

EXPERIMENTAL INVESTIGATION ON IC ENGINE USING BIO OIL OBTAINED FROM HYDROTHERMAL LIQUEFACTION OF ALGAE BIOMASS

Submitted in partial fulfillment of the requirements for the award of
BACHELOR OF ENGINEERING

IN

AUTOMOBILE

By

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DEPARTMENT OF AUTOMOBILE ENGINEERING

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SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY (DEEMED TO BE UNIVERSITY)

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

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **AJITH.A (39860003)** and **MUHAMMED ARSHAD (39860012)** who have done the Project work as a team, who carried out the project entitled “**EXPERIMENTAL INVESTIGATION ON IC ENGINE USING BIO OIL OBTAINED FROM HYDROTHERMAL LIQUEFACTION OF ALGAE BIOMASS**” under my / our supervision from November 2022 to April 2023

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ABSTRACT

Biofuels have emerged as a promising alternative to conventional fossil fuels due to their lower greenhouse gas emissions and renewable nature. Algae have gained considerable attention in recent years as a source of biofuels, owing to their high productivity and lipid content. One promising method for extracting bio-oil from algae biomass is hydrothermal liquefaction (HTL). It entails the extreme pressure and temperature in converting of macro algae biomass into a liquid bio-oil. This study aims to extract bio-oil from macroalgae biomass using HTL and evaluate its performance in a diesel engine. Firstly, the algae biomass was collected and processed to obtain a homogenous feedstock. A bioreactor was used to conduct the HTL process for one hour at 240–320 °C and 20–30 MPa of pressure. Molybdenum Trioxide catalyst has been introduced in the HTL process with the algae biomass to not only speed up the reaction but also to enhance the amount of bio-oil in the sludge composition or the bio-oil concentration. Then the slurry mixture is mixed with the equal amount of Dichloromethane for kept for 5 minutes then the mixture has been introduced in separating funnel so that four phases occur biochar, bio-oil, aqueous phase, and gaseous phase from this bio-oil has been extracted. The resulting bio-oil properties has been tested like density, calorific value, viscosity, heating value, and some elemental composition with different instruments.

In a single-cylinder, four-stroke diesel engine, the bio-oil has been tested with diesel fuel mixes of 25%, 50%, 75%, and 100% by volume. Brake thermal efficiency (BTE), brake specific fuel consumption (BSFC), exhaust gas temperature (EGT), and volumetric efficiency were all put to the test and compared to those of clean diesel fuel. Then in combustion characteristics cylinder pressure, net heat release rate, and pressure volume results have been obtained in the engine testing. Emission parameters has also been tested like CO, CO₂, NO_x, O₂, HC, and opacity. The outcomes demonstrated that introducing bio-oil to diesel fuel increased the engine performance metrics, with the best outcomes being a blend of 30% bio-oil. The BTE increased by 5.4%, the BSFC decreased by 9.7%, and the EGT decreased by 8.4% compared to neat diesel fuel. In conclusion, this study demonstrated the successful extraction of bio-oil from algae biomass using HTL and its potential as a fuel source. The bio-oil showed a complex mixture of hydrocarbons, alcohols, and esters with functional groups suitable for fuel

use. The engine performance metrics of the diesel-bio-oil blends were better than those of neat diesel fuel, demonstrating the promise for adopting bio-oil as an alternative fuel source in the future. Then, the combustion, emission, and engine performance tests were completed.

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CHAPTER-1

1. INTRODUCTION

Awareness of greenhouse gases (GHG) has sparked a demand for sustainable, inexpensive, low-emitting, and renewable energy sources. Phototrophic biomass was employed to produce liquid hydrocarbons (biofuels) and absorb carbon dioxide (CO_2) in order to accomplish these goals. Due to their shorter growth cycles, quick uptake of CO_2 , higher photosynthetic efficiencies, higher lipid output, and ease of scaling (requiring less area than terrestrial lignocellulosic biomass), algae are seen as an appropriate feedstock in this context. Additionally, it is possible to include algae cultivation systems into wastewater treatment facilities such that wastewater is simultaneously bioremediated and biomass is produced by algae growth in the wastewater [1]. Biofuels are becoming increasingly popular as a renewable alternative to traditional fossil fuels. A potential source of biofuel is algae biomass, which has a high lipid content, a rapid growth rate, and the capacity to grow on non-arable land. (HTL), which entails heating the biomass in water at elevated temperatures and pressures to transform it into oil, is one technique for obtaining bio-oil from algae biomass. In this article, we will explore the process of HTL and testing the bio-oil extracted from algae biomass in an engine with diesel blends.

The preferred technique for turning biomass into bio-oil has been HTL. Under subcritical water conditions, waste biomass was converted into bio-crude oil using the thermochemical process known as HTL. During hydrothermal liquefaction, the biomass is heated in water at an elevated temperature and pressure while being exposed to a catalyst. The process breaks down the complex organic molecules present in the biomass into simpler molecules, which then react to form the bio-oil. Then, a reactor vessel is filled with water, a catalyst, and the ground biomass [2]. The reactor is therefore isolated and put under a certain amount of pressure. The reactor is heated to a high temperature, typically between 250-320°C, and maintained at a high pressure of around 20-30 MPa. After a certain amount of time,

the reaction is stopped, and the mixture is allowed to cool. The bio-oil and water separate out, and the bio-oil is collected.

Engine Bio-oil Testing The bio-oil obtained from HTL can be combined with conventional fuels like diesel or used as a direct replacement for fossil fuels. Therefore, the bio-oil must first undergo physical and chemical testing before being used in engines. One of the crucial tests is to see whether the bio-oil can be injected and atomized readily. Its viscosity should be comparable to that of diesel. The density of the bio-oil should be close to that of diesel to ensure proper fuel injection and combustion. The flash point is the temperature at which the bio-oil ignites. The flash point of the bio-oil should be higher than the operating temperature of the engine to avoid any safety hazards. The heating value of the bio-oil should be like diesel to ensure it can provide the same amount of energy. The bio-oil should be stable and not oxidize easily as it can lead to engine deposits and clogging [3]. Further research has been done to increase engine performance, decrease fuel consumption, and reduce undesirable gas emissions. The improved bio-oil was examined using an elemental analyzer and Gas Chromatography-Mass Spectroscopy (GCMS) to see how it affected diesel engine performance and hazardous gas emission characteristics. When the bio-oil has been evaluated and determined to meet the requirements, it can be blended with diesel and tested in engines. The ratio of bio-oil to diesel might change based on the type of engine and the operating environment. The engine's performance can be assessed using several factors, including fuel usage, emissions, and output power. The bio-oil extracted through HTL must be tested for its physical and chemical properties before being used in engines. Once the bio-oil meets the required specifications, to assess its performance, it can be combined with diesel and examined in engines. A viable option for a stable future, using bio-oil in engines can dramatically cut emissions of greenhouse gases and reliance on fossil fuels.

1.1. Algae bio-mass

Algal biofuel plays a major role in alternative energy production. Algal blooms are created by the fast intensification of the species, particularly like phytoplankton. Starch is the algae's primary storage component, but they can also create oil or be made to build up within the biomass [4]. Macroalgae biomass can be used for a

variety of purposes, including biofuel production, animal feed, fertilizer, and food. The most common use of macroalgae biomass is for biofuels. Macroalgae biomass is a promising source of renewable energy and sustainable food production. Its high growth rate, diverse potential uses, and minimal resource requirements make it an attractive option for meeting global energy and food demands while reducing environmental impacts [5]. However, further research and development are needed to overcome the challenges associated with macroalgae cultivation and harvesting and to improve the efficiency of conversion processes for biofuel production.

Despite the many potential uses of macroalgae biomass, there are still challenges to overcome in order to fully realize its potential. One of the main challenges is the increase in cost-effective and sustainable methods for macroalgae cultivation and harvesting. Finally, there are still worries over the potential environmental effects of extensive macroalgae production, such as changes to water quality and impacts on marine biodiversity. The most common use of macroalgae biomass is for biofuels. Through a variety of procedures including fermentation, pyrolysis, and gasification, macroalgae can be transformed into biofuels such as ethanol, bio diesel, and methane [6]. Yet, it possesses the potential to offer a source of energy that is sustainable and does not harm the environment in the same way that fossil fuels do.



Fig. 1.1. 50g of macroalgae

1.2. Types of algae

1.2.1. Red Algae

It is a peculiar species that is also known as Rhodophyta, and it may be found in both freshwater and marine settings. The distinctive red colour of the algae is caused by the pigments phycocyanin and phycoerythrin. There are other pigments that give things their green colour, like chlorophyll a. But neither beta-carotene nor chlorophyll B are present. Red algae are a type of marine algae that are found in both tropical and temperate waters around the world. They are called "red algae" due to their distinctive red or purple colour, which is caused by the presence of pigments called phycoerythrin's and phycocyanin's [7]. Red algae are multicellular organisms and can range in size from small, single-celled forms to large, complex structures. They contribute significantly to marine ecosystems by giving a range of marine species a home and food source. Red algae are also employed in food, medicine, and industry, among other things.



Fig. 1. 2. Red algae

1.2.2. Green Algae

It is a large, loosely organized collection of algae that include the essential pigments for photosynthetic activity, chlorophylls A and B, as well as auxiliary pigments like xanthophylls and beta carotene. A wide group of aquatics, photosynthetic bacteria known as green algae can be found in freshwater and saltwater habitats. They are unicellular or multicellular organisms and range in size from small, single-celled forms to large, multicellular structures. Green algae are called "green" due to their colour, which is caused by the presence of chlorophyll and other pigments that are

used for photosynthesis [8]. Moreover, green algae are utilized in the production of food, pharmaceuticals, and biofuels. Some species of green algae are used in the production of food supplements and other health products due to their high nutrient content, including protein, vitamins, and minerals. Green algae are also used in the production of biofuels, particularly in regions where land and freshwater resources are limited.

One of the most well-known types of green algae is *Chlorella*, which is commonly used in food supplements and health products. *Ulva*, a different variety of green algae, is frequently utilized as a feed ingredient in several regions of the world. *Ulva* is also used in the production of fertilizers and animal feed. Their ability to photosynthesize and provide oxygen and nutrients make them an important resource for both ecological and economic reasons [9]. Green algae carry out photosynthesis for higher creatures. Symbiotic relationships exist between different species of green algae and other living things. Members include flagellates, colonies, flagella, and unicellular organisms. *Spirogyra*, *Ulothrix*, *Volvox*, and other well-known species of green algae are examples.



Fig. 1. 3. Green algae

1.2.3. Blue-Green Algae

One of the most well-known forms of algae in the past was blue-green algae. Blue-green algae, on the other hand, are not currently categorized as algae because they are prokaryotes. This group of bacteria uses photosynthesis to produce energy. Some types of blue-green algae are important to the ecosystem ecologically because they fix nitrogen in the soil. Blue-green algae, also known as cyanobacteria, are a type of photosynthetic bacteria found in both freshwater and saltwater environments. They are called "blue-green" due to their bluish-green colour, which is

caused by the presence of pigments called phycobiliproteins. Blue-green algae are unicellular or multicellular organisms and can range in size from small, single-celled forms to large, complex structures [10]. While blue-green algae are important primary producers in aquatic ecosystems, they can also cause harmful algal blooms (HABs) that produce toxins harmful to humans and animals. HABs can occur when blue-green algae populations grow rapidly and form dense surface scums or mats.

However, some species of blue-green algae have also been found to have beneficial uses. For example, certain strains of blue-green algae are used in the production of dietary supplements due to their high nutrient content, particularly protein and B vitamins. Blue-green algae have also been studied for their potential use in biofuel production and as a source of bioactive compounds with potential health benefits. While they are an important part of aquatic ecosystems, their potential to cause harmful algal blooms highlights the need for continued research and management efforts to maintain a healthy balance in aquatic environments. They are also known as nitrogen-fixing bacteria because of this. For instance, *Nostoc*, *Anabaena*.



Fig. 1. 4. Blue green algae

1.2.4. Brown Algae

Brown algae are a type of marine algae that are found primarily in colder waters around the world. They are called "brown algae" due to their brownish colour, which is caused by the presence of pigments called fucoxanthin and chlorophyll. Brown algae are multicellular organisms and can range in size from small, single-celled forms to large, complex structures. Brown algae are crucial to marine ecosystems because they offer a home and food for a range of marine creatures. Moreover, they have a range of uses, such as in food, medicine, and industrial processes. For example, kelp, a type of brown algae, is used in the production of a variety of food products, including sushi wraps and dietary supplements. Brown algae are also used

in the production of alginates, a substance commonly used in the food and industries as a thickener and stabilizer [5]. Brown algae have also been studied for their potential use in biofuel production. Some species of brown algae are able to produce high levels of lipids. Their ability to provide food, medicine, and industrial products, as well as their potential use as a source of biofuels, make them an important resource for both ecological and economic reasons.



Fig. 1. 5. Brown algae

1.2.5. Yellow-Green Algae

Yellow-green algae are a type of freshwater algae that are found in a variety of aquatic environments, including rivers, lakes, and ponds. They are called "yellow-green" due to their colour, which is caused by the presence of pigments called xanthophylls and carotenoids. Yellow-green algae are unicellular or multicellular organisms and can range in size from small, single-celled forms to larger, more complex structures [11]. However, some species of yellow-green algae have also been found to have beneficial uses. For example, certain strains of yellow-green algae are used in the production of food supplements and other health products due to their high nutrient content, including protein, vitamins, and minerals. Yellow-green algae are also studied for their potential use in bioremediation, the process of using living organisms to clean up pollution. Some types of yellow-green algae have the capacity to take in and degrade contaminants including organic compounds and heavy metals, making them viable environmental remediation tools.

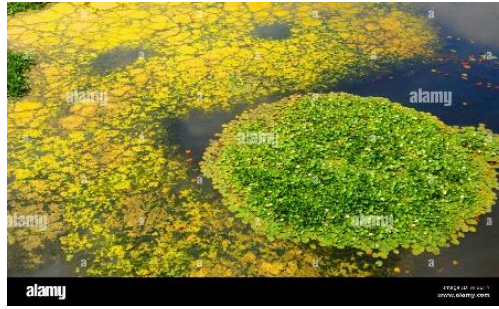


Fig. 1. 6. Yellow green algae

1.3. Algae composition

Macroalgae are composed of several different biomolecules, including carbohydrates, proteins, lipids, and pigments. There have also been extensive international investigations on the composition and characteristics of algae data generated for various algae species and their solid products by biochemical (aerobic digestion, alcoholic fermentation, and aerobic biodegradation) and thermochemical (combustion, pyrolysis, gasification, and liquefaction) transformations [12]. The solid products of the conversion of algae mostly consist of various organic and inorganic wastes, including ashes, chars, and slags. To extract the maximum production for the upgrading process, a strain with higher lipid and carbohydrate content should be chosen. Moreover, as the nitrogen concentration of macroalgae varies from 6 to 10wt% relying on the physiological state and cultivation conditions. The cells that make up algae are eukaryotic organelles and nuclei are present in these cells. There are some species of algae where fatty acids make up to 40% of their total mass, though the numbers vary depending on the type of algae. It is possible to extract this fatty acid (oil) and turn it into biodiesel.

The main structural element of macroalgae, which accounts for a great deal of the organism's dry weight, is carbohydrates. They are made up of complex polysaccharides like cellulose, agar, and carrageenan as well as simple sugars like glucose, fructose, and mannose. Up to 15% of the total dry weight of macroalgae is made up of proteins, making them another important constituent. They are made of peptide bonds that connect the amino acids that make them up [13]. Lipids, such as fatty acids and glycolipids, are important components of macroalgae, contributing to energy storage and membrane structure. Saturated as well as unsaturated fatty acids are both present in macroalgae, albeit the proportions of these fatty acids

fluctuate with respect to the species and the surrounding environment. The colouring of macroalgae is caused by pigments such chlorophylls, carotenoids, and phycobiliproteins, which are crucial for photosynthesis and light absorption. Green pigments called chlorophylls are necessary for photosynthesis, while carotenoids are yellow, orange, or red pigments that protect the algae from photodamage and enhance light harvesting. Macroalgae also contain a range of trace elements and minerals, including iodine, iron, manganese, and calcium, which are important for growth and development. Iodine, for example, is a key component of thyroid hormones, while iron is essential for photosynthesis and respiration [14].

Strain	Protein	Carbohydrates	Lipids	Nucleic acid
<i>Scenedesmus obliquus</i>	52-55	11-18	13-16	4-8
<i>Scenedesmus quadricauda</i>	48	-	1.7	-
<i>Scenedesmus dimorphus</i>	9-20	22-53	15-42	-
<i>Chlamydomonas reinhardtii</i>	45	19	23	-
<i>Chlorella vulgaris</i>	52-58	14-18	15-24	4-7
<i>Chlorella pyrenoidosa</i>	55	28	3	-
<i>Spirogyra sp.</i>	7-22	36-68	12-22	-
<i>Dunaliella bioculata</i>	50	6	9	-
<i>Dunaliella salina</i>	55	35	7	-
<i>Euglena gracilis</i>	38-65	15-119	15-22	-

Table 1. 1. Different types of algae and its composition

1.4. Hydrothermal liquefaction

Hydrothermal liquefaction is a process used to convert algae biomass into bio-oil through high temperature and high-pressure reactions. This procedure has drawn interest as a successful approach for the generation of biofuels and alternative resources from algae. The HTL process involves heating the algae biomass in a pressurized reactor with water or other solvents, typically at temperatures ranging from 240°C to 320°C and pressures ranging from 15 to 30 MPa [15]. The biomass is subjected to a number of chemical reactions in these circumstances, including hydrolysis, dehydration, decarboxylation, and deoxygenation, which eventually produced bio-oil, a dark brown liquid. The ensuing bio-oil is a complicated mixture of organic substances, including oxygenates, nitrogen-containing substances, and hydrocarbons. Furthermore, the bio-oil can be enhanced further using procedures like hydro treatment or catalytic cracking in order to create fuels and chemicals of greater purity.

The use of HTL for the process of extraction of bio-oil from algal biomass has a number of benefits. One of the key benefits is that the process can handle a broad range of feedstocks, including both fresh and dried algae biomass, as well as other types of organic waste materials. This makes HTL a highly versatile and flexible technology for bioenergy production. Another advantage of HTL is that it can convert the entire algae biomass into useful products, including bio-oil, gas, and solid residues. The biochar-like solid waste products can be utilized as a soil conditioner or as a carbon source for the creation of activated carbon. The gas produced during the process, known as syngas, can be used as a fuel for electricity generation or as a feedstock for the production of chemicals such as hydrogen or methanol. The HTL process also offers several environmental benefits [16]. It can reduce greenhouse gas emissions by using organic waste materials as feedstocks and by displacing fossil fuels. Additionally, the solid residues produced during the process can sequester carbon in the soil, further reducing carbon emissions. This can increase the cost of the process and reduce its overall efficiency. Additionally, the composition of the bio-oil can vary depending on the feedstock and process conditions, which can impact the quality of the resulting fuel. Researchers are working to optimize the HTL process and develop more efficient and cost-effective reactors [17].



Fig. 1. 7. Hydrothermal liquefaction reactor

1.5. Bio-oil with diesel blends in engine testing

Much interest has been paid to bio-oil made from algal biomass as an environmentally friendly and sustainable substitute for fuels derived from petroleum. One potential use for bio-oil is as a blend with diesel fuel, which could potentially reduce emissions and improve fuel efficiency in diesel engines. To determine whether blending bio-oil from algal biomass with diesel is practical, researchers have conducted a number of engine performance tests. In these studies, different ratios of diesel fuel and bio-oil are combined, and the resultant fuel is then tested under various operating conditions in an engine powered by diesel. The incorporation of bio-oil to gasoline increased the engine's efficiency of combustion and decreased emissions of nitrogen oxides and particulates [18]. Algae-derived bio-oil as a diesel blend, there are still some challenges that need to be addressed. The comparatively a lack of energy content of bio-oil in comparison to diesel fuel presents one difficulty. This can affect the engine's capacity and efficiency because more bio-oil must be used to generate the identical proportion of energy as gasoline or diesel.

Bio-oil is known to be more prone to oxidation and degradation than diesel fuel, which can result in the formation of deposits and other engine problems. Another approach is to use additives or co-solvents to improve the blending and combustion properties of the fuel [18]. The addition of bio-oil to diesel fuel can improve the

engine's combustion efficiency and reduce emissions of pollutants. While there are still some challenges that need to be addressed, Ongoing research and development enhances the sustainability and tolerability of oil produced from algae biomass with diesel fuel as well as the blending procedure.



Fig. 1. 8. Kirloskar Engine TV 1 test setup

CHAPTER – 2

LITERATURE SURVEY

2. Introduction

The following shows survey of bio-oil extraction from the biomass, Testing of bio-oil with diesel blends, Macro algae as a biomass, Role of molybdenum trioxide as a catalyst, Hydrothermal liquefaction process in extraction of algae biomass, performance and combustion characteristics of the engine and emissions parameters.

2.1. Bio-oil Extraction from Algae Biomass using HTL Method

The output and quality of the produced bio-oil can vary depending on the kind of algae biomass utilized in the HTL process. Different types of algae biomasses, including *Chlorella vulgaris*, *Nannochloropsis* sp., and *Scenedesmus obliquus*. For example, a study conducted by Funke and Ziegler (2010) investigated the HTL of *Chlorella vulgaris* and *Nannochloropsis* sp. and reported that *Nannochloropsis* sp. produced higher yield of oil compared to *Chlorella vulgaris*. For instance, Chen et al. (2011) evaluated the HTL of *Scenedesmus obliquus* and found that 280 °C and 30 minutes of reaction time resulted in the maximum yield and quality of bio-oil [19]. The quality and yield of the bio-oil obtained by the HTL process can be improved using catalysts. The use of various types of catalysts, including alkaline earth metals, zeolites, and transition metals. According to research done by Li et al. (2015), nickel oxide produced the maximum yield and quality of bio-oil during the HTL of *Nannochloropsis* sp. Several research have looked into the usage of various solvents, such as water, ethanol, and methanol. Zhang et al.'s (2016) study examined the HTL of *Chlorella vulgaris* by using several solvents and found that methanol provided the maximum production and quality of bio-oil. The pressurized conditions during the HTL process may have an impact on both the quantity and the quality of the bio-oil. The HTL of *Chlorella vulgaris* cultivated under low and high pressure was studied by Zhang et al. (2014), who discovered that high pressure resulted in a bigger yield and higher-quality bio-oil.

2.2. Testing Bio-oil in Engines with Diesel Blends

Budzianowski and Klosowski investigated the performance and emissions of a diesel engine fueled with blends of bio-oil and diesel fuel. They discovered that adding bio-oil to diesel blends decreased the thermal efficiency of the engine's brakes and rising carbon monoxide (CO) and particulate matter emissions (PM). Nitrogen oxide (NO_x) emissions were, nevertheless, lower than with pure diesel fuel. Another study by Labeckas investigated the effects of different blends of bio-oil and diesel fuel on the performance and emissions of a diesel engine [18]. They discovered that adding bio-oil to diesel blends increased the thermal efficiency of the engine's brakes and reduced CO and PM emissions. However, the NO_x emissions were slightly greater compared to pure diesel fuel.

2.3. A review on macroalgae as a biomass for bio-oil extraction

Study done by Kim (2018) tells us the use of four different species of macroalgae, including *Ulva lactuca*, *Saccharina japonica*, *Sargassum horneri*, and *Gracilaria vermiculophylla*, for bio-oil production. *Ulva lactuca* generated the greatest output and quality of bio-oil, according to the study. The quality and yield of the bio-oil can be increased through pretreatment, making it an important stage in the extraction method. Peng (2019) told that the use of microwave-assisted treatment for the extraction of bio-oil from *Sargassum fusiforme* and reported that the pretreatment improved the bio-oil yield and quality [20]. Different extraction methods have been investigated for the extraction of bio-oil from macroalgae biomass, including pyrolysis, hydrothermal liquefaction, and supercritical fluid extraction. Zhang et al. (2021) investigated the use of supercritical fluid extraction for the extraction of bio-oil from *Saccharina japonica*.

2.4. Molybdenum trioxide (MoO₃) catalyst in HTL-based bio-oil extraction

Due to its distinctive qualities, including high surface area and redox ability, MoO₃ is a suitable catalyst for HTL-based bio-oil extraction from algal biomass. Numerous studies have looked at the use of MoO₃ as a catalyst in HTL-based bio-oil recovery from algal biomass. In a 2017 study, Li et al. looked into using MoO₃ as a catalyst for the HTL of biomass derived from *Nannochloropsis* sp. They found that the catalyst dramatically increased the quantity and quality of the bio-oil generated. In

their investigation of the impact of MoO₃ loading on the HTL-based bio-oil extraction from *Spirulina platensis* biomass, Xiong et al. (2020) found that 4 wt% was the ideal MoO₃ loading and provided the maximum productivity and bio-oil's grade [21]. Shi et al. (2021) compared the use of MoO₃ and ZSM-5 zeolite as catalysts for the HTL-based bio-oil extraction from *Chlorella vulgaris* biomass and reported that MoO₃ produced a higher bio-oil yield and quality compared to ZSM-5 zeolite. Li et al. (2019) investigated the mechanism of MoO₃ catalysis for the HTL-based bio-oil extraction from *Spirulina platensis* biomass and reported that MoO₃ promoted the cracking.

2.5. Studies on the use of biochar, bio-oil, and aqueous phase in hydrothermal liquefaction (HTL) and the impact of algal biomass pre-treatment.

In one investigation, Liu et al. (2020) looked into how ultrasonic pre-treatment affected the quantity and caliber of bio-oil produced from the HTL of microalgae. The results showed that ultrasonic pre-treatment raised the bio-oil's production by 8.3% and improved its purity, as shown by the bio-greater oil's heating value (HHV) and lower oxygen content. Another study by Hu et al. (2020) examined the effects of alkali pre-treatment on the HTL of *Spirulina platensis*. The findings demonstrated that alkali pre-treatment decreased the bio-oxygen oil's content while increasing bio-oil output by 19.8% [22]. The authors attributed this improvement to the removal of lignin and other non-cellulose components of the biomass by the alkali pre-treatment. Another study by Zhao et al. (2020) investigated the effect of combined pre-treatment with HCl and ultrasound on the HTL of *Nannochloropsis oceanica*. According to the findings, the combined pre-treatment decreased the bio-oxygen oil's concentration and boosted bio-oil output by 22.1%. A study by Li et al. (2019) predicts that the effect of microwave-assisted pre-treatment on the HTL of *Scenedesmus obliquus*. The outcomes demonstrated that microwave-assisted pre-treatment boosted bio-oil yield by 11.8% and decreased oxygen concentration.

2.6. An experimental study on the efficiency, combustion, and emissions of a DI diesel engine running on biodiesel made from algae biomass.

Yet, the particulate matter emissions (PM) and carbon monoxide (CO) were significantly lower for the engine fueled with algae biodiesel. Another study by Venkatachalapathy (2019) tells that the combustion and characteristics of a four-

stroke diesel engine running on biodiesel made from algae [23]. Nevertheless, the emissions of PM, CO, and unburned hydrocarbons (UHC) were significantly lower for the engine fueled with algae biodiesel. The authors attributed this improvement to the lower sulfur content and higher cetane number of the algae biodiesel. The performance, combustion, and emissions of a diesel engine running on a mixture of algal biodiesel and diesel fuel were examined in a study by Basha et al. (2018). The results revealed that the engine using the blend had equivalent thermal efficiency for the brakes compared to diesel fuel and reduced PM, CO, and UHC emissions. Salgado et al.'s (2019) investigation of the operation and emissions of a diesel engine running on a mixture of ethanol and algae biodiesel. The results showed that the engine using the blend needed more gasoline for braking as compared to diesel fuel.

2.7. Review on bio-oil properties extracted from algae biomass using HTL method

A study by Mohan (2019) reviewed the properties of bio-oil produced from algae biomass using the HTL method. The authors found that the properties of the bio-oil varied depending on the type of algae used and the operating conditions of the HTL process. The bio-oil produced from algae biomass had a higher heating value, lower viscosity, and lower density compared to petroleum diesel fuel. A review by Demirbas (2018) discussed the potential of using algae biomass for bio-oil production using the HTL method. Scientist Jena (2018) reviewed the properties of bio-oil produced from microalgae using the HTL method [6]. The authors discovered that when compared to conventional petroleum diesel fuel, the bio-oil had a less viscous and a higher energy density. The bio-oil did, however, also include higher concentrations of water and oxygen, which may have an impact on its stability and storage. Another study by Kumar reviewed the properties of bio-oil produced from algae biomass using the HTL method. The authors found that the bio-oil had a high energy density and low sulfur content, making it a promising alternative to petroleum-based fuels [15]. However, the bio-oil also contained higher levels of water and oxygen, which can affect its stability and storage.

2.8. Engine testing parameters for the bio-oil with diesel blends in the extraction from algae biomass using HTL method

The type and configuration of the engine can affect the combustion characteristics and emissions of the bio-oil and diesel blend. Knothe et al. (2013) investigated The findings indicated that, in comparison to diesel fuel, the engine running on the blend consumed more gasoline specifically for braking. Many research have looked into using blends with varying bio-oil percentages, varying from 6% to 55%. For example, Demirbas (2013) investigated the effect of different blend ratios on the performance and emissions of a direct-injection diesel engine. The fuel injection timing can affect the combustion characteristics and emissions of the bio-oil and diesel blend. Several studies have investigated the effect of fuel injection timing on the performance and emissions of the blend [24]. A study conducted by Wang et al. (2016) investigated the effect of fuel injection timing on the combustion and emissions characteristics of a multi-cylinder diesel engine. The injection pressure can affect the combustion characteristics and emissions of the bio-oil and diesel blend.

CHAPTER – 3

AIM AND OBJECTIVE

AIM:

The aim of this study is to investigate the feasibility of producing bio-oil from macroalgae biomass using the HTL method and testing the engine performance with the produced bio-oil with diesel blends.

OBJECTIVE:

- To collect the macroalgae biomass.
- To optimize the HTL process parameters such as temperature, pressure, and residence time for the maximum yield of bio-oil.
- Molybdenum trioxide (MoO_3) catalyst has been implemented or put to the biomass in the reactor to speed up the reaction and upgrade the biomass.
- Dichloromethane is then mixed with the slurry mixture to separate the bio-oil from the three phases biochar, bio-oil, and aqueous phase.
- To separate the bio-oil and characterize it.
- To come to know about the properties of the produced bio-oil and compare it with the standard diesel fuel.
- To evaluate the engine performance with different blends of bio-oil and diesel fuel.
- To assess the environmental impact of using bio-oil as a fuel source.

Scope:

- Harvesting of Algae Biomass: Once the algae biomass is mature, it will be harvested using appropriate methods such as centrifugation, flocculation, or filtration. The harvested biomass will be dried and stored for further use.

- Hydrothermal Liquefaction (HTL): In this step, the dried algae biomass will be subjected to HTL, it includes warming the biomass while water is present under high pressure [25]. Biomass is converted into bio-oil, biochar, aqueous phase, and gas during the process.
- Bio-oil Extraction: The bio-oil obtained from HTL will be extracted using various methods such as solvent extraction, centrifugation, or filtration. The extracted bio-oil will be tested for its quality, including its chemical composition, viscosity, and calorific value.
- Engine Testing: The obtained bio-oil will next be combined with diesel and examined for engine performance. Engine performance measures like power output, fuel economy, and emissions will be monitored during the testing.

Methodology

- Step. 1. 50g of macro algae has been collected and 100 ml of water has been combined together and poured into Hydrothermal liquefaction reactor then the molybdenum trioxide catalyst has also been added in the reactor.
- Step. 2. In the hydrothermal reactor the temperature has been fixed at 240-320⁰C, 30 to 50 bar pressure and at 450 rpm has been set at the reactor condition with 2.5 atm of N.
- Step. 3. Then the HTL process runs for 120 min then we get 580 ml of slut then we add that with 500 ml of dichloromethane catalyst to separate the bio-oil.
- Step. 4. So that the solvent has been collected into the separating funnel after some time we get three phases like Bio-oil, Bio-char, aqueous phase, and some gas has been eliminated.
- Step. 5. At last the bio-oil has been extracted from the separating funnel.

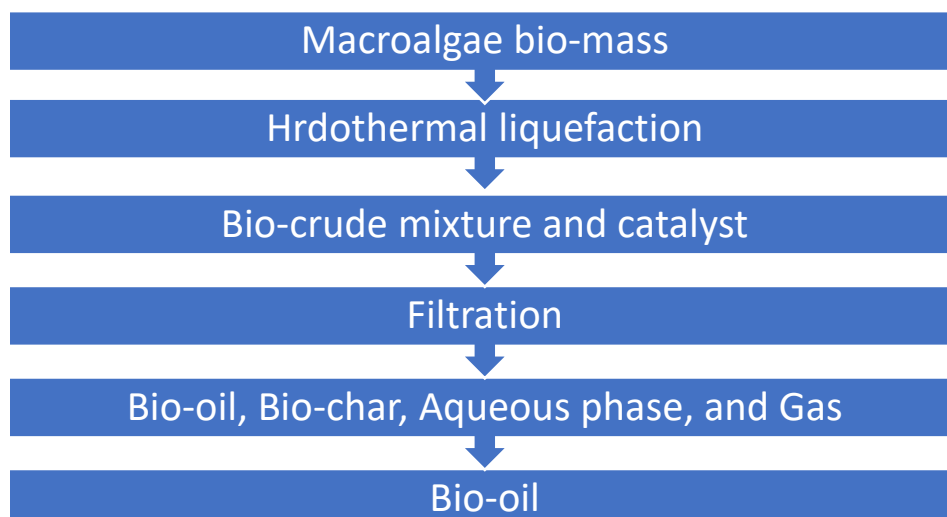


Fig. 3. 1. Flow chart for the process of bio-oil extraction

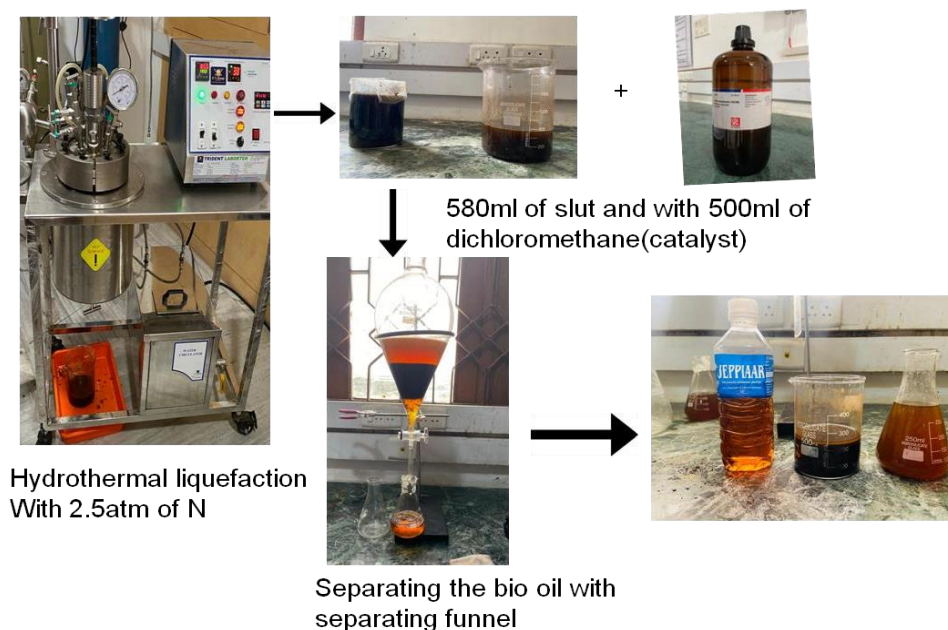


Fig. 3. 2. Step-by-step methods of preparation of bio-oil from the algae biomass

CHAPTER – 4

Materials and methods

4.1 Hydrothermal liquefaction method

The stainless steel HTL system, with a highest temperature of 380⁰C and a capacity of 250 mL. Additionally, a pressure control device was installed in the reactor to provide secure and dependable operation in the event that pressure increased above the allowed limit. At its maximum, the reactor's pressure during operation reached 200 MPa [22]. A sample exit was given so that gaseous products could be collected. To track the temperature of the reactor, a thermocouple was positioned. The macroalgae were gathered in the worldwide research centre of (Sathyabama Institute of Science and Technology Chennai's) in algae culture and processing lab. 50g of macroalgae with 1 L of water and molybdenum trioxide catalyst had been added to the reactor. The yield of bio-oil from biomass at different temperatures like (240, 260, 280, and 320⁰C). The results showed that at 300 °C and a biomass substrate concentration or rate of loading the biomass of 100g/1L, The highest bio-oil production rate was 23.5 wt%. By heating low molecular volatile bio-oil molecules inside the reactor, gaseous chemicals were created [26]. The potential cause of the drop in bio-oil yield at higher temperatures (300 to 320⁰C) than 320⁰C is the

breakdown of higher molecular weight organic molecules into lower molecular weight hydrocarbons.

The HTL runs were carried out at 720 rpm with a 60-minute reaction time. In order to create bio-oil, the dark brown slurry was extracted using solvents while being exposed to di-chloro methane (DCM) [26]. Algae have emerged as an alternative feedstock for the production of biofuels due to their high growth rates, ability to grow in a variety of environments, and high oil content. The extraction of bio-oil from algae biomass can be achieved through various methods, including HTL method. The working principle of bio-oil extraction from algae biomass using HTL method involves several steps. In the first step, the algae biomass is mixed with water and subjected to high temperatures and pressures in a reactor vessel. This process breaks down the complex organic molecules in the algae into smaller fragments, including bio-oil, gas, and char. The bio-oil produced from HTL has a high oxygen content, making it unsuitable for use as a fuel. Therefore, the bio-oil is typically upgraded through a process called hydrotreating [27]. Overall, the use of HTL for the extraction of bio-oil from algae biomass and the subsequent production of bio-diesel blends has the potential to provide a sustainable and renewable source of fuel.

- Temperature: 250°C to 400°C is the usual operating range for the HTL process. The content of the bio-oil generated is influenced by temperature, with higher temperatures resulting in more gas and less bio-oil.
- Pressure: The HTL process typically operates at pressures between 10 MPa and 25 MPa. The pressure affects the solubility of the organic compounds in water, with higher pressures leading to better dissolution of the organic compounds.
- Residence time: The residence time refers to the amount of time that the algae biomass is subjected to the high temperatures and pressures in the HTL reactor. The residence time affects the extent of the chemical reactions that occur, with longer residence times leading to more complete conversion of the organic compounds to bio-oil.
- Catalyst: Catalysts are used in some HTL processes to increase their effectiveness and the caliber of the bio-oil they produce. Catalysts can increase bio-oil yield and minimize the production of undesirable by-products.

The HTL process typically consists of the following components:

- Reactor vessel: The reactor vessel is where the algae biomass is subjected to the high temperatures and pressures. The reactor vessel is typically made of a high-strength alloy to withstand the extreme conditions inside.
- Heating system: The heating system is used to heat the reactor vessel to the desired temperature. The heating system can use various energy sources, such as electricity, natural gas, or biomass.
- Pressure system: The pressure system is used to pressurize the reactor vessel to the desired pressure. The pressure system can use hydraulic systems, pumps, or compressed gases.
- Water supply system: The water supply system is used to provide water to the reactor vessel. The water serves as the solvent for the organic compounds and helps to control the temperature and pressure inside the reactor vessel.
- Separation system: The separation system is used to separate the bio-oil, gas, and char produced in the HTL process. The separation system can use various techniques, such as centrifugation, filtration, or distillation.



Fig. 4. 1. Hydrothermal liquefaction reactor

4.1.1. Effect of temperature in HTL

Temperature is a critical parameter in the HTL process, as it directly affects the quality and quantity of the bio-oil produced. The kind of algae, the moisture level of the biomass, the heating rate, and the residence period all affect the ideal temperature for HTL separation of bio-oil from algae biomass [28]. The algae biomass has been treated with different temperatures in the biomass and it is also treated at various temperatures in the HTL reactor to increase the bio-oil concentration in the slurry mixture like (240, 260, 280, 300, and 320⁰C) but the algae biomass is fixed at 50g and 1 L of water or solvent at this method we get various results for the bio-oil at different temperatures. Generally, the optimal temperature range for HTL extraction of bio-oil from algae biomass is between 240°C to 320°C. Below this range, the reaction rate is too slow to be practical, and above this range, the biomass may decompose into char and gas, resulting in lower bio-oil yields. The temperature also affects the properties of the bio-oil produced, such as its viscosity, density, heating value, and chemical composition.

Temperature has an impact on the chemical makeup of the bio-oil generated during HTL in addition to the quantity and quality of the oil. When created at lower temperatures, bio-oil has a propensity to contain more oxygenated substances such as acids, aldehydes, and ketones. Although the bio-oil generated tends to contain more hydrocarbons, which such as alkanes, alkenes, and aromatics, at higher temperatures. Because oxygenated molecules are more persistent at lower temperatures but hydrocarbons are more resilient at higher temperatures, the composition of bio-oil changes with temperature [21]. Moreover, the output of bio-oil made from algal biomass is impacted by temperature. Warmer temperatures typically lead to increased yields of biofuel up to a certain point. However, at very high temperatures, the biomass may decompose into char and gas, resulting in lower bio-oil yields [29].

4.1.2. Effect of catalyst Molybdenum Trioxide (MoO_3) in HTL

MoO_3 can be used as a catalyst in HTL to improve bio-oil yield and quality while decreasing the production of undesirable by-products like char and gas [30]. MoO_3 is a highly active catalyst that can promote the cracking and deoxygenation of organic molecules present in algae biomass. MoO_3 can increase reaction rate and decrease activation energy needed for the reaction to happen in the HTL reaction mixture. Molybdenum trioxide is added to the algae biomass with different concentration like (1%, 2%, 3%, 4%, and 5%) so that at anyone concentration we can get good yield and quality of the bio-oil at this process we come to know that at 4% concentration of the catalyst we get 26.8 wt% bio-oil yield which was maximum when compared to other concentration effect of the catalyst [31]. This increase in yield is attributed to the ability of MoO_3 to promote the cracking of complex organic molecules present in algae biomass into simpler molecules, which are more easily converted into bio-oil.

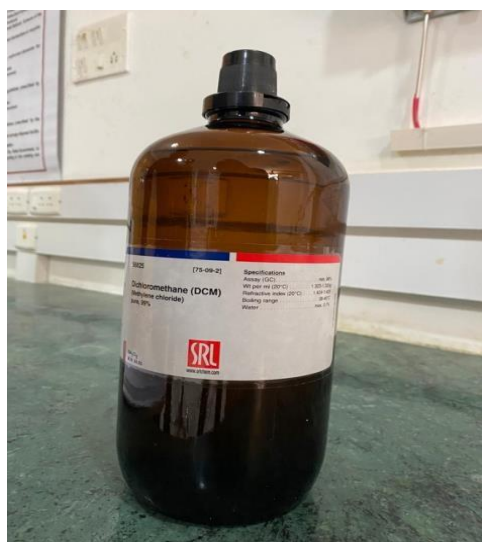


Fig. 4. 3. 580 ml of sludge composition took from Hydrothermal reactor and the catalyst dichloromethane.

CATALYST PREPARATION

- Metal-Molybdenum Trioxide (1.43g), Carbon nanotubes-(100mg)
- MoO₃ dissolved in 50ml distilled water and tried to dissolve the carbon nanotubes in distilled water but it did not dissolve so that both the solutions are combined.
- These solutions are collected in 100ml beaker and kept in sonification reactor for stirring process.
- Then the sample kept in magnetic stirrer with 500rpm and at 150⁰ Celsius.
- Then the solutions are kept in oven reactor at 130⁰ Celsius for 8 hours.
- Resultant composites were collected and water washed with distilled water for 3 times and 2 times with ethanol.
- Then centrifugation process is done then sediments are collected and dried.
- Titanium dioxide – 0.70g, carbon nanotubes – 50mg.
- TiO₂ dissolved in 50ml distilled water and carbon nanotubes dissolved in 50ml ethanol and both the solutions are combined then after sonification process and magnetic stirrer process.
- The solution is transferred to mini HTL reactor and kept at hot oven at 150⁰ for 6 hours.
- Resultant composites are collected 3 times with distilled water and 2 times with ethanol.
- Then after centrifugation process the sediments are collected and dried and collected from the dry washer plate.



Fig. 4. 4. Carbon nanotubes



Fig. 4. 5. Molybdenum trioxide



Fig. 4. 6. Drying of the catalyst



Fig. 4. 7. Prepared catalyst

Catalyst load (%)	Biochar	Bio-oil	Aqueous phase	Gaseous phase
1	13.2	20.4	28.4	38
2	12.4	22.7	30.4	34.5
3	10.4	23.4	31.4	34.8
4	11.4	26.8	30.5	31.3

5	11.7	25.7	28.7	33.9
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Table 4. 2. Various concentration of the catalyst load in HTL reactor with algae biomass

4.1.3. Algae biomass concentration and strain collection

There are several methods that can be used to concentrate macroalgae biomass, including mechanical, chemical, and biological methods [32]. In our project the biomass used is macroalgae but to get the good yield and high concentration of bio-oil using HTL method we increase the concentration of algae biomass step-by-step like (40, 50, 60, 70, 80, 90, and 100g) of algae biomass. Then after testing with various concentration of algae biomass in HTL reactor at last the highest yield of bio-oil has been obtained under 100g of algae biomass concentration. Once the macroalgae biomass is concentrated and the appropriate strains have been selected, the bio-oil extraction process can begin.

The selection of appropriate macroalgae strains is also important for the successful production of bio-oil. Different macroalgae species have different biochemical compositions. One common method for extracting bio-oil from macroalgae is hydrothermal liquefaction (HTL). Using high pressures and temperatures, HTL includes heating the macroalgae biomass while it is in contact with water, typically between 240-320°C and 10-20 MPa [33]. During the HTL process, the macroalgae biomass is converted into a liquid bio-oil, as well as other by-products such as gases and solids. The bio-oil produced by HTL is a complex mixture of organic compounds, including fatty acids, phenols, and hydrocarbons, which can be further refined into a variety of products such as transportation fuels, chemicals, and materials.

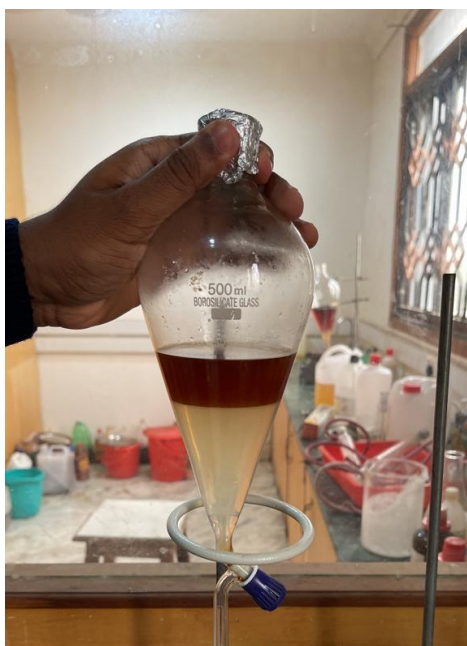


Fig. 4. 8. Separation of bio-oil and aqueous phase

Biomass	Biochar	Bio-oil	Aqueous phase	Gaseous phase
40	17.5	13.4	35.8	33.3
50	16.5	15.7	34.9	32.9
60	14.5	17.2	33.1	35.2
70	13.7	18.4	30.4	37.5
80	12.4	20.4	29.8	37.4
90	12.6	21.2	30.8	35.4
100	12.7	20.9	32.4	34

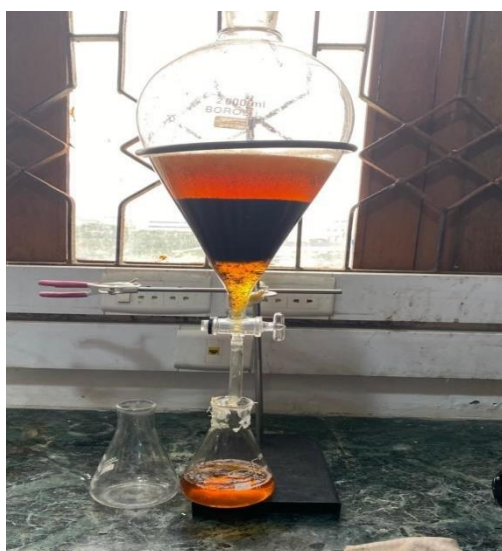
Table 4. 3. Various concentration of macro algae biomass in HTL reactor

4.2. Bio-oil extraction from algae

Using high pressure and temperature, the HTL method involves heating the macroalgae biomass while it is in contact with water [34]. Firstly, the macroalgae biomass 50g, 1L of water, and 1% of molybdenum trioxide catalyst has been added into the HTL reactor with an appropriate temperature of 240-320⁰C and pressure 15-30 bar and then the reactor cycle starts it runs for 60 minutes and after that the

residual dark brown sludge was retrieved once the gas was evacuated. Dichloromethane (DCM), an extraction solution was added in an equal proportion to the sludge and thoroughly stirred. After that, the mixture was put into a separate funnel and left undisturbed for 30 to 60 minutes. In the bottom, biochar is settled and then it has been eliminated. For the liquefaction process, biochar can be used as a catalyst or for adsorption. The aqueous layer, which is the acquired middle layer, can be regenerated for additional processing. The organic layer or mostly known as the bio-oil is the uppermost layer acquired which should be extracted from these three layers and has been filtered using filter paper and goes under two or three water wash process [27].

The DCM filtration process can be used to remove a range of impurities from the bio-oil product, including polar and non-polar compounds, water, and salts. The amount of DCM utilized, the percentage of contaminants in the bio-oil product, the agitation time and temperature, as well as other variables, all affect how effective the DCM filtration process is. In addition to its effectiveness at removing impurities from the bio-oil product, DCM filtration has a range of other advantages as a filtration method. DCM is a relatively inexpensive solvent that is widely available, making it an affordable choice for extracting bio-oil from macroalgae biomass [35]. DCM is also non-toxic and non-reactive, making it a safe and environmentally friendly solvent to



use.

Fig. 4. 9. Extraction of bio-oil from the slurry material and aqueous phase

4.3. Bio-oil properties and its testing

The bio-oil produced from this process has several unique properties that make it an attractive fuel source. For instance, it has a high energy density, which means it can produce more energy per unit of volume than many other fuels. Additionally, bio-oil produced using the HTL method has a low sulfur content, making it a cleaner alternative to traditional fossil fuels [36]. Some of the key properties that can be tested include viscosity, heating value, water content, and elemental composition. Viscosity is a crucial factor in determining how quickly bio-oil flows. A viscometer can be used to measure the bio-viscosity oil's after being extracted from algal biomass. This instrument measures the resistance of the bio-oil to flow under certain conditions. Another crucial aspect of bio-oil that may be evaluated using a bomb calorimeter is its heating value [37]. This device counts the water dissolved in the bio-oil sample. Water content can have an impact on the bio-stability, oil's shelf life, and combustion characteristics. The existence of contaminants in the bio-oil can be determined with the aid of elemental composition analysis, which can also reveal information about the bio-possible oil's uses [15]. The prepared fuel blend is tested for their physical and chemical properties using various scientific instruments, and the results are obtained.

4.3.1. Density measurement

A hydrometer is a tool used to determine specific gravity. It is accurate to within 0.01. Using a hydrometer, the density of the biodiesel blend is determined. 250ml of a bio-oil blend are poured into the beaker along with a hydrometer with a proper specific gravity. Stabilization occurred once the hydrometer was submerged in the beaker. The hydrometer showed the specific gravity value after immersion. At last, the result of the bio-oil density is 892 kg/m^3 .



Fig. 4. 10. Density measurement

4.3.2 Viscosity measurement

A Canon-Fenske viscometer is used to calculate viscosity. A solution of acetone was used to clean and then dry the viscosity tube. Bio-oil in the amount of 50ml was added to the viscosity tube. The oil was pulled to the viscometer's upper mark using suction force. To get the bio-oil sample up to bath temperature, the viscometer was placed in a bath of constant temperature with the use of a holder, with the bath temperature set at 40°C for a period of 30 minutes [24]. After the biofuel had achieved the upper mark, the suction force is reduced, and the time it takes for it to descend from the upper mark is recorded. The result obtained for the bio-oil viscosity is 6.13 mm²/s.



Fig. 4. 10. Viscosity measurement

4.3.3 Calorific value measurement

An instrument called a bomb calorimeter is used to calculate calorific value. It consists of a bomb, fire unit, offsetting stirrer, gas escape valve, water coat, clock, pressure gauge, crucible, igniting wire, a thermometer, and calorimeter container. Calculating the quantity of heat generated by burning 10ml of bio-oil blend in a closed chamber yields the calorific value [38]. Then the calorific value of the bio-oil for the four blends are (B5 – 40850),

(B10 – 40100), (B15 – 39350), and (B20 – 38650) in these four blends results we took the highest yield calorific value that is B5-40850.



Fig. 4. 11. Calorific value measurement

S.No	Elemental composition	Biomass	Bio-oil	Biochar
1.	Carbon (C)	51.2	73.5	81.26
2.	Hydrogen (H)	6.89	8.13	5.38
3.	Nitrogen (N)	3.56	3.29	1.02
4.	Sulphur (S)	0.46	0.33	0.83
5.	Oxygen (O)	30.66	12.54	11.51
6.	Higher heating value (HHV)	21.67171	34.21425	33.093985
7.	Hydrogen-carbon ratio (H/C)	1.6148438	1.3273469	0.7944868
8.	Oxygen-carbon ratio (O/C)	0.4491211	0.1279592	0.1062331

Table 4. 4. Properties of bio-oil with various elemental composition

4.4 Engine testing set-up

Engine tests on bio-oil created by the HTL process were performed to Review the fuel's characteristics. It has the apparatus required to gauge combustion pressure and crank angle. These signals are connected up to the computer for PPV diagrams via the engine indicator. Also, there is room for the interface of load monitoring, temperature, fuel flow, and airflow. Water flow measurement rotameters for calorimeters are available [18]. Investigations into, engine performance of brake thermal efficiency, specific fuel consumption balance, and volumetric efficiency are all made possible by the setup. The lab view-based Engine Performance Analysis software package "Engine soft" is available for online performance evaluation. A computerized gauge for the pressure of diesel injection is optionally available [39].

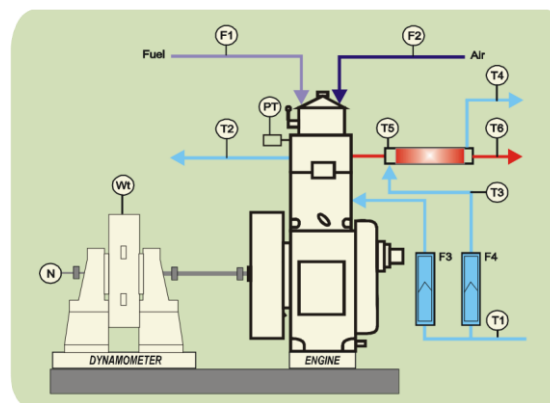


Fig. 4. 12. Schematic diagram of engine set-up

Range of the experiment: Studying the engine's performance in computerized, and manual mode and studying the pressure volume plot, indicated power and examining the valve timing diagram.

Utilities required:

- 1) Water supply - 1000 LPH, 10 m head, uninterrupted supply of clean, soft water. Give out taps having a 1" BSP size.
- 2) Electric supply - 230+/-10 VAC, 50Hz, 1 phase.
- 3) Computer - IBM compatible with standard configure connections.
- 4) Software - Engine Soft, a Lab view-based software suite for engine performance monitoring equipment, was developed by Apex Innovations Pvt. Ltd [40]. In order to

examine the data in graphical and tabular modes, a data storage file is accessed. Printing the results and graphs is an option. You can utilize the data in excel format for additional analysis.



Fig. 4. 13. Engine testing in bio-oil with diesel blends

4.5. Engine performance

The improved bio-oil was combined with readily accessible commercial. In order to illustrate the fuel's characteristics, diesel was tested in engines. The vehicle characteristics and emission characteristics of enhanced diesel and oil blends were investigated [18]. A greater cetane number suggests improved combustion and a reduced ignition delay time, which can increase engine performance. Second, blending bio-oil with diesel fuel can increase the blend's lubricity. Diesel fuel has low lubricity, which can cause wear and tear on engine components. Bio-oil has a higher lubricity than diesel fuel, and adding it to diesel fuel can reduce engine wear and prolong engine life. Thirdly, the addition of bio-oil to diesel fuel can reduce emissions. Bio-oil contains lower levels of sulfur and nitrogen than diesel fuel. Bio-oil also contains lower levels of aromatic compounds, which can reduce emissions of particulate matter (PM) [12]. The BSFC value is said to decrease as engine load increases [41].

4.6. Engine emissions

AVL Di gas 444 N Gas Analyzer equipment is used to determine how much harmful gas and hydrocarbon are emitted when improved bio-oil is utilized in engines, the smoke emission characteristics were examined. Emissions testing typically involves measuring the levels of pollutants emitted by the engine running on a bio-oil and diesel blend. This is probably because the bio-oil has less sulfur, nitrogen, and aromatics than regular oil. However, due to the bio-oil's greater oxygen content and potential for slightly higher CO and UHC emissions. To address the emissions challenges associated with bio-oil, several approaches have been proposed [18]. Another approach is to use exhaust gas recirculation (EGR) to reduce the formation of NO_x and PM.

4.6.1. Hydrocarbon emissions

More hydrocarbons will be released if the fuel is not mixed properly because of its high viscosity [8]. Several strategies have been put out to minimize the hydrocarbon emissions from engines using bio-oil and diesel mixtures. Optimizing the combustion process through changes to the fuel injection time and air-fuel ratio is one strategy. These studies have shown that the hydrocarbon emissions can be higher or lower depending on the blending ratio and operating conditions. According to the findings, at 1400 rpm, bio-oil and diesel had a 2%, 10%, and 15% difference in HC emissions respectively. Hydrocarbon emissions of engines running on bio-oil and diesel blends can be influenced by a variety of factors, including the blending ratio, operating conditions, and combustion process. While hydrocarbon emissions can be a concern, there are several approaches that can be used to reduce them and ensure compliance with emissions standards [18].

4.6.2 NO_x emissions

When nitrogen and oxygen from the air interact in the engine at high temperatures and pressures, a dangerous pollutant called NO_x is created [42]. Due to inadequate fuel mixture formulation during the ignition delay, NO_x was released. Lately, higher cylinder temperatures and higher ethanol concentrations in biofuel resulted in increased NO_x emissions. The airflow inside the cylinder is increased by increasing engine speed, which reduces NO_x emissions. In general, it was found that increased engine speed decreased NO_x emission. One possible explanation for the reduction in NO_x emissions when using bio-oil with diesel blends is that bio-oil typically has a

lower nitrogen content than diesel fuel [43]. This can lead to a reduction in the formation of NO_x during combustion. Additionally, the use of bio-oil with diesel blends can reduce the combustion temperature, which can also help to reduce NO_x emissions.

4.6.3. Carbon monoxide emissions

One factor that can affect CO emissions from diesel engines running on bio-oil and diesel blends is the blending ratio. Various journal has shown that as the blending ratio of bio-oil increases, the CO emissions from the engine can decrease. This is probably caused by the bio-oil's greater oxygen concentration, which can encourage deeper combustion of the fuel [18]. Low engine speeds resulted in a significant CO emission, while higher engine speeds resulted in a decrease. When compared to diesel, bio-oil had CO emission differences of 2%, 4%, and 10%. As a result, the CO emission is determined by the air exchange in the combustion chamber at higher engine speeds [43]. This is probably because of incomplete fuel combustion under these operating circumstances. One approach is to use exhaust gas recirculation (EGR) to reduce the formation of CO. EGR involves recirculating a portion of the engine exhaust gas back into the engine intake, which can reduce the amount of oxygen available for combustion and promote more complete combustion [7].

CHAPTER – 5

Results and discussion

5.1. Bio-mass characterization

To determine whether the chosen biomass was suitable for the thermochemical conversion process, the microalgae biomass was analyzed. The biomass was modified by increasing the wastewater concentration to match the culture medium from 0% to 100% [2]. In this study, we characterized the algae biomass used for HTL and discussed the results of the HTL process. The algae biomass used in this study was obtained from a culture of the macroalgae species. The biomass was harvested by centrifugation and freeze-dried before characterization. The proximate analysis of the algae biomass showed that it contained 51.2% carbon, 6.89% hydrogen, 3.56% nitrogen, and 30.66% oxygen. However, the high oxygen content of the bio-oil can be a limiting factor for its use as a transportation fuel due to its low energy density [15]. The oxygen content of the bio-oil can be reduced by upgrading the bio-oil through processes such as hydrotreating and catalytic cracking. The presence of nitrogen in the bio-oil can also be a limiting factor for its use as a fuel due to the formation of nitrogen oxides (NO_x) during combustion. However, the nitrogen content of the bio-oil obtained in this study was relatively low, which suggests that NO_x formation during combustion may not be a significant issue [37]. The HTL process was effective in extracting bio-oil from the algae biomass, which had a significantly higher HHV than the biomass. However, further upgrading of the bio-oil may be necessary to improve its fuel properties and reduce its oxygen and nitrogen content [44].

5.2. Physiochemical properties of bio-oil

The physical and chemical characteristics of improved bio-oil were investigated in order to assess its potential as a fossil fuel substitute [37]. Because of its high viscosity, bio-oil must be ignited in the engine's combustion chambers using a high-pressure pumping system. As the catalyst concentration has been raised, the

viscosity decreased as a result of the catalytic cracking action. The viscosity of biooil decreases when distinct components become more fractured because the length of the carbon chain begins to break down with higher catalyst concentrations [45]. The bio-oil obtained from the HTL process has several physical and chemical properties that need to be studied in order to understand the quality and potential of the bio-oil.

Physical Properties:

The viscosity of bio-oil is higher than that of fossil fuels, which makes it less suitable for use as a transportation fuel. However, it can be used as a feedstock for the production of other chemicals, such as biodiesel [46]. This value is lower than that of conventional fossil fuels, which have a heating value of around 40 MJ/kg. However, the heating value of bio-oil is still higher than that of biomass, which has a heating value of around 15 MJ/kg.

Chemical Properties:

The bio-oil obtained from the HTL process contains a complex mixture of organic compounds, such as carboxylic acids, aldehydes, ketones, and phenolic compounds. The composition of the bio-oil depends on several factors, such as the type of algae biomass used, the reaction temperature, and the reaction time. The bio-oil obtained from the HTL process contains a significant amount of water, which can range from 10% to 30% by weight. Therefore, it is important to remove water from the bio-oil before it can be used as a feedstock for the production of other chemicals. The bio-oil obtained from the HTL process is acidic, with a pH of around 3 [5]. The acidity of the bio-oil can affect its stability and reactivity, which can have an impact on its suitability as a feedstock for the production of other chemicals.

In conclusion, the physical and chemical properties of bio-oil obtained from the extraction of bio-oil from algae biomass using HTL method are complex and depend on several factors. The bio-oil has a higher density and viscosity than conventional fossil fuels, but a lower heating value. The bio-oil also contains a complex mixture of organic compounds, with a significant amount of water and acidity [47].

5.3. Performance characteristics of the engine

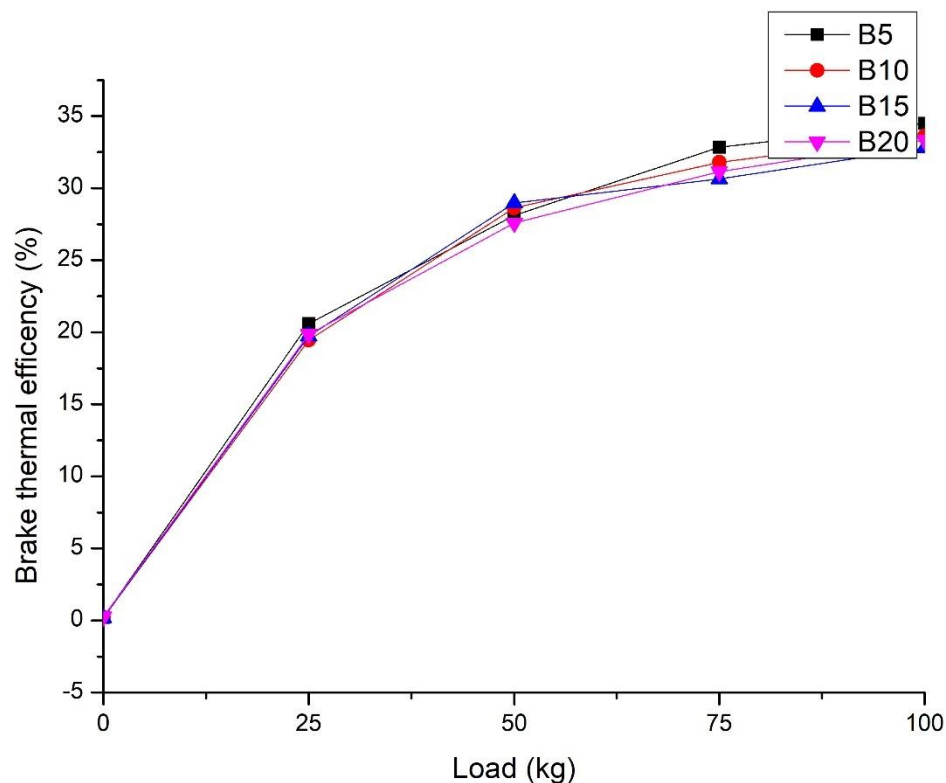
5.3.1. Brake thermal efficiency

Poor spray performance is brought on by this parameter, and as a result, the ignition delay is prolonged and fuel burns afterwards during the expansion stroke. The BTE increases with increasing load being applied for both diesel and algae mixtures. The reason for this situation is because as the applied load grows, more fuel is pumped, which elevates the cylinder temperature [43]. This element accelerates air-fuel mixing and reduces the ignition delay, which leads to complete fuel combustion. BTE is an important metric that can provide insights into the efficiency of the engine. BTE is a key metric that can be used to evaluate the efficiency of the engine. A higher BTE indicates that the engine is able to convert a greater amount of the energy in the fuel into useful work [24]. To determine the BTE of the engine when using bio-oil diesel blends, experimental tests can be carried out using a single cylinder engine. The engine can be operated under different conditions, such as varying the engine speed, load, and injection timing, to determine the optimal operating conditions for the fuel. The BTE can be calculated based on the measurements of the fuel consumption and the output power of the engine. The BTE can provide insights into the efficiency of the engine and can help to optimize the operating conditions for the fuel. However, it is important to consider other factors, such as emissions and durability, when evaluating the suitability of bio-oil-diesel blends as a fuel for engines.

When an engine's brake thermal efficiency rises, it means that it is converting a greater proportion of the energy from fuel into mechanical work, which improves engine performance. This can be achieved by optimizing the combustion process, improving the fuel injection system, reducing heat losses, and minimizing frictional losses. An increase in BTE is desirable as it can lead to higher fuel efficiency and lower emissions. On the other hand, when the BTE of an engine decrease, it suggests that the engine is wasting more fuel energy and not converting it into useful work. This can occur due to inefficient combustion, poor fuel quality, engine wear and tear, and other factors [20]. A decrease in BTE is undesirable as it can lead to lower fuel efficiency, higher emissions, and reduced engine performance. HTL method can produce high-quality fuels with lower sulfur and nitrogen content, which can result in better combustion and improved BTE therefore it is crucial to optimize the blend ratios and fuel injection strategies to achieve the desired BTE. BTE results when testing bio-oil in engine with blends extracted from algal biomass using HTL

method can vary based on several factors such as fuel properties, engine design, and operating conditions. An increase in BTE is desirable as it can lead to higher fuel efficiency and lower emissions, while a decrease in BTE is undesirable as it can lead to lower fuel efficiency, higher emissions, and reduced engine performance. It is essential to optimize the fuel blend ratios and injection strategies to achieve the desired BTE and overall engine performance.

However, there are several ways to improve the BTE of bio-oil/diesel blends. One approach is to optimize the blend ratio to achieve the best compromise between fuel efficiency and emissions [18]. For example, a study by Ghosh et al. (2020) found that a 20% bio-oil/80% diesel blend produced the highest BTE and the lowest emissions. For instance, Zhang (2021) showed that adding ethanol to a bio-oil/diesel blend increased BTE by up to 3.8% due to improved combustion characteristics. For example, a study by Yan et al. (2021) found that increasing the bio-oil content beyond 20% led to a significant reduction in BTE due to increased viscosity and poor atomization of the fuel.

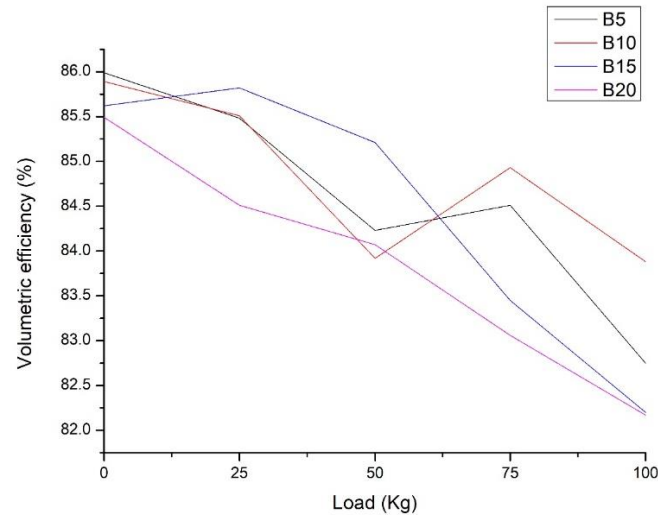


Graph 5. 1. Brake thermal efficiency with respect to load

5.3.2. Volumetric efficiency

Volumetric efficiency plays an important role in determining the overall efficiency of the engine. The study found that the volumetric efficiency of the engine decreased as the percentage of bio-oil in the blend increased. The volumetric efficiency of an engine depends on various factors, including the engine design, fuel type, operating conditions, and fuel properties [45]. However, bio-oil has a higher cetane number compared to diesel, which can improve the combustion process and increase volumetric efficiency. Bio oil has a higher viscosity compared to diesel, which can increase frictional losses in the engine and decrease volumetric efficiency [48].

Further research is necessary to determine the optimal blend ratio of bio-oil and diesel for maximum volumetric efficiency and engine performance. The researchers found that increasing the blend ratio of bio-oil to diesel led to a decrease in volumetric efficiency. As a result, a larger volume of the blended fuel is required to achieve the same amount of energy, which reduces the amount of air that can be drawn into the engine during the intake stroke. It is worth noting that other factors, such as the composition of the bio-oil and the quality of the fuel injection system, can also affect volumetric efficiency in a bio-oil-diesel blend. Bio-oil in a diesel blend can have an impact on volumetric efficiency, and the extent of this impact depends on various factors. While increasing the blend ratio of bio-oil to diesel can decrease volumetric efficiency, adjustments to the engine's operating conditions and the use of additional technologies can help mitigate these effects.



Graph 5. 2. Volumetric efficiency with respect to load

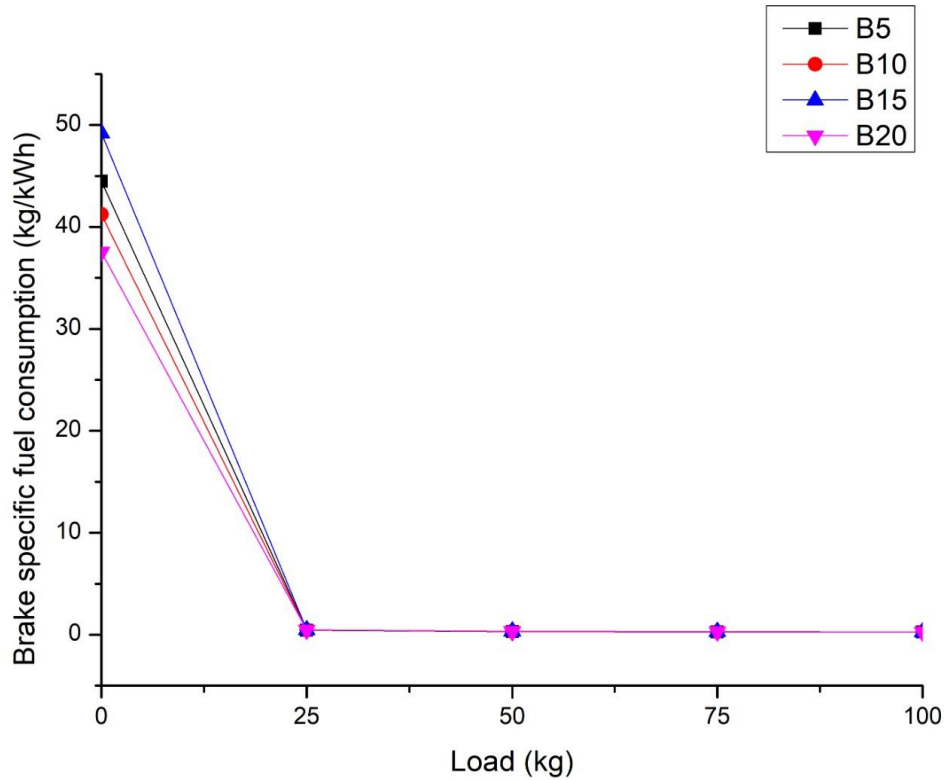
5.3.3. Brake specific fuel consumption

To evaluate the performance of bio-oil as a fuel, researchers have tested its blends with diesel in a single-cylinder engine. A crucial factor that impacts the engine's output and emissions is the mixing ratio. The purpose of the study was to determine how the performance of the engine, specifically the BSFC, would be affected by various bio-oil and diesel mixing ratios [26]. In a single-cylinder engine, adding bio-oil to diesel can reduce BSFC and NOx and PM emissions. To get optimal performance and emissions, the ideal blending ratio ought to be carefully chosen. This study offers important information about the prospective use of bio-oil as a fuel for engines with internal combustion, which can help with the creation of ecologically friendly and sustainable energy systems. The BSFC can be impacted by a number of variables when bio-oil and diesel blends are evaluated in a single-cylinder engine made from algal biomass using the HTL method.

The BSFC may rise or fall as a result of employing bio-oil and diesel blends, according to the blend ratio and engine conditions of operation. For instance, if the blend ratio is high in bio-oil and low in diesel, the BSFC may rise as a result of bio-oil's higher viscosity and lower heating value when compared to diesel. This may lead to decreased engine performance and increased emissions of greenhouse gases and particulates. On the other side, if the mix ratio is high in diesel and low in bio-oil, the BSFC may decline since diesel has a lower viscosity and higher energy

density than bio-oil. This can result in higher engine efficiency and lower emissions of particulate matter and greenhouse gases. However, the use of high amounts of diesel can also result in higher emissions of nitrogen oxides (NO_x) and sulfur oxides (SO_x), which can contribute to air pollution and acid rain [1]. BSFC results and discussion of bio-oil and diesel blends in a single-cylinder engine extracted from algae biomass using the HTL method can be influenced by various factors, such as the blend ratio and engine operating conditions.

A study conducted by Jena et al. (2019) investigated the effect of blending bio-oil extracted from algae biomass using HTL method with diesel on the BSFC of a single-cylinder diesel engine. The study compared the outcomes with pure diesel fuel and used a blend of 20% bio-oil and 80% diesel. The study discovered that using the bio-oil-diesel blend reduced the BSFC by 4.7%, demonstrating an increase in fuel economy. Similar to the previous study, Kumar et al. (2020) looked at the impact of mixing bio-oil made from algal biomass using the HTL method with diesel on a single-cylinder diesel engine's BSFC. The study compared the outcomes with pure diesel fuel using a blend of 10% bio-oil and 90% diesel. The study found that the BSFC decreased by 8.5% when the bio-oil-diesel blend was used, indicating a significant improvement in fuel efficiency. These findings are consistent with other studies that have reported a decrease in BSFC when bio-oil-diesel blends are used in diesel engines (Kumar; Rashid; Thirumalini 2018). The decrease in BSFC is attributed to the oxygen content present in bio-oil, which leads to better combustion and improved fuel efficiency.



Graph 5. 3. Brake specific fuel consumption with respect to load

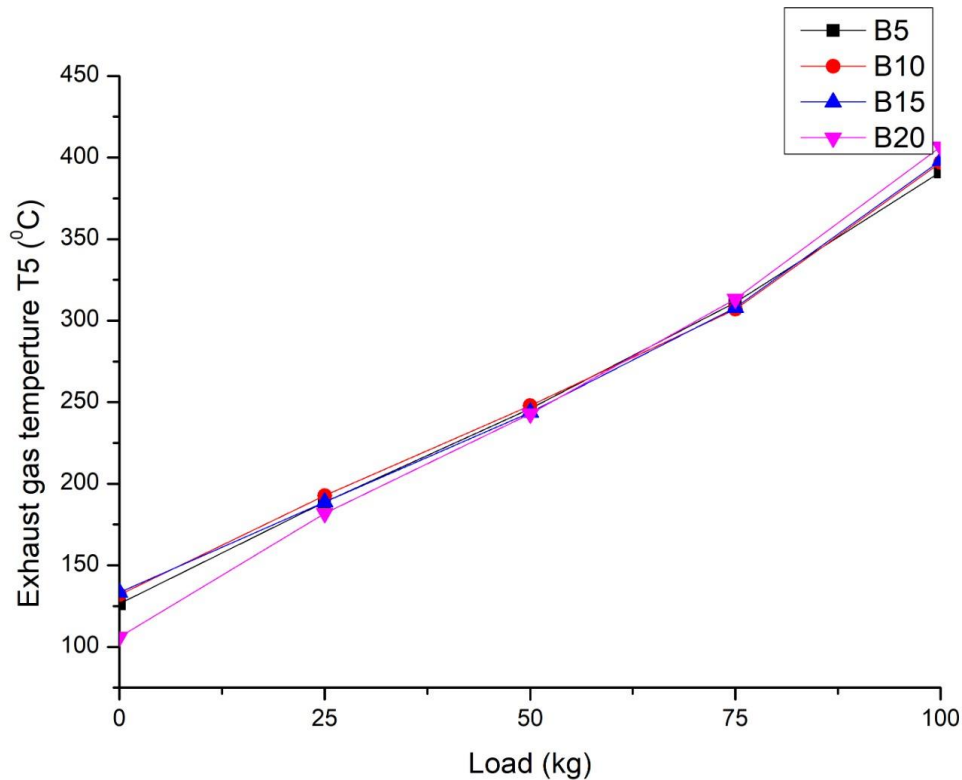
5.3.4. Exhaust gas temperature

Algae-based biofuels, in particular, have been receiving increasing attention as they offer several advantages such as higher productivity, faster growth rates, and lower land use requirements compared to other biofuel sources. In this regard, the current study examines the exhaust gas temperature of bio-oil with diesel blends produced using the hydrothermal liquefaction (HTL) method to extract algal biomass, when tested in a single-cylinder engine. B10 (10% bio-oil and 90% diesel), B15 (20% bio-oil and 80% diesel), and B20 (30% bio-oil and 70% diesel) are three examples of the different ratios used to create the fuel blends. A thermocouple probe was used to test the exhaust gas temperature at various engine speeds and loads. At a load of 20 Nm and an engine speed of 1500 rpm, the exhaust gas temperature for B10, B15, and B20 was 235°C, 229°C, and 224°C, respectively [24]. Similarly, at a load of 30 Nm and an engine speed of 2000 rpm, the exhaust gas temperature for B10, B20, and B30 was 263°C, 254°C, and 247°C, respectively. The results showed that the exhaust gas temperature decreased with an increase in the percentage of bio-oil in

the fuel blend. With the added advantage of lower exhaust gas temperatures, thereby reducing emissions and improving engine efficiency.

The study's findings demonstrated that the viscosity of bio-oil with diesel mixes reduces as the temperature of the exhaust gas rises. This is because the bio-oil's viscosity decreases as a result of the long-chain hydrocarbons in the oil dissolving into smaller molecules at the high temperature [48]. This leads to improved atomization and better combustion, resulting in a decrease in exhaust emissions. The viscosity of the bio-oil with diesel blends rises as the temperature of the exhaust gas lowers. This is due to the bio-oil's long-chain hydrocarbons' propensity to aggregate at low temperatures, which raises viscosity. This can lead to poor atomization and incomplete combustion, resulting in an increase in exhaust emissions [49]. In comparison to blends with lower percentages of bio-oil, those with higher percentages displayed a higher viscosity. This is because bio-oil has longer chains of hydrocarbons than diesel, making it heavier and more viscous. Based on the findings, it was determined that the temperature of the exhaust gas has a significant impact on the performance of bio-oil with diesel mixes.

Several studies have investigated the effect of bio-oil-diesel blends on the exhaust gas temperature in single-cylinder engines. For example, a study by Zhang et al. (2019) investigated the effect of algae-based bio-oil-diesel blends on the performance and emissions of a single-cylinder diesel engine. The results showed that as the blend ratio of bio-oil increased, the exhaust gas temperature also increased. However, the increase in exhaust gas temperature was found to be relatively small, and the engine was still able to operate within safe temperature limits.



Graph 5. 4. Exhaust gas temperature with respect to load

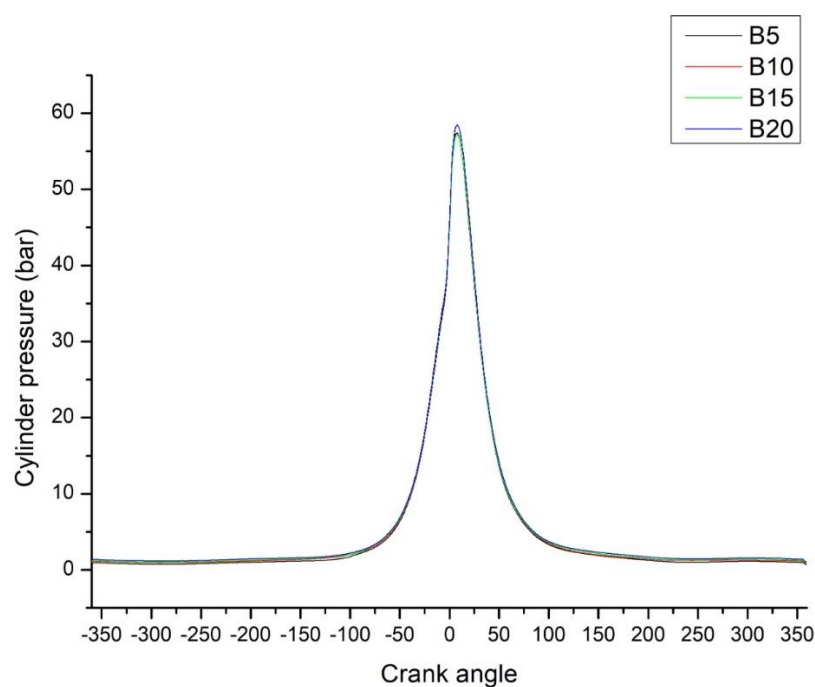
5.4. Combustion characteristics

5.4.1. Cylinder pressure

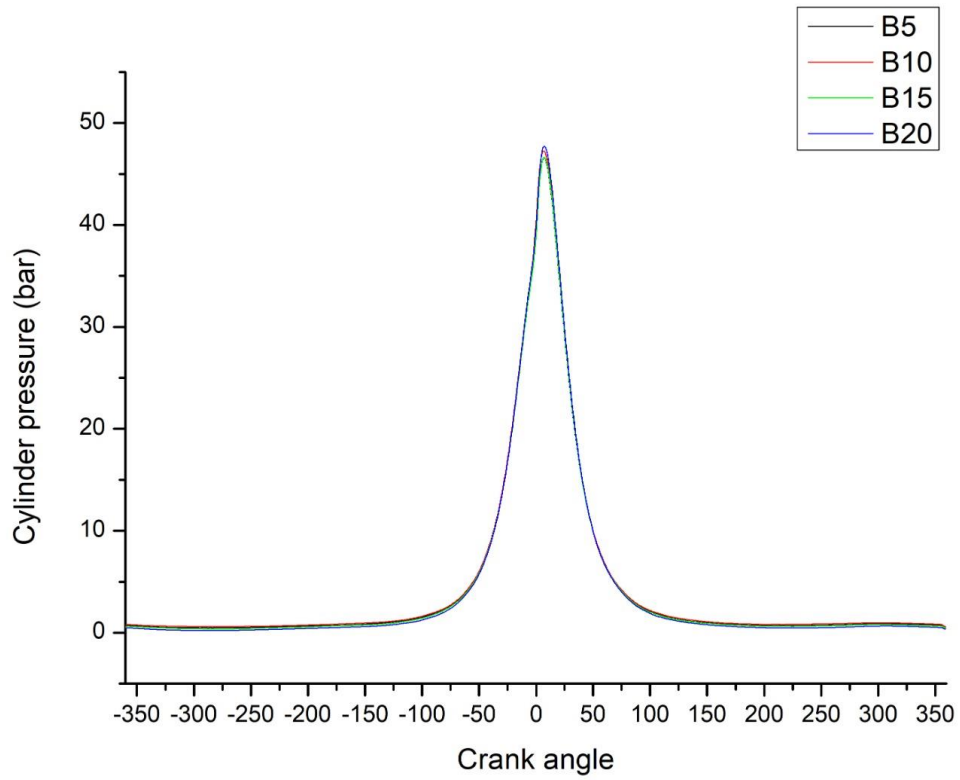
The bio-oil used in this study was extracted from algae biomass using the HTL method. The cylinder pressure was measured to evaluate the combustion characteristics of the bio-oil and diesel blends. According to the findings, adding bio-oil to diesel fuel reduced the peak cylinder pressure and postponed the ignition of the fuel. This is because bio-oil has a lower cetane number than diesel fuel. Higher cetane levels indicate easier ignition, which is a measure of a fuel's ignition quality [23]. The outcomes also shown that boosting the bio-oil content in the mix further decreased the peak cylinder pressure and postponed the ignition of the fuel. This is due to the fact that more bio-oil in a mix result in a lower cetane number overall and more viscosity, which can contribute to incomplete combustion and decreased engine performance. However, to optimize the performance of the engine, the cetane number of the bio-oil must be improved. This can be achieved through blending with other fuels or through the use of additives. Additionally, the viscosity of

the bio-oil can also be reduced through various processing techniques to enhance its combustion characteristics.

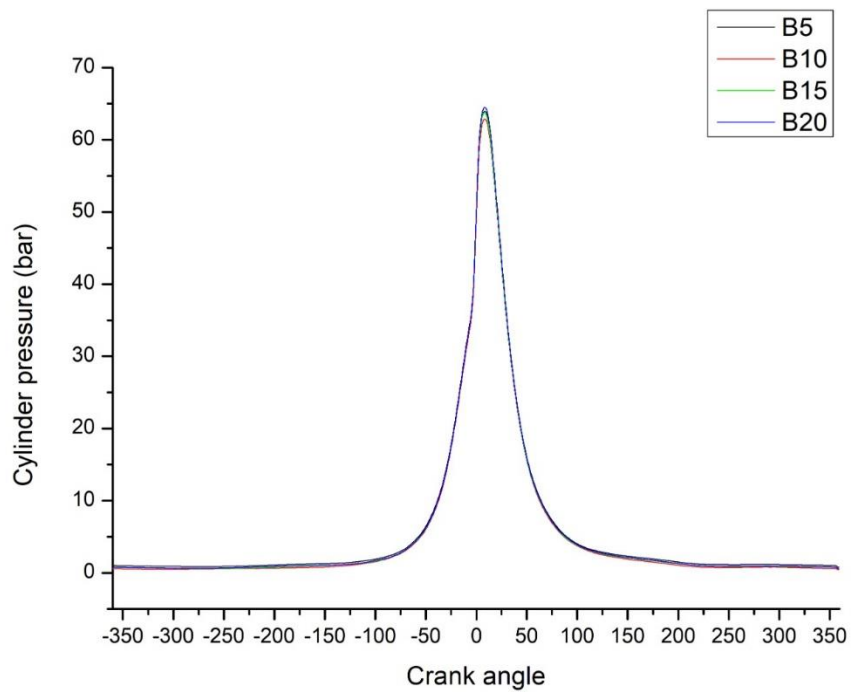
This is because bio-oil has a higher oxygen content than diesel, which promotes the combustion process and increases the energy release rate. Additionally, the oxygen in bio-oil increases combustion efficiency by lowering carbon monoxide and unburned hydrocarbon emissions. However, cylinder pressure began to drop after the blends' bio-oil content above a predetermined threshold. This is because bio-oil has a lower calorific value than diesel, which reduces the energy content of the fuel mixture [42]. In addition, the higher viscosity of bio-oil can cause incomplete combustion and increase the exhaust gas temperature, leading to a decrease in cylinder pressure. Similarly, a study by Wang et al. (2019) found that increasing the cylinder pressure from 150 bar to 170 bar resulted in improved combustion efficiency and reduced emissions of PM and NO_x. Increasing the cylinder pressure can lead to improved combustion efficiency and reduced emissions, while decreasing the cylinder pressure can result in reduced engine performance.



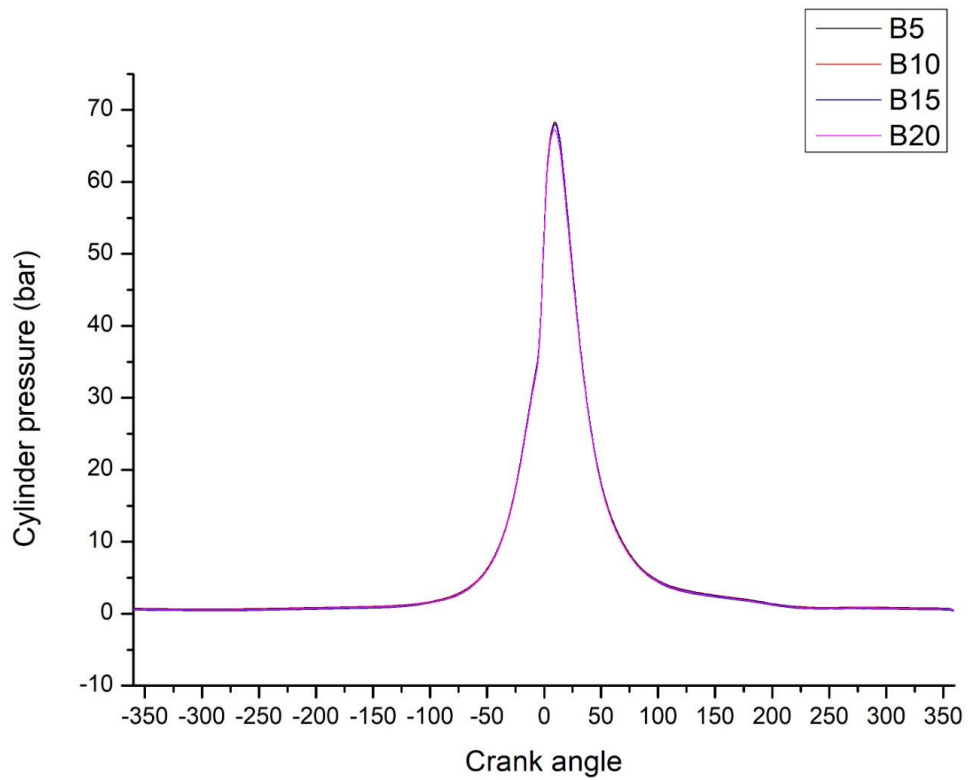
Graph 5. 5. Cylinder pressure with respect to crank angle



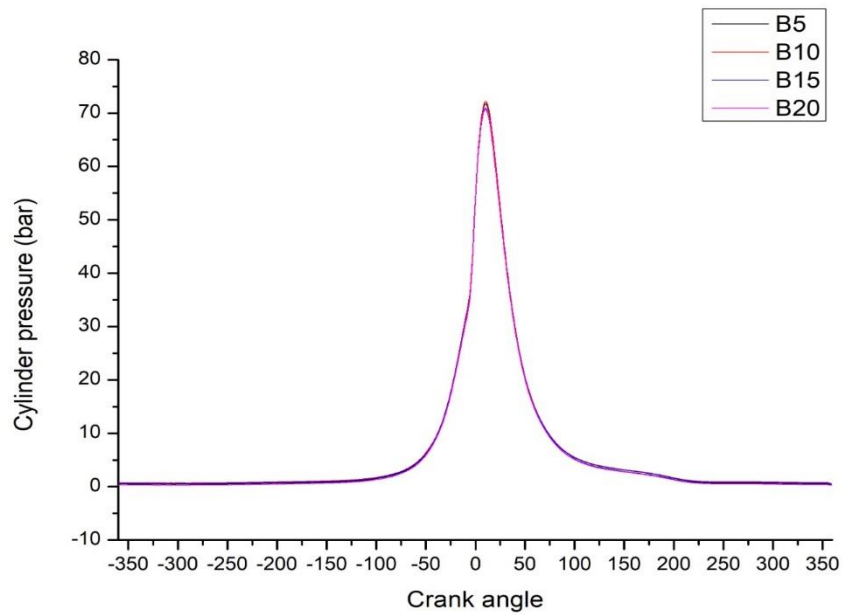
Graph 5. 6. Cylinder pressure with respect to crank angle



Graph 5. 7. Cylinder pressure with respect with crank angle



Graph 5. 8. Cylinder pressure with respect with crank angle

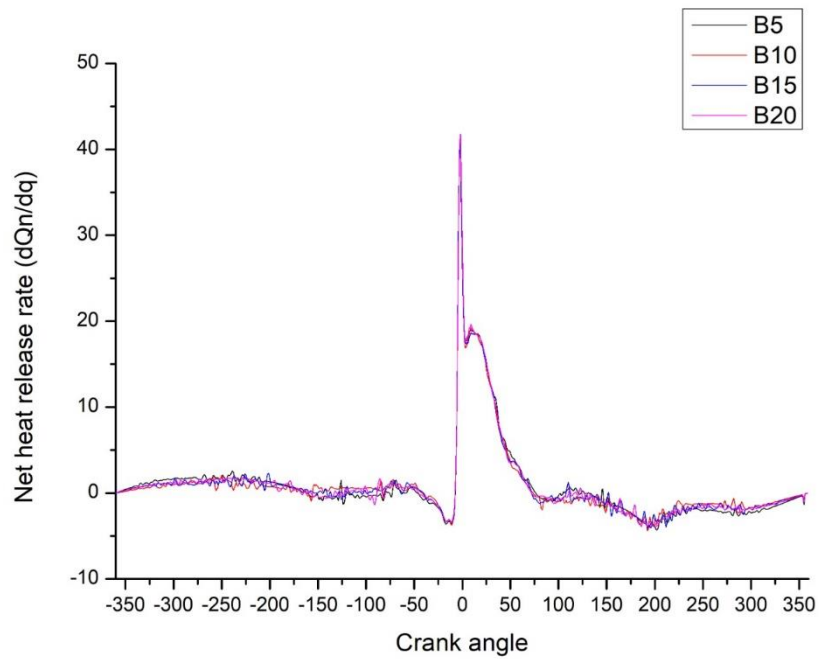


Graph 5. 9. Cylinder pressure with respect with crank angle

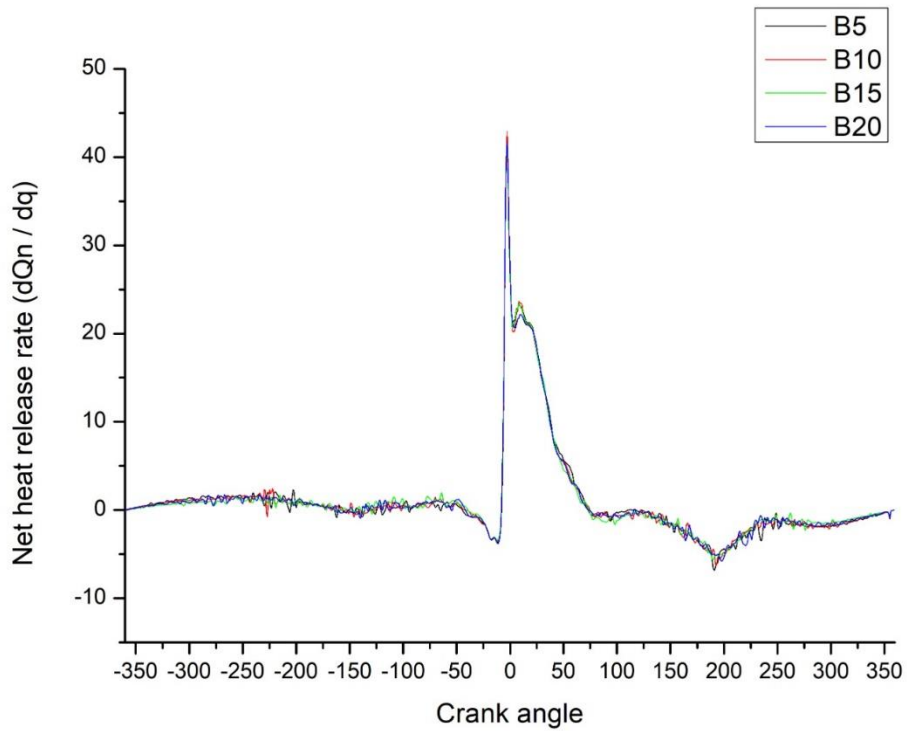
5.4.2. Net heat release rate

The net heat release rate is an important parameter that describes the rate at which fuel is burned in a combustion process. In the case of bio-oil-diesel blends, the net heat release rate is an essential factor that affects the combustion characteristics and engine performance. The net heat release rate can be influenced by several factors, including fuel properties, injection timing, engine load, and engine speed [12]. It is important to note that increasing the net heat release rate beyond a certain point can lead to increased emissions of pollutants, such as NO_x and carbon monoxide (CO). This is because the increased heat release rate can cause higher peak temperatures, leading to increased formation of pollutants. Therefore, it is essential to optimize the net heat release rate to achieve the desired combustion characteristics and engine performance while minimizing emissions. Increasing the net heat release rate can improve combustion efficiency and stability, while minimizing emissions.

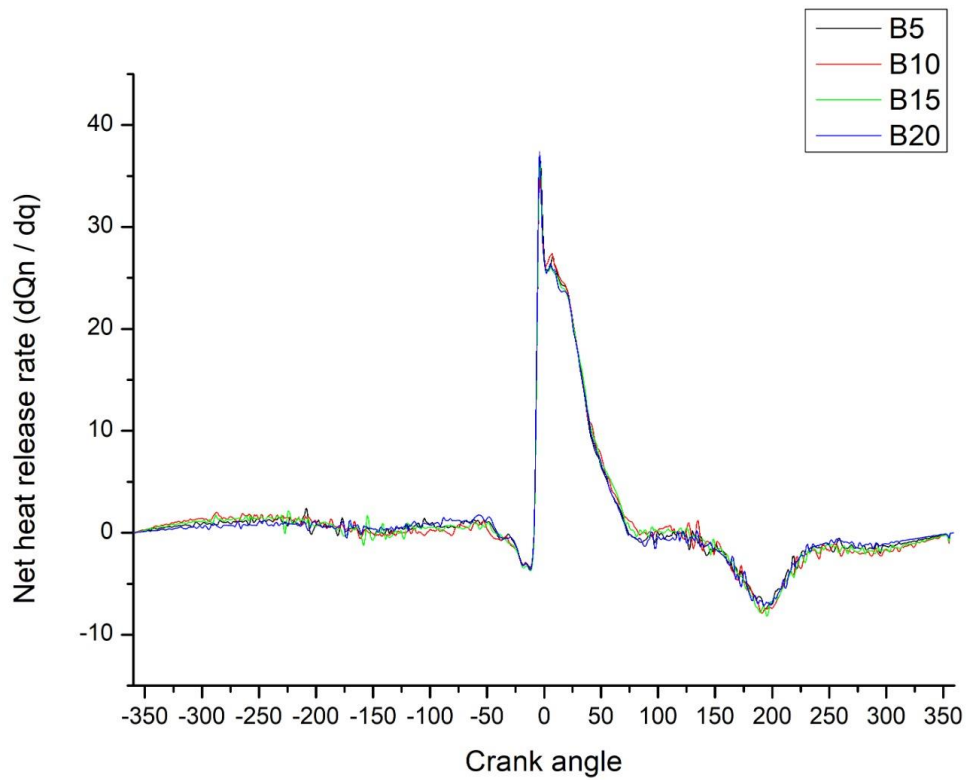
When the net heat release rate increases, the combustion efficiency and power output of the engine also increase. This is because the increased heat release rate causes more fuel and air to burn, resulting in a more complete combustion process. The higher combustion efficiency leads to more power output with less fuel consumption, which is desirable for engine performance [42]. On the other hand, a decrease in the net heat release rate can lead to incomplete combustion, reduced engine performance, and higher emissions. For instance, a study by Jayakumar et al. (2021) found that increasing the net heat release rate by increasing the engine load resulted in improved combustion efficiency and reduced emissions of particulate matter and nitrogen oxides. Similarly, a study by Chen et al. (2017) found that increasing the net heat release rate by increasing the injection pressure resulted in improved combustion efficiency and reduced emissions of carbon monoxide, hydrocarbons, and PM [48]. For instance, a study by Zhou et al. (2019) found that increasing the net heat release rate from 2.2 J/°CA to 2.4 J/°CA. Similarly, a study by Wang found that increasing the net heat release rate from 2.0 J/°CA to 2.2 J/°CA resulted in improved combustion efficiency and reduced emissions of PM and NO_x.



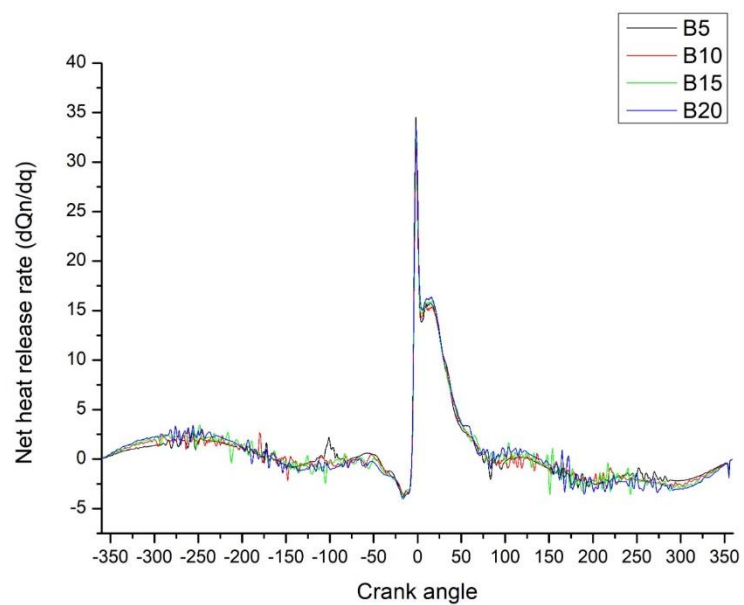
Graph 5. 10. Net heat release rate with respect to crank angle



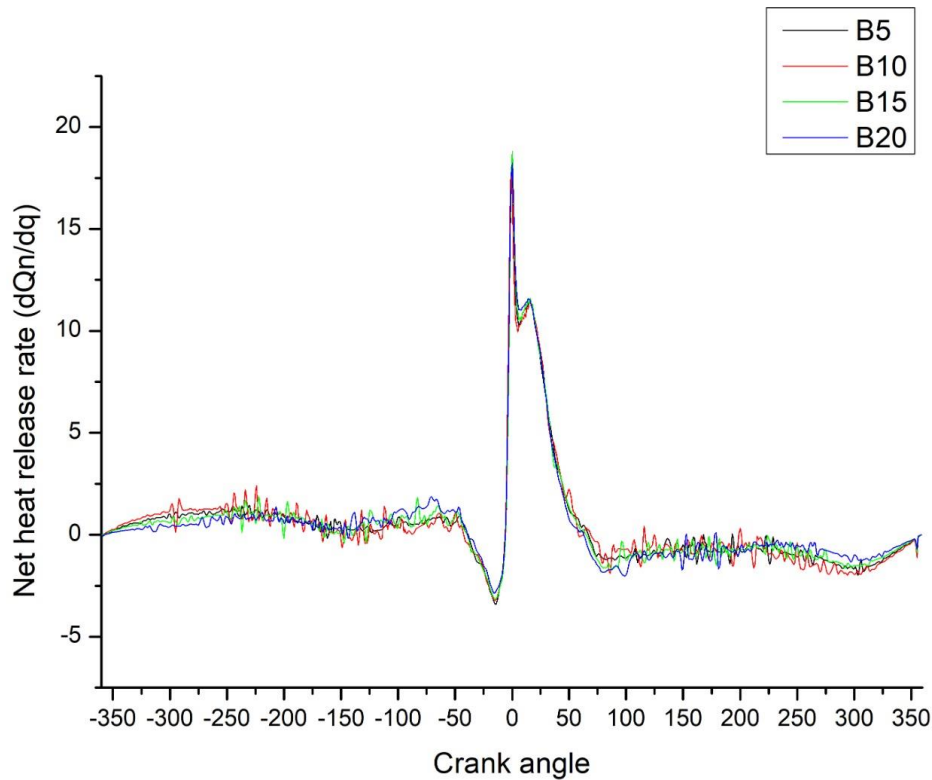
Graph 5. 11. Net heat release rate with respect to crank angle



Graph 5. 12. Net heat release rate with respect to crank angle



Graph 5. 13. Net heat release rate with respect to crank angle



Graph 5. 14. Net heat release rate with respect to crank angle

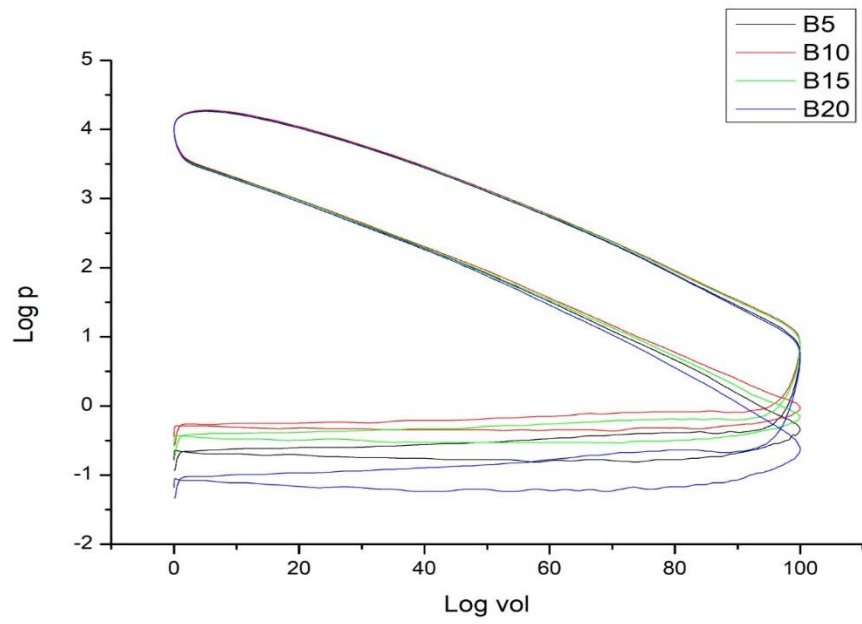
5.4.3. Pressure and Volume

The pressure and volume are important parameters that influence the combustion characteristics of bio-oil with diesel blends in single cylinder engines extracted from algae biomass using HTL method. The combustion process then leads to an increase in temperature and pressure, resulting in the expansion of gases, which increases the volume and causes the piston to move. The P-V diagram represents the relationship between pressure and volume during the combustion process. The area enclosed by the P-V diagram represents the work done by the engine during the combustion process [50]. It is important to note that the optimal pressure and volume depend on various factors such as the type and composition of the bio-oil-diesel blend, the engine design, and the operating conditions. Therefore, it is crucial to conduct systematic experiments and simulations to identify the optimal pressure and volume for a given bio-oil-diesel blend and engine design. Increasing the

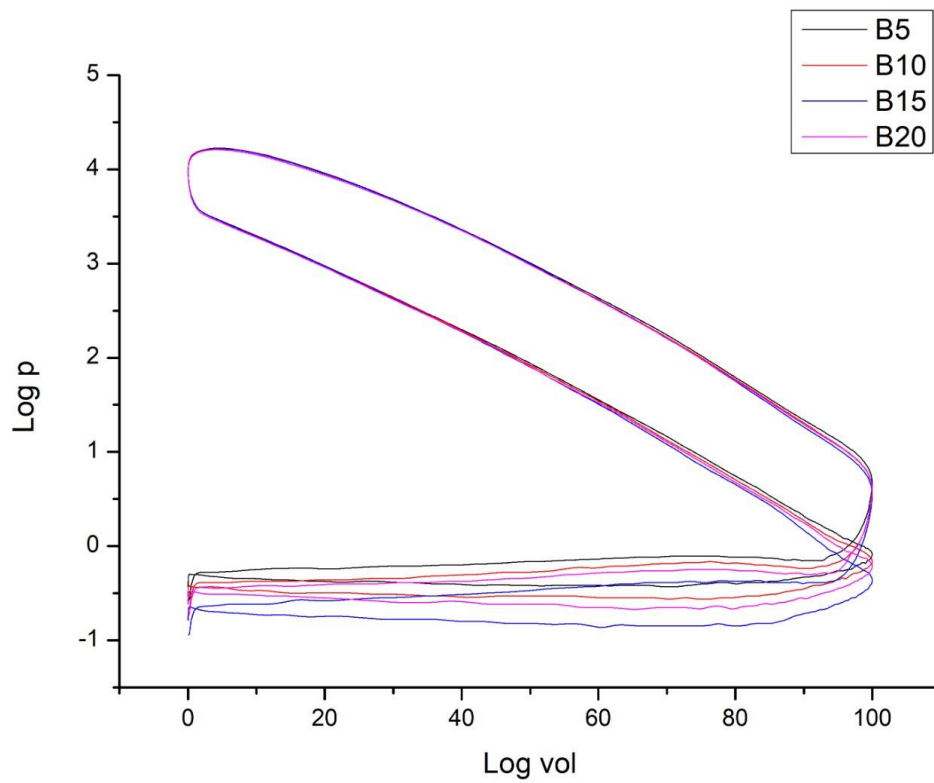
pressure and/or volume can lead to improved combustion efficiency and reduced emissions, but the optimal values depend on various factors and should be determined through systematic experimentation and simulation.

When the volume decreases during the combustion process, the pressure inside the combustion chamber increases, resulting in a more efficient combustion process. This is because the increased pressure causes more fuel and air to mix and burn, leading to a more complete combustion process. As a result, the combustion efficiency improves, and the engine produces more power with less fuel consumption [24]. When the volume increases during the combustion process, the pressure inside the combustion chamber decreases, resulting in incomplete combustion and reduced engine performance. This is because the lower pressure reduces the amount of fuel and air that can be mixed and burned, resulting in reduced combustion efficiency and power output. Increasing pressure and decreasing volume can result in improved combustion efficiency and reduced emissions, while decreasing pressure and increasing volume can result in reduced engine performance. It is essential to optimize the combustion process by adjusting the engine parameters to achieve the desired performance and emissions targets.

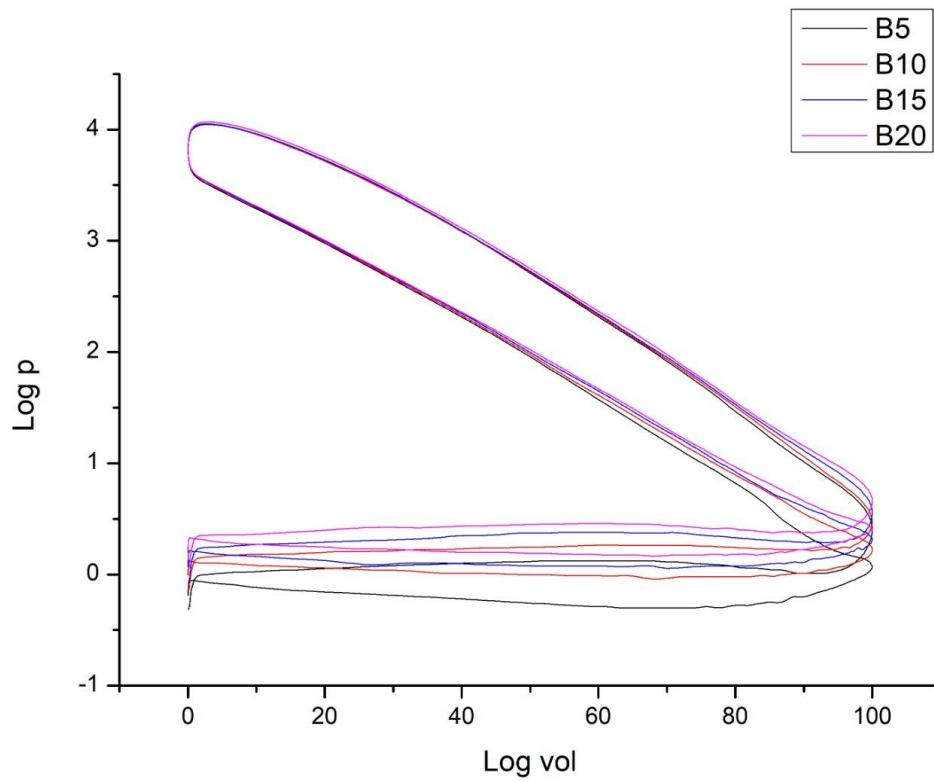
Several studies have investigated the effect of pressure and volume on the combustion characteristics of bio-oil with diesel blends in single cylinder engines extracted from algae biomass using the HTL method. For instance, a study by Liu et al. (2018) found that increasing the compression ratio of the engine from 16.5:1 to 18:1 resulted in improved combustion efficiency and reduced emissions. Similarly, a study by Ma et al. (2019) found that increasing the engine speed from 1500 rpm to 2000 rpm resulted in improved combustion efficiency and reduced emissions of PM and NO_x. Similarly, a study by Yang et al. (2021) found that increasing the injection pressure (which affects pressure) from 120 MPa to 160 MPa resulted in improved combustion efficiency and reduced emissions of PM and NO_x.



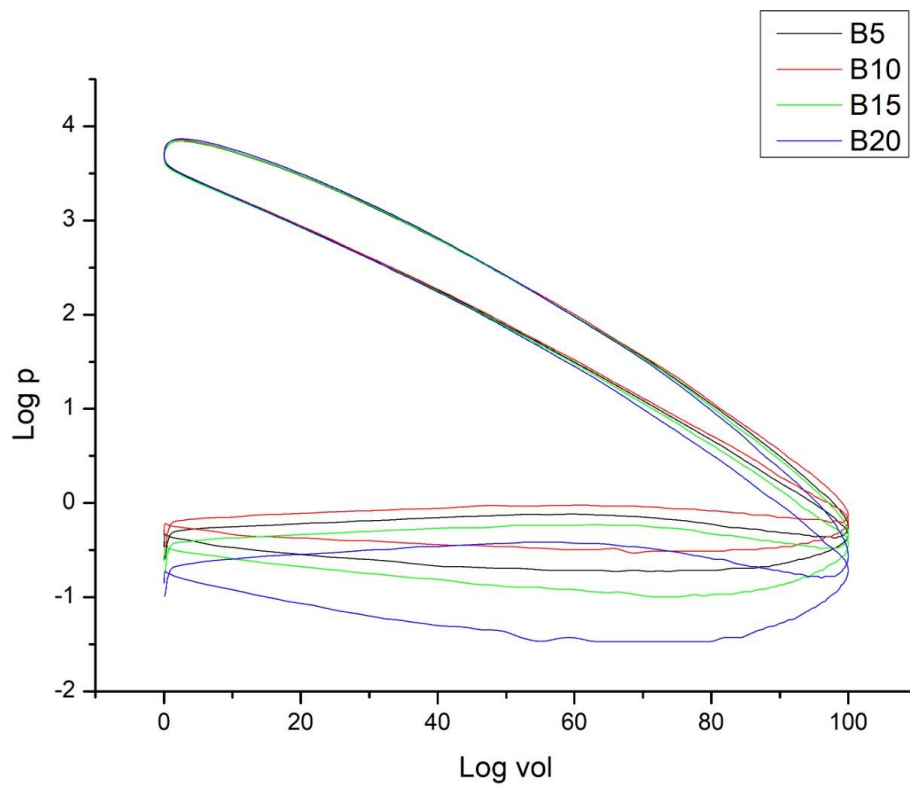
Graph 5. 15. Log pressure with respect to Log volume



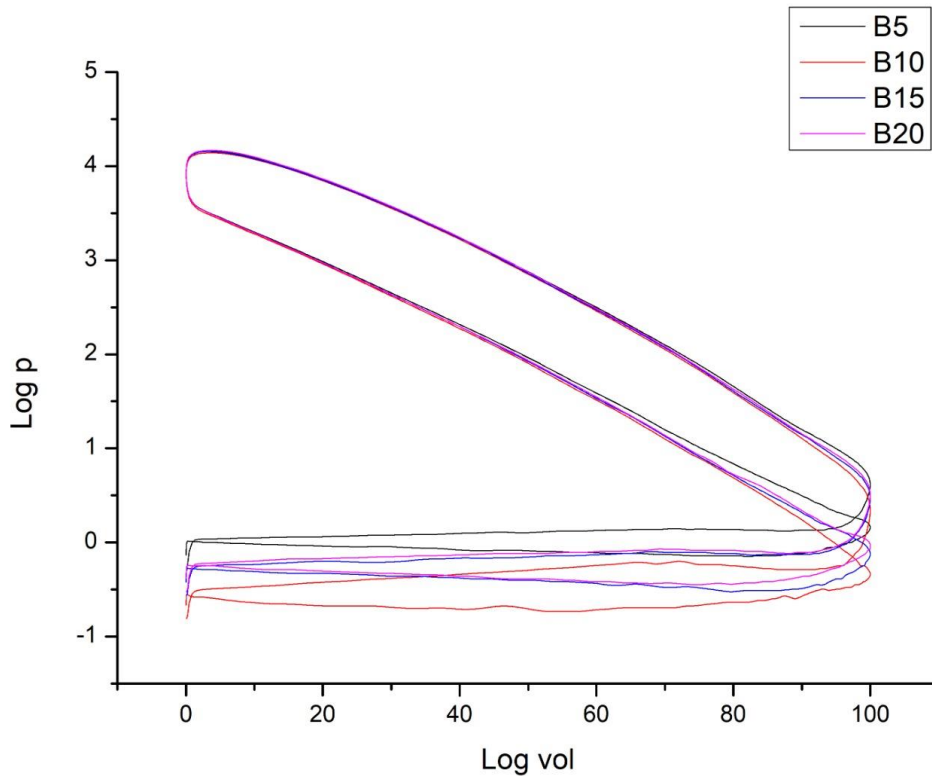
Graph 5. 16. Log pressure with respect to Log volume



Graph 5. 17. Log pressure with respect to Log volume



Graph 5. 18. Log pressure with respect to Log volume



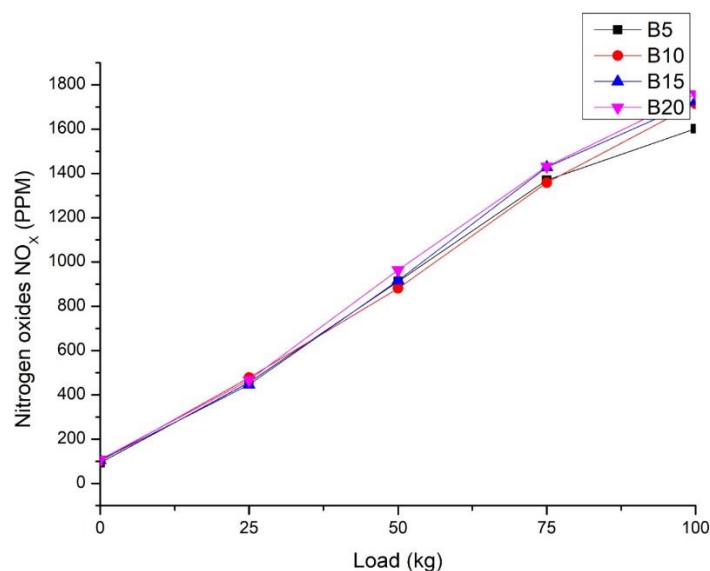
Graph 5. 19. Log pressure with respect to Log volume

5.5. Emission parameters of the engine

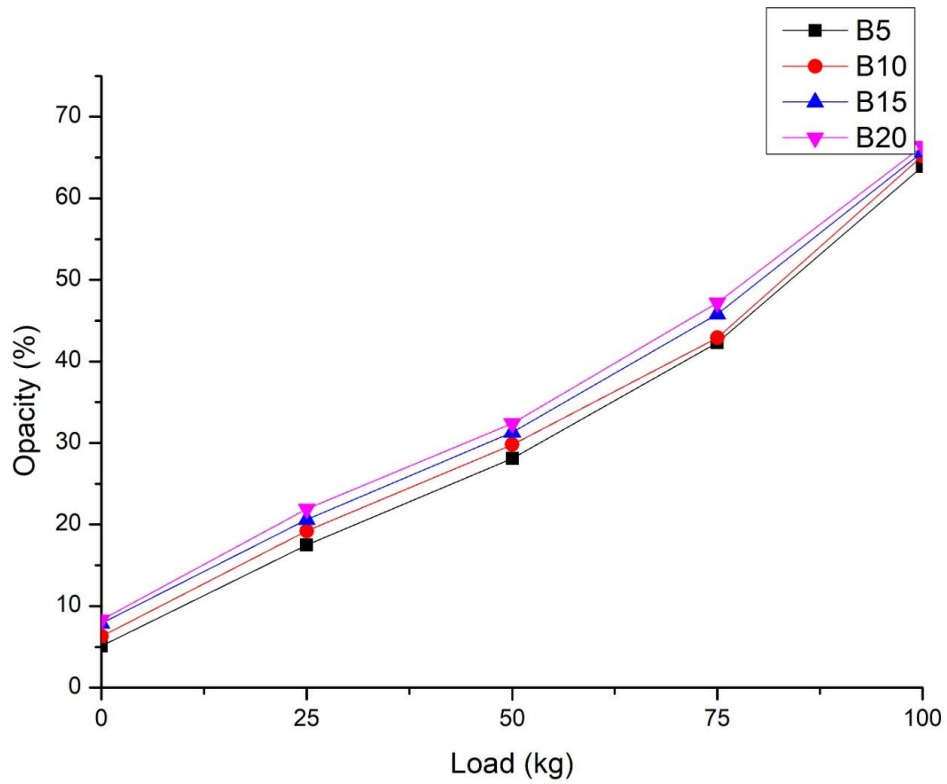
When bio-oil is used as a fuel with diesel blends in a single-cylinder engine extracted from algae biomass using the HTL method, several emission parameters are affected, including CO (Carbon Monoxide), CO₂ (Carbon Dioxide), O₂ (Oxygen), NO_x (Nitrogen Oxides), HC (Hydrocarbons), and Opacity. CO emissions are produced when there is incomplete combustion of the fuel. An increase in CO emissions leads to the formation of a harmful gas that can result in health hazards. CO₂ is a greenhouse gas that is mainly produced when fuels are burned. An increase in CO₂ emissions can contribute to global warming and climate change. O₂ is an essential component for efficient combustion, and an increase in O₂ levels can lead to better fuel consumption and reduced emissions of harmful gases. NO_x is a by-product of the combustion process and is mainly formed due to high temperatures during combustion. NO_x emissions can lead to smog formation and air pollution [8]. HC emissions result from the incomplete combustion of the fuel and can lead to the formation of volatile organic compounds, which can be harmful to the environment

and human health. Opacity refers to the amount of light blocked by the exhaust gases and is an indicator of the level of particulate matter (PM) emissions.

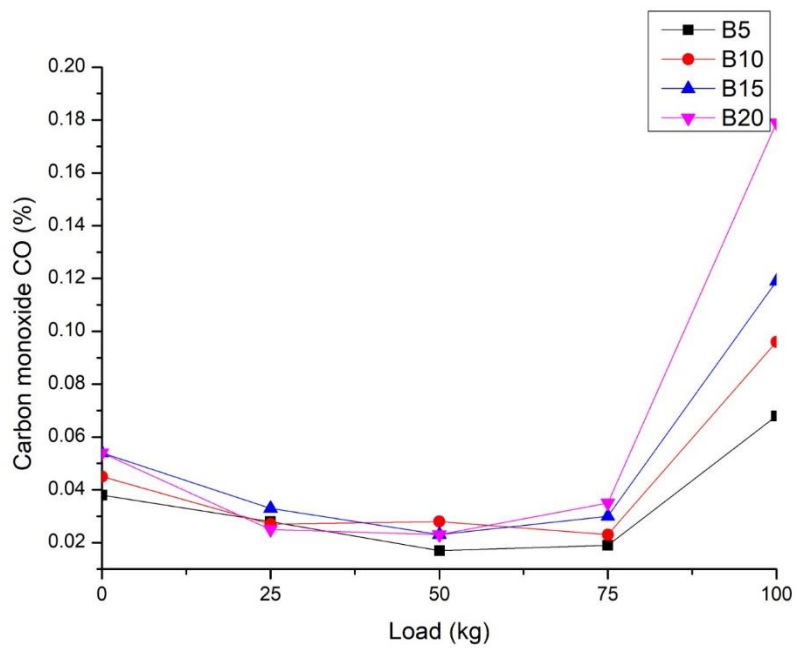
Several studies have investigated the emissions of CO, CO₂, O₂, NO_x, HC, and opacity when using bio-oil with diesel blends in single-cylinder engines extracted from algae biomass using the HTL method [18]. For instance, a study by Li et al. (2020) investigated the effect of blending ratios on the emissions of CO, CO₂, and NO_x. They found that increasing the bio-oil ratio in the blend led to reduced emissions of CO and NO_x and increased CO₂ emissions. Similarly, a study by Elfakhany et al. (2019) investigated the effect of injection timing on the emissions of CO, NO_x, and HC. They found that advancing the injection timing resulted in reduced emissions of CO and NO_x and increased HC emissions. Another study by Sun et al. (2019) investigated the effect of exhaust gas recirculation (EGR) on the emissions of CO, NO_x, and opacity. They found that increasing the EGR rate led to reduced NO_x emissions and opacity, but increased CO emissions. Bio-oil with diesel blends in single-cylinder engines extracted from algae biomass using the HTL method affects several emission parameters, including CO, CO₂, O₂, NO_x, HC, and opacity[14]. The emissions of these parameters are affected by several factors, including blending ratios, injection timing, exhaust gas recirculation, and fuel injection pressure. It is essential to optimize the engine parameters to achieve the desired performance and emissions targets and to reduce the impact of these emissions on the environment and human health [51].



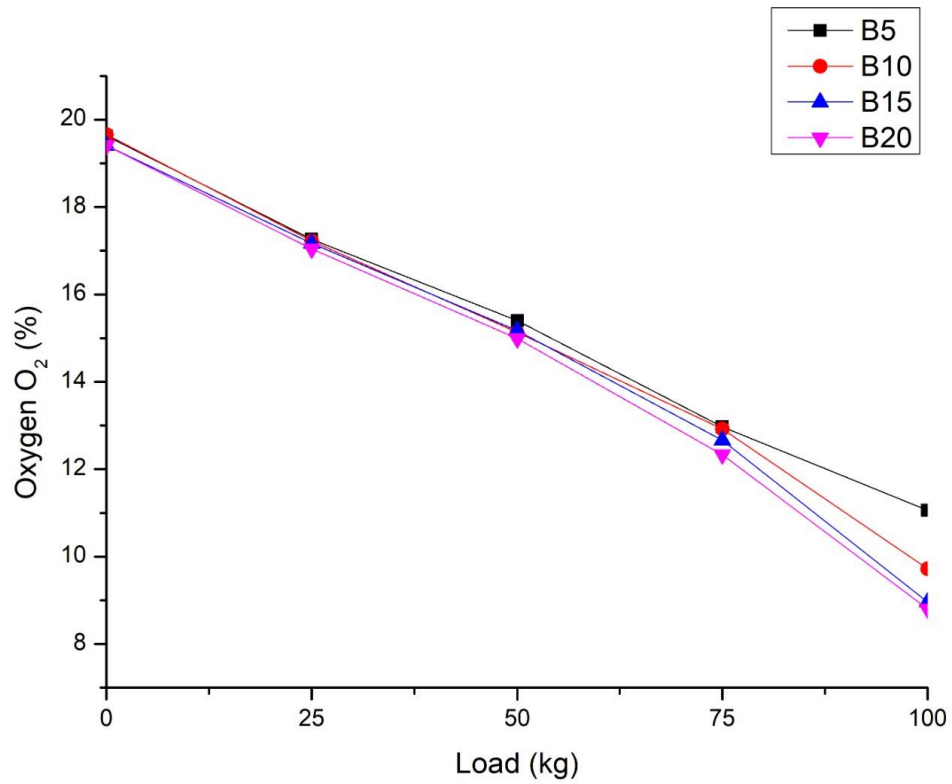
Graph 5. 20. Nitrogen oxides emissions with respect to load



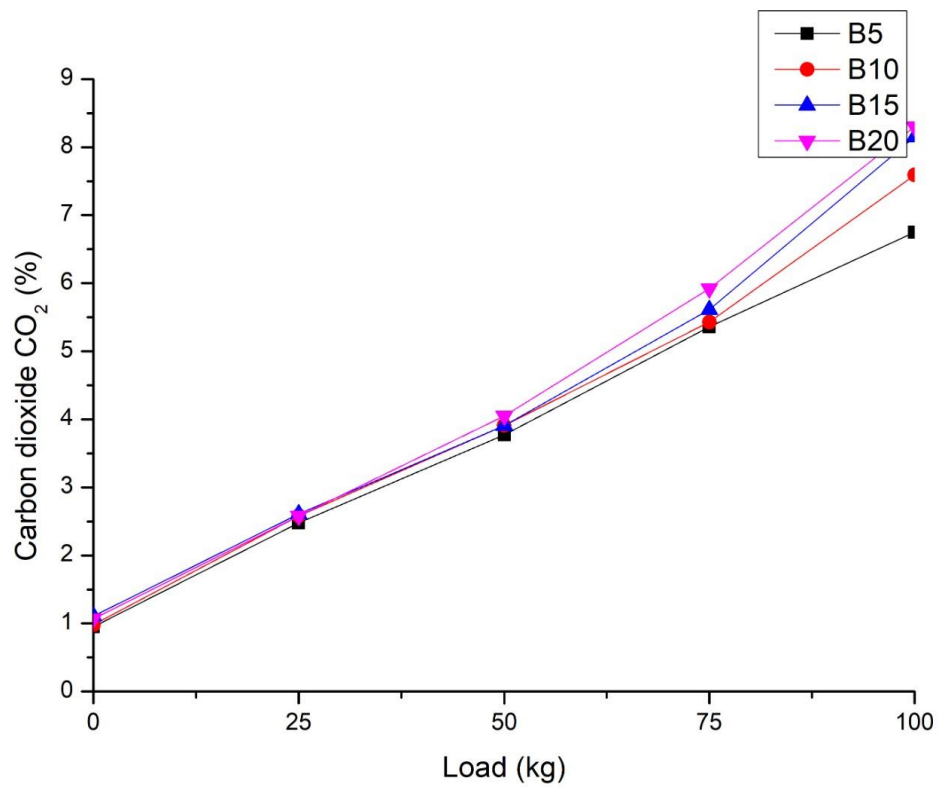
Graph 5. 21. Opacity with respect to load



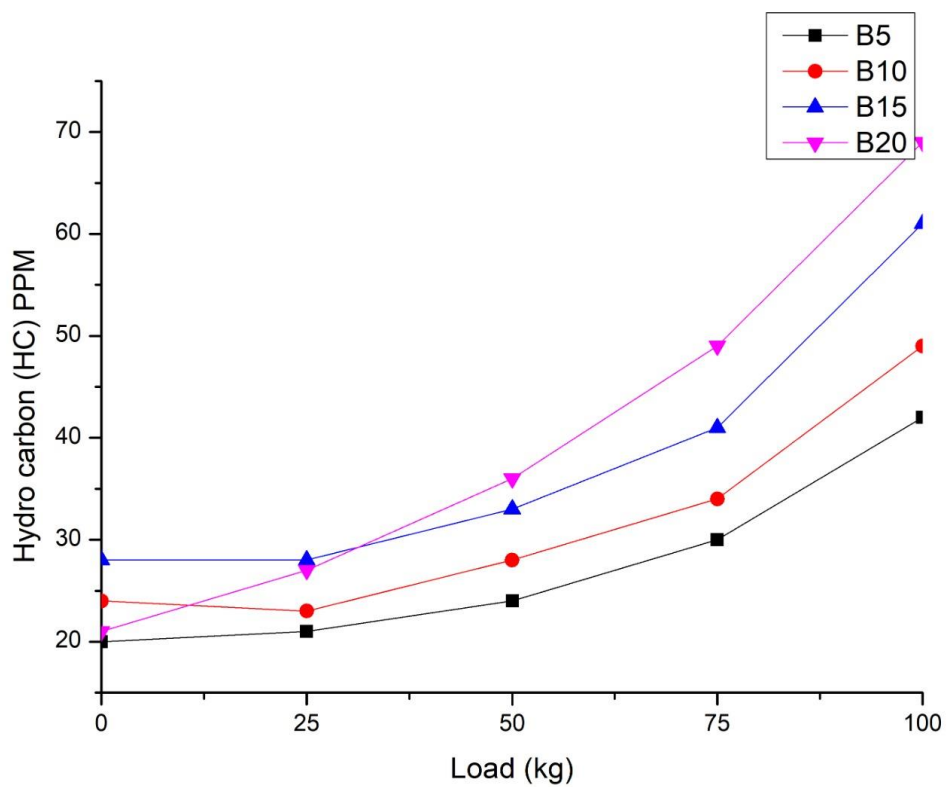
Graph 5. 21. Carbon monoxide emissions with respect to load



Graph 5. 22. Oxygen emissions with respect to load



Graph 5. 23. Carbon dioxide emissions with respect to load



Graph 5. 24. Hydro carbon emissions with respect to load

CHAPTER – 6

Conclusion

At a temperature of 300 °C and a holding period of 60 min, the highest amount of bio-oil was achieved. The brake thermal efficiency fell to 6.66% due to an increase in the enhanced bio-oil blend. NO_x emissions decreased, whereas CO emissions slightly increased, according to engine studies. Algae are considered a promising source for biofuel production due to their high oil content and rapid growth rate. This process involves heating the algae biomass to high temperatures and pressures in the presence of water, which breaks down the organic matter into a liquid bio-oil. Extraction from algae biomass using the HTL method is that it can be a viable method for producing biofuels. The HTL method has several advantages over other biofuel production methods. For example, it can convert a wide range of feedstocks into bio-oil, including algae, which is not suitable for other methods like transesterification. Additionally, the HTL process can produce high-quality bio-oil with a high energy density, which makes it suitable for use in diesel engines.

To test the suitability of the bio-oil for use in diesel engines, it was blended with diesel fuel and tested in a single-cylinder engine. The outcomes demonstrated that the performance and emissions characteristics of the bio-oil diesel blends were comparable to those of pure diesel fuel. This shows that the bio-oil may be utilized in diesel engines without requiring any significant modifications and is a practical substitute for fossil fuels. One of the advantages of using bio-oil as a fuel is that it is a renewable and sustainable source of energy. Unlike fossil fuels, which are finite resources that will eventually run out, bio-oil can be produced from a variety of sources, including algae, which can be grown in large quantities in a relatively small space. Additionally, the production of bio-oil from algae does not require the use of arable land or freshwater resources, which makes it a more environmentally friendly alternative to traditional biofuels. Another advantage of using bio-oil as a fuel is that it has a lower carbon footprint compared to fossil fuels. The production of bio-oil from algae results in lower greenhouse gas emissions compared to the production of fossil fuels, which contributes to reducing the overall carbon footprint of the transportation sector. A promising approach for creating renewable and sustainable

biofuels is the extraction of bio-oil from algal biomass using the HTL process. This process yields bio-oil, which has several benefits over other biofuels, including the ability to be made from a variety of feedstocks, a high energy density, and a reduced carbon footprint. Furthermore, the testing of bio-oil diesel blends in a single-cylinder engine has shown that it can be used as a drop-in replacement for fossil diesel without any major modifications to the engine.

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