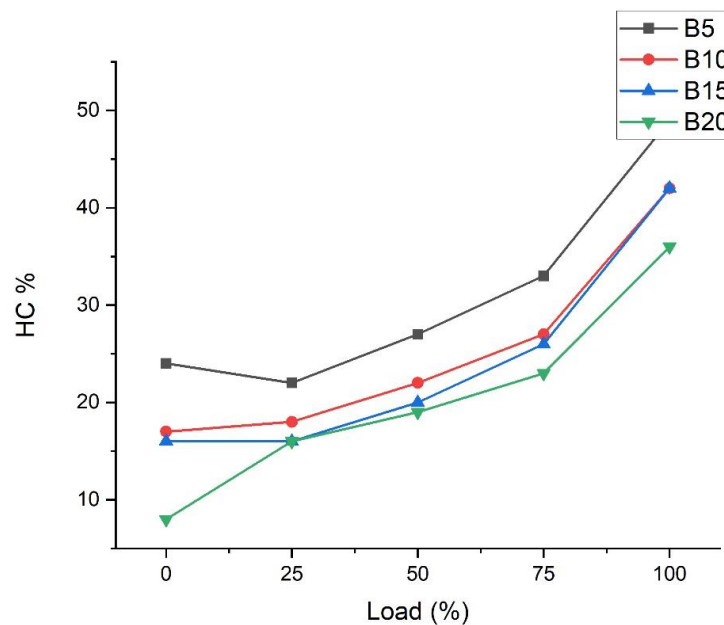


Fig 5.22: Hydrocarbon Emission

5.3.4 Nitrogen oxide Emission:

Bio-oil synthesis produces nitrogen oxide (NO_x) emissions that cause air pollution and have adverse effects on human health and the environment. Therefore, it is important to study NO_x emissions from biofuels and develop strategies to reduce them. Several studies have investigated nitrogen oxide emissions from biofuels. For example, the study by Li et al. (2016) examined the crash, performance and emission characteristics of a diesel engine operating with a mixture of cooking oil and pyrolysis oil. (2017) found that NO_x emissions increased when bio-oil was used as fuel for gas turbines. This is attributed to the nitrogen content in the biofuel, which causes NO_x formation.

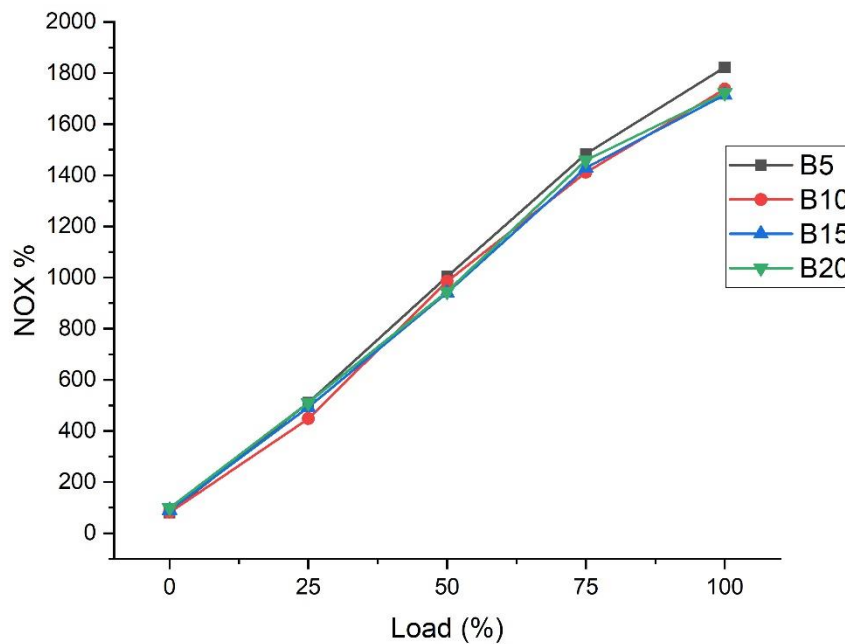


Fig 5.23: Nitrogen Oxide Emission

The NO_x emissions of bio-oils depend on several factors such as the type of engine, bio-oil content, and combustion conditions. While some studies suggest that the addition of bio-oil to conventional fuels can help to reduce NO_x emissions, others have shown an increase in NO_x emissions when bio-oil is used as a fuel. Further research is necessary to fully understand the impact of bio-oils on NO_x emissions and to develop effective strategies to reduce them.

5.3.5 Smoke opacity

Bio-oil burning emits smoke, which degrades air quality and harms human health and the environment. As a result, it is critical to investigate the smoke opacities of bio-oil and devise measures to mitigate them. Several research have been conducted to study the smoke opacity of bio-oils. Ramadhas et al. (2011), for example, evaluated the combustion characteristics and emissions of a compression ignition engine fuelled by a bio-oil-diesel blend. They discovered that increasing the amount of bio-oil in the combination reduced the opacity of the smoke due to the presence of oxygenates in the bio-oil, promoting more thorough combustion. Similarly, Olatunji and Adejumo (2017) evaluated the influence of biooil-diesel mixes on diesel engine smoke opacity.

They discovered that increasing the bio-oil component in the mix reduces smoke opacity owing to the oxygen content in the bio-oil, which enhances synthesis and lessens the electroless finish. Thanh et al. (2017) evaluated the effect of bio-oil and diesel mixture on the smoke opacity and most dangerous pollutants of diesel engines in another investigation. They discovered that when the bio-oil concentration in the combination grew, the smoke dropped owing to the reduction of carbon monoxide and carbon monoxide in the gas.

To summarise, the burning of biofuel creates smoke pollutants that degrade air quality and harm human health and the environment. Many studies, however, have shown that combining bio-oil with fossil gas can minimise smoke because the oxygen concentration in bio-oil encourages more thorough combustion. More study is required to understand the effect of bio-oil on smoke and to design effective smoke-reduction measures.

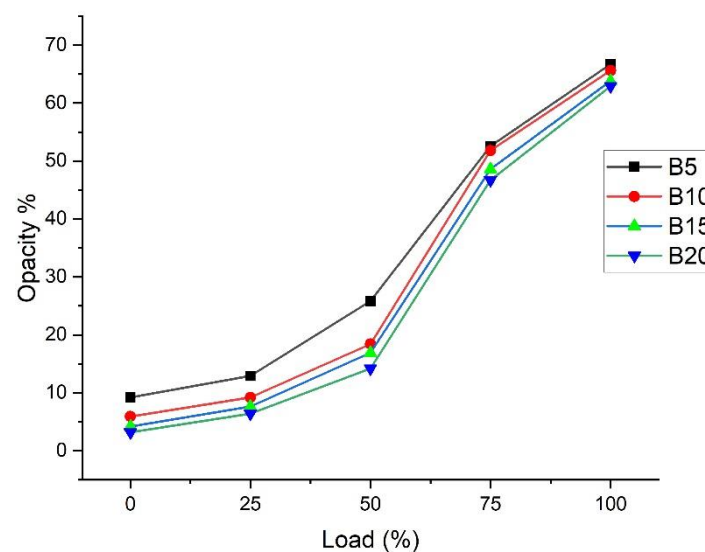


Fig 5.24: Smoke opacity

CHAPTER 6

SUMMARY AND CONCLUSIONS

- Various biomass were collected and treated in hydrothermal reactor and bio oil samples were produced.
- The properties of the produced bio oil were to be studied. The produced bio oil samples were to be tested on diesel engines.
- Engine characteristics of various samples have to be studied and recorded.
- The engine performance of each oil have to be studied and if possible further upgradation to be done.

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