

PRODUCTION OF BIODIESEL FROM *PONGAMMIA PINNATA* OIL USING SEAWEED-DERIVED AS BIOCHAR WITH ZINC OXIDE AS A CATALYST: STUDIES ON INTERNAL COMBUSTION ENGINE

Submitted in partial fulfillment of the requirements for the award of
Bachelor of Technology Degree in
Chemical Engineering

by

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SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
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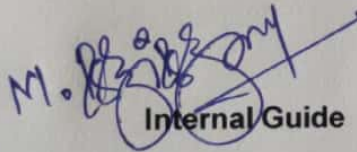
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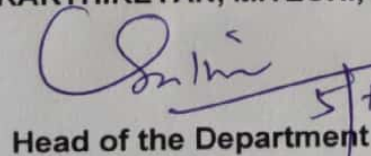
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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **DHANUSH KODI K (40190007), SAJIN JOHNY (40190022)** who carried out the project entitled "**PRODUCTION OF BIODIESEL FROM PONGAMMIA PINNATA OIL USING SEAWEED-DERIVED AS BIOCHAR WITH ZINC OXIDE AS A CATALYST: STUDIES ON INTERNAL COMBUSTION ENGINE**" under our supervision from November 2023 to April 2024.


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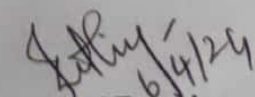

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DECLARATION

We, Dhanush Kodi AND Sajin Johny hereby declare that the Project Report entitled "PRODUCTION OF BIODIESEL FROM *PONGAMMIA PINNATA* OIL USING SEAWEED-DERIVED AS BIOCHAR WITH ZINC OXIDE AS A CATALYST: STUDIES ON INTERNAL COMBUSTION ENGINE" done by us under the guidance of DR. M KARTHIKEYAN, M.TECH., Ph.D. is submitted in partial fulfillment of the requirements for the award of Bachelor of Engineering degree in Computer Science and Engineering.

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DATE: 05-04-2024

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ABSTRACT

The utilization of alternative fuels has gained significant attention due to environmental concerns and the depletion of fossil fuel reserves. This project focuses on the innovative use of seaweed with zinc oxide as a catalyst to produce biodiesel from pongamia pinnata oil. Seaweed (*Eucheuma Cottonii*), a sustainable and abundant marine biomass, offers numerous advantages as a catalyst, including its eco-friendliness, renewability, and biodegradability. We prepared the bio-char from seaweed after that zinc oxide was doped with biochar to make it as a novel catalyst. Our oil has high FFA value so we want to go with two-step process to produce biodiesel. The esterification reaction have done use of sulfuric acid (H_2SO_4) as a catalyst for this reaction we done this reaction mainly to reduce the FFA value of pongamia pinnata oil. After that esterification reaction we have undergone with transesterification process in this process Tri-glycerides react with alcohol when a catalyst is present, creating fatty acid alkyl ester (biodiesel) as outcome and glycerol as a by-product. Characterization techniques such as Fourier-transform infrared spectroscopy (FTIR), x-ray diffraction (XRD), scanning Electron Microscope (SEM), Energy Dispersive X-Ray (EDX) and gas chromatography-mass spectrometry (GC-MS) were employed to analyse the chemical composition and purity of the produced biodiesel. Furthermore, the performance of the produced biodiesel was evaluated in an internal combustion engine. Engine test was carried with internal combustion engine and the total fuel consumption, specific fuel consumption, brake thermal efficiency and indicated thermal efficiency was found for B10 and B20 blends. The findings indicated promising results in terms of engine performance and emissions reduction, suggesting the viability of biodiesel derived from Pongamia pinnata oil as a sustainable alternative fuel.

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LIST OF ABBREVIATIONS

ZnO	Zinc Oxide
FAME	Fatty acid methyl ester
FTIR	Fourier Transform Infrared Radiation
XRD	X-ray Diffraction
FESEM	Field-Emission Scanning Electron Microscopy
EDAX	Energy Dispersive X-ray Analysis
FFA	Free Fatty Acid
WTE	Waste-To-Energy
GCMS	Gas Chromatography Mass Spectrometry
ICE	Internal Combustion Engine
BTE	Break Thermal Efficiency

CHAPTER 1

INTRODUCTION

1.1 BIODIESEL:

Biodiesel is a renewable, environmentally friendly alternative to conventional diesel fuel, derived from natural sources such as vegetable oils, animal fats, or recycled cooking grease. Its production, properties, and potential impact make it a compelling option in the quest for sustainable energy solutions. The production of biodiesel involves a chemical process called transesterification, wherein triglycerides present in oils and fats react with an alcohol (typically methanol or ethanol) in the presence of a catalyst (usually sodium hydroxide or potassium hydroxide). This reaction breaks down the triglycerides into fatty acid methyl esters (FAME), which constitute biodiesel, and glycerine, a valuable by-product used in various industries.

Source of biodiesel:

Edible oil: Soybean, Canola, Palm, Sunflower, Corn.

Non-edible oil: Karanja, Jatropha, neem, rubber.

Animal fat: Tallow and lard

Recycled cooking grease: Waste cooking oil from restaurants and households can be recycled into biodiesel.

Biodiesel combustion emits fewer greenhouse gases compared to petroleum diesel, as it contains fewer sulphur and aromatic compounds. Biodiesel is biodegradable, meaning it breaks down quickly in the environment, reducing pollution risks in case of spills. Unlike finite fossil fuels, biodiesel can be produced indefinitely from replenishable feedstocks, contributing to long-term energy sustainability. Biodiesel production reduces reliance on fossil fuels, enhancing energy security and mitigating the risks associated with oil price fluctuations and supply disruptions. Biodiesel can be used as a standalone fuel or blended with petroleum diesel in various proportions. Common blends include B5 (5% biodiesel, 95% diesel), B20 (20% biodiesel, 80% diesel), and B100 (pure biodiesel). It possesses properties

similar to petroleum diesel, such as energy content and lubricating capabilities, making it compatible with existing diesel engines and infrastructure.

1.2 PONGAMIA PINNATA OIL:

Karanja, scientifically known as *Pongamia pinnata*, is a versatile tree native to the Indian subcontinent and widely cultivated in tropical and subtropical regions around the world. It has gained attention as a potential feedstock for biofuel production due to several favorable characteristics.

High oil content: *pongamia pinnata* seeds contain oil content ranging from 27% to 40%, making it a rich source of feedstock for biodiesel production. This high oil content makes Karanja economically viable for biofuel production compared to other oilseed crops.

Non-Edible Feedstock: One of the significant advantages of pongamia oil is that it comes from a non-edible source. Unlike edible oil crops such as soybean or palm oil, which compete with food production, Karanja offers a sustainable alternative that does not impact food security or agricultural land dedicated to food crops. This aspect addresses concerns about food-versus-fuel competition, which has been a subject of debate in the biofuel industry

Adaptability to marginal lands: *pongamia pinnata* trees are well-suited to grow in a variety of soil types, including degraded and marginal lands, where other crops may struggle to thrive. This adaptability makes Karanja cultivation feasible in areas unsuitable for traditional agriculture, thereby minimizing competition with food crops and maximizing land utilization for biofuel production.

Nitrogen Fixation: *pongamia pinnata* is a leguminous tree capable of fixing atmospheric nitrogen through symbiotic associations with nitrogen-fixing bacteria in its root nodules. This nitrogen-fixing ability enhances soil fertility and reduces the need for synthetic fertilizers, making Karanja cultivation environmentally sustainable and cost-effective.

Local Availability: In many regions where *pongamia pinnata* is native or cultivated, such as India, Southeast Asia, and parts of Africa, the availability of *pongamia pinnata* seeds presents an opportunity for local biofuel production, reducing

dependence on imported fossil fuels and promoting energy security and rural development.

Agroforestry potential: pongamia pinnata trees can be integrated into agroforestry systems, providing additional benefits such as soil conservation, carbon sequestration, and biodiversity enhancement. Agroforestry practices that combine Karanja cultivation with food crops or other tree species can improve overall land productivity and resilience to climate change while diversifying income sources for farmers.

Environmental Benefits: Biodiesel produced from Karanja oil offers environmental benefits, including reduced greenhouse gas emissions, improved air quality, and lower environmental impact compared to fossil diesel. The use of biodiesel derived from Karanja helps mitigate climate change, reduce dependence on finite fossil fuels, and contribute to sustainable development goals.

The utilization of Karanja in biofuel production offers a promising avenue for sustainable energy production, combining economic viability with environmental and social benefits. However, further research and development efforts are needed to optimize cultivation practices, enhance oil extraction efficiency, and scale up Karanja-based biofuel production to realize its full potential in the global energy transition.

1.3 CLASSIFICATION OF CATALYST:

Homogeneous catalyst: Catalysts that are in the same phase as the reactants. They are typically dissolved or dispersed in the reaction mixture. Examples include acids, bases, and enzymes.

Heterogeneous catalyst: Catalysts that are in a different phase from the reactants. They are often solid catalysts used in gas or liquid-phase reactions. Examples metal oxides and zeolites.

Acid catalyst: Catalysts that facilitate reactions by donating protons (H^+ ions), thereby lowering the activation energy required for the reaction to proceed. Examples sulfuric acid and Lewis acids.

Base catalyst: Catalysts that facilitate reactions by accepting protons (H^+ ions) or donating hydroxide ions (OH^-), thereby lowering the activation energy. Examples include sodium hydroxide and Lewis bases.

Biocatalyst: Catalysts derived from biological sources, such as enzymes and microorganisms, used in various industries including food processing, pharmaceuticals, and biotechnology.

1.4 THE SELECTION OF HETEROGENEOUS CATALYST:

Heterogeneous catalysts play a vital role in the production of biodiesel, a renewable and environmentally friendly alternative to conventional diesel fuel. Heterogeneous catalysts are particularly well-suited for biodiesel production due to their distinct advantages in terms of efficiency, recyclability, and ease of separation. Let see some of the main reason for using heterogeneous catalyst.

Ease of separation: One of the primary advantages of heterogeneous catalysts is their ease of separation from the reaction mixture. Unlike homogeneous catalysts, which dissolve in the reaction medium and are challenging to recover and recycle, heterogeneous catalysts exist as distinct solid phases. This facilitates their separation from the reaction products through simple filtration or centrifugation processes, allowing for their reuse in subsequent reaction cycles. This property significantly reduces operational costs and waste generation in industrial processes.

Reusability: Heterogeneous catalysts can often be reused multiple times without significant loss of activity or selectivity. After separation from the reaction mixture, they can undergo regeneration treatments to restore their catalytic properties. This reusability not only reduces the consumption of catalysts but also contributes to the sustainability and cost-effectiveness of chemical processes.

Control of reaction condition: Heterogeneous catalysts allow for better control of reaction conditions, particularly in multiphase systems. By immobilizing the catalyst on a solid support or carrier material, the surface area, porosity, and reactivity of the catalyst can be tailored to suit specific reaction requirements. This enables precise control over reaction kinetics, selectivity, and product distribution, leading to improved process efficiency and product quality.

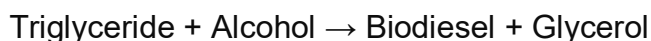
Versatility: Heterogeneous catalysts exhibit versatility in catalyzing various types of

reactions, including hydrogenation, oxidation, reduction, hydrolysis, and condensation reactions. They can be tailored to catalyze specific transformations by adjusting the composition, morphology, and surface properties of the catalyst materials. This versatility allows for their widespread use across different industries and applications, making them indispensable in modern chemical manufacturing processes.

1.5 ZINC OXIDE (ZnO):

Zinc oxide (ZnO) has been explored for various applications, including biodiesel production. Biodiesel is a renewable fuel derived from vegetable oils, animal fats, or recycled cooking grease. It is considered an alternative to conventional petroleum diesel because it is biodegradable, non-toxic, and produces fewer emissions. Zinc oxide finds utility in biodiesel production primarily as a catalyst in the transesterification process, which is the key step in converting triglycerides (found in oils and fats) into biodiesel.

Biodiesel production involves a chemical process called transesterification. In this reaction, triglycerides present in oils and fats are reacted with an alcohol (typically methanol or ethanol) in the presence of a catalyst to yield biodiesel (alkyl esters) and glycerol as a byproduct.



Reusability: Unlike alkaline catalysts (such as NaOH and KOH) which are consumed in the reaction and require neutralization, zinc oxide can be reused multiple times without significant loss of activity. This attribute makes it cost-effective and environmentally friendly.

Mild reaction condition: Zinc oxide catalyst operates under relatively mild reaction conditions compared to alkaline catalysts. Transesterification reactions using zinc oxide catalyst typically occur at lower temperatures and pressures, reducing energy consumption and operational costs.

Reduce Corrosivity: Alkaline catalysts can be corrosive, which necessitates the use of corrosion-resistant equipment. Zinc oxide, being less corrosive, offers advantages in terms of equipment selection and maintenance.

Less soap formation: Zinc oxide catalyst tends to produce lower amounts of soap byproducts compared to alkaline catalysts. Soap formation can be problematic as it

can lead to emulsification issues and difficulties in separating the biodiesel from glycerol during the reaction.

Environmental condition: ZnO is considered a relatively environmentally friendly catalyst compared to some other alternatives. It is non-toxic and does not pose significant environmental risks during its synthesis or use in biodiesel production.

1.6 SEAWEED:

Seaweed, also known as macro algae, refers to a diverse group of marine algae. Seaweeds are categorized into three main groups based on pigmentation and cellular structure: brown algae, red algae, and green algae. Seaweeds inhabit oceans and other saltwater bodies worldwide, thriving in shallow coastal waters as well as deeper ocean environments.

Seaweeds play critical roles in marine ecosystems, contributing to nutrient cycling, oxygen production, and habitat provision. They provide food and shelter for various marine organisms, supporting diverse communities of fish, invertebrates, and other species. Certain seaweeds form extensive underwater forests, such as kelp forests, which serve as essential habitats and nurseries for marine life.

Seaweed aquaculture, or seaweed farming, has emerged as a promising industry for sustainable food production and environmental conservation. Cultivated seaweeds are harvested for food, feed, biofuel production, and other commercial purposes. Seaweed farming offers environmental benefits such as carbon sequestration, nutrient remediation, and habitat restoration.

Seaweed has been utilized by humans for various purposes for thousands of years, including food, medicine, agriculture, and industry. It is a dietary staple in many coastal cultures, valued for its nutritional content and culinary versatility. Seaweed extracts are used in pharmaceuticals, cosmetics, textiles, and bioplastics. seaweed is a diverse and ecologically important group of marine organisms with numerous commercial, industrial, and environmental applications.

1.7 BENEFITS OF USING SEAWEED AS A CATALYST:

Using seaweed as a catalyst in biodiesel production offers several potential benefits, primarily due to its unique chemical composition and properties. Let see some of the advantages of using seaweed as a catalyst in biodiesel synthesis:

Abundant and renewable resource: Seaweed is abundant in oceans and coastal regions worldwide, offering a sustainable and renewable source of raw material for catalyst production. Unlike some traditional catalysts derived from fossil fuels or rare metals, seaweed-derived catalysts are environmentally friendly and contribute to the utilization of renewable resources.

Biodegradability: Seaweed-derived catalysts are typically biodegradable, meaning they can be broken down into harmless substances by natural processes after use. This characteristic aligns with the principles of green chemistry and sustainable manufacturing, reducing the environmental impact associated with catalyst disposal and waste management.

Catalytic activity: Certain components of seaweed, such as polysaccharides, proteins, and minerals, possess catalytic activity or can be modified to exhibit catalytic properties. These natural compounds can facilitate the transesterification reaction involved in biodiesel synthesis, converting triglycerides into fatty acid alkyl esters (biodiesel) and glycerol. Seaweed-derived catalysts may offer comparable or even superior catalytic performance to traditional catalysts, depending on their composition and processing methods.

Low Cost: Seaweed-based catalysts may be cost-effective compared to conventional catalysts, particularly if seaweed is harvested from coastal regions or cultivated in aquaculture farms. The relatively low cost of seaweed as a raw material, coupled with simple processing techniques, can result in economically viable catalysts for biodiesel production, especially in regions with abundant seaweed resources.

1.8 TYPES OF SEAWEED:

There are thousands of species of seaweed, also known as marine algae, found in oceans around the world. There are three main types of seaweed let see one by one,

Red seaweed (Rhodophyta):

- Red seaweeds are often found in deeper waters but can also grow in intertidal zones.
- They are characterized by their red pigmentation due to the presence of phycoerythrin and phycocyanin pigments.

Brown seaweed (Phaeophyta):

- Brown seaweeds are the most diverse group of seaweeds, ranging from small filamentous forms to large kelps.
- They typically inhabit cooler waters and can be found in intertidal zones as well as subtidal areas.
- Brown seaweeds get their color from the pigment fucoxanthin, which masks the green chlorophyll pigment.

Green seaweed (chlorophyta):

- Green seaweeds are primarily found in intertidal zones and shallow waters, often attached to rocks or other substrates.
- They contain chlorophyll as their primary pigment, giving them a green coloration.

1.9 EUCHEUMA COTTONII (RED SEAWEED):

Eucheuma cottonii, commonly known as sea moss or red seaweed, possesses several advantageous properties that make it a promising catalyst for biodiesel production. Its alkaline nature facilitates the transesterification reaction, a key step in biodiesel synthesis, by promoting the conversion of triglycerides into fatty acid methyl esters (FAMES) and glycerol. This alkalinity accelerates the rate of esterification, enhancing the efficiency of the biodiesel production process. Moreover, the structure of *Eucheuma cottonii* contains active sites that can further catalyse the interaction between triglycerides and alcohol, expediting biodiesel formation. These active sites may arise from the presence of functional groups or surface morphology conducive to catalytic activity. In addition to its catalytic properties, the use of *Eucheuma cottonii* aligns with principles of sustainability and green chemistry. *Eucheuma cottonii* cultivation can offer environmental benefits beyond biodiesel production. As a marine organism, it plays a role in coastal

ecosystem health, including nutrient cycling, carbon sequestration, and shoreline stabilization. Sustainable seaweed farming practices can contribute to ecosystem restoration efforts and mitigate the impacts of climate change on coastal communities.

As a natural resource, it offers a biodegradable and environmentally friendly alternative to synthetic catalysts commonly used in biodiesel production. Its renewable nature and minimal environmental impact make it an attractive option for industries seeking to reduce their carbon footprint and environmental footprint. Furthermore, *Eucheuma cottonii* demonstrates potential cost-effectiveness and compatibility with various feedstock oils, enhancing its attractiveness for biodiesel production. Its ability to effectively catalyze the transesterification reaction across a range of feedstock sources contributes to its versatility and applicability in different production settings.

Despite these promising characteristics, further research is needed to optimize the effectiveness of *Eucheuma cottonii* as a biodiesel catalyst. This includes understanding its catalytic mechanisms fully and assessing its scalability for commercial applications. Continued investigation into the optimal reaction conditions, catalyst loading, and catalyst recovery methods will be crucial in maximizing its efficiency and economic viability in large-scale biodiesel production.

1.10 CATALYST PREPARATION:

Biochar production:

- Seaweed is dried, fragmented, and processed into biochar.
- This involves exposing the seaweed to direct sunlight to remove moisture and enhance texture.
- Once dried, the seaweed is fragmented into smaller, manageable pieces. Fragmentation helps in increasing the surface area, which is beneficial for the catalytic process.

Zinc oxide for catalyst:

Zinc oxide is obtained, often from a laboratory, and measured in the desired amount. Take 3 gram of zinc for doping with biochar.

Preparation of catalyst solution:

- Distilled water is measured and poured into a container.
- The 9 grams of seaweed biochar is added to the water and stirred for a specific duration to ensure thorough mixing and dissolution of biochar particles.
- After achieving a homogeneous solution, 3 grams of zinc oxide is added gradually while continuing to stir. This step aims to evenly disperse zinc oxide particles throughout the solution.

Stirring of solution:

The solution is stirred with the help of magnetic stirrer for a designated period to facilitate the interaction between biochar and zinc oxide, promoting the formation of active catalytic sites.

Filtration and drying:

- Once the desired reaction time is reached, the solution is filtered to remove any undissolved particles or impurities.
- The filtered catalyst solution may undergo a drying process to remove excess moisture, resulting in the formation of a solid catalyst material.

1.11 CATALYST CHARACTERIZATION:

The seaweed/ZnO catalyst system has undergone thorough characterization employing a suite of analytical techniques including FTIR (Fourier Transform Infrared Spectroscopy), XRD (X-ray Diffraction), FESEM (Field-Emission Scanning Electron Microscopy), and EDS (Energy Dispersive X-ray Spectroscopy), providing comprehensive insights into its structural, compositional, and morphological properties.

FTIR spectroscopy revealed prominent peaks corresponding to characteristic functional groups within both the seaweed and the ZnO catalyst. Specifically, distinctive absorption bands associated with polysaccharides, proteins, and cellulose present in the seaweed were identified. Furthermore, shifts or alterations

in peak positions indicated potential chemical interactions or bonding between the seaweed constituents and the ZnO catalyst.

XRD analysis elucidated the crystalline structure of the seaweed/ZnO catalyst composite. By examining diffraction patterns, the presence of specific phases within the ZnO catalyst and any alterations induced by interaction with the seaweed were identified. Changes in peak intensities, positions, or the emergence of new peaks provided valuable insights into modifications in crystallinity and phase transformations occurring within the composite system.

FESEM imaging unveiled the surface morphology and microstructure of the seaweed/ZnO catalyst composite at high resolution. Detailed visualization showcased the distribution and morphology of ZnO nanoparticles immobilized on the seaweed surface. Additionally, changes in surface features or the appearance of unique structures highlighted the effects of catalyst loading and interaction on the composite's morphology.

EDS elemental analysis facilitated quantitative assessment of the elemental composition within the seaweed/ZnO catalyst composite. By detecting characteristic X-ray emissions, the presence and distribution of elements, including zinc and other constituents, were mapped across the sample. Elemental mapping provided spatial information regarding the dispersion of the ZnO catalyst and highlighted any variations in elemental composition induced by the composite formation.

1.12 ESTERIFICATION PROCESS:

Esterification is a process that may occur alongside transesterification, especially when dealing with low-quality or high-free fatty acid feedstocks, such as waste cooking oil or animal fats. In this process, free fatty acids (FFAs) present in the feedstock react with alcohol to form esters and water. Unlike transesterification, esterification does not involve the breakdown of triglycerides. Instead, it focuses on converting FFAs into esters. The reaction is catalyzed by acidic catalysts, such as sulfuric acid or acidic ion exchange resins. Esterification is particularly important when dealing with feedstocks containing high levels of FFAs, as these can hinder the transesterification process or lead to soap formation. By converting FFAs into esters, esterification helps improve the overall yield and quality of biodiesel. After esterification, the mixture may undergo additional processing steps, such as

neutralization to remove any remaining catalyst or purification to remove impurities, before being combined with the biodiesel produced through transesterification

1.13 TRANSESTERIFICATION PROCESS:

Transesterification is a fundamental chemical process in biodiesel production, serving as the main pathway to convert oils or fats into biodiesel, a renewable alternative to conventional diesel fuel. The process involves the reaction of triglycerides, which are the primary components of oils and fats, with an alcohol, typically methanol or ethanol, in the presence of a catalyst. The triglycerides are sourced from various feedstocks such as vegetable oils, animal fats, or recycled cooking oils. During transesterification, the alcohol molecules replace the glycerol component of the triglyceride, resulting in the formation of biodiesel and glycerol as byproducts. The catalyst, commonly sodium or potassium hydroxide, plays a crucial role in accelerating the reaction by providing an alternate pathway with lower activation energy. This catalyst is usually mixed with the alcohol prior to the reaction. Transesterification is typically conducted at elevated temperatures, usually between 50 to 70 degrees Celsius, to facilitate the reaction, although the exact conditions may vary depending on the specific feedstock and catalyst used. Excess alcohol is often employed to shift the equilibrium towards ester formation and improve the reaction yield. Once the reaction is complete, the mixture is allowed to settle, and the biodiesel layer is separated from the glycerol layer. The biodiesel undergoes further purification steps, such as washing to remove impurities and residual catalyst, before being used as a fuel for diesel engines.

1.14 PROPERTIES OF BIODIESEL:

Density: Biodiesel typically has a slightly higher density than petroleum diesel. The density of biodiesel varies depending on the feedstock and production process but generally falls within the range of 0.86 to 0.90 g/cm³

Viscosity: Biodiesel has higher viscosity than petroleum diesel, which can affect fuel flow and atomization in diesel engines. Biodiesel's viscosity is influenced by factors such as temperature and blend ratio, and it can be adjusted through blending with lighter fuels.

Flash Point: Biodiesel has a higher flash point compared to petroleum diesel, making it safer to handle and store. The flash point of biodiesel typically exceeds 130°C reducing the risk of ignition during storage and transportation.

Cloud Point: Biodiesel tends to have a higher cloud point than petroleum diesel, which refers to the temperature at which solid particles begin to form and the fuel appears cloudy.

Pour Point: Biodiesel generally has a higher pour point than petroleum diesel, which is the temperature at which the fuel becomes too viscous to flow freely. The pour point of biodiesel can be influenced by factors such as the presence of saturated fatty acids and cold flow additives.

Cetane Number: Biodiesel typically has a higher cetane number than petroleum diesel, which measures the fuel's ignition quality. A higher cetane number indicates better combustion efficiency and smoother engine operation.

Oxygen Content: Biodiesel contains oxygen atoms in its molecular structure, resulting in a higher oxygen content compared to petroleum diesel. This property improves combustion efficiency and reduces particulate emissions.

1.15 PERFORMANCE OF BIODIESEL IN IC ENGINE:

Performance evaluation of biodiesel in internal combustion engines is a crucial aspect in assessing its suitability as an alternative fuel. This evaluation involves comprehensive testing to determine various engine parameters, combustion characteristics, emissions profile, and overall efficiency when operating on biodiesel blends compared to traditional diesel fuel.

Engine Efficiency:

- Measurement of engine power output and fuel consumption to evaluate the efficiency of biodiesel combustion.
- Assessment of engine thermal efficiency, indicating the percentage of fuel energy converted into useful work.
- Analysis of engine torque and specific fuel consumption to understand the mechanical performance of biodiesel blends in internal combustion engines.

Combustion Characteristics:

- Evaluation of ignition delay, combustion duration, and heat release rate to characterize the combustion process of biodiesel blends.
- Determination of ignition quality, indicated by parameters such as ignition delay and combustion stability, to assess engine operability and performance.

Emissions Profile:

- Monitoring of exhaust gas emissions, including nitrogen oxides (NO_x), carbon monoxide (CO), hydrocarbons (HC), particulate matter (PM), and sulfur dioxide (SO₂).
- Comparison of emission levels between biodiesel blends and traditional diesel fuel to assess the environmental impact and compliance with emission regulations.

Engine Durability:

- Examination of engine wear and tear, including piston ring and cylinder liner wear, valve seat recession, and lubricant degradation, when operating on biodiesel blends.
- Assessment of engine components and lubrication systems for compatibility and performance under biodiesel operating conditions.

Cold Start Performance:

- Investigation of cold start characteristics, including cold start time and engine warm-up duration, to evaluate the suitability of biodiesel blends for cold weather conditions.
- Analysis of fuel properties such as viscosity, cloud point, and pour point to understand their impact on engine starting and performance during cold starts.

Long-term Performance:

- Long-term monitoring of engine performance and emissions under continuous operation with biodiesel blends to assess durability and reliability.

- Evaluation of engine maintenance requirements, including cleaning intervals for fuel injectors, filters, and exhaust after treatment systems, when using biodiesel blends.

Overall Efficiency and Sustainability:

- Integration of performance, emissions, and durability data to determine the overall efficiency and sustainability of biodiesel blends in internal combustion engines.
- Comparative analysis of biodiesel blends with traditional diesel fuel in terms of energy security, environmental impact, and economic viability.

1.16 RESOURCE MANAGEMENT AND WASTE UTILIZATION:

The concept of a circular economy has emerged as a transformative approach to sustainable resource management, aiming to minimize waste generation and maximize resource efficiency. Central to this paradigm is waste valorization, which involves converting waste materials into valuable resources through innovative processes and technologies. By fostering a closed-loop system where resources are continuously reused, recycled, or repurposed, the circular economy reduces reliance on finite raw materials and minimizes environmental impact.

Key to the circular economy is the efficient use of resources and the reduction of waste generation throughout the product lifecycle. Strategies such as product design for longevity, durability, and recyclability help maximize resource utilization. Waste valorization technologies, including pyrolysis, gasification, bio-refining, and chemical conversion, enable the transformation of diverse waste streams into biofuels, bio-based chemicals, biomaterials, and renewable energy.

Closed-loop systems integrate recycling and recovery processes to ensure the continuous circulation of materials and resources within the economy. Material recovery facilities (MRFs) and waste-to-energy (WTE) plants play a crucial role in recovering valuable materials from waste streams and generating renewable energy from non-recyclable residues. By reducing reliance on virgin raw materials, circular economy practices contribute to sustainable resource management, mitigate resource depletion, and minimize environmental pollution.

Circular economy principles create economic opportunities by fostering innovation, entrepreneurship, and the development of new business models centered around resource efficiency and waste valorization. Policy support and regulatory frameworks, such as extended producer responsibility (EPR) and landfill bans, incentivize waste reduction, recycling, and resource recovery. Collaboration among stakeholders, including governments, industries, academia, and civil society, is essential for advancing circular economy initiatives and waste valorization efforts, facilitating the exchange of best practices and technology transfer for sustainable waste management and resource recovery.

1.17 ENVIRONMENTAL AND ECONOMIC IMPLEMENTATION OF BIODIESEL PRODUCTION:

Implementing biodiesel production involves considerations of both environmental sustainability and economic viability. From an environmental perspective, biodiesel offers significant benefits over conventional fossil fuels. It reduces greenhouse gas emissions, including carbon dioxide and particulate matter, which contribute to climate change and air pollution. Additionally, biodiesel production often utilizes renewable feedstocks such as vegetable oils, animal fats, or waste cooking oil, reducing dependence on finite fossil fuel resources. By promoting the use of biodiesel, countries can mitigate environmental degradation, improve air quality, and enhance overall environmental sustainability.

On the economic front, the implementation of biodiesel production presents opportunities for job creation, economic growth, and energy security. Biodiesel production facilities generate employment opportunities across various sectors, including agriculture, manufacturing, and transportation. Moreover, biodiesel production can stimulate local economies by supporting farmers and biofuel producers, reducing reliance on imported petroleum products, and enhancing energy independence. Furthermore, biodiesel production can diversify revenue streams for agricultural communities, providing an additional source of income through the cultivation of biodiesel feedstock crops. Overall, the environmental and economic implementation of biodiesel production offers a promising pathway towards achieving sustainable development goals and fostering a greener, more resilient economy.

In addition to its environmental and economic benefits, the implementation of biodiesel production contributes to energy diversification and security. By reducing reliance on imported fossil fuels, biodiesel production enhances energy independence and resilience to global supply disruptions. Furthermore, biodiesel can be produced domestically from locally available feedstocks, reducing the vulnerability of energy markets to geopolitical tensions and price fluctuations. This localization of biodiesel production strengthens national energy security strategies, ensuring a reliable and sustainable energy supply for the future.

Moreover, the adoption of biodiesel production aligns with global sustainability agendas and commitments to reduce carbon emissions and combat climate change. As countries strive to meet their climate targets under international agreements such as the Paris Agreement, integrating biodiesel into the energy mix becomes imperative. Biodiesel offers a renewable and low-carbon alternative to traditional fossil fuels, helping countries transition towards cleaner and more sustainable energy systems. By investing in biodiesel production infrastructure and technology, nations can accelerate their transition to a low-carbon economy and contribute to global efforts to mitigate the impacts of climate change.

1.18 CHALLENGES AND LIMITATIONS OF BIODIESEL UTILIZATION:

Feedstock Availability and Competition:

- Limited availability and competition for feedstock sources such as vegetable oils, animal fats, and waste oils pose challenges for biodiesel production.
- Competition with food and feed markets for feedstock resources can lead to conflicts over land use and potential environmental impacts such as deforestation and habitat destruction.

Land Use Change and Environmental Impact:

- Expansion of biodiesel feedstock cultivation, particularly in ecologically sensitive areas, may contribute to land use change, deforestation, and loss of biodiversity.
- Intensive agricultural practices associated with feedstock cultivation can result in soil degradation, water pollution, and greenhouse gas emissions, undermining the environmental benefits of biodiesel.

Technological Challenges and Process Efficiency:

- Biodiesel production processes, such as transesterification, require specialized equipment and infrastructure, leading to high capital investment and operational costs.
- Challenges in achieving high conversion efficiency, purity, and quality of biodiesel products may hinder commercial-scale production and competitiveness with petroleum diesel.

Fuel Compatibility and Engine Performance:

- Biodiesel blends may exhibit differences in fuel properties such as viscosity, lubricity, and cetane number compared to petroleum diesel, affecting engine performance and compatibility.
- Cold weather operability issues, including increased viscosity and filter plugging, may arise with biodiesel use in low temperatures, necessitating engine modifications or fuel heating systems.

1.19 APPLICATIONS OF BIODIESEL:

Biodiesel, derived from renewable sources such as vegetable oils or animal fats, has emerged as a promising alternative to traditional petroleum-based diesel fuel. Its diverse applications span various sectors, offering numerous economic, environmental, and societal benefits. Below are some key areas where biodiesel finds extensive use:

Transportation Sector: Biodiesel is widely utilized as a fuel for transportation vehicles, including cars, trucks, buses, and trains. Its compatibility with existing diesel engines allows for seamless integration into existing fleets, offering a cleaner and greener alternative to conventional diesel fuel. Biodiesel blends, such as B20 (20% biodiesel, 80% diesel), are commonly used in diesel engines, reducing greenhouse gas emissions and air pollutants like particulate matter and sulfur oxides.

Agricultural Machinery: In the agricultural sector, biodiesel serves as an efficient and environmentally friendly fuel for farm equipment and machinery. Tractors,

combines, and other agricultural vehicles can operate smoothly on biodiesel blends, reducing dependence on fossil fuels and promoting sustainable farming practices. Biodiesel production from on-farm resources such as waste vegetable oil or oilseed crops further enhances the agricultural sector's energy independence and sustainability.

Marine Industry: Biodiesel offers a viable alternative for marine vessels, including ships, boats, and ferries. Biodiesel blends can be used in marine diesel engines, providing a cleaner and more sustainable option for maritime transportation. By reducing emissions of sulfur oxides, nitrogen oxides, and particulate matter, biodiesel helps mitigate environmental impacts associated with marine transportation and contributes to cleaner waterways and coastal ecosystems.

Power Generation: Biodiesel can also be used in stationary diesel engines for power generation purposes. In remote or off-grid areas, biodiesel-powered generators offer a reliable and renewable energy source, reducing reliance on traditional fossil fuels and diesel generators. Biodiesel can be produced locally, utilizing regionally available feedstocks, thereby enhancing energy security and resilience in decentralized power systems.

Heating Applications: Biodiesel can be utilized as a heating fuel in residential, commercial, and industrial applications. Biodiesel blends, such as B5 (5% biodiesel, 95% diesel), can be used in oil-fired furnaces and boilers for space heating and water heating. Its cleaner combustion characteristics result in reduced emissions of greenhouse gases and air pollutants, contributing to improved indoor air quality and public health.

Aviation Industry: While biodiesel is not commonly used as aviation fuel due to stringent performance requirements, research and development efforts are underway to explore its potential application in aviation biofuels. Sustainable aviation fuels derived from biodiesel feedstocks hold promise for reducing greenhouse gas emissions and enhancing the environmental sustainability of air travel.

CHAPTER 2

LITERATURE SURVEY

Naveen Kumar et al.(2021) the utilization of petroleum-based products in engines poses significant environmental hazards. Consequently, there is a growing focus on enhancing alternative fuel quality through extensive research. Among the innovative approaches, nanoparticles stand out as a promising technology for improving fuel characteristics. Their study aims to investigate the effects of CuO nanoparticles on emission levels, combustion dynamics, and overall engine performance in diesel engines using jojoba biodiesel blends as the primary fuel source. The experimental design involved blending CuO nanoparticles at different concentrations with JB20 fuel. Notably, the results indicate that the fuel blend containing CuO nanoparticles exhibited superior Brake Thermal Efficiency (BTE) compared to other Jojoba biodiesel fuel samples. In assessing the impact of CuO nanoparticles, the researchers examined various combustion properties such as ignition delay, Heat Release Rate (HRR), and cylinder pressure. Furthermore, the introduction of CuO nanoparticles was found to mitigate emissions of smoke, carbon monoxide (CO), and hydrocarbons from the engines running on JB20 fuel [1]

Abdul Razak R.K et al. (2018) Using various transesterification stages, biodiesel was produced from *Pongamia pinnata*, *Calophyllum inophyllum*, and leftover cooking oil with varying free fatty acid contents. It was discovered what the chemical and physical characteristics of biodiesel were, including its density, viscosity, fire point, and calorific value. Studies on engine performance were conducted using mixes of diesel, such as B50, B65, and B80, and 100% biodiesel generated from various sources. *Pongamia pinnata* biodiesel was shown to have the greatest Brake Thermal Efficiency (BTE) of all the biodiesels utilised in the comparison. *Pongamia pinnata* biodiesel yields the greatest BTE for the B65 mix. *Pongamia pinnata* and *Calophyllum inophyllum* biodiesel had the greatest BTE for a B50 combination. In comparison to other biodiesel blends and for individual biodiesels, B50 has superior performance characteristics in every area for both types of biodiesels and blends [2]

Ramachandran Kasirajan et al. (2021) As fossil diesel reserves dwindle, the search for alternative fuels derived from non-edible sources becomes increasingly

urgent. In this study, researchers employed a two-step process to convert *Chrysophyllum albidum* seeds, an inedible source, into biodiesel. Initially, lipid extraction was carried out using a mixed solvent in a superheated extractor, and gas chromatography (GC) was utilized to analyze the fatty acid content. Subsequently, a homogeneous H_2SO_4 catalyst was employed for esterification followed by transesterification. Several factors were investigated to optimize the transesterification process, including the molar ratio of methanol to oil, catalyst loading, reaction temperature, reaction time, and stirring rate. Spectroscopic analysis was employed to confirm the conversion of oil to biodiesel, while the physical-chemical characteristics of the biodiesel were examined. The results suggest that the two-step esterification and transesterification technique is highly suitable for producing biodiesel from *Chrysophyllum albidum* seeds [3]

Chuan Yuan et al. (2021) We synthesized a variety of seaweed-derived biochar catalysts (SDBC) that are both inexpensive and environmentally friendly. Our findings revealed that incorporating metals into SDBC at elevated temperatures resulted in the formation of highly porous structures with increased aromatic rings, consisting of at least six benzene rings, as well as heteroatoms and defects. Notably, the seaweed-derived biochars were primarily composed of inorganic minerals in the form of NaCl and KCl. To assess the efficacy of SDBC, we conducted catalytic pyrolysis of *Enteromorpha clathrate* ex situ. The results demonstrated that, compared to the control group, the bio-oils produced through catalytic pyrolysis exhibited a significant decrease in carboxylic acids. Interestingly, this decrease could be attributed to the presence of hydroxyl groups in the biochar, which could react with carboxylic groups to form fatty acid methyl esters (FAMEs). Our findings suggest that the Cu-BC-800 catalyst, in particular, shows promise as a metal-modified biochar catalyst for producing acid-free biooils enriched with esters and sugars [4]

Balasubramani Ravindran et al. (2021) Heterogeneous catalysts are essential for the transesterification process in the synthesis of biodiesel, and much study has been done recently to discover a good catalyst for this process. Heterogeneous catalysts are favored over homogeneous catalysts because of their disadvantages, which include sluggish reaction rates, expensive costs because food-grade oils are used, issues related to the separation process, and environmental damage. The

biowastes that are appropriately calcined for the manufacture of heterogeneous base catalyst are animal bones and shells. The catalysts made from organic waste are both reasonably priced and environmentally beneficial. The goal of this review is to synthesize heterogeneous basic catalysts from natural resources or biowastes for the transesterification of oils to produce biodiesel. Potential feedstocks, such as vegetable oils and animal fat, can be safely and effectively converted into biodiesel/FAME by using calcined catalysts, which can increase the yield by more than Utilizing catalysts produced from biowaste to produce biofuel sustainably has a lot of potential [5]

Steven Lim et al. (2018) As the demand for fossil fuels continues to rise while their finite reserves dwindle, biodiesel emerges as a promising alternative. However, the use of commercial homogeneous catalysts in biodiesel production presents challenges such as severe corrosion and separation difficulties, leading to increased production and maintenance costs. This research delves into a comprehensive review of literature concerning the utilization of biomass as a precursor for catalysts in biodiesel synthesis. Employing biomass as a catalyst precursor offers numerous advantages over conventional commercial catalysts. Biomass is readily available, cost-effective, reusable, non-toxic, and biodegradable. Many studies have explored carbon materials derived from biomass, which serve as effective supports for active sites due to their high porosity and surface area characteristics. Reviewing various cutting-edge synthesis processes, ranging from the synthesis of the supporting material (carbon) to the functionalization process forming the complete catalyst, this research evaluates the latest developments in biomass-derived basic, acidic, and magnetic heterogeneous catalysts. Methods such as sulfonation by reduction, arylation, and direct sulfonation with sulfuric acid are investigated, with findings suggesting that these methods are less hazardous and produce activity at active sites comparable to conventional approaches. Under optimal conditions, the majority of biomass-based catalysts exhibit robust catalytic activity, yielding biodiesel. Additionally, this research examines various kinetic models derived from reaction kinetic studies catalyzed by biomass-based catalysts, representing a crucial step towards the larger-scale commercialization of these catalysts in the biodiesel production industry.[6]

Mohd Hamid Hussain et al.(2023) Research into alternative fuels is driven by the depletion of fossil fuel reserves and strict emission regulations, particularly regarding greenhouse gas emissions from diesel engines. Hydro processed renewable diesel, derived from sustainable sources like non-edible seeds, animal fats, and algae oil, is being explored as a potential substitute for traditional diesel. Its higher cetane value compared to petro-diesel suggests promising prospects for compression ignition engines. Hydro-deoxygenation, facilitated by hydrogen gas and a catalyst, is a crucial step in producing renewable diesel, akin to hydro-desulfurization in crude vegetable oil refinement. Refineries commonly employ sulfided catalysts based on nickel molybdenum or cobalt molybdenum for these processes. Fractional distillation is then used to separate the resultant product at various boiling temperatures due to its diverse composition. Physicochemical evaluations of hydroprocessed renewable diesel reveal superior characteristics such as cetane number, flash point, and pour point compared to biodiesel and petroleum diesel. However, both types of diesel exhibit similar thermal stability and kinematic viscosity.[7]

Habsah Alwi et al. (2022) Biodiesel is a potential future fuel substitute for diesel derived from petroleum, as well as a source of new renewable energies. The total amount of diesel derived from petroleum consumed worldwide increased in the last ten years, according to the BP Statistical Review of World Energy. Even while it lessens reliance on fossil fuels, the manufacturing of biodiesel raises concerns about how to dispose of waste cooking oil (WCO) and related environmental harm issues. An estimated from animal and vegetable fats are thrown away annually in Malaysia without being handled as trash. As a raw material with significant promise for the biodiesel process, is acknowledged. Triglyceride and oxygen react to produce biodiesel. and alcohol, with plants and animals being the main sources of triglyceride as a raw material. Studies on the transesterification process variable with the ideal conditions for biodiesel synthesis from have been conducted. This study compares biodiesel to petroleum diesel and looks at the different aspects of the transesterification process as a raw material for biodiesel synthesis [8]

Monika et al. (2023) Given the depletion of current energy resources and the global increase in energy demand, the development of sustainable energy resources is

imperative. However, the combustion of fossil fuels releases toxic pollutants into the atmosphere, such as sulfur, nitrogen, carbon oxide, and particulate matter. In comparison to fossil fuels, biodiesel as an alternative fuel has a number of benefits, including the capacity to be produced from a variety of feedstocks, reduced emissions of air pollutants, and renewability. It is possible to produce biodiesel from used cooking oil as a feedstock. Because cooking oil has a negative environmental impact, disposing of it is a difficulty for the environment. The essential step in the low-cost, mild reaction conditions required to produce biodiesel is transesterification. A great deal of research has been done on optimizing transesterification to increase biodiesel yield and lower conversion costs. Because heterogeneous catalysts are applied repeatedly, they can significantly increase both the yield and the cost of biodiesel synthesis. In an effort to increase process sustainability, the current publication provides a thorough analysis of the properties of spent cooking oil, variables influencing the transesterification reaction, and the use of heterogeneous catalyst in the biodiesel manufacturing process [9]

Majid Saidi et al.(2024) This study used strontium stannate, a perovskite catalyst, to examine the transesterification process of used cooking oil to make biodiesel. Various characterisation experiments were employed to determine the structure of the synthesized catalyst. The production of SrSnO_3 was confirmed by powder x-ray diffraction and fourier transform infrared spectroscopy of synthesized samples. The synthesis of SrSnO_3 was confirmed by energy-dispersive x-ray spectroscopy and relative elemental quantities; elemental mapping revealed a perfect distribution in the sample. Four crucial parameters—operating time, temperature, methanol to oil molar ratio, and catalyst loading—as well as the ways in which they interact were examined in order to study the catalytic performance. In order to optimize the settings, response surface methodology was also used. Based on data analysis and transesterification process optimization, the highest possible yield of biodiesel synthesis was achieved. The study's findings demonstrated that the synthesis of biodiesel from used cooking oil is significantly impacted by the use of strontium stannate as a catalyst. Research on the catalyst's reusability revealed a slight decline, and the sixth cycle's biodiesel production efficiency reached a still-significant level [10]

Ali Salehi Zamani et al. (2023) In this study, a batch reactor with a reaction period ranging from 60 to 300 minutes was used to examine the catalytic hydrodeoxygenation (HDO) of neem seed oil (NSO) over an industrial Ni/MgSiO₃ catalyst. Selectivity, high deoxygenation efficiency, and cost-effectiveness have all been addressed. It was investigated how the operating factors affected the yield and selectivity toward alkanes that resemble diesel. The findings showed that the ideal reaction setting for the diesel-like alkanes to yield was Analyzing the reaction mechanism showed that it proceeded along the decarboxylation path, and nearly all of the studies demonstrated the reaction's selectivity towards the products that came from this path. At ideal conditions, the impact of catalyst loading was also studied. An intriguing outcome saw the production of diesel-like alkanes catalyst loading. Stability and efficiency of the catalyst are assessed under ideal circumstances. The catalyst showed outstanding activity and stability in the first four cycles, with nearly constant alkane yields; however, the catalyst's efficiency declined in the following cycles.[11]

Jan Nizar et al. (2018) The economically viable possibility of producing biodiesel from waste oils is appealing, but the transesterification process is severely hampered by the waste oils' high levels of free fatty acids (FFA). The focus of the current study is on using waste cooking oil (WCO) to produce biodiesel. A high FFA content was indicated by the acid value. Several acid catalysts were used to esterify the WCO; the H₂SO₄ catalyzed reaction proved to be the most effective because the FFA decreased. Fatty acid methyl ester (FAME) yield and an alkali catalyst (KOH) were present during transesterification. The acid value, saponification value, iodine value, cetane number, specific gravity, viscosity, cloud point, pour point, and calorific value were used to characterize the biodiesel. It was also done to analyze the generated biodiesel using gas chromatography (GC). Alkali catalyzed transesterification was an effective way to manufacture biodiesel from WCO based on ASTM specifications. The findings showed that cooking oil waste can reduced in contamination and used as a fuel source by turning it into biodiesel [12]

Sajad Roastmi et al. (2019) Researchers are working to produce and use biofuels in response to the diminishing supply of fossil fuels and the increasing demand for

energy resources. Researchers are particularly interested in biodiesel because it addresses the issue of oil costs and offers environmental advantages among biofuels. The current study investigates the effects of catalyst concentration, methanol-to-oil ratio, ultrasonic power, and residence time of hydrodynamic reactors on methyl esters yield, with the goal of producing biodiesel continuously and optimally. The response surface method was employed to maximize the waste oil's transesterification process. The study's findings showed that while the methyl esters output increases with longer residence times, it decreases with shorter residence times. The yield of methyl esters increases with increasing catalyst, while it decreases with increasing catalyst concentration. The yield increases as the methanol-to-oil ratio rises, and the methyl esters yield exhibits a trend of gradual inclination up to the methanol-to-oil ratio. In this investigation, the ideal parameters were the methanol-to-oil ratio, residence duration, catalyst concentration, and ultrasonic power; under these circumstances, the methyl esters yield and the energy consumed were obtained, respectively. In conclusion, the recommended approach is appropriate for producing biodiesel according to the energy consumption and production of methyl esters [13]

Rafael Silva Capaz et al. (2022) Due to its many benefits, including biodegradability and lower CO₂ and greenhouse gas emissions, biodiesel is being considered as a viable alternative to diesel fuel due to the growing global need for biofuels and the development of sustainable and cleaner processes. In the past 15 years, biodiesel production has expanded quickly across the globe, mostly as a result of government incentives. Nevertheless, the primary barrier to this growth has been the cost of manufacturing, which is still greater than that of petroleum diesel. Implementing biorefineries, where the production of other value-added products is fully exploited, supplying a wide range of products and energy, is one way to maximize the feasibility of biodiesel production, since a wide variety of raw materials, such as vegetable oils, animal fats, and waste oils, can be used for biodiesel production. Even though the US, Brazil, Germany, and other nations have established biorefineries, their primary focus is on producing first-generation biodiesel using edible feedstocks like soybeans. This chapter thoroughly explains the current and emerging technology pathways for producing biodiesel, along with its primary benefits, drawbacks, and difficulties. Furthermore, possible uses for by-products are discussed in the context of biorefineries, and a brief overview of their life cycle

analysis and environmental impact—including the context of low-carbon policies—is provided[14]

Robert Iomer et al.(2022)Interest in alternative energy sources is rising due to environmental and resource worries. Biodiesel, derived from leftover cooking oil through trans esterification, is gaining traction as a viable substitute for diesel oil in internal combustion engines. Its renewability and similar qualities to diesel make it a promising alternative, especially with concerns over conventional fuel depletion and environmental impact. Biodiesel is derived from fats, raising concerns about food supply displacement. To address this, emphasis is on using used cooking oil as feedstock. A catalytic approach was employed to produce biodiesel from culinary oils like refined sunflower, vacuum-fried sunflower, and used soybean oil. However, free fatty acids and water hinder the trans esterification process by consuming catalyst and lowering effectiveness. Pre-treatment was used to reduce moisture content before acid esterification. In order to neutralize the FFA content, alkali esterification was used, which decreased the FFA content and increased the yield[15]

CHAPTER 3

AIM AND SCOPE

3.1 AIM:

- To utilize the pongamia pinnata oil as sustainable and renewable source for biodiesel production.
- To synthesize the biochar from Eucheuma cottonii (seaweed).
- To dope the synthesized biochar with ZnO with the help of magnetic stirrer to make it as a catalyst for biodiesel production
- To convert pongamia pinnata oil to biodiesel using magnetic stirrer in both esterification and transesterification process
- Creating a cost-efficient catalyst with high effectiveness for the transesterification process.
- To study on internal combustion engine to know the engine performance.

3.2 SCOPE:

- Conducting comprehensive analysis of Pongamia pinnata oil, seaweed-derived biochar, and zinc oxide catalyst to determine their suitability for biodiesel production.
- Assessing parameters such as moisture content, elemental composition, surface morphology, and catalytic activity to understand their impact on biodiesel quality and engine performance.
- Experimenting with various reaction conditions including temperature, catalyst dosage, and reaction time to optimize the biodiesel production process.
- Investigating the effects of different process parameters on biodiesel yield, purity, and characteristics to achieve optimal fuel properties for engine application.
- Testing the combustion characteristics, emissions profile, and durability of internal combustion engines fueled by biodiesel blends derived from Pongamia pinnata oil with seaweed-derived biochar and zinc oxide catalyst.

CHAPTER 4

MATERIALS AND METHODOLOGY

4.1 MATERIALS AND CHEMICALS:

Using biochar made from seaweed and a zinc oxide catalyst to produce biodiesel from *Pongamia pinnata* oil is a sustainable method that emphasises the value of using renewable resources. *Pongamia pinnata*, often known as the Indian Beech tree, is a flexible and plentiful source of oil-rich seeds since it grows well in a variety of temperatures and soil types. We can lessen our dependency on fossil fuels and lessen the negative environmental effects of conventional diesel production by making use of this natural resource. An additional level of environmental friendliness is added to the process by using seaweed biomass for the synthesis of biochar. Seaweeds are maritime plants that grow quickly and are essential to the health of marine ecosystems. We may redirect organic waste from landfills and perhaps reduce carbon dioxide emissions by using seaweed biomass that has been pyrolyzed to make biochar, which sequesters carbon. Because of its efficiency and little negative effects on the environment, zinc oxide is a very significant catalyst choice for the transesterification process. Zinc oxide, in contrast to certain conventional catalysts, is non-toxic and readily removed from the biodiesel product, minimising the need for labor-intensive purification procedures and cutting down on waste production. Simple alcohol methanol serves as a reactant during the transesterification process, enabling the oil's triglycerides to be converted into fatty acid methyl esters (FAME), which are the primary building blocks of biodiesel. It is a sensible option for large-scale biodiesel production because to its accessibility and cost. Esterification with sulfuric acid may be required in situations when the *Pongamia pinnata* oil has high quantities of free fatty acids in order to lessen acidity and increase the transesterification reaction's effectiveness. Even though sulfuric acid is corrosive, it may be handled safely with the right tools and procedures.

It is crucial to guarantee the safety of the workers engaged in the production process. A thorough training programme on handling chemicals and operating equipment, in addition to providing the proper safety gear like lab coats, gloves, and goggles, reduces the likelihood of accidents and exposure to dangerous materials.

We can securely generate biodiesel from *Pongamia pinnata* oil by combining these components, chemicals, and safety precautions with close attention to detail and adherence to best practices, helping to create a more ecologically friendly and sustainable energy landscape. Moreover, adding biochar made from seaweed biomass improves the overall sustainability of the biodiesel manufacturing process in addition to acting as a catalyst. Because of its high porosity and surface area, biochar offers an abundance of active sites for the catalytic reaction to take place. Furthermore, after being used to produce biodiesel, its carbon-rich content is finally utilised as a soil amendment, closing the loop on resource utilisation and advancing the ideas of the circular economy. This all-encompassing strategy not only meets the pressing demand for alternative fuels but also fits in with the larger objectives of resource efficiency and environmental stewardship.

MATERIALS REQUIRED:

- *Pongamia Pinnata* Seed oil
- Seaweed (*Eucheuma Cottonii*)
- Zinc Oxide
- Methanol
- Distilled Water

APPARATUS REQUIRED:

- Hot Plate Magnetic Stirrer
- Magnetic Pellet
- Weighing Machine
- Filter Paper
- Hot Air Oven
- Furnace
- Round Bottom Flask(250 ml capacity)
- Thermometer
- Beaker (250ml Capacity)
- Measuring Tube (100ml Capacity)
- Separating Funnel
- Heating Mantle

4.2 EXTRATION OF OIL FROM PONGAMIA SEEDS:

The extraction of oil from Karanja (*Pongamia pinnata*) seeds using an oil expeller involves a mechanical process that separates the oil from the seeds. Detailed explanation of the extraction process:

Preparation of pongamia seeds: The process begins with the collection of mature Karanja seeds from the tree. These seeds are then cleaned thoroughly to remove any dirt, debris. Proper cleaning ensures that only the seeds enter the oil extraction process. After cleaning, the seeds are dried to reduce their moisture content. Drying is crucial as it improves the efficiency of the oil extraction process and prevents spoilage

Feeding seeds into expeller: Once the seeds are prepared, they are fed into the hopper of the oil expeller. The expeller consists of a large screw-like shaft that rotates and presses the seeds against a barrel.

Mechanical pressing: As the seeds enter the expeller, they increasing pressure along the length of the shaft. The screw compresses the seeds against the barrel of the expeller, This pressure squeezes the seeds tightly, causing them to rupture. The ruptured seeds release the oil.

Oil separation: The released oil flows out through small openings barrel of the expeller. These openings allow the oil to escape while retaining the solid residue, known as the cake or meal. The cake continues to move along the expeller's shaft until it reaches the end of the process. The oil, on the other hand, is collected directly from the expeller's

Collection of oil: The collected oil may undergo further filtration to remove any remaining impurities or solid particles. Filtration helps improve the quality and purity of the extracted oil, making it suitable for various applications. The filtered oil is then stored in appropriate containers under suitable conditions to maintain its quality.

Storage: Proper storage is essential to preserve the quality of the extracted oil. The oil is stored in clean, airtight containers away from direct sunlight and heat sources.



Fig 4.1: Pongamia Pinnata Seed



Fig 4.2: Oil Expeller



Fig 4.3: Pongamia Pinnata Oil

4.3 SEAWEED:

4.3.1 COLLECTION OF SEAWEED:

- There are lot of variety of species, in this project we have taken Red Seaweed (Eucheuma Cottonii).

- We collected the live piece seaweed from Rameshwaram, Tamil Nadu.
- The decision to collect live pieces stems from the region's rich biodiversity and optimal conditions for the growth of this particular seaweed species.
- This strategic selection and sourcing process ensure that we have access to high-quality raw materials essential for the success of our project.



Fig 4.4: Seaweed

- The drying process under the warm embrace of direct sunlight not only removes excess moisture but also enhances the seaweed's texture, imparting a desirable crispness.
- Once dried to perfection, the seaweeds are carefully fragmented into smaller, manageable pieces, a meticulous step that sets the stage for the subsequent phases of our project.
- By doing this process, it will provide us with more efficiency in our project.

4.3.2 CALCINATION PROCESS:

- After size reduction, the seaweed enters the crucial stage of calcination, where excess moisture content is removed to enhance its properties for further processing.
- The calcination process, conducted at a precise temperature of 150°C, ensures thorough dehydration while preserving the seaweed's beneficial compounds and structural integrity.

- After the seaweed is dried and processed, it's put into a pot and sealed with white cement. This keeps it safe from moisture and maintains its quality. This helps us to store and move it easily for further process.



Fig 4.5: Calcination



Fig 4.6: Sealed Seaweed

4.3.3 CONVERSION OF SEAWEED INTO BIOCHAR:

- The sealed pot with the seaweed inside is put into the furnace and heated to 210°C for 2 hours to turn it into biochar.
- Once the biochar is ready, it's carefully taken out and crushed into a fine powder form.
- This powder undergoes sieving to remove any large pieces, ensuring a smooth and uniform texture. Finally, the powdered biochar is ready to be used for the upcoming process.



Fig 4.7: Furnace



Fig 4.8: Powdered Biochar

4.3.4 DOPING PROCESS USING MAGNETIC STIRRER:

- I have created Biochar for using it as a catalyst. I have taken Zinc Oxide from our college laboratory.
- I have then measured 9 grams of Seaweed and 3 grams of Zinc Oxide using a weighing machine.
- 150ml of distilled water is poured into a beaker and stirred for 20 minutes. This helps to dissolve any substances in the water and ensures it's evenly mixed. After stirring, the water is clean and free of impurities before further use.
- After 20 minutes add Biochar into the distilled water and run it for Half an Hour.
- After half an hour the color of the solution changes to black.
- After the change in color to black, add Zinc Oxide into the solution and run it for 3 hours at a medium pace which makes the solution into lite gray color.



Fig 4.9: Stirring of Distilled Water



Fig 4.10: Adding Biochar to Distilled Water

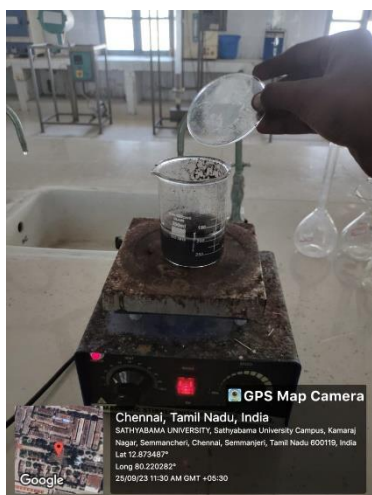


Fig 4.11: Adding Zinc Oxide

- After the process, the solution is filtered by using filter paper to remove the water content.



Fig 4.12: Gray colour solution will appear



Fig 4.13: Filtering

- To remove the moisture content, the filtered slurry content is placed inside the hot air oven.
- After all these processes we will get the final catalyst and it will be used in the transesterification process.



Fig 4.14: Drying the catalyst



Fig 4.15: Final catalyst

4.4 CHARACTERIZATION:

4.4.1 FTIR (FOURIER TRANSFORM INFRARED SPECTROSCOPY):

FTIR, or Fourier Transform Infrared Spectroscopy, is a technique utilized for analyzing the molecular composition of materials by measuring their absorption of infrared light. This method relies on the principle that molecules absorb infrared radiation at distinct frequencies corresponding to their vibrational modes. In an FTIR setup, an infrared source emits a broad spectrum of light, which passes through the sample. The sample's molecules absorb specific wavelengths, while others are transmitted. A detector measures the intensity of transmitted light, generating a spectrum that provides insights into the sample's molecular structure. Key components of an FTIR instrument include the interferometer, which modulates the infrared light, and a computer system for data processing. Samples can be solids, liquids, or gases, prepared accordingly for analysis. Interpretation of the resulting spectrum involves identifying peaks corresponding to specific molecular vibrations. FTIR finds applications across various fields, including chemistry, materials science, pharmaceuticals, and environmental monitoring, owing to its ability to provide detailed information about chemical composition and structure.

4.4.2 XRD (X-RAY DIFFRACTION):

X-ray diffraction (XRD) analysis is a fundamental technique employed to unveil the atomic and molecular structure of crystalline materials. By directing X-rays onto a sample, the interaction with the atoms within the crystal lattice results in diffraction patterns that encode crucial information about the material's internal arrangement. This method, rooted in Bragg's law, enables the determination of the spacing between atomic planes and the orientation of crystal grains. Instrumentation typically involves an X-ray source, a sample holder, a detector, a goniometer for sample rotation, and specialized software for data analysis. Sample preparation involves finely powdering the material to ensure random crystallite orientation. During data collection, diffraction patterns are gathered over a range of angles, revealing distinct peaks corresponding to specific crystallographic planes. Analysis of these patterns facilitates the identification of crystal structures and phases, aiding in applications across materials science, geology, pharmaceuticals, chemistry, and engineering. XRD analysis serves as a cornerstone technique for understanding the properties and behavior of crystalline materials in diverse scientific and industrial domains.

4.4.3 FESEM WITH EDX:

Spectroscopy (EDX) is a sophisticated analytical technique used to investigate the surface morphology and elemental composition of materials with remarkable detail. In FESEM, a finely focused electron beam generated by a field-emission electron gun scans the sample surface, producing high-resolution images. This allows for the visualization of microstructures, surface features, and nano-scale details. Meanwhile, the EDX system detects characteristic X-rays emitted by the sample upon electron beam excitation. These X-rays carry information about the elemental composition of the sample, enabling qualitative and quantitative elemental analysis. By combining high-resolution imaging capabilities with elemental analysis, FESEM with EDX provides comprehensive insights into the structure, composition, and chemistry of materials. This technique finds widespread applications in materials science, nanotechnology, geology, biology, and various other fields, facilitating research and development across diverse disciplines.

4.4.4GCMS:

Gas Chromatography-Mass Spectrometry (GC-MS) is a sophisticated analytical technique used for identifying and quantifying components within complex mixtures. In GC-MS, the sample is introduced into a gas chromatograph where it undergoes separation based on its affinity for the stationary phase within the column. As the separated components exit the column, they enter the mass spectrometer, where they are ionized and fragmented. The resulting ions are separated based on their mass-to-charge ratio, generating a mass spectrum unique to each compound. By comparing these spectra to known standards or databases, the identity of the components can be determined. Additionally, the abundance of ions in the mass spectrum provides quantitative information about the concentration of each compound. GC-MS finds applications across various fields, including environmental analysis, forensic science, pharmaceuticals, food safety, and petrochemical analysis, owing to its high sensitivity, selectivity, and versatility in compound identification and quantification.

4.5 DETERMINATION OF ACID VALUE AND FREE FATTY ACID VALUE:

The determination of acid value is a critical analytical procedure used in various industries, particularly in the production of biodiesel, edible oils, and fats. It provides essential information about the concentration of free fatty acids present in a sample, which is indicative of its quality, stability, and suitability for use in different applications.

Acid value is defined as the quantity of Sodium Hydroxide (NaOH) in milligrams required to neutralize the free acids present in one gram of the sample. The determination of acid value involves a simple titration method, typically using a standardized NaOH solution and a suitable indicator to detect the endpoint of the reaction. In the context of biodiesel production, the acid value of feedstock oils is a crucial parameter that influences the transesterification process. High acid values indicate elevated levels of free fatty acids, which can adversely affect the efficiency of the transesterification reaction and the quality of the biodiesel product. Therefore, monitoring and controlling the acid value of feedstock oils are essential to ensure optimal process performance and biodiesel quality.

The determination of acid value begins with sample preparation, where the oil or fat is dissolved in a suitable solvent to facilitate the titration process. The sample solution is then titrated with a standardized NaOH solution under controlled conditions until the endpoint of the titration is reached. The endpoint is typically detected using a pH indicator, such as phenolphthalein or methyl orange, which changes color upon neutralization of the free acids.

Steps to find the acid value of the Pongamia Pinnata Oil:

- Prepare 0.1N NaOH solution
- Add few drop of phenolphthalein indicator to 50 ml of ethanol
- After added Titrate the solution against NaOH to neutralize
- Neutralized ethanol is added to 10g of oil and it is heated using hot plate .
- After 20min add few drop of indicator and titrate against 0.1N of NaOH
- Before titrate note the initial burette reading
- Start to titrate the solution when the solution changed into pink colour stop the titrate
- Note the final burette reading.

4.5.1 CALCULATION OF ACID VALUE:

Sample Weight =10g

Normality of NaOH (N) =0.1N

Volume of NaOH Solution (V)= Final Burette Reading – Initial Burette Reading

$$= 30.1 - 0.2 = 29.9$$

Molecular weight of NaOH = 40.01

$$\text{Acid Value} = \frac{\text{molecular weight of NaOH} \times N \times V}{10} = \frac{40.01 \times 0.1 \times 29.9}{10} = 11.96$$

10

10

$$\text{Free fatty acid (FFA)} = 11.96/2 = 5.98$$



Fig 4.16: Before Titration



Fig 4.17: After Titration

4.6 ESTERIFICATION PROCESS:

- Take 60ml of Pogamia Pinnata Oil and pour it into flask and heated upto 60°C.
- Take 40ml of Methanol and is added to the pre-heated Pogammia Pinnata Oil and it is stirred for few minutes.
- Add 1.5ml of Sulphuric Acid is added to the mixture.
- Heat and Stir the mixture continuously for about 45 mins at room temperature.
- After the completion of reaction, we have to remove the excess impuritues Sulphuric Acid and Alcohol from the mixture. For that we need to pour it into the seperating funnel.
- Alcohol, Sulphuric Acid and other impurities will be settled to the top layer of the solution.
- The rest of the solution which is settled below will be used for Transesterification process.
- These processes helps to reduce the FFA value of oil below 1%.

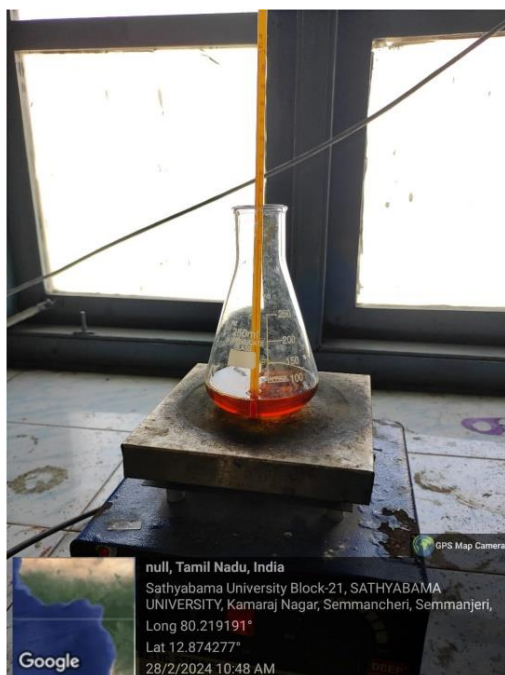


Fig 4.18: Heating of Oil

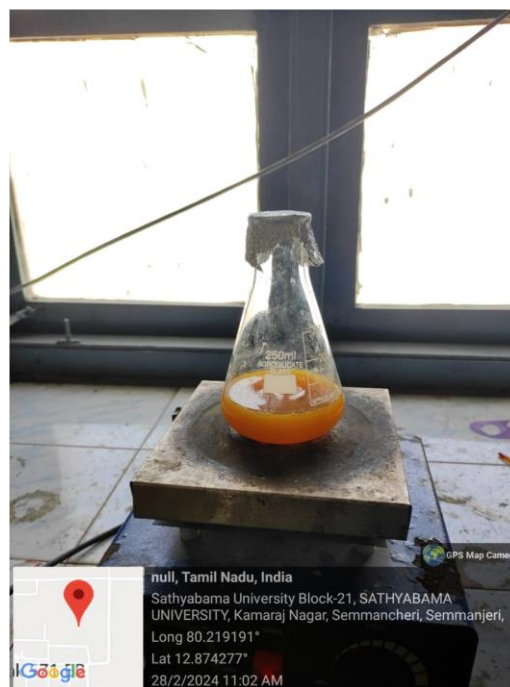


Fig 4.19: Stirring the Solution



Fig 4.20: Separation of the Solution

4.7 TRANSESTERIFICATION PROCESS:

- Heating the oil which is collected from the esterification process at the degree of 60°C in round bottom flask using magnetic stirrer.
- After reaching 60°C , Methanol and the catalyst is added to the round bottom flask, then we will be closing it with the Condensor.
- We need to stir the solution continuously for 1 Hour, the heat should be maintained at 50°C .
- After that we need to pour the solution into the separating funnel, leave it for 1 day.
- In the separating funnel the solution is separated to two layers.
- Biodiesel is separated to the top and the glycerol will be settled to the bottom.
- Separate the biodiesel from the separating funnel and is collected to container.



Fig 4.21: Heating of Oil in RB Flask



Fig 4.22: Stirring the Solution for 1 Hr



Fig 4.23: Separation of Biodiesel from the solution

4.8 PRODUCTION OF BIODIESEL IN DIFFERENT RATIO:

RATIO	OIL (ml)	METHANOL (ml)	OIL (mass)	METHANOL (mass)	Catalyst wt%	CATALYST (gram)	Time (min)	Yield %
1 : 3	40	4.9	36	3.87	5	2.1	45	-
1 : 6	40	9.8	36	7.75	5	2.3	45	46
1 : 9	40	14.7	36	11.6	5	2.5	45	59
1 : 12	40	19.6	36	15.5	5	2.71	45	64
1 : 15	40	24.5	36	19.37	5	2.91	45	74
1 : 18	40	29.4	36	23.25	5	3.12	45	80
1 : 21	40	34.3	36	27.13	5	3.32	45	85
1 : 24	40	39.2	36	31	5	3.5	45	72
1 : 27	40	44.1	36	34.8	5	3.73	45	66
1 : 30	40	49	36	38.7	5	3.93	45	-

Table 4.1 Production Of Biodiesel In Various Ratio

From the above table we got highest yield in 1:21ratio which is in the percentage of 85%

4.9 ENGINE:

IC Engine set up under test is Research Diesel having power 3.50 kW @ 1500 rpm which is 1 Cylinder, Four stroke, Constant Speed, Water Cooled, Diesel Engine, with Cylinder Bore 87.50(mm), Stroke Length 110.00(mm), Connecting Rod length 234.00(mm), Compression Ratio 17.50, Swept volume 661.45 (cc)



Fig 4.24: Engine

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 CHARACTERIZATION OF CATALYST AND OIL

5.1.1 FTIR (SEAWEED) :

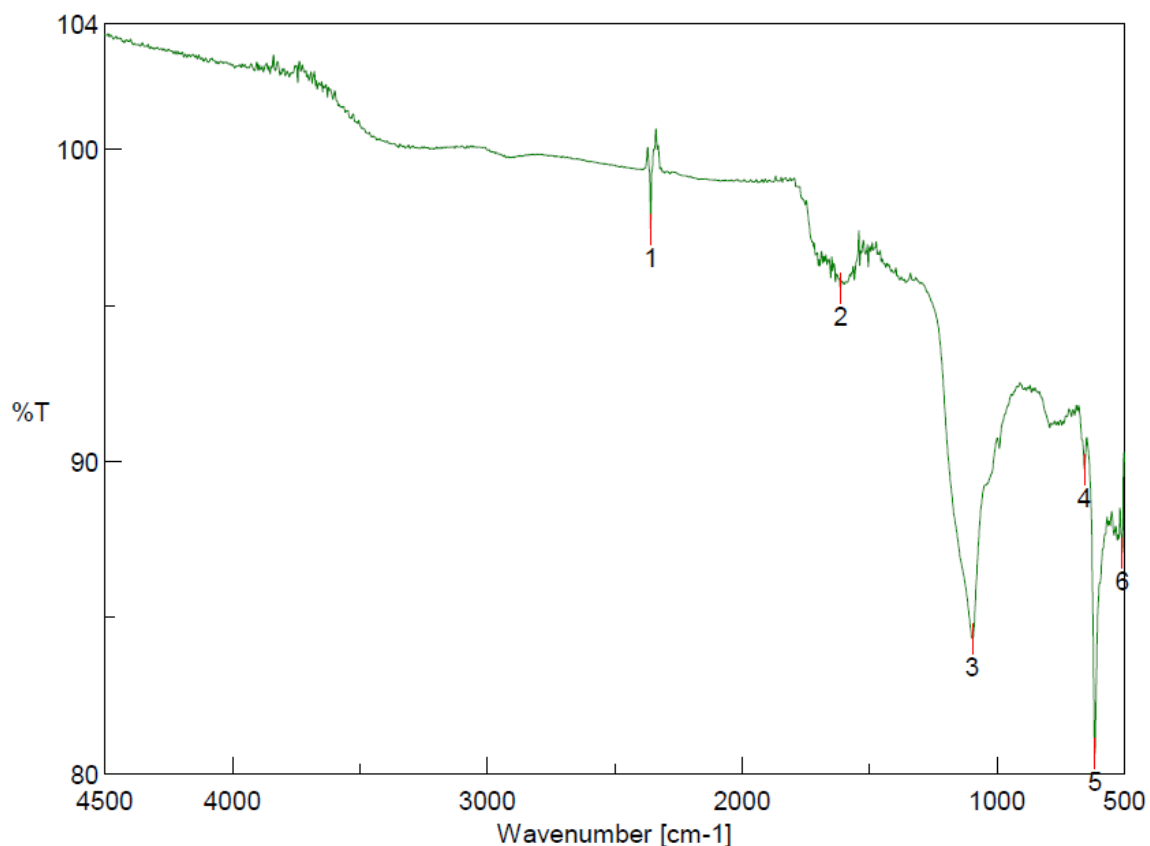


Fig 5.1: FTIR for Seaweed

From the above graph peak level at different position indicates the different functional groups present in it.

2358.5cm-1 shows the presence of O=C=O stretching carbon dioxide with strong intensity. 1614.1cm-1 shows the presence of C=C stretching with strong intensity. 1097.3cm-1 Shows the presence of C-O stretching alcohol with strong intensity. 656.6cm-1 shows the presence of C-Br stretching halo compound with strong intensity. 508.1cm-1 shows the presence of C-I stretching with strong intensity.

5.1.2 FTIR (SEAWEED/ZnO):

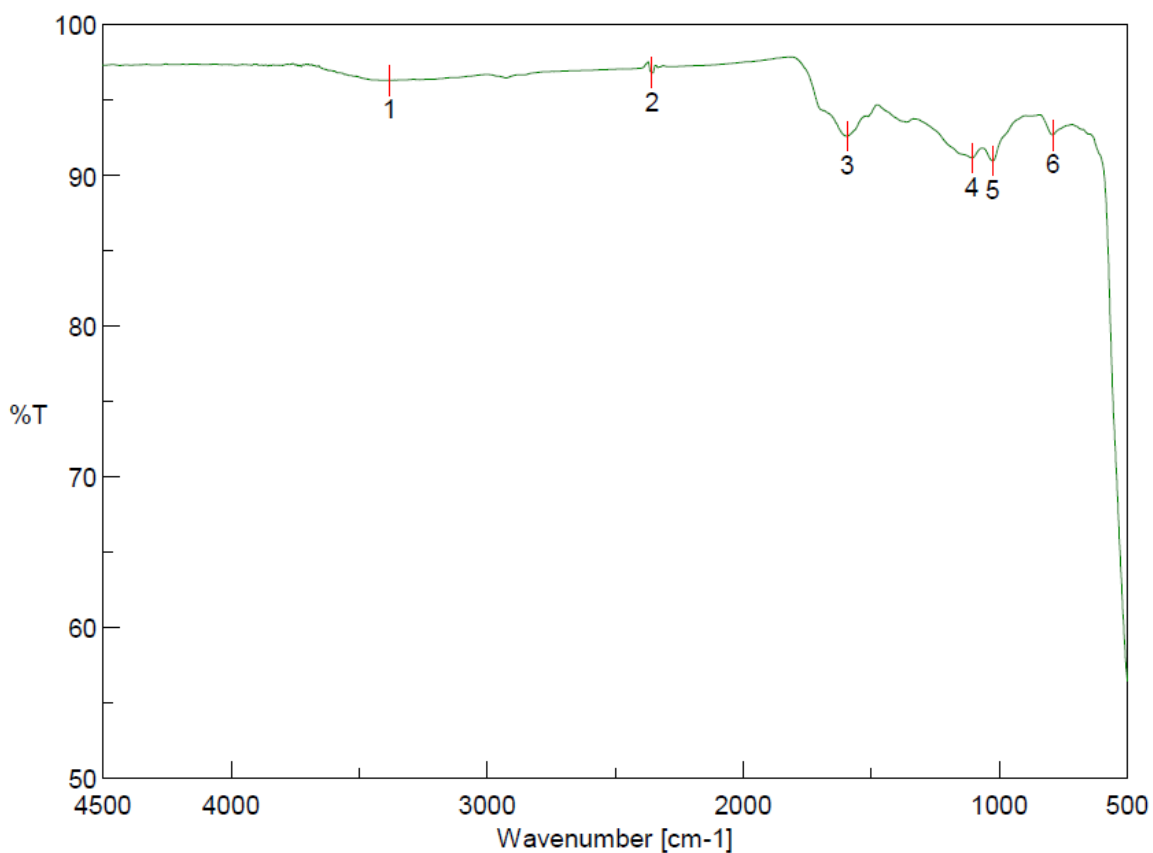


Fig 5.2: FTIR for Seaweed/zno

From above graph shows the ftir analysis for seaweed with zinc oxide we discuss the graph in detail about what are all the functional group present in it in each peak and also their intensity.

3380.6cm⁻¹ shows the presence of O-H stretching alcohol with strong broad.2356.5cm⁻¹ shows the presence of O=C=O stretching carbon dioxide with strong intensity.1594.8cm⁻¹ shows the presence of N-H bending amine with medium intensity.1106.9cm⁻¹ shows the presence of C-F stretching fluoro with strong intensity.791.6cm⁻¹ shows the presence of C-Cl stretching halo with strong intensity.

5.1.3 FESEM (SEAWEED/ZnO):

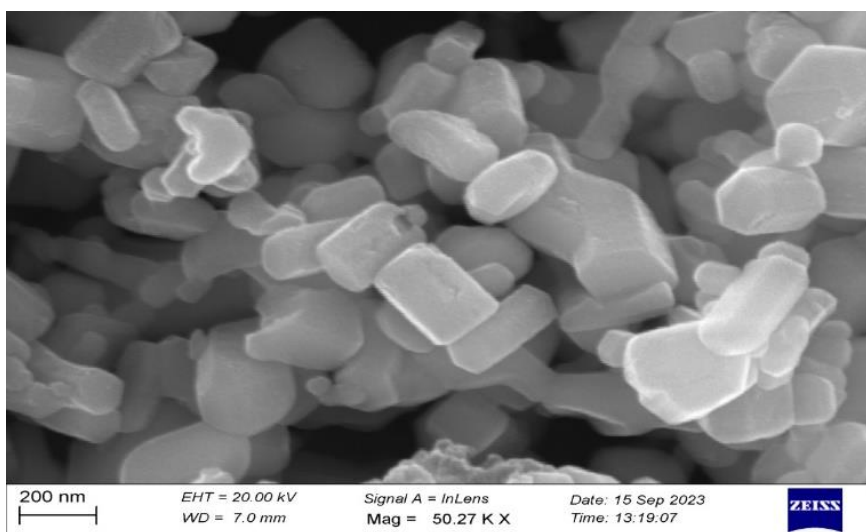


Fig 5.3: SEM Image under 50.27 KX magnification

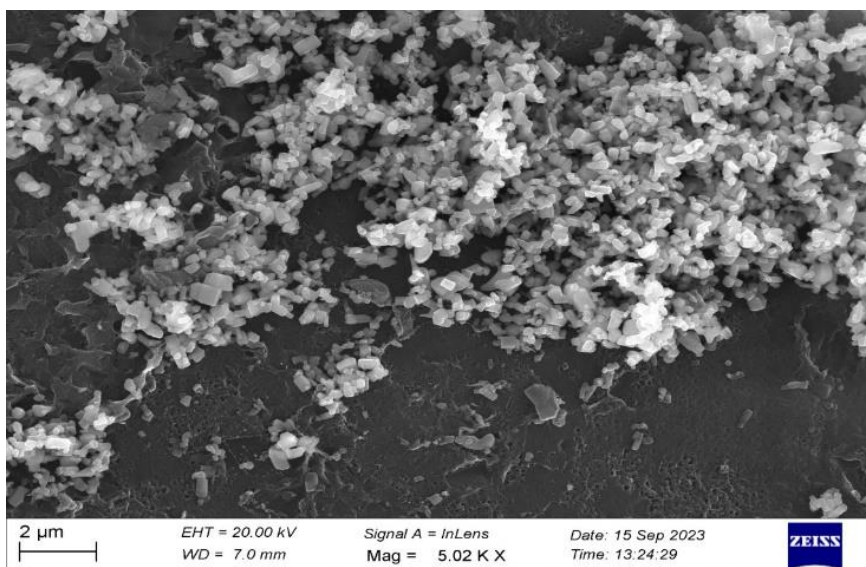


Fig 5.4: SEM Image under 5.02 KX magnification

The FESEM analysis of synthesized catalyst which consists of doped seaweed and zinc oxide. The FESEM analysis in the above picture shows the heterogeneous structure of catalyst. FESEM is used to find the size, shape, and distribution of catalyst particles because of their catalytic activity and selectivity.

5.1.4 EDAX (SEAWEED/ZnO):

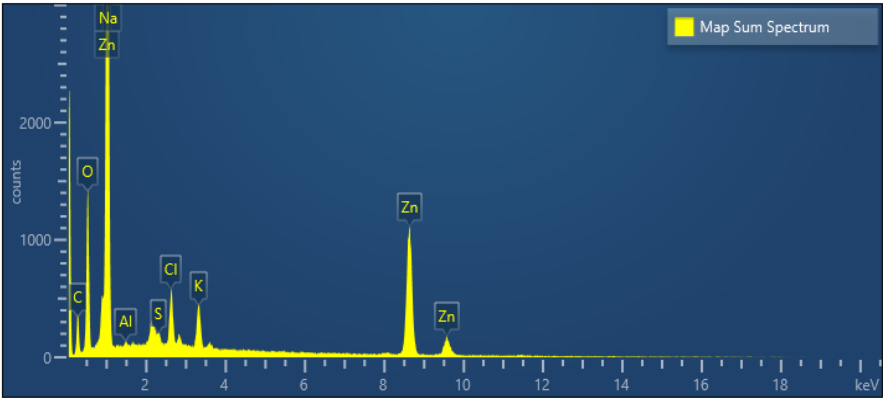


Fig 5.5: EDAX Mapping

Map Sum Spectrum				
Element	Line Type	Weight %	Weight % Sigma	Atomic %
C	K series	24.55	1.28	46.02
O	K series	21.21	0.48	29.86
Na	K series	6.40	0.49	6.27
Al	K series	0.27	0.06	0.23
S	K series	0.14	0.06	0.10
Cl	K series	2.35	0.08	1.49
K	K series	2.13	0.08	1.23
Zn	K series	42.94	0.82	14.79
Total		100.00		100.00

Table 5.1: Elemental Composition In Seaweed/ZnO

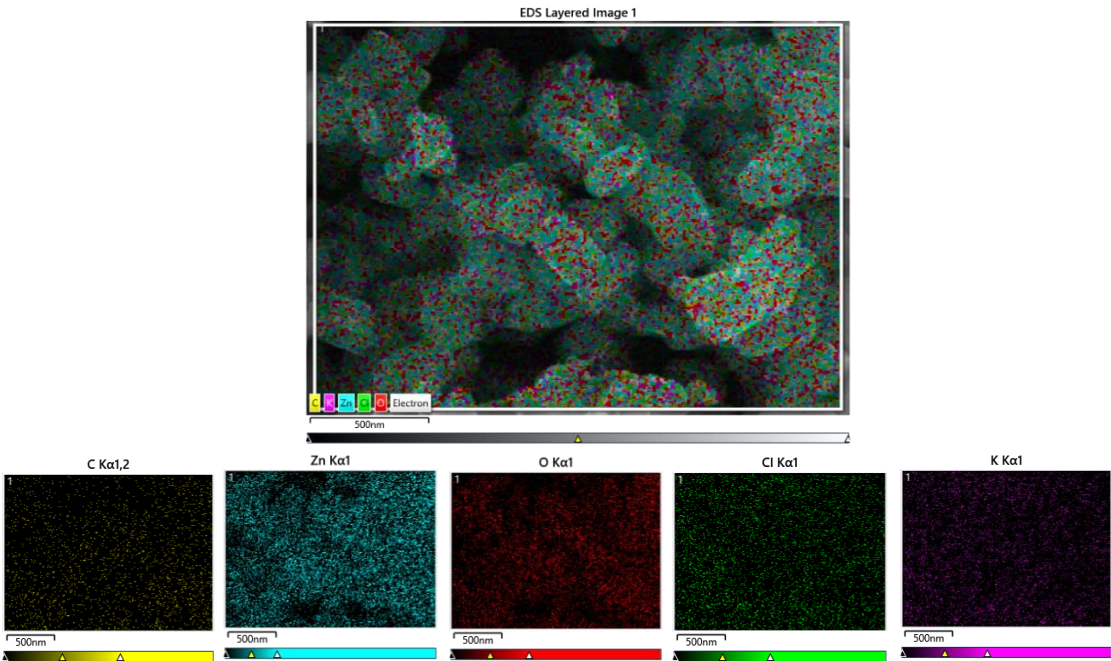


Fig 5.6: EDAX Image

Based on the EDAX map you provided, here's an explanation of the elemental distribution observed in your seaweed/ZnO sample:

The strong presence of carbon (C) and oxygen (O) throughout the map suggests these elements are abundant, which is consistent with the composition of seaweed, which is mainly organic matter (carbohydrates, proteins). Zinc (Zn) appears concentrated in specific regions throughout the map, indicated by the yellow color intensity. This suggests that ZnO particles are not uniformly distributed on the seaweed surface but rather localized in clusters. The presence of sodium (Na) is likely due to residual salts from seawater on the seaweed surface.

5.1.5 XRD (SEAWEED/ZnO):

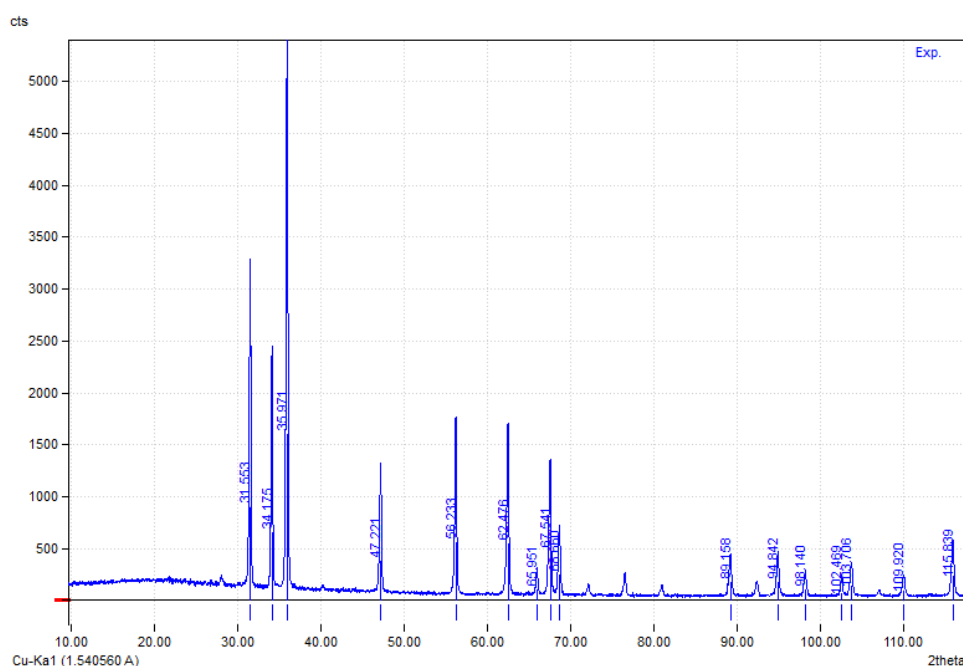


Fig 5.7: XRD

Based on the XRD graph you provided of the seaweed/ZnO composite, here's an analysis of the likely crystalline phases present:

This broad peak is likely due to amorphous organic material originating from the seaweed component. Seaweed typically contains complex carbohydrates like cellulose and alginate, which can diffract X-rays and contribute to a broad peak in this region. These peaks match well with the crystallographic planes of ZnO (zinc oxide). Their presence confirms the existence of ZnO in your seaweed/ZnO composite. These might be due to minor crystalline components in the seaweed or

the presence of other metal oxides depending on the specific seaweed species and preparation process. Without additional information or reference data, pinpointing these phases is challenging.

The X-ray diffraction (XRD) graph suggests that your seaweed/ZnO composite consists of two main crystalline phases.

- Amorphous Organic Material:** This broad peak indicates the presence of non-crystalline organic matter, likely from the seaweed component.
- ZnO:** The sharp peaks at specific angles confirm the presence of crystalline ZnO nanoparticles or particles within the composite.

5.1.6 GCMS (POMGAMIA PINNATA OIL):

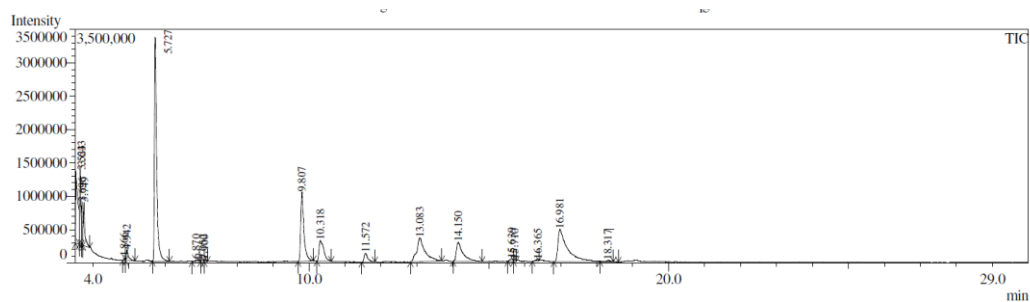


Fig 5.8: GCMS of Oil

Peak Report TIC				
Peak#	R.Time	Area	Area%	Name
1	3.523	4758261	8.60	Cyclohexane
2	3.643	2680297	4.84	Cyclopentane, 1,3-dimethyl-
3	3.696	1392835	2.52	Cyclopentane, 1,3-dimethyl-
4	3.749	1735345	3.13	Cyclopentane, 1,3-dimethyl-, trans-
5	4.866	113548	0.21	2-METHYL-2-PENTANOL
6	4.942	665290	1.20	Methyl Isobutyl Ketone
7	5.727	14227818	25.70	BENZENE, METHYL-
8	6.870	226761	0.41	Cyclopentanol, 1-methyl-
9	7.052	133450	0.24	3-HYDROXY-2,2-DIMETHYLPROPANAL
10	7.100	88482	0.16	CYCLOHEXANE, (1-HEXADECYLHEPT
11	9.807	6331299	11.44	Ethylbenzene
12	10.318	2850517	5.15	BENZENE, 1,2-DIMETHYL-
13	11.572	925147	1.67	BENZENE, 1,2-DIMETHYL-
14	13.083	5656828	10.22	SILANE, ETHENYLTRIMETHYL-
15	14.150	3707791	6.70	Valeric acid, 2-ethoxyethyl ester
16	15.639	223227	0.40	Pentanoic acid, 2-propenyl ester
17	15.710	106957	0.19	1-METHYL-2-PROPENYL PROPYL ETHI
18	16.365	125224	0.23	Hydroperoxide, 1-methylpentyl
19	16.981	9262932	16.73	Oxalic acid, cyclohexyl ethyl ester
20	18.317	146018	0.26	Mesitylene
		55358027	100.00	

Table 5.2: Peak Report of GCMS for Pongamia Pinnata Oil

The table lists the peak number, retention time (R. Time), area, area percent, and peak report for each component. The retention time is the time it takes for a component to flow through the GC column. The area is a measure of the amount of

the component that is present in the sample. The area percent is the percentage of the total area that is accounted for by that component. The peak report lists the tentative identification of the component. from above result for pongamia oil demonstrates the presence of Valeric acid, and Pentanoic acid. The presence of pentanoic acid (valeric acid) and other organic acids in the GCMS analysis of pongamia oil is indicative of the fatty acid profile of the oil. Pongamia oil, like many other plant oils, is a triglyceride, meaning it contains triglycerides - molecules formed by three fatty acids esterified to glycerol. These fatty acids vary in chain length and saturation, influencing the properties of the oil. The high content of short-chain fatty acids like valeric acid might make pongamia oil less favorable for biodiesel production compared to oils rich in longer-chain fatty acids. The presence of specific fatty acids can influence the oil's drying properties, making it potentially suitable for applications in paints and coatings

5.2 POST STUDY OF CATALYST:

5.2.1 FTIR (SEAWEED/ZnO):

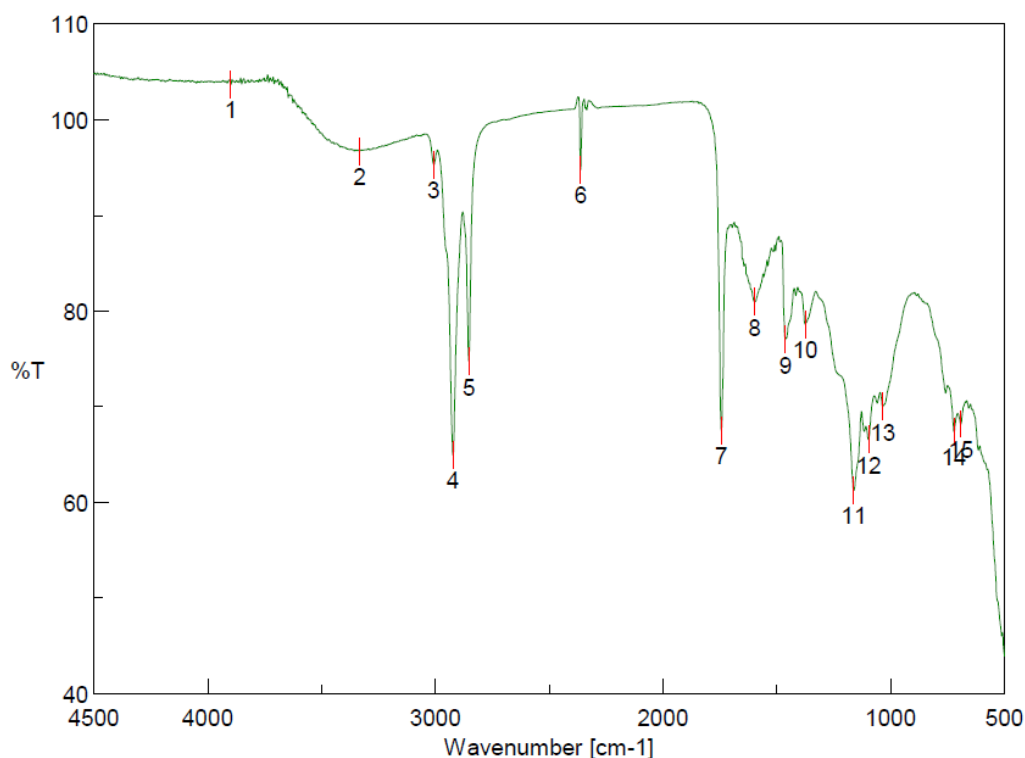


Fig 5.9: FTIR for seaweed/ZnO after biodiesel

Based on the FTIR image you sent of your seaweed/ZnO composite, here's an interpretation of the functional groups likely present:

Peak around 3300-3600 cm^{-1} is attributed to O-H stretching vibrations from hydroxyl groups (OH) present in various molecules, including carbohydrates, proteins, and water. Peaks Around cm^{-1} correspond to C-H stretching vibrations from aliphatic hydrocarbons (organic molecules with carbon-hydrogen chains) commonly found in seaweed. Peak Around 1650 cm^{-1} is assigned to C=O stretching vibrations from carbonyl groups (C=O) in various organic molecules like ketones or carboxylic acids. In seaweed, this could be due to the presence of carbonyl groups in alginate or other carbohydrates Peaks Around 1450-1550 cm^{-1} is represent C-H bending vibrations and can be attributed to various organic components in the seaweed Peak Around 1030 cm^{-1} is due to C-O stretching vibrations from carbohydrates or polysaccharides in the seaweed The FTIR spectrum suggests that the main components in your seaweed/ZnO composite are organic molecules originating from the seaweed. The presence of functional groups like O-H, C-H, and C=O is consistent with the presence of carbohydrates, proteins, and other organic biomolecules typically found in seaweed

5.2.2 FESM (SEAWEED/ZnO):

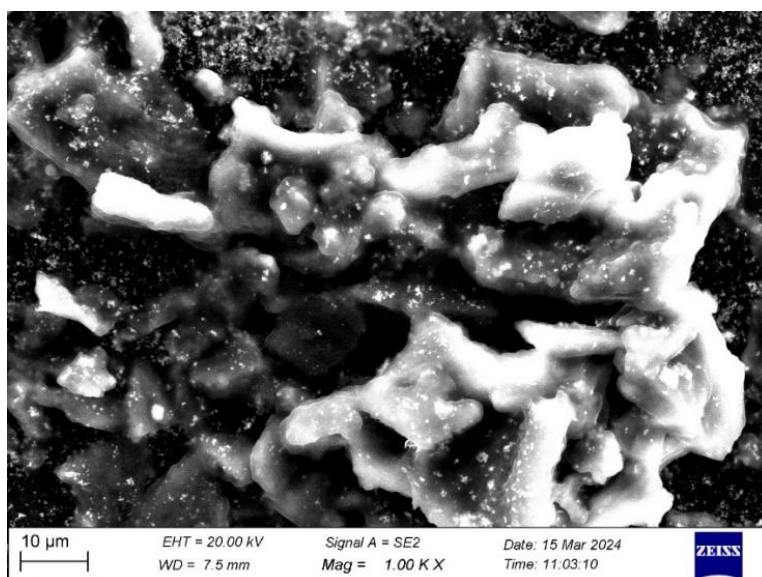


Fig 5.10: SEM Image under 1 KX magnification

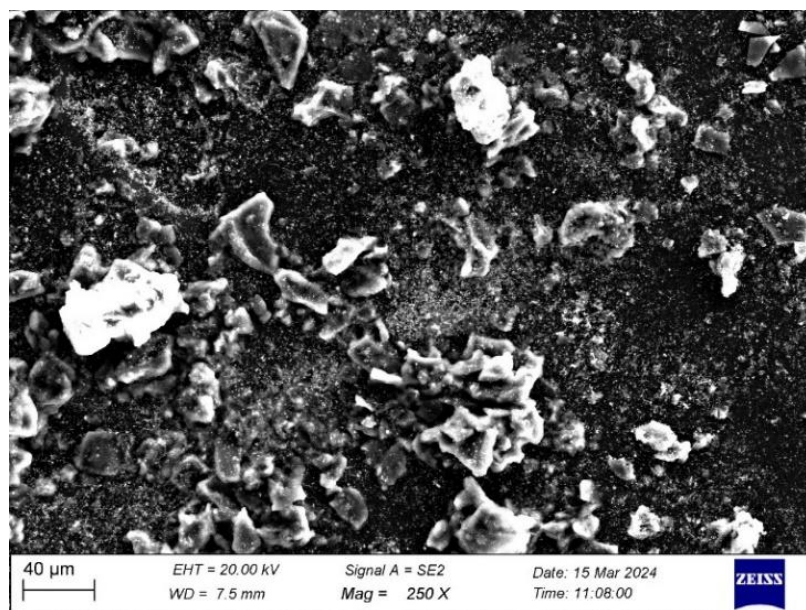


Fig 5.11: SEM Image under 250 KX magnification

The Sem image shows the elements present in your sample include Sodium (Na), Silicon (Si), Sulfur (S), Zinc (Zn), Carbon (C) from the result The necessity of this post-study is to analyse whether the pores or active sites of the catalyst got enclosed, and it's confirmed that the pores or surface of the catalyst got lit up due to the reaction between methanol and oil, which ensures that the catalyst is involved in the reaction, is filtered, and further it is used for any other purpose.

5.2.3 EDAX (SEAWEED/ZnO):

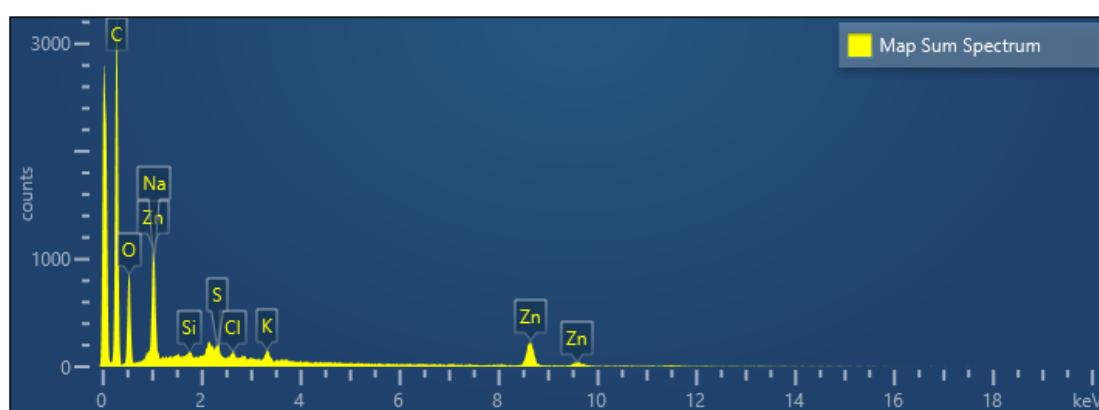


Fig 5.12: EDAX Mapping

Map Sum Spectrum				
Element	Line Type	Weight %	Weight % Sigma	Atomic %
C	K series	69.53	0.53	79.95
O	K series	20.05	0.43	17.31
Na	K series	0.82	0.14	0.49
Si	K series	0.16	0.03	0.08
S	K series	0.28	0.04	0.12
Cl	K series	0.25	0.03	0.10
K	K series	0.46	0.04	0.16
Zn	K series	8.45	0.25	1.79
Total		100.00		100.00

Table 5.3: Elemental Composition in Seaweed/ZnO

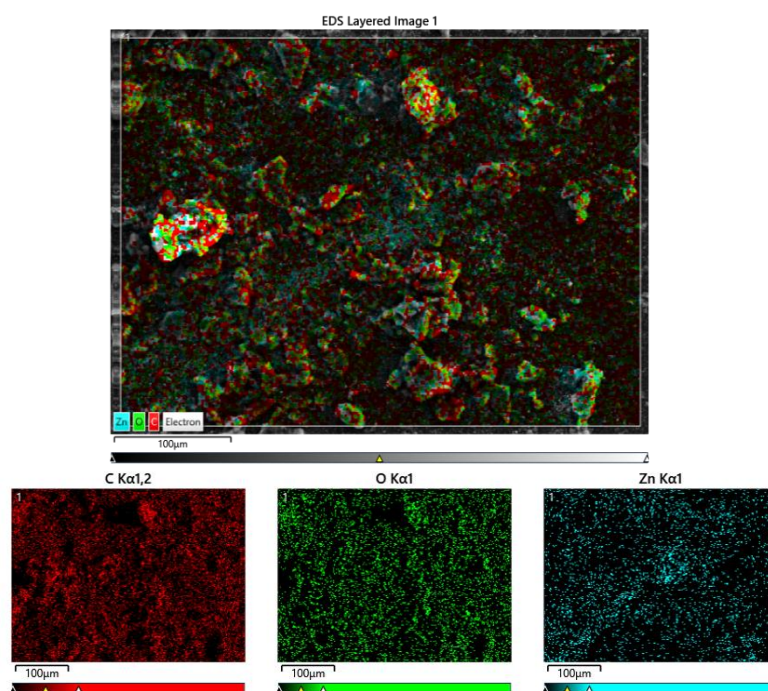


Fig 5.13: EDAX Image

5.2.4 CATALYST REUSABILITY:

Catalysts play a crucial role in chemical reactions by speeding up the reaction rate and increasing the efficiency of the process. Reusability of catalysts is an important aspect in industrial applications as it not only reduces costs but also minimizes waste generation and environmental impact. In the context of biodiesel production from seaweed, the reuse of catalysts, particularly those based on zinc oxide (ZnO), can offer significant advantages. The catalyst can be separated from the glycerol phase through techniques such as filtration or centrifugation. The recovered catalyst may still contain some impurities or traces of reactants. The recovered catalyst is then regenerated to restore its activity and effectiveness. This typically involves washing the catalyst with suitable solvents to remove impurities and reactants

adsorbed on its surface. Additionally, calcination or other treatments may be applied to restore the catalyst's surface properties. The regenerated catalyst is then reused in subsequent batches of biodiesel production. This cycle of use, recovery, regeneration, and reuse can be repeated multiple times, depending on the catalyst's stability and the effectiveness of regeneration processes. Reusing catalysts reduces the need for frequent replacement, leading to cost savings in catalyst procurement. By extending the catalyst's lifespan, less waste is generated from spent catalyst disposal, contributing to environmental sustainability. Reusable catalysts maintain their catalytic activity over multiple cycles, ensuring consistent and efficient biodiesel production. Utilizing catalyst reusability conserves resources that would otherwise be consumed in the production of new catalysts. Overall, the reusability of catalysts, particularly in biodiesel production from seaweed, offers significant advantages in terms of cost-effectiveness, environmental sustainability, and process efficiency, making it a key focus area in industrial applications.

5.3 CHARACTERIZATION OF BIODIESEL:

5.3.1 FTIR (BIODIESEL):

FTIR can show the sort and number of functional groups present in the material, as well as the degree of unsaturation and other structural features, FTIR spectroscopy is incredibly useful for the investigation of biodiesel.

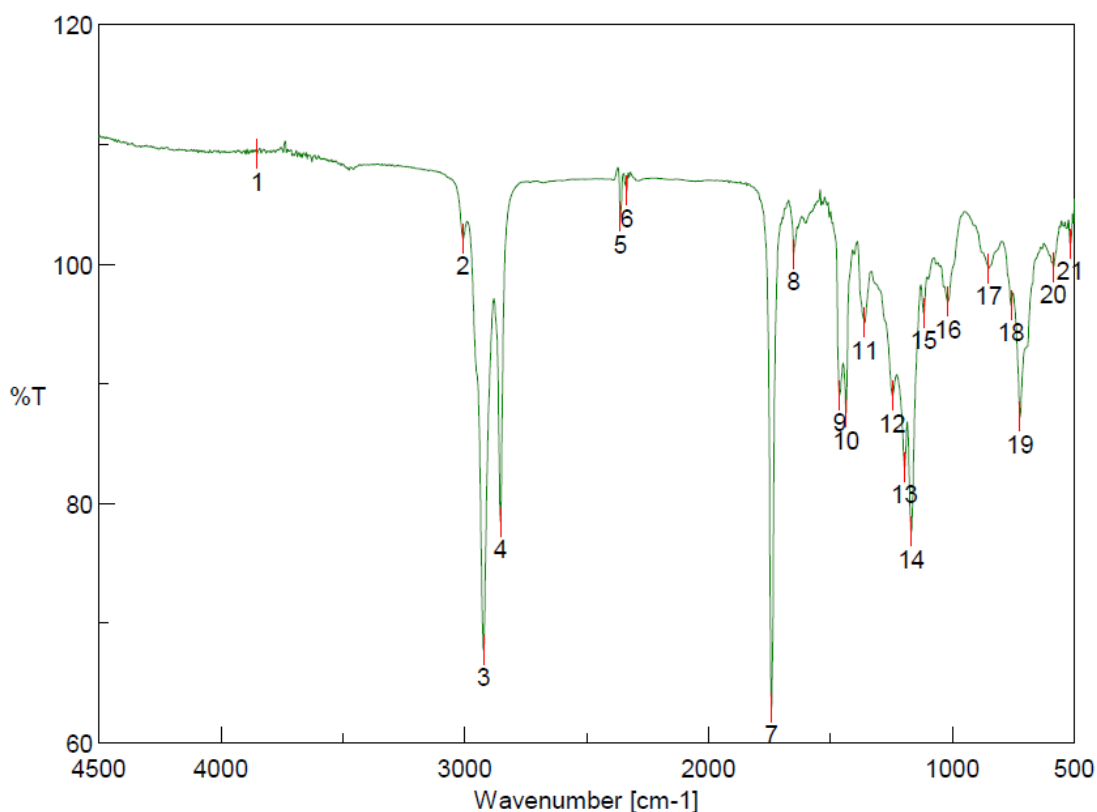


Fig 5.14: FTIR for Biodiesel

The above graph shows the ftir result of biodiesel we should analyse the graph to know what are all the functional groups present in it.

3006.4cm-1 shows the presence of O-H stretching carboxylic acid with strong broad. 2922.5cm-1 shows the presence of C-H stretching alkane with medium intensity. 2361.4cm-1 shows the presence of O=C=O stretching carbon dioxide with strong intensity. 1741.4cm-1 shows the presence of C=O stretching ester with strong intensity. 1359.5cm-1 shows the presence of S=O stretching sulfonate with strong intensity. 585.2cm-1 Shows the presence of C-Cl stretching halo with strong intensity.

5.3.2 PROPERTIES OF BIODIESEL:

S.No	Parameters	Results
1	Calorific value (MJ/Kg)	35
2	Kinematic Viscosity @ 40 (°C)	5.2
3	Pour point by ASTM method (°C)	-3.8
4	Fire point by PMCC method (°C)	176
5	Flash point by PMCC method (°C)	164
6	Density (g/cc)	0.793

Table 5.4: Biodiesel Properties

5.3.3 GCMS (BIODIESEL):

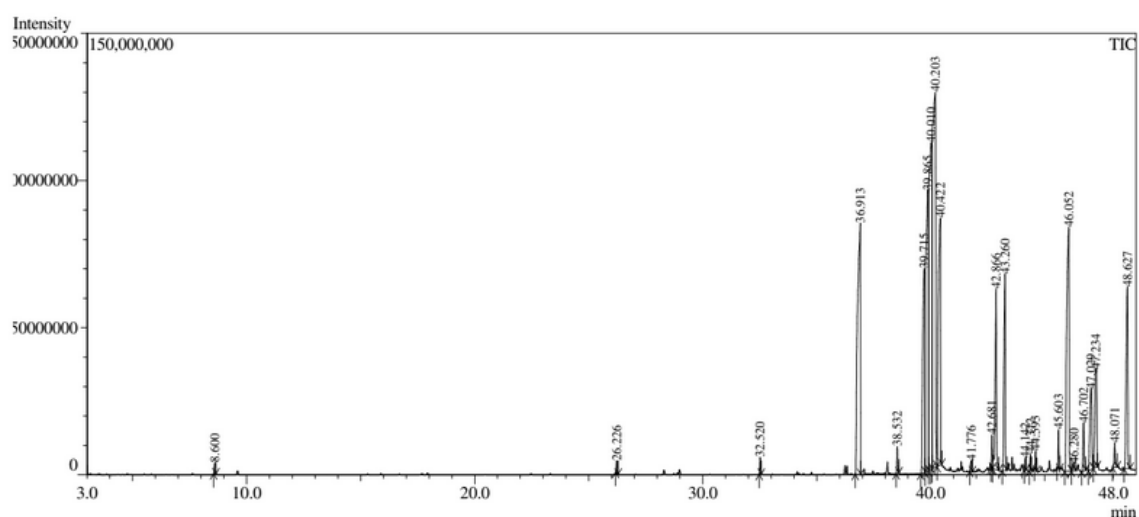


Fig 5.15: GCMS for Biodiesel

Peak Report TIC				
Peak#	R.Time	Area	Area%	Name
1	8.600	10385558	0.15	BENZOIC ACID, METHYL ESTER
2	26.226	12916049	0.19	DODECANOIC ACID, METHYL ESTER
3	32.520	13609374	0.20	TETRADECANOIC ACID, METHYL ESTER
4	36.913	748646375	11.05	HEXADECANOIC ACID, METHYL ESTER
5	38.532	23533520	0.35	Heptadecanoic acid, methyl ester
6	39.715	468466009	6.91	9,12-Octadecadienoic acid (Z,Z)-, methyl ester
7	39.865	754105222	11.13	9-Octadecenoic acid, methyl ester, (E)-
8	40.010	977446760	14.42	9,12-OCTADECADIENOIC ACID (Z,Z)-, Methyl ester
9	40.203	1201071312	17.72	9-OCTADECENOIC ACID, METHYL ESTER
10	40.422	567706932	8.38	OCTADECANOIC ACID, METHYL ESTER
11	41.776	12886695	0.19	Methyl (11R,12R,13S)-(Z)-12,13-epoxy-11-octadecenoate
12	42.681	27831826	0.41	9-OCTADECENSAEURE, 12-HYDROXY-
13	42.866	260549633	3.84	cis-13-Eicosenoic acid, methyl ester
14	43.260	284254373	4.19	METHYL ICOSANOATE
15	44.142	9935156	0.15	1-Propyl-3-(propen-1-yl)adamantane
16	44.372	14523408	0.21	2-METHOXY-2,6,10,15,19,23-HEXAMETHYLOCTADECANOIC ACID, METHYL ESTER
17	44.593	14198638	0.21	HENEICOSANOIC ACID, METHYL ESTER
18	45.603	33261274	0.49	13-Docosenoic acid, methyl ester
19	46.052	582441223	8.60	DOCOSANOIC ACID, METHYL ESTER
20	46.280	12492806	0.18	2-Pyrazoline, 1-benzoyl-3-ethyl-5-hydroxy-5-methyl-
21	46.702	56631261	0.84	2,2-DIMETHYL-7-HYDROXY-6-[(2'-PHENYL)-FURFURYLOXYMETHYL]BENZOPYRAN-4(4H)-ONE
22	47.029	160355557	2.37	2-PHENYL-FURO[B]BENZOPYRAN-4(4H)-ONE
23	47.234	197107849	2.91	2-[5-(2-METHYL-1,3-BENZOXAZOL-7-YL)-2-PHENYLBENZOPYRAN-4(4H)-ONE
24	48.071	29248266	0.43	9-Octadecenoic acid (Z)-, 2,3-dihydroxypropyl ester
25	48.627	302727094	4.47	Tetracosanoic acid, methyl ester
		6776332170	100.00	

Table 5.5: Peak Report of GCMS for Biodiesel

The above table and peaks present in the graph demonstrate the presence of methyl ester, which is the main component of biodiesel, and confirm whether the oil is converted into biodiesel, which is attained by the transesterification process. This confirms the presence of methyl esters and acids present in the pongamia biodiesel. As pongamia pinnata oil is converted to biodiesel, the triglycerides it contains undergo transesterification, which yields these methyl esters of fatty acids

5.4 INTERNAL COMBUSTION ENGINE STUDY:

A research focusing on performance, emissions, and engine optimisation would be conducted on internal combustion engines (ICEs) powered by biodiesel. The investigation of the IC engine is conducted for several blends (B10, B20). One of the most important metrics for evaluating the efficiency of an internal combustion engine is brake thermal efficiency, or BTE. It computes the output of useable work relative to the total energy input of the engine. In assessing the performance of engines with different fuels, BTE is an important factor to take into account. Determine how much heat is produced while the engine's biodiesel burns. This means accounting for the energy content and combustion efficiency of the biodiesel fuel. The combustion efficiency accounts for two types of losses: incomplete combustion and environmental heat loss. Calculate the engine's work output by using the torque and rotational speed. It is possible to calculate the amount of work completed in a single engine cycle using the engine displacement volume and the

torque-speed relationship. Compare the break thermal efficiency of conventional diesel fuel with biodiesel fuel under identical running circumstances.

This comparison reveals the relative efficacy of using biodiesel as a fuel in internal combustion engines. The performance of engines or other machinery operating on biodiesel fuel is typically compared to that of engines or other machinery running on standard diesel fuel in order to assess the mechanical efficiency of biodiesel. The aim of this study is to ascertain the impact of biodiesel on the mechanical efficiency of the system. Torque analysis for biodiesel is the process of comparing an engine's or piece of equipment's torque generation while using biodiesel fuel to normal diesel fuel. Torque is a crucial parameter for assessing an engine's mechanical performance as it shows the spinning force generated by the engine's drivetrain. Plot torque curves for both conventional diesel fuel and biodiesel to examine the torque output of the engine across its operating range.

5.4.1 Engine Study (B10%)

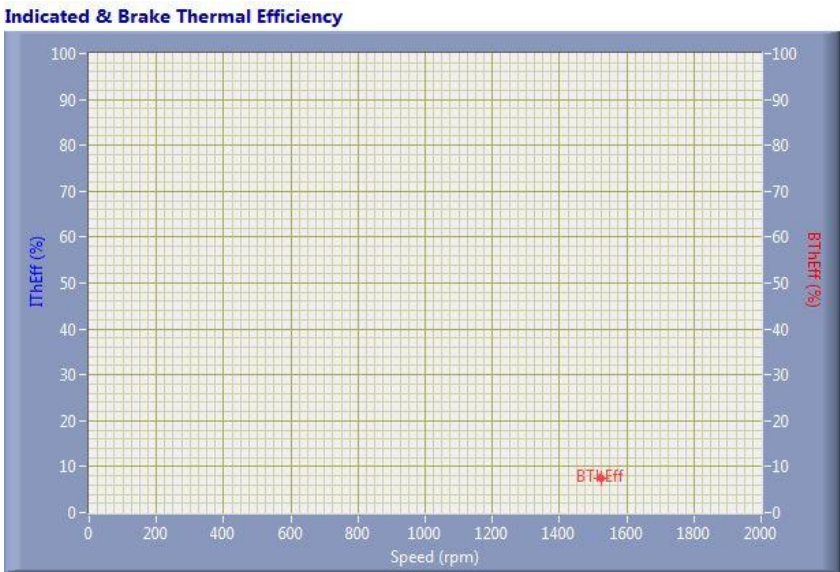


Figure 5.16: Break Thermal Efficiency for B10

Indicated & Brake Thermal Efficiency

Speed (rpm)	Load (kg)	IThEff (%)	BThEff (%)
1525.00	0.60	138.43	7.53

Table 5.6: Break Thermal Efficiency Data for B10

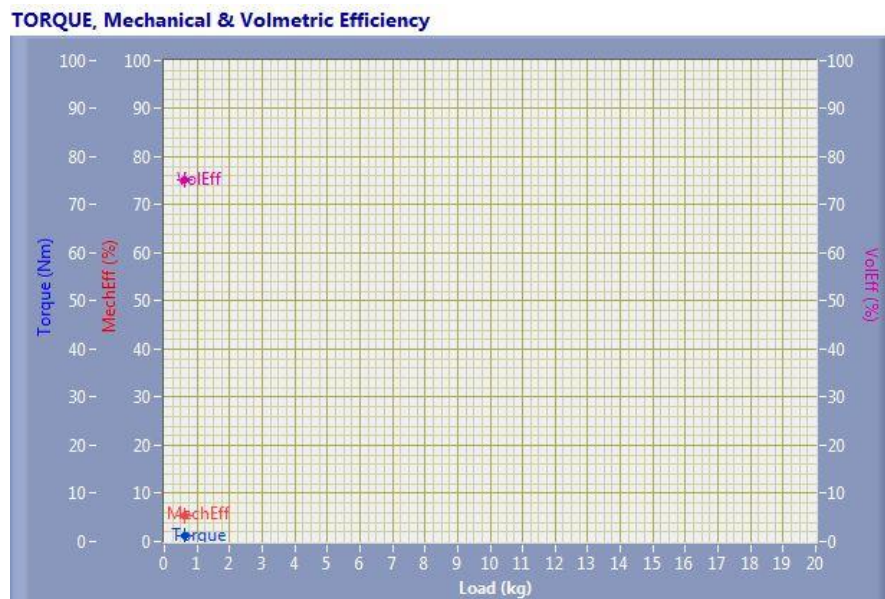


Fig 5.17 IC Engine Study For B10

TORQUE, Mechanical & Volmerti Efficiency

Speed (rpm)	Load (Kg)	Torque (Nm)	Mech Eff. (%)	Vol Eff. (%)
1525.00	0.60	1.10	5.44	75.09

Table 5.7 IC Engine Study Data for B10

5.4.2 Engine Study (B20%)

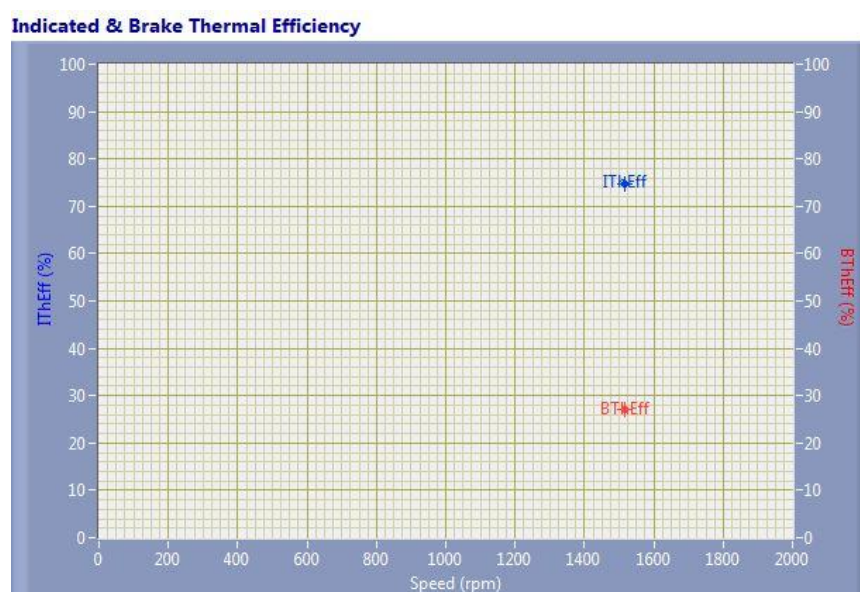


Fig 5.18: Break Thermal Efficiency for B20

Speed (rpm)	Load (kg)	<u>IThEff (%)</u>	<u>BThEff (%)</u>
1518.00	9.23	74.68	26.95

Table 5.8: Break Thermal Efficiency Data for B20

TORQUE, Mechanical & Volumetric Efficiency

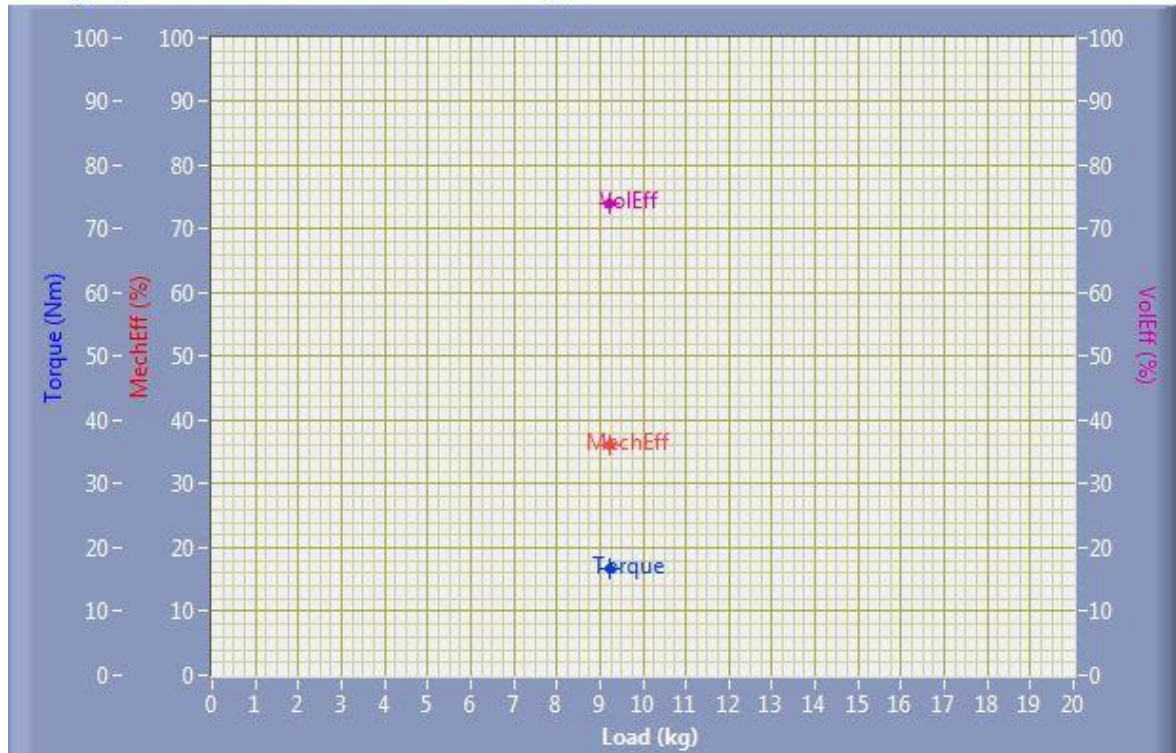


Fig 5.19: IC Engine Study For B20

Speed (rpm)	Load (Kg)	Torque (Nm)	<u>Mech Eff. (%)</u>	Vol Eff. (%)
1518.00	9.23	16.74	36.09	74.18

Table 5.9: IC Engine Study Data for B20

5.5 EMISSION ANALYSIS FOR VARIOUS BLENDS:

Emissions from internal combustion engines using biodiesel are essential for assessing the fuel's environmental impact and contrasting it with regular diesel. It describes the steps taken to assess emissions while using biodiesel fuel in an engine. It indicates the parameters of the emissions that were measured, such as hydrocarbons (HC), carbon monoxide (CO), particulate matter (PM), nitrogen oxides

(NO_x), and other pollutants. Give specifics about the test parameters, such as the load, engine speed, and composition of the biodiesel blend.

Name of the gas	Load	Load	Load	Load
	0	3	6	9
CO	0.01	0.04	0.05	0.06
HC	1	2	2	3
CO ₂	0.30	1.10	1	1.10
O ₂	20.64	19.41	19.61	19.30
NOX	23	52	61	68
SMOKE DENSITY	3.5	43.6	55.03	62.5

TABLE 5.10: Emission Analysis for B10

Name of the gas	Load	Load	Load	Load
	0	3	6	9
CO	0.01	0.03	0.04	0.04
HC	1	2	3	4
CO ₂	0.50	0.70	0.80	1
O ₂	2.333	19.65	19.83	19.57
NOX	32	35	34	41
SMOKE DENSITY	3.8	58.2	62.8	67.8

TABLE 5.11: Emission Analysis for B20

The above tables show the amount of gas emitted for different loads of biodiesel input. It is done for two blends of B10 and B20. The emission values of various gases were studied through the fine gas detector. The CO gas emission for B10 and B20 ranges within 0.01 to 0.06 and 0.01 to 0.04 for different loads respectively. As the emission range meets the standards it can be used as an alternative eco-friendly source. Whereas the CO₂ gas emission for B10 and B20 ranges from 0.30 to 1.10 and 0.50 to 1 for the different loads respectively

CHAPTER 6

SUMMARY AND CONCLUSIONS

6.1 SUMMARY:

We have done the biodiesel using pongamia pinnata oil. The oil is extracted from pongamia seeds by using oil expeller naturally the pongamia seed has the best oil yield compare to other nonedible oil. We have planned to do the biodiesel with heterogeneous catalyst. The seaweed, which was collected from rameshwaram, which is cleaned, washed and dried. After dried the seaweed is sealed and kept in furnace for 1hr with 210°C for convert into biochar. The biochar was further dried in hot air oven to remove excess moisture. We take zinc oxide which is doped with seaweed and stir for 3hrs to make it as a heterogeneous catalyst. we have tested the acid value for pongamia oil is contain high FFA value. so we have decided to go for two step process which is esterification and transesterification. Esterification process is done with oil, methanol and sulfuric acid with 60°C and 45 min stirring. after esterification process the oil will reduce the FFA value less than 1. Now transesterification process takes place for 1hr with the heterogeneous catalyst we prepared by using magnetic stirrer. After the reaction over the solution is poured into separating funnel after 6hrs the biodiesel is transfer to the container and is used for internal combustion engine study to know the engine performance and also emission. The biodiesel helps to reduce the greenhouse has emission and also it is eco-friendly. By using pongamia oil with is easily available, renewable source and also cost effective.

6.2 CONCLUSION:

In conclusion, the study underscores the technical viability and potential benefits of producing biodiesel from Pongamia pinnata oil using seaweed-derived biochar with zinc oxide as a catalyst. The catalytic system comprising zinc oxide supported on seaweed-derived biochar exhibits remarkable efficiency in promoting the transesterification reaction, leading to high biodiesel yields. Optimized reaction conditions ensure the attainment of favorable fuel properties, facilitating seamless integration with existing diesel engines without compromising performance. Engine testing confirms the satisfactory performance of the biodiesel blend, coupled with

reduced emissions, aligning with environmental sustainability objectives. Economically, the utilization of *Pongamia pinnata* oil as a feedstock and seaweed-derived biochar as a catalyst support presents a cost-effective and sustainable approach to biodiesel production. Looking ahead, future research avenues may explore scale-up studies and long-term engine durability testing to further validate the commercial viability and environmental benefits of this biodiesel production process.

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CHAPTER 1

INTRODUCTION

1.1 BIODIESEL:

Biodiesel is a renewable, environmentally friendly alternative to conventional diesel fuel, derived from natural sources such as vegetable oils, animal fats, or recycled cooking grease. Its production, properties, and potential impact make it a compelling option in the quest for sustainable energy solutions. The production of biodiesel involves a chemical process called transesterification, wherein triglycerides present in oils and fats react with an alcohol (typically methanol or ethanol) in the presence of a catalyst (usually sodium hydroxide or potassium hydroxide). This reaction breaks down the triglycerides into fatty acid methyl esters (FAME), which constitute biodiesel, and glycerine, a valuable by-product used in various industries.

Source of biodiesel:

Edible oil: Soybean, Canola, Palm, Sunflower, Corn.

Non-edible oil: Karanja, Jatropha, neem, rubber.

Animal fat: Tallow and lard

Recycled cooking grease: Waste cooking oil from restaurants and households can be recycled into biodiesel.

Biodiesel combustion emits fewer greenhouse gases compared to petroleum diesel, as it contains fewer sulphur and aromatic compounds. Biodiesel is biodegradable, meaning it breaks down quickly in the environment, reducing pollution risks in case of spills. Unlike finite fossil fuels, biodiesel can be produced indefinitely from replenishable feedstocks, contributing to long-term energy sustainability. Biodiesel production reduces reliance on fossil fuels, enhancing energy security and mitigating the risks associated with oil price fluctuations and supply disruptions. Biodiesel can be used as a standalone fuel or blended with petroleum diesel in various proportions. Common blends include B5 (5% biodiesel, 95% diesel), B20 (20% biodiesel, 80% diesel), and B100 (pure biodiesel). It possesses properties

similar to petroleum diesel, such as energy content and lubricating capabilities, making it compatible with existing diesel engines and infrastructure.

1.2 PONGAMIA PINNATA OIL:

Karanja, scientifically known as Pongamia pinnata, is a versatile tree native to the Indian subcontinent and widely cultivated in tropical and subtropical regions around the world. It has gained attention as a potential feedstock for biofuel production due to several favorable characteristics.

High oil content: pongamia pinnata seeds contain oil content ranging from 27% to 40%, making it a rich source of feedstock for biodiesel production. This high oil content makes Karanja economically viable for biofuel production compared to other oilseed crops.

Non-Edible Feedstock: One of the significant advantages of pongamia oil is that it comes from a non-edible source. Unlike edible oil crops such as soybean or palm oil, which compete with food production, Karanja offers a sustainable alternative that does not impact food security or agricultural land dedicated to food crops. This aspect addresses concerns about food-versus-fuel competition, which has been a subject of debate in the biofuel industry.

Adaptability to marginal lands: pongamia pinnata trees are well-suited to grow in a variety of soil types, including degraded and marginal lands, where other crops may struggle to thrive. This adaptability makes Karanja cultivation feasible in areas unsuitable for traditional agriculture, thereby minimizing competition with food crops and maximizing land utilization for biofuel production.

Nitrogen Fixation: pongamia pinnata is a leguminous tree capable of fixing atmospheric nitrogen through symbiotic associations with nitrogen-fixing bacteria in its root nodules. This nitrogen-fixing ability enhances soil fertility and reduces the need for synthetic fertilizers, making Karanja cultivation environmentally sustainable and cost-effective.

Local Availability: In many regions where pongamia pinnata is native or cultivated, such as India, Southeast Asia, and parts of Africa, the availability of pongamia pinnata seeds presents an opportunity for local biofuel production, reducing

dependence on imported fossil fuels and promoting energy security and rural development.

Agroforestry potential: pongamia pinnata trees can be integrated into agroforestry systems, providing additional benefits such as soil conservation, carbon sequestration, and biodiversity enhancement. Agroforestry practices that combine Karanja cultivation with food crops or other tree species can improve overall land productivity and resilience to climate change while diversifying income sources for farmers.

Environmental Benefits: Biodiesel produced from Karanja oil offers environmental benefits, including reduced greenhouse gas emissions, improved air quality, and lower environmental impact compared to fossil diesel. The use of biodiesel derived from Karanja helps mitigate climate change, reduce dependence on finite fossil fuels, and contribute to sustainable development goals.

The utilization of Karanja in biofuel production offers a promising avenue for sustainable energy production, combining economic viability with environmental and social benefits. However, further research and development efforts are needed to optimize cultivation practices, enhance oil extraction efficiency, and scale up Karanja-based biofuel production to realize its full potential in the global energy transition.

1.3 CLASSIFICATION OF CATALYST:

Homogeneous catalyst: Catalysts that are in the same phase as the reactants. They are typically dissolved or dispersed in the reaction mixture. Examples include acids, bases, and enzymes.

Heterogeneous catalyst: Catalysts that are in a different phase from the reactants. They are often solid catalysts used in gas or liquid-phase reactions. Examples metal oxides and zeolites.

Acid catalyst: Catalysts that facilitate reactions by donating protons (H^+ ions), thereby lowering the activation energy required for the reaction to proceed. Examples sulfuric acid and Lewis acids.

Base catalyst: Catalysts that facilitate reactions by accepting protons (H^+ ions) or donating hydroxide ions (OH^-), thereby lowering the activation energy. Examples include sodium hydroxide and Lewis bases.

Biocatalyst: Catalysts derived from biological sources, such as enzymes and microorganisms, used in various industries including food processing, pharmaceuticals, and biotechnology.

1.4 THE SELECTION OF HETEROGENEOUS CATALYST:

Heterogeneous catalysts play a vital role in the production of biodiesel, a renewable and environmentally friendly alternative to conventional diesel fuel. Heterogeneous catalysts are particularly well-suited for biodiesel production due to their distinct advantages in terms of efficiency, recyclability, and ease of separation. Let see some of the main reason for using heterogeneous catalyst.

Ease of separation: One of the primary advantages of heterogeneous catalysts is their ease of separation from the reaction mixture. Unlike homogeneous catalysts, which dissolve in the reaction medium and are challenging to recover and recycle, heterogeneous catalysts exist as distinct solid phases. This facilitates their separation from the reaction products through simple filtration or centrifugation processes, allowing for their reuse in subsequent reaction cycles. This property significantly reduces operational costs and waste generation in industrial processes.

Reusability: Heterogeneous catalysts can often be reused multiple times without significant loss of activity or selectivity. After separation from the reaction mixture, they can undergo regeneration treatments to restore their catalytic properties. This reusability not only reduces the consumption of catalysts but also contributes to the sustainability and cost-effectiveness of chemical processes.

Control of reaction condition: Heterogeneous catalysts allow for better control of reaction conditions, particularly in multiphase systems. By immobilizing the catalyst on a solid support or carrier material, the surface area, porosity, and reactivity of the catalyst can be tailored to suit specific reaction requirements. This enables precise control over reaction kinetics, selectivity, and product distribution, leading to improved process efficiency and product quality.

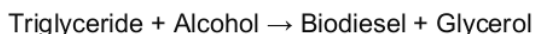
Versatility: Heterogeneous catalysts exhibit versatility in catalyzing various types of

87 reactions, including hydrogenation, oxidation, reduction, hydrolysis, and condensation reactions. They can be tailored to catalyze specific transformations by adjusting the composition, morphology, and surface properties of the catalyst materials. This versatility allows for their widespread use across different industries and applications, making them indispensable in modern chemical manufacturing processes.

1.5 ZINC OXIDE (ZNO):

2 Zinc oxide (ZnO) has been explored for various applications, including biodiesel production. Biodiesel is a renewable fuel derived from vegetable oils, animal fats, or recycled cooking grease. It is considered an alternative to conventional petroleum diesel because it is biodegradable, non-toxic, and produces fewer emissions. Zinc oxide finds utility in biodiesel production primarily as a catalyst in the transesterification process, which is the key step in converting triglycerides (found in oils and fats) into biodiesel.

5 Biodiesel production involves a chemical process called transesterification. In this reaction, triglycerides present in oils and fats are reacted with an alcohol (typically methanol or ethanol) in the presence of a catalyst to yield biodiesel (alkyl esters) and glycerol as a byproduct.



43 **Reusability:** Unlike alkaline catalysts (such as NaOH and KOH) which are consumed in the reaction and require neutralization, zinc oxide can be reused multiple times without significant loss of activity. This attribute makes it cost-effective and environmentally friendly.

113 **Mild reaction condition:** Zinc oxide catalyst operates under relatively mild reaction conditions compared to alkaline catalysts. Transesterification reactions using zinc oxide catalyst typically occur at lower temperatures and pressures, reducing energy consumption and operational costs.

Reduce Corrosivity: Alkaline catalysts can be corrosive, which necessitates the use of corrosion-resistant equipment. Zinc oxide, being less corrosive, offers advantages in terms of equipment selection and maintenance.

Less soap formation: Zinc oxide catalyst tends to produce lower amounts of soap byproducts compared to alkaline catalysts. Soap formation can be problematic as it

⁷⁵ can lead to emulsification issues and difficulties in separating the biodiesel from glycerol during the reaction.

Environmental condition: ZnO is considered a relatively environmentally friendly catalyst compared to some other alternatives. It is non-toxic and does not pose significant environmental risks during its synthesis or use in biodiesel production.

1.6 SEAWEED:

²³ Seaweed, also known as macroalgae, refers to a diverse group of marine algae. ⁵⁵ Seaweeds are categorized into three main groups based on pigmentation and cellular structure: brown algae, red algae, and green algae. Seaweeds inhabit oceans and other saltwater bodies worldwide, thriving in shallow coastal waters as well as deeper ocean environments.

Seaweeds play critical roles in marine ecosystems, contributing to nutrient cycling, oxygen production, and habitat provision. They provide food and shelter for various marine organisms, supporting diverse communities of fish, invertebrates, and other species. Certain seaweeds form extensive underwater forests, such as kelp forests, which serve as essential habitats and nurseries for marine life.

Seaweed aquaculture, or seaweed farming, has emerged as a promising industry for sustainable food production and environmental conservation. Cultivated seaweeds are harvested for food, feed, biofuel production, and other commercial purposes. Seaweed farming offers environmental benefits such as carbon sequestration, nutrient remediation, and habitat restoration.

Seaweed has been utilized by humans for various purposes for thousands of years, including food, medicine, agriculture, and industry. It is a dietary staple in many coastal cultures, valued for its nutritional content and culinary versatility. Seaweed extracts are used in pharmaceuticals, cosmetics, textiles, and bioplastics. seaweed is a diverse and ecologically important group of marine organisms with numerous commercial, industrial, and environmental applications.

1.7 BENEFITS OF USING SEAWEED AS A CATALYST:

Using seaweed as a catalyst in biodiesel production offers several potential benefits, primarily due to its unique chemical composition and properties. Let see some of the advantages of using seaweed as a catalyst in biodiesel synthesis:

Abundant and renewable resource: Seaweed is abundant in oceans and coastal regions worldwide, offering a sustainable and renewable source of raw material for catalyst production. Unlike some traditional catalysts derived from fossil fuels or rare metals, seaweed-derived catalysts are environmentally friendly and contribute to the utilization of renewable resources.

Biodegradability: Seaweed-derived catalysts are typically biodegradable, meaning they can be broken down into harmless substances by natural processes after use. This characteristic aligns with the principles of green chemistry and sustainable manufacturing, reducing the environmental impact associated with catalyst disposal and waste management.

Catalytic activity: Certain components of seaweed, such as polysaccharides, proteins, and minerals, possess catalytic activity or can be modified to exhibit catalytic properties. These natural compounds can facilitate the transesterification reaction involved in biodiesel synthesis, converting triglycerides into fatty acid alkyl esters (biodiesel) and glycerol. Seaweed-derived catalysts may offer comparable or even superior catalytic performance to traditional catalysts, depending on their composition and processing methods.

Low Cost: Seaweed-based catalysts may be cost-effective compared to conventional catalysts, particularly if seaweed is harvested from coastal regions or cultivated in aquaculture farms. The relatively low cost of seaweed as a raw material, coupled with simple processing techniques, can result in economically viable catalysts for biodiesel production, especially in regions with abundant seaweed resources.

1.8 TYPES OF SEAWEED:

There are thousands of species of seaweed, also known as marine algae, found in oceans around the world. There are three main types of seaweed let see one by one,

Red seaweed (Rhodophyta):

- Red seaweeds are often found in deeper waters but can also grow in intertidal zones.
- They are characterized by their red pigmentation due to the presence of phycoerythrin and phycocyanin pigments.

Brown seaweed (Phaeophyta):

- Brown seaweeds are the most diverse group of seaweeds, ranging from small filamentous forms to large kelps.
- They typically inhabit cooler waters and can be found in intertidal zones as well as subtidal areas.
- Brown seaweeds get their color from the pigment fucoxanthin, which masks the green chlorophyll pigment.

Green seaweed (Chlorophyta):

- Green seaweeds are primarily found in intertidal zones and shallow waters, often attached to rocks or other substrates.
- They contain chlorophyll as their primary pigment, giving them a green coloration.

1.9 EUCHEUMA COTTONII (RED SEAWEED):

Eucheuma cottonii, commonly known as sea moss or red seaweed, possesses several advantageous properties that make it a promising catalyst for biodiesel production. Its alkaline nature facilitates the transesterification reaction, a key step in biodiesel synthesis, by promoting the conversion of triglycerides into fatty acid methyl esters (FAMES) and glycerol. This alkalinity accelerates the rate of esterification, enhancing the efficiency of the biodiesel production process. Moreover, the structure of Eucheuma cottonii contains active sites that can further catalyze the interaction between triglycerides and alcohol, expediting biodiesel formation. These active sites may arise from the presence of functional groups or surface morphology conducive to catalytic activity. In addition to its catalytic properties, the use of Eucheuma cottonii aligns with principles of sustainability and green chemistry. Eucheuma cottonii cultivation can offer environmental benefits beyond biodiesel production. As a marine organism, it plays a role in coastal

ecosystem health, including nutrient cycling, carbon sequestration, and shoreline stabilization. Sustainable seaweed farming practices can contribute to ecosystem restoration efforts and mitigate the impacts of climate change on coastal communities.

As a natural resource, it offers a biodegradable and environmentally friendly alternative to synthetic catalysts commonly used in biodiesel production. Its renewable nature and minimal environmental impact make it an attractive option for industries seeking to reduce their carbon footprint and environmental footprint. Furthermore, *Eucheuma cottonii* demonstrates potential cost-effectiveness and compatibility with various feedstock oils, enhancing its attractiveness for biodiesel production. Its ability to effectively catalyze the transesterification reaction across a range of feedstock sources contributes to its versatility and applicability in different production settings.

Despite these promising characteristics, further research is needed to optimize the effectiveness of *Eucheuma cottonii* as a biodiesel catalyst. This includes understanding its catalytic mechanisms fully and assessing its scalability for commercial applications. Continued investigation into the optimal reaction conditions, catalyst loading, and catalyst recovery methods will be crucial in maximizing its efficiency and economic viability in large-scale biodiesel production.

1.10 CATALYST PREPARATION:

Biochar production:

- Seaweed is dried, fragmented, and processed into biochar.
- This involves exposing the seaweed to direct sunlight to remove moisture and enhance texture.
- Once dried, the seaweed is fragmented into smaller, manageable pieces. Fragmentation helps in increasing the surface area, which is beneficial for the catalytic process.

Zinc oxide for catalyst:

Zinc oxide is obtained, often from a laboratory, and measured in the desired amount. Take 3 gram of zinc for doping with biochar.

Preparation of catalyst solution:

- Distilled water is measured and poured into a container.
- The 9 grams of seaweed biochar is added to the water and stirred for a specific duration to ensure thorough mixing and dissolution of biochar particles.
- After achieving a homogeneous solution, 3 grams of zinc oxide is added gradually while continuing to stir. This step aims to evenly disperse zinc oxide particles throughout the solution.

Stirring of solution:

The solution is stirred with the help of magnetic stirrer for a designated period to facilitate the interaction between biochar and zinc oxide, promoting the formation of active catalytic sites.

Filtration and drying:

- ⁹⁶ Once the desired reaction time is reached, the solution is filtered to remove any undissolved particles or impurities.
- The filtered catalyst solution may undergo a drying process to remove excess moisture, resulting in the formation of a solid catalyst material.

1.11 CATALYST CHARACTERIZATION:

The seaweed/ZnO catalyst system has undergone thorough characterization employing a suite of analytical techniques including FTIR (Fourier Transform Infrared Spectroscopy), XRD (X-ray Diffraction), FESEM (Field-Emission Scanning Electron Microscopy), and EDS (Energy Dispersive X-ray Spectroscopy), providing comprehensive insights into its structural, compositional, and morphological properties.

FTIR spectroscopy revealed prominent peaks corresponding to characteristic functional groups within both the seaweed and the ZnO catalyst. Specifically, distinctive absorption bands associated with polysaccharides, proteins, and cellulose present in the seaweed were identified. Furthermore, shifts or alterations

in peak positions indicated potential chemical interactions or bonding between the seaweed constituents and the ZnO catalyst.

XRD analysis elucidated the crystalline structure of the seaweed/ZnO catalyst composite. By examining diffraction patterns, the presence of specific phases within the ZnO catalyst and any alterations induced by interaction with the seaweed were identified. Changes in peak intensities, positions, or the emergence of new peaks provided valuable insights into modifications in crystallinity and phase transformations occurring within the composite system.

FESEM imaging unveiled the surface morphology and microstructure of the seaweed/ZnO catalyst composite at high resolution. Detailed visualization showcased the distribution and morphology of ZnO nanoparticles immobilized on the seaweed surface. Additionally, changes in surface features or the appearance of unique structures highlighted the effects of catalyst loading and interaction on the composite's morphology.

EDS elemental analysis facilitated quantitative assessment of the elemental composition within the seaweed/ZnO catalyst composite. By detecting characteristic X-ray emissions, the presence and distribution of elements, including zinc and other constituents, were mapped across the sample. Elemental mapping provided spatial information regarding the dispersion of the ZnO catalyst and highlighted any variations in elemental composition induced by the composite formation.

1.12 ESTERIFICATION PROCESS:

Esterification is a process that may occur alongside transesterification, especially when dealing with low-quality or high-free fatty acid feedstocks, such as waste cooking oil or animal fats. In this process, free fatty acids (FFAs) present in the feedstock react with alcohol to form esters and water. Unlike transesterification, esterification does not involve the breakdown of triglycerides. Instead, it focuses on converting FFAs into esters. The reaction is catalyzed by acidic catalysts, such as sulfuric acid or acidic ion exchange resins. Esterification is particularly important when dealing with feedstocks containing high levels of FFAs, as these can hinder the transesterification process or lead to soap formation. By converting FFAs into esters, esterification helps improve the overall yield and quality of biodiesel. After esterification, the mixture may undergo additional processing steps, such as

neutralization to remove any remaining catalyst or purification to remove impurities, before being combined with the biodiesel produced through transesterification

1.13 TRANSESTERIFICATION PROCESS:

Transesterification is a fundamental chemical process in biodiesel production, serving as the main pathway to convert oils or fats into biodiesel, a renewable alternative to conventional diesel fuel. The process involves the reaction of triglycerides, which are the primary components of oils and fats, with an alcohol, typically methanol or ethanol, in the presence of a catalyst. The triglycerides are sourced from various feedstocks such as vegetable oils, animal fats, or recycled cooking oils. During transesterification, the alcohol molecules replace the glycerol component of the triglyceride, resulting in the formation of biodiesel and glycerol as byproducts. The catalyst, commonly sodium or potassium hydroxide, plays a crucial role in accelerating the reaction by providing an alternate pathway with lower activation energy. This catalyst is usually mixed with the alcohol prior to the reaction. Transesterification is typically conducted at elevated temperatures, usually between 50 to 70 degrees Celsius, to facilitate the reaction, although the exact conditions may vary depending on the specific feedstock and catalyst used. Excess alcohol is often employed to shift the equilibrium towards ester formation and improve the reaction yield. Once the reaction is complete, the mixture is allowed to settle, and the biodiesel layer is separated from the glycerol layer. The biodiesel undergoes further purification steps, such as washing to remove impurities and residual catalyst, before being used as a fuel for diesel engines.

1.14 PROPERTIES OF BIODIESEL:

Density: Biodiesel typically has a slightly higher density than petroleum diesel. The density of biodiesel varies depending on the feedstock and production process but generally falls within the range of 0.86 to 0.90 g/cm³

Viscosity: Biodiesel has higher viscosity than petroleum diesel, which can affect fuel flow and atomization in diesel engines. Biodiesel's viscosity is influenced by factors such as temperature and blend ratio, and it can be adjusted through blending with lighter fuels.

Flash Point: Biodiesel has a higher flash point compared to petroleum diesel, making it safer to handle and store. The flash point of biodiesel typically exceeds 130°C reducing the risk of ignition during storage and transportation.

Cloud Point: Biodiesel tends to have a higher cloud point than petroleum diesel, which refers to the temperature at which solid particles begin to form and the fuel appears cloudy.

Pour Point: Biodiesel generally has a higher pour point than petroleum diesel, which is the temperature at which the fuel becomes too viscous to flow freely. The pour point of biodiesel can be influenced by factors such as the presence of saturated fatty acids and cold flow additives.

Cetane Number: Biodiesel typically has a higher cetane number than petroleum diesel, which measures the fuel's ignition quality. A higher cetane number indicates better combustion efficiency and smoother engine operation.

Oxygen Content: Biodiesel contains oxygen atoms in its molecular structure, resulting in a higher oxygen content compared to petroleum diesel. This property improves combustion efficiency and reduces particulate emissions.

1.15 PERFORMANCE OF BIODIESEL IN IC ENGINE:

Performance evaluation of biodiesel in internal combustion engines is a crucial aspect in assessing its suitability as an alternative fuel. This evaluation involves comprehensive testing to determine various engine parameters, combustion characteristics, emissions profile, and overall efficiency when operating on biodiesel blends compared to traditional diesel fuel.

Engine Efficiency:

- Measurement of engine power output and fuel consumption to evaluate the efficiency of biodiesel combustion.
- Assessment of engine thermal efficiency, indicating the percentage of fuel energy converted into useful work.
- Analysis of engine torque and specific fuel consumption to understand the mechanical performance of biodiesel blends in internal combustion engines.

Combustion Characteristics:

- Evaluation of ignition delay, combustion duration, and heat release rate to characterize the combustion process of biodiesel blends.
- Determination of ignition quality, indicated by parameters such as ignition delay and combustion stability, to assess engine operability and performance.

Emissions Profile:

- Monitoring of exhaust gas emissions, including nitrogen oxides (NO_x), carbon monoxide (CO), hydrocarbons (HC), particulate matter (PM), and sulfur dioxide (SO₂).
- Comparison of emission levels between biodiesel blends and traditional diesel fuel to assess the environmental impact and compliance with emission regulations.

Engine Durability:

- Examination of engine wear and tear, including piston ring and cylinder liner wear, valve seat recession, and lubricant degradation, when operating on biodiesel blends.
- Assessment of engine components and lubrication systems for compatibility and performance under biodiesel operating conditions.

Cold Start Performance:

- Investigation of cold start characteristics, including cold start time and engine warm-up duration, to evaluate the suitability of biodiesel blends for cold weather conditions.
- Analysis of fuel properties such as viscosity, cloud point, and pour point to understand their impact on engine starting and performance during cold starts.

Long-term Performance:

- Long-term monitoring of engine performance and emissions under continuous operation with biodiesel blends to assess durability and reliability.
- Evaluation of engine maintenance requirements, including cleaning intervals for fuel injectors, filters, and exhaust aftertreatment systems, when using biodiesel blends.

Overall Efficiency and Sustainability:

- Integration of performance, emissions, and durability data to determine the overall efficiency and sustainability of biodiesel blends in internal combustion engines.
- Comparative analysis of biodiesel blends with traditional diesel fuel in terms of energy security, environmental impact, and economic viability.

1.16 RESOURCE MANAGEMENT AND WASTE UTILIZATION:

The concept of a circular economy has emerged as a transformative approach to sustainable resource management, aiming to minimize waste generation and maximize resource efficiency. Central to this paradigm is waste valorization, which involves converting waste materials into valuable resources through innovative processes and technologies. By fostering a closed-loop system where resources are continuously reused, recycled, or repurposed, the circular economy reduces reliance on finite raw materials and minimizes environmental impact.

Key to the circular economy is the efficient use of resources and the reduction of waste generation throughout the product lifecycle. Strategies such as product design for longevity, durability, and recyclability help maximize resource utilization. Waste valorization technologies, including pyrolysis, gasification, biorefining, and chemical conversion, enable the transformation of diverse waste streams into biofuels, bio-based chemicals, biomaterials, and renewable energy.

Closed-loop systems integrate recycling and recovery processes to ensure the continuous circulation of materials and resources within the economy. Material recovery facilities (MRFs) and waste-to-energy (WTE) plants play a crucial role in recovering valuable materials from waste streams and generating renewable energy from non-recyclable residues. By reducing reliance on virgin raw materials, circular economy practices contribute to sustainable resource management, mitigate resource depletion, and minimize environmental pollution.

Circular economy principles create economic opportunities by fostering innovation, entrepreneurship, and the development of new business models centered around

resource efficiency and waste valorization. Policy support and regulatory frameworks, such as extended producer responsibility (EPR) and landfill bans, incentivize waste reduction, recycling, and resource recovery. Collaboration among stakeholders, including governments, industries, academia, and civil society, is essential for advancing circular economy initiatives and waste valorization efforts, facilitating the exchange of best practices and technology transfer for sustainable waste management and resource recovery.

1.17 ENVIRONMENTAL AND ECONOMIC IMPLEMENTATION OF BIODIESEL PRODUCTION:

Implementing biodiesel production involves considerations of both environmental sustainability and economic viability. From an environmental perspective, biodiesel offers significant benefits over conventional fossil fuels. It reduces greenhouse gas emissions, including carbon dioxide and particulate matter, which contribute to climate change and air pollution. Additionally, biodiesel production often utilizes renewable feedstocks such as vegetable oils, animal fats, or waste cooking oil, reducing dependence on finite fossil fuel resources. By promoting the use of biodiesel, countries can mitigate environmental degradation, improve air quality, and enhance overall environmental sustainability.

On the economic front, the implementation of biodiesel production presents opportunities for job creation, economic growth, and energy security. Biodiesel production facilities generate employment opportunities across various sectors, including agriculture, manufacturing, and transportation. Moreover, biodiesel production can stimulate local economies by supporting farmers and biofuel producers, reducing reliance on imported petroleum products, and enhancing energy independence. Furthermore, biodiesel production can diversify revenue streams for agricultural communities, providing an additional source of income through the cultivation of biodiesel feedstock crops. Overall, the environmental and economic implementation of biodiesel production offers a promising pathway towards achieving sustainable development goals and fostering a greener, more resilient economy.

In addition to its environmental and economic benefits, the implementation of biodiesel production contributes to energy diversification and security. By reducing reliance on imported fossil fuels, biodiesel production enhances energy independence and resilience to global supply disruptions. Furthermore, biodiesel can be produced domestically from locally available feedstocks, reducing the vulnerability of energy markets to geopolitical tensions and price fluctuations. This localization of biodiesel production strengthens national energy security strategies, ensuring a reliable and sustainable energy supply for the future.

Moreover, the adoption of biodiesel production aligns with global sustainability agendas and commitments to reduce carbon emissions and combat climate change. As countries strive to meet their climate targets under international agreements such as the Paris Agreement, integrating biodiesel into the energy mix becomes imperative. Biodiesel offers a renewable and low-carbon alternative to traditional fossil fuels, helping countries transition towards cleaner and more sustainable energy systems. By investing in biodiesel production infrastructure and technology, nations can accelerate their transition to a low-carbon economy and contribute to global efforts to mitigate the impacts of climate change.

1.18 CHALLENGES AND LIMITATIONS OF BIODIESEL UTILIZATION:

Feedstock Availability and Competition:

- Limited availability and competition for feedstock sources such as vegetable oils, animal fats, and waste oils pose challenges for biodiesel production.
- Competition with food and feed markets for feedstock resources can lead to conflicts over land use and potential environmental impacts such as deforestation and habitat destruction.

Land Use Change and Environmental Impact:

- Expansion of biodiesel feedstock cultivation, particularly in ecologically sensitive areas, may contribute to land use change, deforestation, and loss of biodiversity.
- Intensive agricultural practices associated with feedstock cultivation can result in soil degradation, water pollution, and greenhouse gas emissions, undermining the environmental benefits of biodiesel.

Technological Challenges and Process Efficiency:

- Biodiesel production processes, such as transesterification, require specialized equipment and infrastructure, leading to high capital investment and operational costs.
- Challenges in achieving high conversion efficiency, purity, and quality of biodiesel products may hinder commercial-scale production and competitiveness with petroleum diesel.

Fuel Compatibility and Engine Performance:

- Biodiesel blends may exhibit differences in fuel properties such as viscosity, lubricity, and cetane number compared to petroleum diesel, affecting engine performance and compatibility.
- Cold weather operability issues, including increased viscosity and filter plugging, may arise with biodiesel use in low temperatures, necessitating engine modifications or fuel heating systems.

1.19 APPLICATIONS OF BIODIESEL:

Biodiesel, derived from renewable sources such as vegetable oils or animal fats, has emerged as a promising alternative to traditional petroleum-based diesel fuel. Its diverse applications span various sectors, offering numerous economic, environmental, and societal benefits. Below are some key areas where biodiesel finds extensive use:

Transportation Sector: Biodiesel is widely utilized as a fuel for transportation vehicles, including cars, trucks, buses, and trains. Its compatibility with existing diesel engines allows for seamless integration into existing fleets, offering a cleaner and greener alternative to conventional diesel fuel. Biodiesel blends, such as B20 (20% biodiesel, 80% diesel), are commonly used in diesel engines, reducing greenhouse gas emissions and air pollutants like particulate matter and sulfur oxides.

Agricultural Machinery: In the agricultural sector, biodiesel serves as an efficient and environmentally friendly fuel for farm equipment and machinery. Tractors,

combines, and other agricultural vehicles can operate smoothly on biodiesel blends, reducing dependence on fossil fuels and promoting sustainable farming practices. Biodiesel production from on-farm resources such as waste vegetable oil or oilseed crops further enhances the agricultural sector's energy independence and sustainability.

Marine Industry: Biodiesel offers a viable alternative for marine vessels, including ships, boats, and ferries. Biodiesel blends can be used in marine diesel engines, providing a cleaner and more sustainable option for maritime transportation. By reducing emissions of sulfur oxides, nitrogen oxides, and particulate matter, biodiesel helps mitigate environmental impacts associated with marine transportation and contributes to cleaner waterways and coastal ecosystems.

Power Generation: Biodiesel can also be used in stationary diesel engines for power generation purposes. In remote or off-grid areas, biodiesel-powered generators offer a reliable and renewable energy source, reducing reliance on traditional fossil fuels and diesel generators. Biodiesel can be produced locally, utilizing regionally available feedstocks, thereby enhancing energy security and resilience in decentralized power systems.

Heating Applications: Biodiesel can be utilized as a heating fuel in residential, commercial, and industrial applications. Biodiesel blends, such as B5 (5% biodiesel, 95% diesel), can be used in oil-fired furnaces and boilers for space heating and water heating. Its cleaner combustion characteristics result in reduced emissions of greenhouse gases and air pollutants, contributing to improved indoor air quality and public health.

Aviation Industry: While biodiesel is not commonly used as aviation fuel due to stringent performance requirements, research and development efforts are underway to explore its potential application in aviation biofuels. Sustainable aviation fuels derived from biodiesel feedstocks hold promise for reducing greenhouse gas emissions and enhancing the environmental sustainability of air travel.

CHAPTER 2

LITERATURE SURVEY

Naveen Kumar et al.(2021) the utilization of petroleum-based products in engines poses significant environmental hazards. Consequently, there is a growing focus on enhancing alternative fuel quality through extensive research. Among the innovative approaches, nanoparticles stand out as a promising technology for improving fuel characteristics. Their study aims to investigate the effects of CuO nanoparticles on emission levels, combustion dynamics, and overall engine performance in diesel engines using jojoba biodiesel blends as the primary fuel source. The experimental design involved blending CuO nanoparticles at different concentrations with JB20 fuel. Notably, the results indicate that the fuel blend containing CuO nanoparticles exhibited superior Brake Thermal Efficiency (BTE) compared to other Jojoba biodiesel fuel samples. In assessing the impact of CuO nanoparticles, the researchers examined various combustion properties such as ignition delay, Heat Release Rate (HRR), and cylinder pressure. Furthermore, the introduction of CuO nanoparticles was found to mitigate emissions of smoke, carbon monoxide (CO), and hydrocarbons from the engines running on JB20 fuel [1]

Abdul Razak R.K et al. (2018) Using various transesterification stages, biodiesel was produced from Pongamia pinnata, Calophyllum inophyllum, and leftover cooking oil with varying free fatty acid contents. It was discovered what the chemical and physical characteristics of biodiesel were, including its density, viscosity, fire point, and calorific value. Studies on engine performance were conducted using mixes of diesel, such as B50, B65, and B80, and 100% biodiesel generated from various sources. Pongamia pinnata biodiesel was shown to have the greatest Brake Thermal Efficiency (BTE) of all the biodiesels utilised in the comparison. Pongamia pinnata biodiesel yields the greatest BTE for the B65 mix. Pongamia pinnata and Calophyllum inophyllum biodiesel had the greatest BTE for a B50 combination. In comparison to other biodiesel blends and for individual biodiesels, B50 has superior performance characteristics in every area for both types of biodiesels and blends [2]

Ramachandran Kasirajan et al. (2021) As fossil diesel reserves dwindle, the search for alternative fuels derived from non-edible sources becomes increasingly

urgent. In this study, researchers employed a two-step process to convert *Chrysophyllum albidum* seeds, an inedible source, into biodiesel. Initially, lipid extraction was carried out using a mixed solvent in a superheated extractor, and gas chromatography (GC) was utilized to analyze the fatty acid content. Subsequently, a homogeneous H₂SO₄ catalyst was employed for esterification followed by transesterification. Several factors were investigated to optimize the transesterification process, including the molar ratio of methanol to oil, catalyst loading, reaction temperature, reaction time, and stirring rate. Spectroscopic analysis was employed to confirm the conversion of oil to biodiesel, while the physical-chemical characteristics of the biodiesel were examined. The results suggest that the two-step esterification and transesterification technique is highly suitable for producing biodiesel from *Chrysophyllum albidum* seeds [3]

Chuan Yuan et al. (2021) We synthesized a variety of seaweed-derived biochar catalysts (SDBC) that are both inexpensive and environmentally friendly. Our findings revealed that incorporating metals into SDBC at elevated temperatures resulted in the formation of highly porous structures with increased aromatic rings, consisting of at least six benzene rings, as well as heteroatoms and defects. Notably, the seaweed-derived biochars were primarily composed of inorganic minerals in the form of NaCl and KCl. To assess the efficacy of SDBC, we conducted catalytic pyrolysis of *Enteromorpha clathrate* ex situ. The results demonstrated that, compared to the control group, the bio-oils produced through catalytic pyrolysis exhibited a significant decrease in carboxylic acids. Interestingly, this decrease could be attributed to the presence of hydroxyl groups in the biochar, which could react with carboxylic groups to form fatty acid methyl esters (FAMEs). Our findings suggest that the Cu-BC-800 catalyst, in particular, shows promise as a metal-modified biochar catalyst for producing acid-free biooils enriched with esters and sugars [4]

Balasubramani Ravindran et al. (2021) Heterogeneous catalysts are essential for the transesterification process in the synthesis of biodiesel, and much study has been done recently to discover a good catalyst for this process. Heterogeneous catalysts are favored over homogeneous catalysts because of their disadvantages, which include sluggish reaction rates, expensive costs because food-grade oils are used, issues related to the separation process, and environmental damage. The

biowastes that are appropriately calcined for the manufacture of heterogeneous base catalyst are animal bones and shells. The catalysts made from organic waste are both reasonably priced and environmentally beneficial. The goal of this review is to synthesize heterogeneous basic catalysts from natural resources or biowastes for the transesterification of oils to produce biodiesel. Potential feedstocks, such as vegetable oils and animal fat, can be safely and effectively converted into biodiesel/FAME by using calcined catalysts, which can increase the yield by more than Utilizing catalysts produced from biowaste to produce biofuel sustainably has a lot of potential [5]

Steven Lim et al. (2018) As the demand for fossil fuels continues to rise while their finite reserves dwindle, biodiesel emerges as a promising alternative. However, the use of commercial homogeneous catalysts in biodiesel production presents challenges such as severe corrosion and separation difficulties, leading to increased production and maintenance costs. This research delves into a comprehensive review of literature concerning the utilization of biomass as a precursor for catalysts in biodiesel synthesis. Employing biomass as a catalyst precursor offers numerous advantages over conventional commercial catalysts. Biomass is readily available, cost-effective, reusable, non-toxic, and biodegradable. Many studies have explored carbon materials derived from biomass, which serve as effective supports for active sites due to their high porosity and surface area characteristics. Reviewing various cutting-edge synthesis processes, ranging from the synthesis of the supporting material (carbon) to the functionalization process forming the complete catalyst, this research evaluates the latest developments in biomass-derived basic, acidic, and magnetic heterogeneous catalysts. Methods such as sulfonation by reduction, arylation, and direct sulfonation with sulfuric acid are investigated, with findings suggesting that these methods are less hazardous and produce activity at active sites comparable to conventional approaches. Under optimal conditions, the majority of biomass-based catalysts exhibit robust catalytic activity, yielding biodiesel. Additionally, this research examines various kinetic models derived from reaction kinetic studies catalyzed by biomass-based catalysts, representing a crucial step towards the larger-scale commercialization of these catalysts in the biodiesel production industry.[6]

Mohd Hamid Hussain et al.(2023) Research into alternative fuels is driven by the depletion of fossil fuel reserves and strict emission regulations, particularly regarding greenhouse gas emissions from diesel engines. Hydro processed renewable diesel, derived from sustainable sources like non-edible seeds, animal fats, and algae oil, is being explored as a potential substitute for traditional diesel. Its higher cetane value compared to petro-diesel suggests promising prospects for compression ignition engines. Hydro-deoxygenation, facilitated by hydrogen gas and a catalyst, is a crucial step in producing renewable diesel, akin to hydro-desulfurization in crude vegetable oil refinement. Refineries commonly employ sulfided catalysts based on nickel molybdenum or cobalt molybdenum for these processes. Fractional distillation is then used to separate the resultant product at various boiling temperatures due to its diverse composition. Physicochemical evaluations of hydroprocessed renewable diesel reveal superior characteristics such as cetane number, flash point, and pour point compared to biodiesel and petroleum diesel. However, both types of diesel exhibit similar thermal stability and kinematic viscosity.[7]

Habsah Alwi et al. (2022) Biodiesel is a potential future fuel substitute for diesel derived from petroleum, as well as a source of new renewable energies. The total amount of diesel derived from petroleum consumed worldwide increased in the last ten years, according to the BP Statistical Review of World Energy. Even while it lessens reliance on fossil fuels, the manufacturing of biodiesel raises concerns about how to dispose of waste cooking oil (WCO) and related environmental harm issues. An estimated from animal and vegetable fats are thrown away annually in Malaysia without being handled as trash. As a raw material with significant promise for the biodiesel process, is acknowledged. Triglyceride and oxygen react to produce biodiesel. and alcohol, with plants and animals being the main sources of triglyceride as a raw material. Studies on the transesterification process variable with the ideal conditions for biodiesel synthesis from have been conducted. This study compares biodiesel to petroleum diesel and looks at the different aspects of the transesterification process as a raw material for biodiesel synthesis [8]

Monika et al. (2023) Given the depletion of current energy resources and the global increase in energy demand, the development of sustainable energy resources is

imperative. However, the combustion of fossil fuels releases toxic pollutants into the atmosphere, such as sulfur, nitrogen, carbon oxide, and particulate matter. In comparison to fossil fuels, biodiesel as an alternative fuel has a number of benefits, including the capacity to be produced from a variety of feedstocks, reduced emissions of air pollutants, and renewability. It is possible to produce biodiesel from used cooking oil as a feedstock. Because cooking oil has a negative environmental impact, disposing of it is a difficulty for the environment. The essential step in the low-cost, mild reaction conditions required to produce biodiesel is transesterification. A great deal of research has been done on optimizing transesterification to increase biodiesel yield and lower conversion costs. Because heterogeneous catalysts are applied repeatedly, they can significantly increase both the yield and the cost of biodiesel synthesis. In an effort to increase process sustainability, the current publication provides a thorough analysis of the properties of spent cooking oil, variables influencing the transesterification reaction, and the use of heterogeneous catalyst in the biodiesel manufacturing process [9]

Majid Saidi et al.(2024) This study used strontium stannate, a perovskite catalyst, to examine the transesterification process of used cooking oil to make biodiesel. Various characterisation experiments were employed to determine the structure of the synthesized catalyst. The production of SrSnO_3 was confirmed by powder x-ray diffraction and fourier transform infrared spectroscopy of synthesized samples. The synthesis of SrSnO_3 was confirmed by energy-dispersive x-ray spectroscopy and relative elemental quantities; elemental mapping revealed a perfect distribution in the sample. Four crucial parameters—operating time, temperature, methanol to oil molar ratio, and catalyst loading—as well as the ways in which they interact were examined in order to study the catalytic performance. In order to optimize the settings, response surface methodology was also used. Based on data analysis and transesterification process optimization, the highest possible yield of biodiesel synthesis was achieved. The study's findings demonstrated that the synthesis of biodiesel from used cooking oil is significantly impacted by the use of strontium stannate as a catalyst. Research on the catalyst's reusability revealed a slight decline, and the sixth cycle's biodiesel production efficiency reached a still-significant level [10]

Ali Salehi Zamani et al. (2023) In this study, a batch reactor with a reaction period ranging from 60 to 300 minutes was used to examine the catalytic hydrodeoxygenation (HDO) of neem seed oil (NSO) over an industrial Ni/MgSiO₃ catalyst. Selectivity, high deoxygenation efficiency, and cost-effectiveness have all been addressed. It was investigated how the operating factors affected the yield and selectivity toward alkanes that resemble diesel. The findings showed that the ideal reaction setting for the diesel-like alkanes to yield was Analyzing the reaction mechanism showed that it proceeded along the decarboxylation path, and nearly all of the studies demonstrated the reaction's selectivity towards the products that came from this path. At ideal conditions, the impact of catalyst loading was also studied. An intriguing outcome saw the production of diesel-like alkanes catalyst loading. Stability and efficiency of the catalyst are assessed under ideal circumstances. The catalyst showed outstanding activity and stability in the first four cycles, with nearly constant alkane yields; however, the catalyst's efficiency declined in the following cycles.[11]

Jan Nizar et al. (2018) The economically viable possibility of producing biodiesel from waste oils is appealing, but the transesterification process is severely hampered by the waste oils' high levels of free fatty acids (FFA). The focus of the current study is on using waste cooking oil (WCO) to produce biodiesel. A high FFA content was indicated by the acid value. Several acid catalysts were used to esterify the WCO; the H₂SO₄ catalyzed reaction proved to be the most effective because the FFA decreased. Fatty acid methyl ester (FAME) yield and an alkali catalyst (KOH) were present during transesterification. The acid value, saponification value, iodine value, cetane number, specific gravity, viscosity, cloud point, pour point, and calorific value were used to characterize the biodiesel. It was also done to analyze the generated biodiesel using gas chromatography (GC). Alkali catalyzed transesterification was an effective way to manufacture biodiesel from WCO based on ASTM specifications. The findings showed that cooking oil waste can reduced in contamination and used as a fuel source by turning it into biodiesel [12]

Sajad Roastmi et al. (2019) Researchers are working to produce and use biofuels in response to the diminishing supply of fossil fuels and the increasing demand for energy resources. Researchers are particularly interested in biodiesel because it

addresses the issue of oil costs and offers environmental advantages among biofuels. The current study investigates the effects of catalyst concentration, methanol-to-oil ratio, ultrasonic power, and residence time of hydrodynamic reactors on methyl esters yield, with the goal of producing biodiesel continuously and optimally. The response surface method was employed to maximize the waste oil's transesterification process. The study's findings showed that while the methyl esters output increases with longer residence times, it decreases with shorter residence times. The yield of methyl esters increases with increasing catalyst, while it decreases with increasing catalyst concentration. The yield increases as the methanol-to-oil ratio rises, and the methyl esters yield exhibits a trend of gradual inclination up to the methanol-to-oil ratio. In this investigation, the ideal parameters were the methanol-to-oil ratio, residence duration, catalyst concentration, and ultrasonic power; under these circumstances, the methyl esters yield and the energy consumed were obtained, respectively. In conclusion, the recommended approach is appropriate for producing biodiesel according to the energy consumption and production of methyl esters [13]

Rafael Silva Capaz et al. (2022) Due to its many benefits, including biodegradability and lower CO₂ and greenhouse gas emissions, biodiesel is being considered as a viable alternative to diesel fuel due to the growing global need for biofuels and the development of sustainable and cleaner processes. In the past 15 years, biodiesel production has expanded quickly across the globe, mostly as a result of government incentives. Nevertheless, the primary barrier to this growth has been the cost of manufacturing, which is still greater than that of petroleum diesel. Implementing biorefineries, where the production of other value-added products is fully exploited, supplying a wide range of products and energy, is one way to maximize the feasibility of biodiesel production, since a wide variety of raw materials, such as vegetable oils, animal fats, and waste oils, can be used for biodiesel production. Even though the US, Brazil, Germany, and other nations have established biorefineries, their primary focus is on producing first-generation biodiesel using edible feedstocks like soybeans. This chapter thoroughly explains the current and emerging technology pathways for producing biodiesel, along with its primary benefits, drawbacks, and difficulties. Furthermore, possible uses for by-products are discussed in the context of biorefineries, and a brief overview of their life cycle

analysis and environmental impact—including the context of low-carbon policies—is provided[14]

Robert Iomer et al.(2022)Interest in alternative energy sources is rising due to environmental and resource worries. Biodiesel, derived from leftover cooking oil through trans esterification, is gaining traction as a viable substitute for diesel oil in internal combustion engines. Its renewability and similar qualities to diesel make it a promising alternative, especially with concerns over conventional fuel depletion and environmental impact. Biodiesel is derived from fats, raising concerns about food supply displacement. To address this, emphasis is on using used cooking oil as feedstock. A catalytic approach was employed to produce biodiesel from culinary oils like refined sunflower, vacuum-fried sunflower, and used soybean oil. However, free fatty acids and water hinder the trans esterification process by consuming catalyst and lowering effectiveness. Pre-treatment was used to reduce moisture content before acid esterification. In order to neutralize the FFA content, alkali esterification was used, which decreased the FFA content and increased the yield[15]

CHAPTER 3

AIM AND SCOPE

3.1 AIM:

- To utilize the pongamia pinnata oil as sustainable and renewable source for biodiesel production.
- To synthesize the biochar from Eucheuma cottonii (seaweed).
- To dope the synthesized biochar with ZnO with the help of magnetic stirrer to make it as a catalyst for biodiesel production
- To convert pongamia pinnata oil to biodiesel using magnetic stirrer in both esterification and transesterification process
- Creating a cost-efficient catalyst with high effectiveness for the transesterification process.
- To study on internal combustion engine to know the engine performance.

3.2 SCOPE:

- Conducting comprehensive analysis of Pongamia pinnata oil, seaweed-derived biochar, and zinc oxide catalyst to determine their suitability for biodiesel production.
- Assessing parameters such as moisture content, elemental composition, surface morphology, and catalytic activity to understand their impact on biodiesel quality and engine performance.
- Experimenting with various reaction conditions including temperature, catalyst dosage, and reaction time to optimize the biodiesel production process.
- Investigating the effects of different process parameters on biodiesel yield, purity, and characteristics to achieve optimal fuel properties for engine application.
- Testing the combustion characteristics, emissions profile, and durability of internal combustion engines fueled by biodiesel blends derived from Pongamia pinnata oil with seaweed-derived biochar and zinc oxide catalyst.

CHAPTER 4

MATERIALS AND METHODOLOGY

4.1 MATERIALS AND CHEMICALS:

Using biochar made from seaweed and a zinc oxide catalyst to produce biodiesel from *Pongamia pinnata* oil is a sustainable method that emphasises the value of using renewable resources. *Pongamia pinnata*, often known as the Indian Beech tree, is a flexible and plentiful source of oil-rich seeds since it grows well in a variety of temperatures and soil types. We can lessen our dependency on fossil fuels and lessen the negative environmental effects of conventional diesel production by making use of this natural resource. An additional level of environmental friendliness is added to the process by using seaweed biomass for the synthesis of biochar. Seaweeds are maritime plants that grow quickly and are essential to the health of marine ecosystems. We may redirect organic waste from landfills and perhaps reduce carbon dioxide emissions by using seaweed biomass that has been pyrolyzed to make biochar, which sequesters carbon. Because of its efficiency and little negative effects on the environment, zinc oxide is a very significant catalyst choice for the transesterification process. Zinc oxide, in contrast to certain conventional catalysts, is non-toxic and readily removed from the biodiesel product, minimising the need for labor-intensive purification procedures and cutting down on waste production. Simple alcohol methanol serves as a reactant during the transesterification process, enabling the oil's triglycerides to be converted into fatty acid methyl esters (FAME), which are the primary building blocks of biodiesel. It is a sensible option for large-scale biodiesel production because to its accessibility and cost. Esterification with sulfuric acid may be required in situations when the *Pongamia pinnata* oil has high quantities of free fatty acids in order to lessen acidity and increase the transesterification reaction's effectiveness. Even though sulfuric acid is corrosive, it may be handled safely with the right tools and procedures.

It is crucial to guarantee the safety of the workers engaged in the production process. A thorough training programme on handling chemicals and operating equipment, in addition to providing the proper safety gear like lab coats, gloves, and goggles, reduces the likelihood of accidents and exposure to dangerous materials.

We can securely generate biodiesel from *Pongamia pinnata* oil by combining these components, chemicals, and safety precautions with close attention to detail and adherence to best practices, helping to create a more ecologically friendly and sustainable energy landscape. Moreover, adding biochar made from seaweed biomass improves the overall sustainability of the biodiesel manufacturing process in addition to acting as a catalyst. Because of its high porosity and surface area, biochar offers an abundance of active sites for the catalytic reaction to take place. Furthermore, after being used to produce biodiesel, its carbon-rich content is finally utilised as a soil amendment, closing the loop on resource utilisation and advancing the ideas of the circular economy. This all-encompassing strategy not only meets the pressing demand for alternative fuels but also fits in with the larger objectives of resource efficiency and environmental stewardship.

MATERIALS REQUIRED:

- *Pongamia Pinnata* Seed oil
- Seaweed (*Eucheuma Cottonii*)
- Zinc Oxide
- Methanol
- Distilled Water

APPARATUS REQUIRED:

- Hot Plate Magnetic Stirrer
- Magnetic Pellet
- Weighing Machine
- Filter Paper
- Hot Air Oven
- Furnace
- Round Bottom Flask(250 ml capacity)
- Thermometer
- Beaker (250ml Capacity)
- Measuring Tube (100ml Capacity)
- Separating Funnel
- Heating Mantle

4.2 EXTRATION OF ¹³ OIL FROM PONGAMIA SEEDS:

The extraction of oil from Karanja (Pongamia pinnata) seeds using an oil expeller involves a mechanical process that separates ¹³ the oil from the seeds. Detailed explanation of the extraction process:

Preparation of pongamia seeds: The process begins with the collection of mature Karanja seeds from the tree. These seeds are then cleaned thoroughly to remove any dirt, debris. Proper cleaning ensures that only the seeds enter the oil extraction process. After cleaning, the seeds are dried to reduce their moisture content. Drying ³⁶ is crucial as it improves the efficiency of the oil extraction process and prevents spoilage

Feeding seeds into expeller: Once the seeds are prepared, they are fed into the hopper of the oil expeller. The expeller consists of a large screw-like shaft that rotates and presses the seeds against a barrel.

Mechanical pressing: As the seeds enter the expeller, they increasing pressure along the length of the shaft. The screw compresses the seeds against the barrel of the expeller, This pressure squeezes the seeds tightly, causing them to rupture. The ruptured seeds release the oil.

Oil separation: The released oil flows out through small openings barrel of the expeller. These openings allow the oil to escape while retaining the solid residue, known as the cake or meal. The cake continues to move along the expeller's shaft until it reaches the end of the process. The oil, on the other hand, is collected directly from the expeller's

Collection of oil: The collected oil may undergo further filtration to remove any remaining impurities or solid particles. Filtration helps improve the quality and purity ² of the extracted oil, making it suitable for various applications. The filtered oil is then stored in appropriate containers under suitable conditions to maintain its quality.

Storage: Proper storage is essential to preserve the quality of the extracted oil. The oil is stored in clean, airtight containers away from direct sunlight and heat sources.



Fig 4.1: Pongamia Pinnata Seed



Fig 4.2: Oil Expeller



Fig 4.3: Pongamia Pinnata Oil

4.3 SEAWEED:

4.3.1 COLLECTION OF SEAWEED:

- There are lot of variety of species, in this project we have taken Red Seaweed (Eucheuma Cottonii).

- We collected the live piece seaweed from Rameshwaram, Tamil Nadu.
- The decision to collect live pieces stems from the region's rich biodiversity and optimal conditions for the growth of this particular seaweed species.
- This strategic selection and sourcing process ensure that we have access to high-quality raw materials essential for the success of our project.



Fig 4.4: Seaweed

- The drying process under the warm embrace of direct sunlight not only removes excess moisture but also enhances the seaweed's texture, imparting a desirable crispness.
- Once dried to perfection, the seaweeds are carefully fragmented into smaller, manageable pieces, a meticulous step that sets the stage for the subsequent phases of our project.
- By doing this process, it will provide us with more efficiency in our project.

4.3.2 CALCINATION PROCESS:

- After size reduction, the seaweed enters the crucial stage of calcination, where excess moisture content is removed to enhance its properties for further processing.
- The calcination process, conducted at a precise temperature of 150°C, ensures thorough dehydration while preserving the seaweed's beneficial compounds and structural integrity.

- After the seaweed is dried and processed, it's put into a pot and sealed with white cement. This keeps it safe from moisture and maintains its quality. This helps us to store and move it easily for further process.



Fig 4.5: Calcination at 150° C



Fig 4.6: Sealed Seaweed

4.3.3 CONVERSION OF SEAWEED INTO BIOCHAR:

- The sealed pot with the seaweed inside is put into the furnace and heated to 210°C for 2 hours to turn it into biochar.
- Once the biochar is ready, it's carefully taken out and crushed into a fine powder form.
- This powder undergoes sieving to remove any large pieces, ensuring a smooth and uniform texture. Finally, the powdered biochar is ready to be used for the upcoming process.



Fig 4.7: Furnace



Fig 4.8: Powdered Biochar

4.3.4 DOPING PROCESS USING MAGNETIC STIRRER:

- I have created Biochar for using it as a catalyst. I have taken Zinc Oxide from our college laboratory.
- I have then measured 9 grams of Seaweed and 3 grams of Zinc Oxide using a weighing machine.
- 150ml of distilled water is poured into a beaker and stirred for 20 minutes. This helps to dissolve any substances in the water and ensures it's evenly mixed. After stirring, the water is clean and free of impurities before further use.
- After 20 minutes add Biochar into the distilled water and run it for Half an Hour.
- After half an hour the color of the solution changes to black.
- After the change in color to black, add Zinc Oxide into the solution and run it for 3 hours at a medium pace which makes the solution into lite gray color.



Fig 4.9: Stirring of Distilled Water



Fig 4.10: Adding Biochar to Distilled Water



Fig 4.11: Adding Zinc Oxide

- After the process, the solution is filtered by using filter paper to remove the water content.



Fig 4.12: Stirring of Distilled Water



Fig 4.13: Filtering

- To remove the moisture content, the filtered slurry content is placed inside the hot air oven.
- After all these processes we will get the final catalyst and it will be used in the transesterification process.



Fig 4.14: Drying the Catalyst



Fig 4.15: Catalyst

4.4 CHARACTERIZATION:

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4.4.1 FTIR (FOURIER TRANSFORM INFRARED SPECTROSCOPY):

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FTIR, or Fourier Transform Infrared Spectroscopy, is a technique utilized for analyzing the molecular composition of materials by measuring their absorption of infrared light. This method relies on the principle that molecules absorb infrared radiation at distinct frequencies corresponding to their vibrational modes. In an FTIR setup, an infrared source emits a broad spectrum of light, which passes through the sample. The sample's molecules absorb specific wavelengths, while others are transmitted. A detector measures the intensity of transmitted light, generating a spectrum that provides insights into the sample's molecular structure. Key components of an FTIR instrument include the interferometer, which modulates the infrared light, and a computer system for data processing. Samples can be solids, liquids, or gases, prepared accordingly for analysis. Interpretation of the resulting spectrum involves identifying peaks corresponding to specific molecular vibrations. FTIR finds applications across various fields, including chemistry, materials science,

pharmaceuticals, and environmental monitoring, owing to its ability to provide detailed information about chemical composition and structure.

4.4.2 XRD (X-RAY DIFFRACTION):

X-ray diffraction (XRD) analysis is a fundamental technique employed to unveil the atomic and molecular structure of crystalline materials. By directing X-rays onto a sample, the interaction with the atoms within the crystal lattice results in diffraction patterns that encode crucial information about the material's internal arrangement. This method, rooted in Bragg's law, enables the determination of the spacing between atomic planes and the orientation of crystal grains. Instrumentation typically involves an X-ray source, a sample holder, a detector, a goniometer for sample rotation, and specialized software for data analysis. Sample preparation involves finely powdering the material to ensure random crystallite orientation. During data collection, diffraction patterns are gathered over a range of angles, revealing distinct peaks corresponding to specific crystallographic planes. Analysis of these patterns facilitates the identification of crystal structures and phases, aiding in applications across materials science, geology, pharmaceuticals, chemistry, and engineering. XRD analysis serves as a cornerstone technique for understanding the properties and behavior of crystalline materials in diverse scientific and industrial domains.

4.4.3 FESEM WITH EDX:

Spectroscopy (EDX) is a sophisticated analytical technique used to investigate the surface morphology and elemental composition of materials with remarkable detail. In FESEM, a finely focused electron beam generated by a field-emission electron gun scans the sample surface, producing high-resolution images. This allows for the visualization of microstructures, surface features, and nano-scale details. Meanwhile, the EDX system detects characteristic X-rays emitted by the sample upon electron beam excitation. These X-rays carry information about the elemental composition of the sample, enabling qualitative and quantitative elemental analysis. By combining high-resolution imaging capabilities with elemental analysis, FESEM with EDX provides comprehensive insights into the structure, composition, and chemistry of materials. This technique finds widespread applications in materials science, nanotechnology, geology, biology, and various other fields, facilitating research and development across diverse disciplines.

4.4.4 GCMS

Gas Chromatography-Mass Spectrometry (GC-MS) is a sophisticated analytical technique used for identifying and quantifying components within complex mixtures. In GC-MS, the sample is introduced into a gas chromatograph where it undergoes separation based on its affinity for the stationary phase within the column. As the separated components exit the column, they enter the mass spectrometer, where they are ionized and fragmented. The resulting ions are separated based on their mass-to-charge ratio, generating a mass spectrum unique to each compound. By comparing these spectra to known standards or databases, the identity of the components can be determined. Additionally, the abundance of ions in the mass spectrum provides quantitative information about the concentration of each compound. GC-MS finds applications across various fields, including environmental analysis, forensic science, pharmaceuticals, food safety, and petrochemical analysis, owing to its high sensitivity, selectivity, and versatility in compound identification and quantification.

4.5 DETERMINATION OF ACID VALUE AND FREE FATTY ACID VALUE:

The determination of acid value is a critical analytical procedure used in various industries, particularly in the production of biodiesel, edible oils, and fats. It provides essential information about the concentration of free fatty acids present in a sample, which is indicative of its quality, stability, and suitability for use in different applications.

Acid value is defined as the quantity of Sodium Hydroxide (NaOH) in milligrams required to neutralize the free acids present in one gram of the sample. The determination of acid value involves a simple titration method, typically using a standardized NaOH solution and a suitable indicator to detect the endpoint of the reaction. In the context of biodiesel production, the acid value of feedstock oils is a crucial parameter that influences the transesterification process. High acid values indicate elevated levels of free fatty acids, which can adversely affect the efficiency of the transesterification reaction and the quality of the biodiesel product. Therefore, monitoring and controlling the acid value of feedstock oils are essential to ensure optimal process performance and biodiesel quality.

The determination of acid value begins with sample preparation, where the oil or fat is dissolved in a suitable solvent to facilitate the titration process. The sample solution is then titrated with a standardized NaOH solution under controlled conditions until the endpoint of the titration is reached. The endpoint is typically detected using a pH indicator, such as phenolphthalein or methyl orange, which changes color upon neutralization of the free acids.

Steps to find the acid value of the Pongamia Pinnata Oil:

- Prepare 0.1N NaOH solution
- Add few drop of phenolphthalein indicator to 50 ml of ethanol
- After added Titrate the solution against NaOH to neutralize
- Neutralized ethanol is added to 10g of oil and it is heated using hot plate .
- After 20min add few drop of indicator and titrate against 0.1N of NaOH
- Before titrate note the initial burette reading
- Start to titrate the solution when the solution changed into pink colour stop the titrate
- Note the final burette reading.

4.5.1 CALCULATION OF ACID VALUE:

Sample Weight =10g

Normality of NaOH (N) =0.1N

Volume of NaOH Solution (V)= Final Burette Reading – Initial Burette Reading

$$= 30.1 - 0.2 = 29.9$$

Molecular weight of NaOH = 40.01

$$\text{Acid Value} = \frac{\text{molecular weight of NaOH} \times N \times V}{10} = \frac{40.01 \times 0.1 \times 29.9}{10} = 11.96$$

$$\text{Free fatty acid (FFA)} = 11.96/2 = 5.98$$



Fig 4.16: Before Titration



Fig 4.17: After Titration

4.6 ESTERIFICATION PROCESS:

- Take 60ml of Pogamia Pinnata Oil and pour it into flask and heated upto 60°C.
- Take 40ml of Methanol and is added to the pre-heated Pogammia Pinnata Oil and it is stirred for few minutes.
- Add 1.5ml of Sulphuric Acid is added to the mixture.
- Heat and Stir the mixture continuously for about 45 mins at room temperature.
- After the completion of reaction, we have to remove the excess impurities Sulphuric Acid and Alcohol from the mixture. For that we need to pour it into the seperating funnel.
- Alcohol, Sulphuric Acid and other impurities will be settled to the top layer of the solution.
- The rest of the solution which is settled below will be used for Transesterification process.
- These processes helps to reduce the FFA value of oil below 1%.

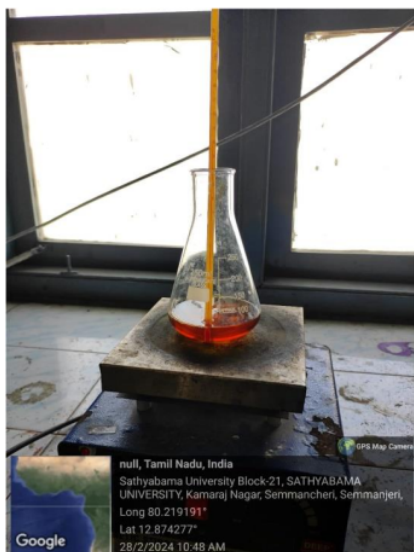


Fig 4.18: Heating of Oil



Fig 4.19: Stirring the Solution



Fig 4.20: Separation of the Solution

4.7 TRANSESTERIFICATION PROCESS:

- Heating the oil which is collected from the esterification process at the degree of 60°C in round bottom flask using magnetic stirrer.
- After reaching 60°C , Methanol and the catalyst is added to the round bottom flask, then we will be closing it with the Condensor.
- We need to stir the solution continuously for 1 Hour, the heat should be maintained at 50°C .
- After that we need to pour the solution into the separating funnel, leave it for 1 day.
- In the separating funnel the solution is separated to two layers.
- Biodiesel is separated to the top and the glycerol will be settled to the bottom.
- Separate the biodiesel from the separating funnel and is collected to container.



Fig 4.21: Heating of Oil in RB Flask



Fig 4.22: Stirring the Solution for 1 Hr



Fig 4.23: Separation of Biodiesel from the solution

4.8 PRODUCTION OF BIODIESEL IN DIFFERENT RATIO:

RATIO	OIL (ml)	METHANOL (ml)	OIL (mass)	METHANOL (mass)	Catalyst wt%	CATALYST (gram)	Time (min)	Yield %
1 : 3	40	4.9	36	3.87	5	2.1	45	-
1 : 6	40	9.8	36	7.75	5	2.3	45	46
1 : 9	40	14.7	36	11.6	5	2.5	45	59
1 : 12	40	19.6	36	15.5	5	2.71	45	64
1 : 15	40	24.5	36	19.37	5	2.91	45	74
1 : 18	40	29.4	36	23.25	5	3.12	45	80
1 : 21	40	34.3	36	27.13	5	3.32	45	85
1 : 24	40	39.2	36	31	5	3.5	45	72
1 : 27	40	44.1	36	34.8	5	3.73	45	66
1 : 30	40	49	36	38.7	5	3.93	45	-

Table 4.1 PRODUCTION OF BIODIESEL IN VARIOUS RATIO

From the above table we got highest yield in 1:21ratio which is in the percentage of 85%

4.9 ENGINE:

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IC Engine set up under test is Research Diesel having power 3.50 kW @ 1500 rpm which is 1 Cylinder, Four stroke, Constant Speed, Water Cooled, Diesel Engine, with Cylinder Bore 87.50(mm), Stroke Length 110.00(mm), Connecting Rod length 234.00(mm), Compression Ratio 17.50, Swept volume 661.45 (cc)



Fig 4.24: Engine

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 CHARACTERIZATION OF CATALYST AND OIL

5.1.1 FTIR (SEAWEED) :

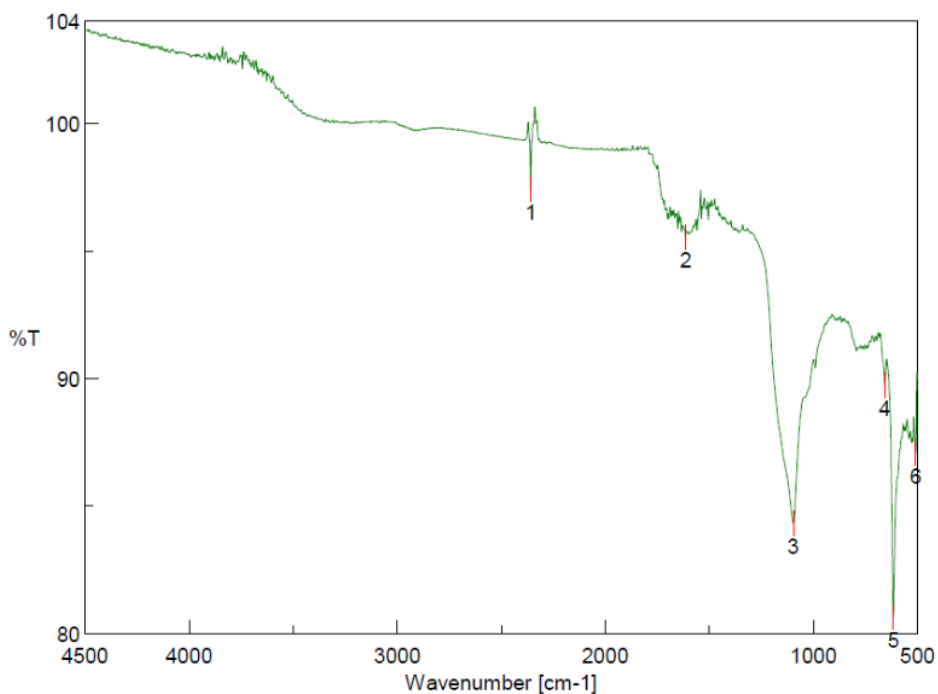


Fig 5.1: FTIR for Seaweed

From the above graph peak level at different position indicates the different functional groups present in it.

2358.5cm⁻¹ shows the presence of O=C=O stretching carbon dioxide with strong intensity. 1614.1cm⁻¹ shows the presence of C=C stretching with strong intensity. 1097.3cm⁻¹ Shows the presence of C-O stretching alcohol with strong intensity. 656.6cm⁻¹ shows the presence of C-Br stretching halo compound with strong intensity. 508.1cm⁻¹ shows the presence of C-I stretching with strong intensity.

5.1.2 FTIR (SEAWEED/ZNO):

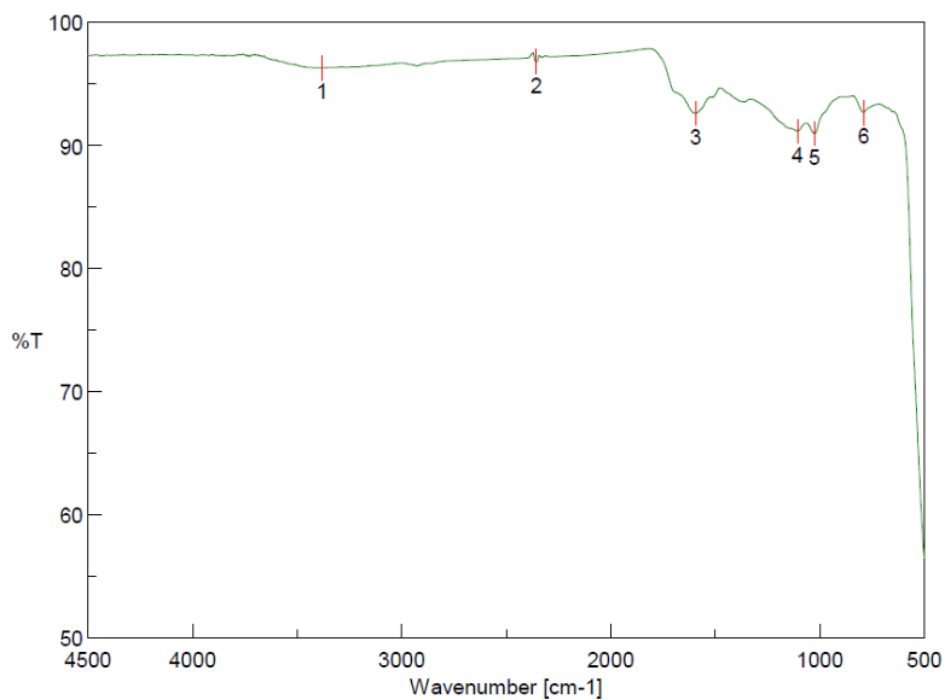


Fig 5.2: FTIR for Seaweed/Zinc Oxide

From above graph shows the ftir analysis for seaweed with zinc oxide we discuss the graph in detail about what are all the functional group present in it in each peak and also their intensity.

3380.6cm⁻¹ shows the presence of O-H stretching alcohol with strong broad. 2356.5cm⁻¹ shows the presence of O=C=O stretching carbon dioxide with strong intensity. 1594.8cm⁻¹ shows the presence of N-H bending amine with medium intensity. 1106.9cm⁻¹ shows the presence of C-F stretching fluoro with strong intensity. 791.6cm⁻¹ shows the presence of C-Cl stretching halo with strong intensity.

5.1.3 FESEM (SEAWEED/ZNO):

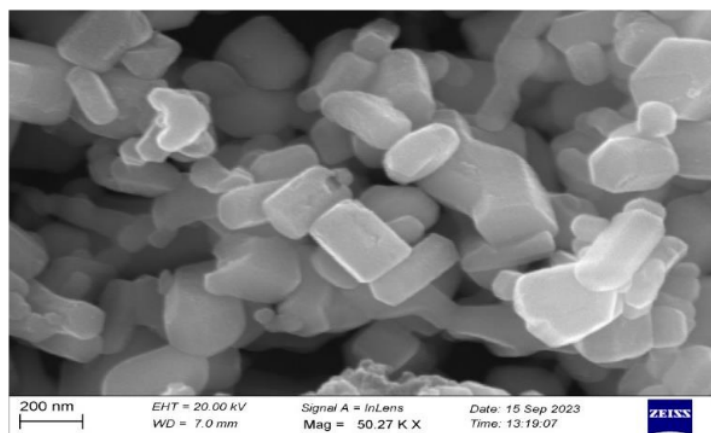


Fig 5.3: SEM Image under 50.27 KX magnification

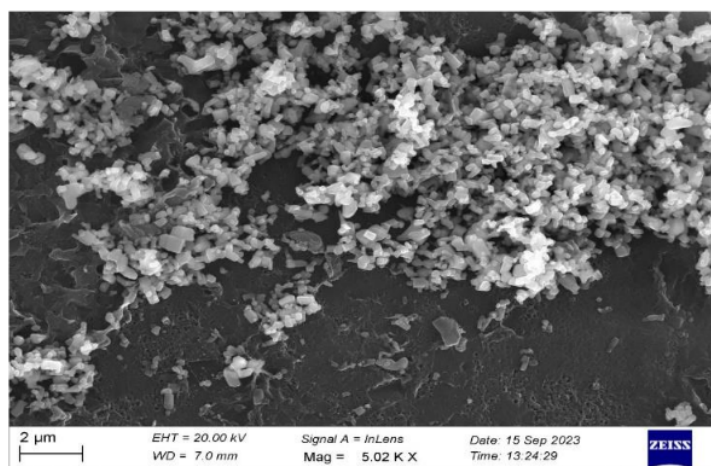


Fig 5.4: SEM Image under 5.02 KX magnification

The FESEM analysis of synthesized catalyst which consists of doped seaweed and zinc oxide. The FESEM analysis in the above picture shows the heterogeneous structure of catalyst. FESEM is used to find the size, shape, and distribution of catalyst particles because of their catalytic activity and selectivity.

5.1.4 EDAX (SEAWEED/ZNO):

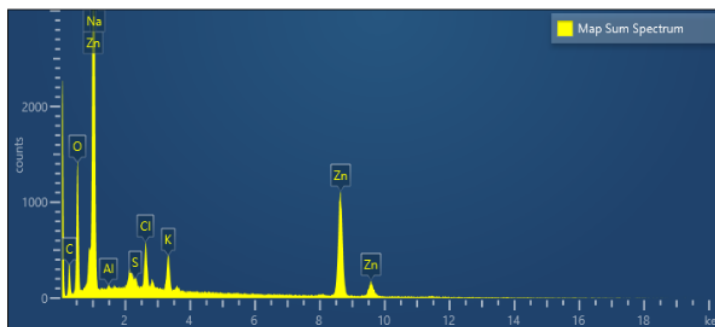


Fig 5.5: EDAX Mapping

Map Sum Spectrum				
Element	Line Type	Weight %	Weight % Sigma	Atomic %
C	K series	24.55	1.28	46.02
O	K series	21.21	0.48	29.86
Na	K series	6.40	0.49	6.27
Al	K series	0.27	0.06	0.23
S	K series	0.14	0.06	0.10
Cl	K series	2.35	0.08	1.49
K	K series	2.13	0.08	1.23
Zn	K series	42.94	0.82	14.79
Total		100.00		100.00

Table 5.1: Elemental Composition in Seaweed/ZnO

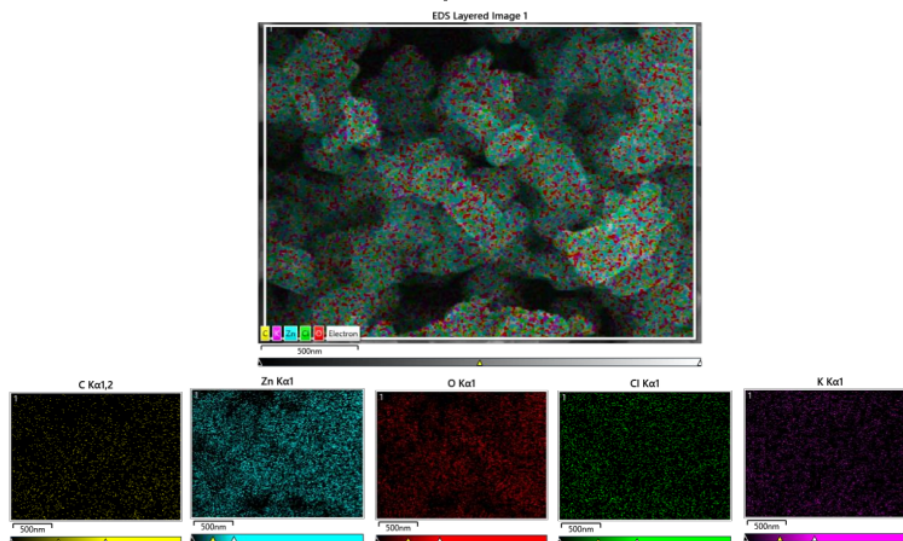


Fig 5.6: EDAX Image

Based on the EDAX map you provided, here's an explanation of the elemental distribution observed in your seaweed/ZnO sample:

The strong presence of carbon (C) and oxygen (O) throughout the map suggests these elements are abundant, which is consistent with the composition of seaweed, which is mainly organic matter (carbohydrates, proteins). Zinc (Zn) appears concentrated in specific regions throughout the map, indicated by the yellow color intensity. This suggests that ZnO particles are not uniformly distributed on the seaweed surface but rather localized in clusters. The presence of sodium (Na) is likely due to residual salts from seawater on the seaweed surface.

5.1.5 XRD (SEAWEED/ZNO):

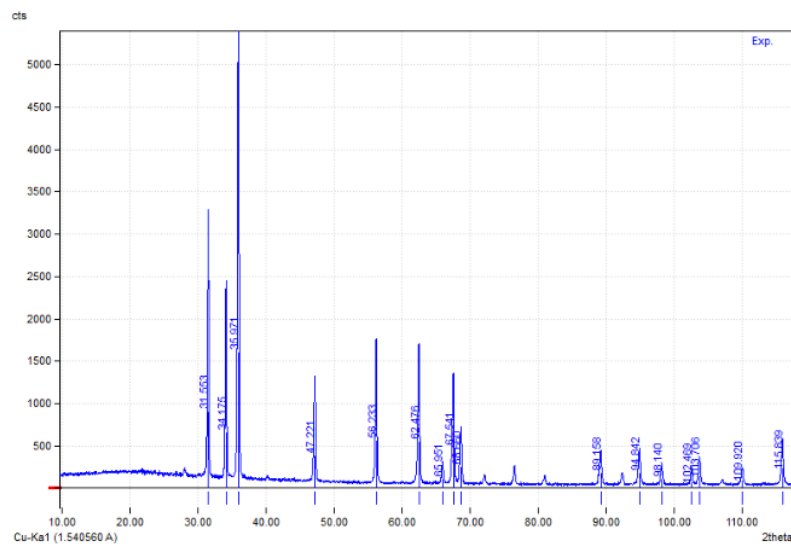


Fig 5.7: XRD

Based on the XRD graph you provided of the seaweed/ZnO composite, here's an analysis of the likely crystalline phases present:

This broad peak is likely due to amorphous organic material originating from the seaweed component. Seaweed typically contains complex carbohydrates like cellulose and alginate, which can diffract X-rays and contribute to a broad peak in this region. These peaks match well with the crystallographic planes of ZnO (zinc oxide). Their presence confirms the existence of ZnO in your seaweed/ZnO composite. These might be due to minor crystalline components in the seaweed or

the presence of other metal oxides depending on the specific seaweed species and preparation process. Without additional information or reference data, pinpointing these phases is challenging.

The X-ray diffraction (XRD) graph suggests that your seaweed/ZnO composite consists of two main crystalline phases.

- **Amorphous Organic Material:** This broad peak indicates the presence of non-crystalline organic matter, likely from the seaweed component.
- **ZnO:** The sharp peaks at specific angles confirm the presence of crystalline ZnO nanoparticles or particles within the composite.

5.1.6 GCMS (POMGAMIA PINNATA OIL):

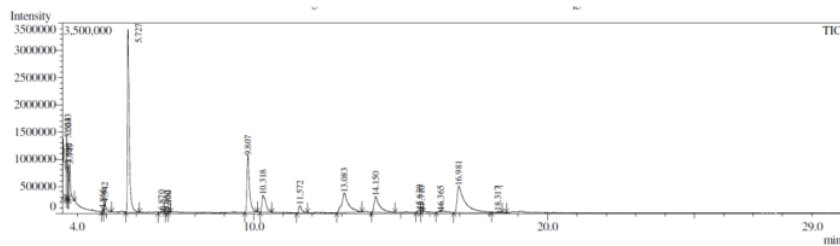


Fig 5.8: GCMS of Oil

Peak Report TIC				
Peak#	R. Time	Area	Area%	Name
1	3.523	4758261	8.60	Cyclohexane
2	3.643	2680297	4.84	Cyclopentane, 1,3-dimethyl-
3	3.696	1392835	2.52	Cyclopentane, 1,3-dimethyl-
4	3.749	1735345	3.13	Cyclopentane, 1,3-dimethyl-, trans-
5	4.866	113548	0.21	2-METHYL-2-PENTANOL
6	4.942	665290	1.20	Methyl Isobutyl Ketone
7	5.727	14227818	25.70	BENZENE, METHYL-
8	6.870	226761	0.41	Cyclopentanol, 1-methyl-
9	7.052	133450	0.24	3-HYDROXY-2,2-DIMETHYLPROPANAL
10	7.100	88482	0.16	CYCLOHEXANE, (1-HEXADECYLHEPT
11	9.807	6331299	11.44	Ethylbenzene
12	10.318	2850517	5.15	BENZENE, 1,2-DIMETHYL-
13	11.572	925147	1.67	BENZENE, 1,2-DIMETHYL-
14	13.083	5656828	10.22	SILANE, ETHENYLTRIMETHYL-
15	14.150	3707791	6.70	Valeric acid, 2-ethoxyethyl ester
16	15.639	223227	0.40	Pentanoic acid, 2-propenyl ester
17	15.710	106957	0.19	1-METHYL-2-PROPENYL PROPYL ETHI
18	16.365	125224	0.23	Hydroperoxide, 1-methylpentyl
19	16.981	9262932	16.73	Oxalic acid, cyclohexyl ethyl ester
20	18.317	146018	0.26	Mesitylene
		55358027	100.00	

Table 5.2: Peak Report of GCMS for Pongamia Pinnata Oil

The table lists the peak number, retention time (R. Time), area, area percent, and peak report for each component. The retention time is the time it takes for a component to flow through the GC column. The area is a measure of the amount of

the component that is present in the sample. The area percent is the percentage of the total area that is accounted for by that component. The peak report lists the tentative identification of the component. from above result for pongamia oil demonstrates the presence of Valeric acid, and Pentanoic acid. The presence of pentanoic acid (valeric acid) and other organic acids in the GCMS analysis of pongamia oil is indicative of the fatty acid profile of the oil. Pongamia oil, like many other plant oils, is a triglyceride, meaning it contains triglycerides - molecules formed by three fatty acids esterified to glycerol. These fatty acids vary in chain length and saturation, influencing the properties of the oil. The high content of short-chain fatty acids like valeric acid might make pongamia oil less favorable for biodiesel production compared to oils rich in longer-chain fatty acids. The presence of specific fatty acids can influence the oil's drying properties, making it potentially suitable for applications in paints and coatings

5.2 POST STUDY OF CATALYST:

5.2.1 FTIR (SEAWEED/ZNO):

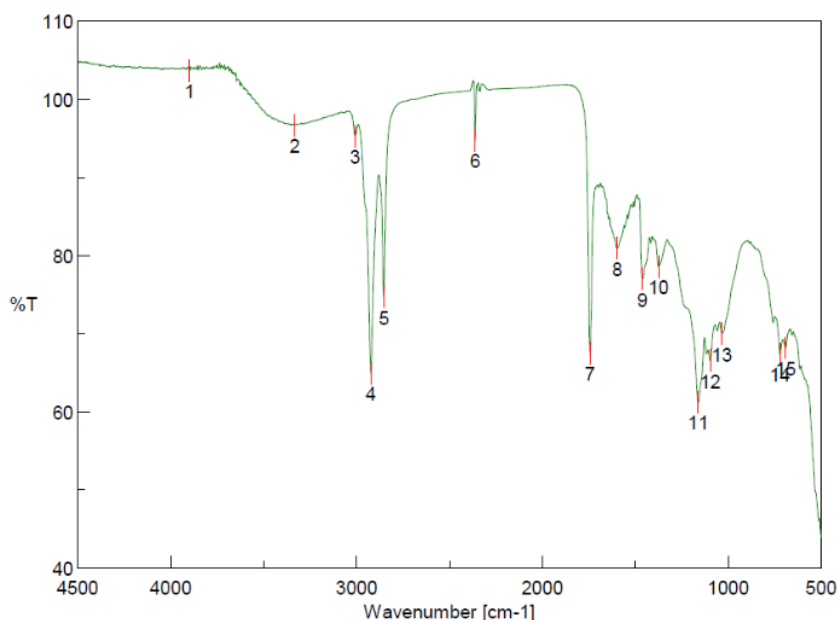


Fig 5.9: seaweed/zno

Based on the FTIR image you sent of your seaweed/ZnO composite, here's an interpretation of the functional groups likely present:

Peak around 3300-3600 ⁷³cm⁻¹ is attributed to O-H stretching vibrations from hydroxyl groups (OH) present in various molecules, including carbohydrates, proteins, and water. Peaks Around ³⁹cm⁻¹ correspond to C-H stretching vibrations from aliphatic hydrocarbons (organic molecules with carbon-hydrogen chains) commonly found in seaweed. Peak Around 1650 ⁸²cm⁻¹ is assigned to C=O stretching vibrations from carbonyl groups (C=O) in various organic molecules like ketones or carboxylic acids. In seaweed, this could be due to the presence of carbonyl groups in alginate or other carbohydrates. Peaks Around 1450-1550 cm⁻¹ represent C-H bending vibrations and can be attributed to various organic components in the seaweed. Peak Around 1030 ⁵¹cm⁻¹ is due to C-O stretching vibrations from carbohydrates or polysaccharides in the seaweed. The FTIR spectrum suggests that the main components in your seaweed/ZnO composite are organic molecules originating from the seaweed. The presence of functional groups like O-H, C-H, and C=O is consistent with the presence of carbohydrates, proteins, and other organic biomolecules typically found in seaweed.

5.2.2 FESM (SEAWEED/ZNO):

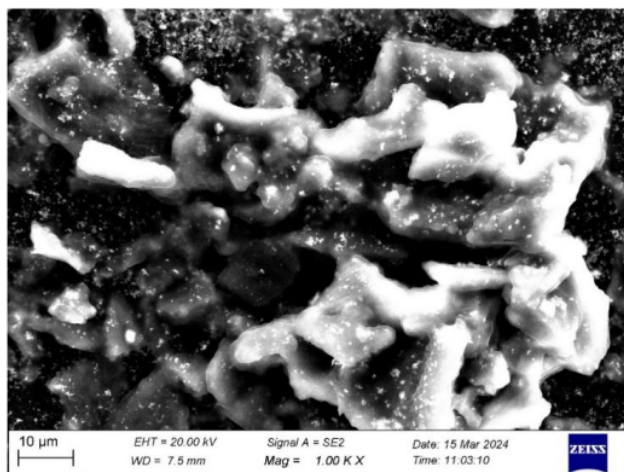


Fig 5.10: SEM Image under 1 KX magnificati

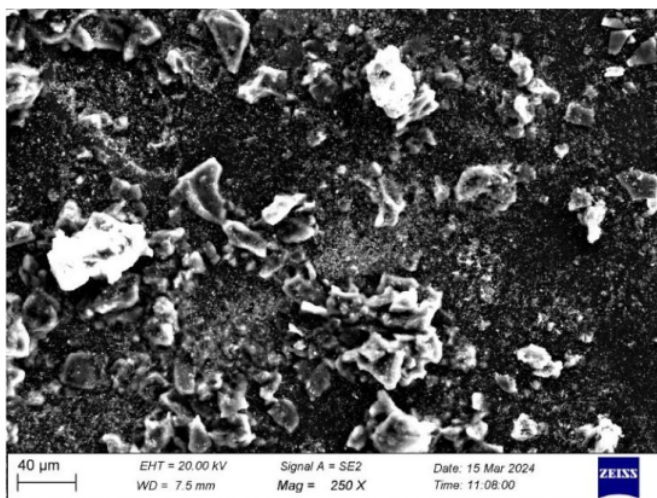


Fig 5.11: SEM Image under 250 KX magnification

The Sem image shows the elements present in your sample include Sodium (Na), Silicon (Si), Sulfur (S), Zinc (Zn), Carbon (C) from the result The necessity of this post-study is to analyse whether the pores or active sites of the catalyst got enclosed, and it's confirmed that the pores or surface of the catalyst got lit up due to the reaction between methanol and oil, which ensures that the catalyst is involved in the reaction, is filtered, and further it is used for any other purpose.

5.2.3 EDAX (SEAWEED/ZNO):

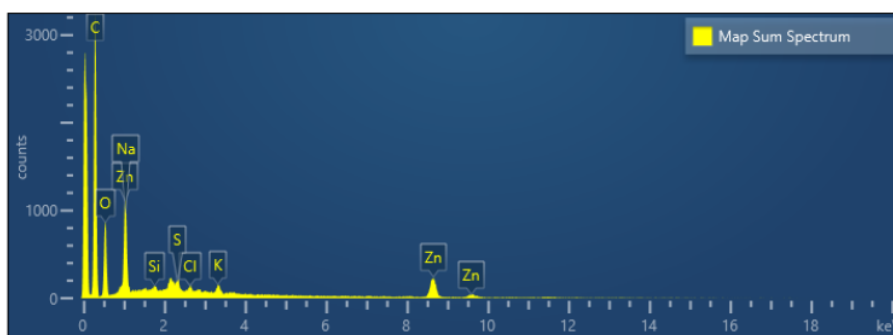


Fig 5.12: EDAX Mapping

Map Sum Spectrum				
Element	Line Type	Weight %	Weight % Sigma	Atomic %
C	K series	69.53	0.53	79.95
O	K series	20.05	0.43	17.31
Na	K series	0.82	0.14	0.49
Si	K series	0.16	0.03	0.08
S	K series	0.28	0.04	0.12
Cl	K series	0.25	0.03	0.10
K	K series	0.46	0.04	0.16
Zn	K series	8.45	0.25	1.79
Total		100.00		100.00

Table 5.3: Elemental Composition in Seaweed/ZnO

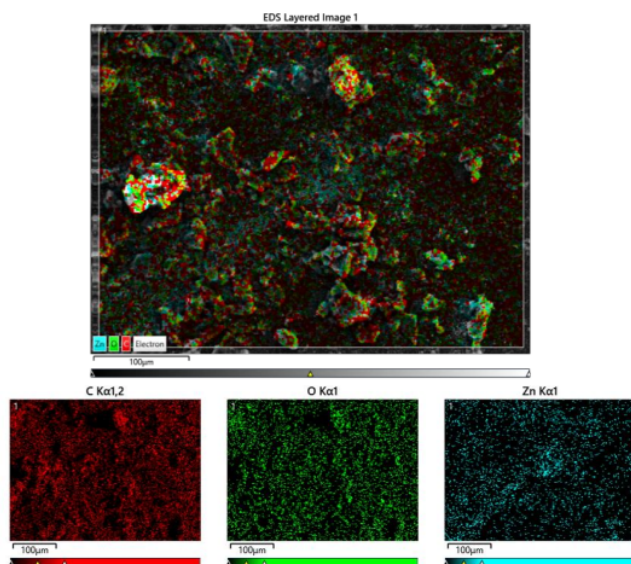


Fig 5.13: EDAX Image

5.2.4 CATALYST REUSABILITY:

Catalysts play a crucial role in chemical reactions by speeding up the reaction rate and increasing the efficiency of the process. Reusability of catalysts is an important aspect in industrial applications as it not only reduces costs but also minimizes waste generation and environmental impact. In the context of biodiesel production from seaweed, the reuse of catalysts, particularly those based on zinc oxide (ZnO), can offer significant advantages. The catalyst can be separated from the glycerol phase through techniques such as filtration or centrifugation. The recovered catalyst may still contain some impurities or traces of reactants. The recovered catalyst is then regenerated to restore its activity and effectiveness. This typically involves washing the catalyst with suitable solvents to remove impurities and reactants.

adsorbed on its surface. Additionally, calcination or other treatments may be applied to restore the catalyst's surface properties. The regenerated catalyst is then reused in subsequent batches of biodiesel production. This cycle of use, recovery, regeneration, and reuse can be repeated multiple times, depending on the catalyst's stability and the effectiveness of regeneration processes. Reusing catalysts reduces the need for frequent replacement, leading to cost savings in catalyst procurement. By extending the catalyst's lifespan, less waste is generated from spent catalyst disposal, contributing to environmental sustainability. Reusable catalysts maintain their catalytic activity over multiple cycles, ensuring consistent and efficient biodiesel production. Utilizing catalyst reusability conserves resources that would otherwise be consumed in the production of new catalysts. Overall, the reusability of catalysts, particularly in biodiesel production from seaweed, offers significant advantages in terms of cost-effectiveness, environmental sustainability, and process efficiency, making it a key focus area in industrial applications.

5.3 CHARACTERIZATION OF BIODIESEL:

5.3.1 FTIR (BIODIESEL):

FTIR can show the sort and number of functional groups present in the material, as well as the degree of unsaturation and other structural features, FTIR spectroscopy is incredibly useful for the investigation of biodiesel.

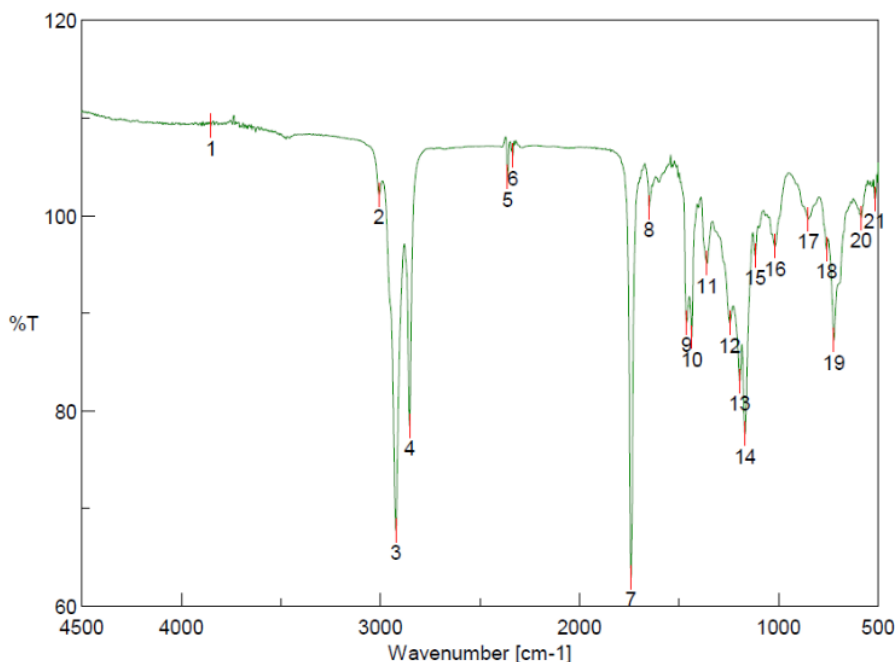


Fig 5.14: FTIR for Biodiesel

The above graph shows the ftir result of biodiesel we should analyse the graph to know what are all the functional groups present in it.

3006.4cm⁻¹ shows the presence of O-H stretching carboxylic acid with strong broad. 2922.5cm⁻¹ shows the presence of C-H stretching alkane with medium intensity. 2361.4cm⁻¹ shows the presence of O=C=O stretching carbon dioxide with strong intensity. 1741.4cm⁻¹ shows the presence of C=O stretching ester with strong intensity. 1359.5cm⁻¹ shows the presence of S=O stretching sulfonate with strong intensity. 585.2cm⁻¹ Shows the presence of C-Cl stretching halo with strong intensity.

5.3.2 PROPERTIES OF BIODIESEL:

S.No	Parameters	Results
1	Calorific value (MJ/Kg)	35
2	Kinematic Viscosity @ 40 (°C)	5.2
3	Pour point by ASTM method (°C)	-3.8
4	Fire point by PMCC method (°C)	176
5	Flash point by PMCC method (°C)	164
6	Density (g/cc)	0.793

Table 5.4: Biodiesel Properties

5.3.3 GCMS (BIODIESEL):

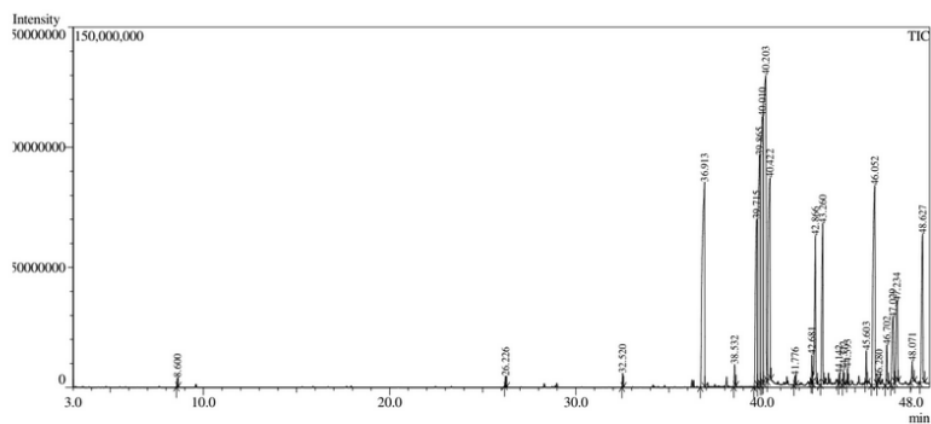


Fig 5.15: GCMS for Biodiesel

Peak Report TIC				
Peak#	R. Time	Area	Area%	Name
1	8.600	10385558	0.15	BENZOIC ACID, METHYL ESTER
2	26.226	12916049	0.19	DODECANOIC ACID, METHYL ESTER
3	32.520	13609374	0.20	TETRADECANOIC ACID, METHYL ESTER
4	36.913	748646375	11.05	HEXADECANOIC ACID, METHYL ESTER
5	38.532	23533520	0.35	Heptadecanoic acid, methyl ester
6	39.715	468466009	6.91	9,12-Octadecadienoic acid (Z,Z)-, methyl ester
7	39.865	754105222	11.13	9-Octadecenoic acid, methyl ester, (E)-
8	40.010	977446760	14.42	9,12-OCTADECADIENOIC ACID (Z,Z)-, Methyl ester
9	40.203	1201071312	17.72	9-OCTADECENOIC ACID, METHYL ESTER
10	40.422	567706932	8.38	OCTADECANOIC ACID, METHYL ESTER
11	41.776	12886695	0.19	Methyl (11R,12R,13S)-(Z)-12,13-epoxy-11-octadecenoate
12	42.681	27831826	0.41	9-OCTADECENSAEURE, 12-HYDROXY-
13	42.866	260549633	3.84	cis-13-Eicosenoic acid, methyl ester
14	43.260	284254373	4.19	METHYLICOSANOATE
15	44.142	9935156	0.15	1-Propyl-3-(propen-1-yl)adamantane
16	44.372	14523408	0.21	2-METHOXY-2,6,10,15,19,23-HEXAMETHYLOCTADECANOIC ACID, METHYL ESTER
17	44.593	14198638	0.21	HENEICOSANOIC ACID, METHYL ESTER
18	45.603	33261274	0.49	13-Docosenoic acid, methyl ester
19	46.052	582441223	8.60	DOCOSANOIC ACID, METHYL ESTER
20	46.280	12492806	0.18	2-Pyrazoline, 1-benzoyl-3-ethyl-5-hydroxy-5-methyl-
21	46.702	56631261	0.84	2,2-DIMETHYL-7-HYDROXY-6-[(2'-PHENYL)-5-OXO-4,5-DIHYDRO-2H-PYRAN-4-YL]OCTANOIC ACID, METHYL ESTER
22	47.029	160355557	2.37	2-PHENYL-FURO[B]BENZOPYRAN-4(4H)-ONE
23	47.234	197107849	2.91	2-[5-(2-METHYL-1,3-BENZOXAZOL-7-YL)-2-PHENYL-5-OXO-4,5-DIHYDRO-2H-PYRAN-4-YL]OCTANOIC ACID, METHYL ESTER
24	48.071	29248266	0.43	9-Octadecenoic acid (Z)-, 2,3-dihydroxypropyl ester
25	48.627	302727094	4.47	Tetracosanoic acid, methyl ester
		6776332170	100.00	

Table 5.5: Peak Report of GCMS for Biodiesel

The above table and peaks present in the graph demonstrate the presence of methyl ester, which is the main component of biodiesel, and confirm whether the oil is converted into biodiesel, which is attained by the transesterification process. This confirms the presence of methyl esters and acids present in the pongamia biodiesel. As pongamia pinnata oil is converted to biodiesel, the triglycerides it contains undergo transesterification, which yields these methyl esters of fatty acids

5.4 INTERNAL COMBUSTION ENGINE STUDY:

A research focusing on performance, emissions, and engine optimisation would be conducted on internal combustion engines (ICEs) powered by biodiesel. The investigation of the IC engine is conducted for several blends (B10, B20). One of the most important metrics for evaluating the efficiency of an internal combustion engine is break thermal efficiency, or BTE. It computes the output of useable work relative to the total energy input of the engine. In assessing the performance of engines with different fuels, BTE is an important factor to take into account. Determine how much heat is produced while the engine's biodiesel burns. This means accounting for the energy content and combustion efficiency of the biodiesel fuel. The combustion efficiency accounts for two types of losses: incomplete combustion and environmental heat loss. Calculate the engine's work output by using the torque and rotational speed. It is possible to calculate the amount of work completed in a single engine cycle using the engine displacement volume and the

torque-speed relationship. Compare the break thermal efficiency of conventional diesel fuel with biodiesel fuel under identical running circumstances.

This comparison reveals the relative efficacy of using biodiesel ⁷⁹as a fuel in internal combustion engines. The performance of engines or other machinery operating on biodiesel fuel is typically compared to that of engines or other machinery running on standard diesel fuel in order to assess the mechanical efficiency of biodiesel. The aim of this study ²⁷is to ascertain the impact of biodiesel on the mechanical efficiency of the system. Torque analysis for biodiesel is the process of comparing an engine's or piece of equipment's torque generation while using biodiesel fuel to normal diesel fuel. Torque is a crucial parameter for assessing an engine's mechanical performance as it shows the spinning force generated by the engine's drivetrain. Plot torque curves for both conventional diesel fuel and biodiesel to examine the torque output of the engine across its operating range.

5.4.1 Engine Study (B10%)

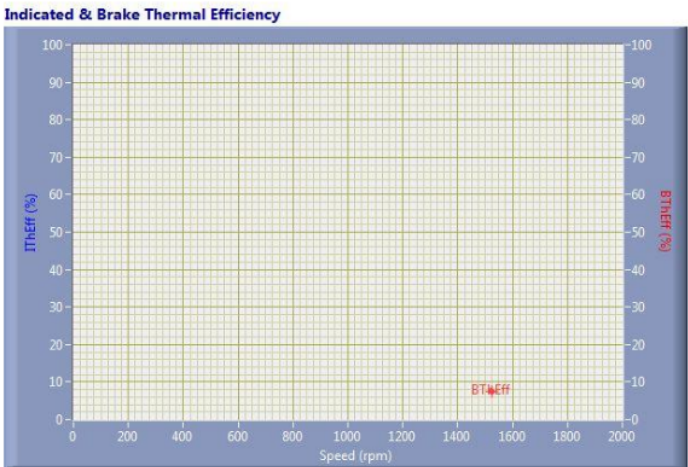


Figure 5.16: Break Thermal Efficiency for B10

Indicated & Brake Thermal Efficiency

Speed (rpm)	Load (kg)	IThEff (%)	BThEff (%)
1525.00	0.60	138.43	7.53

Table 5.6: Break Thermal Efficiency Data for B10

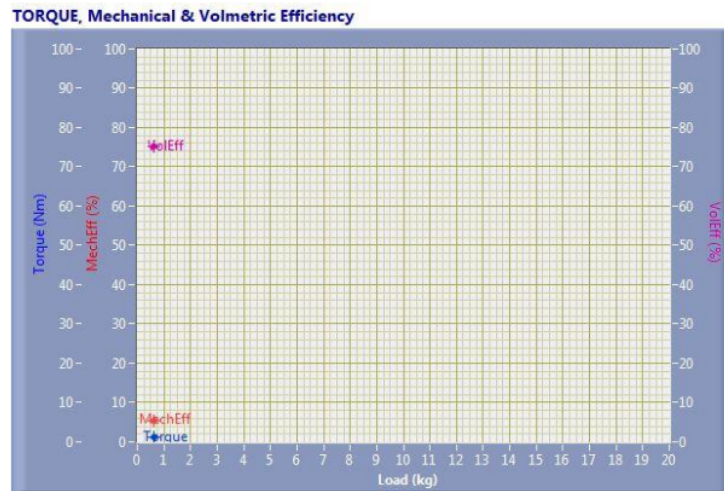


Fig 5.17 IC ENGINE STUDY FOR B10

TORQUE, Mechanical & Volmerti Efficiency

Speed (rpm)	Load (Kg)	Torque (Nm)	Mech Eff. (%)	Vol Eff. (%)
1525.00	0.60	1.10	5.44	75.09

Table 5.7 IC Engine Study Data for B10

5.4.2 Engine Study (B20%)

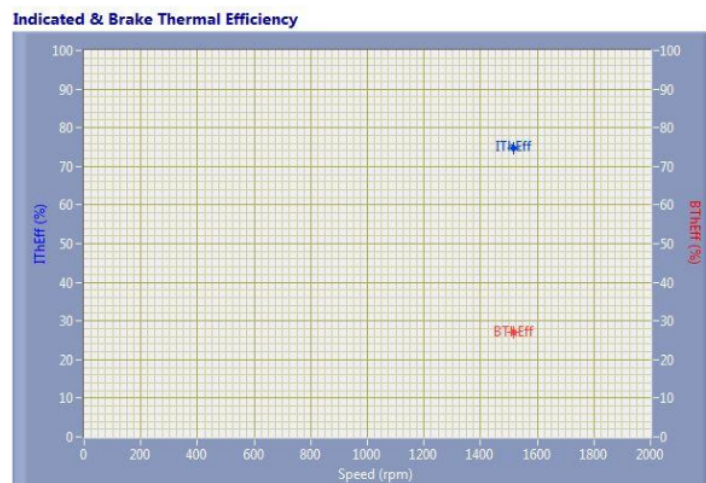


Fig 5.18: Break Thermal Efficiency for B20

Speed (rpm)	Load (kg)	<u>I</u> ThEff (%)	<u>B</u> ThEff (%)
1518.00	9.23	74.68	26.95

Table 5.8: Break Thermal Efficiency Data for B20

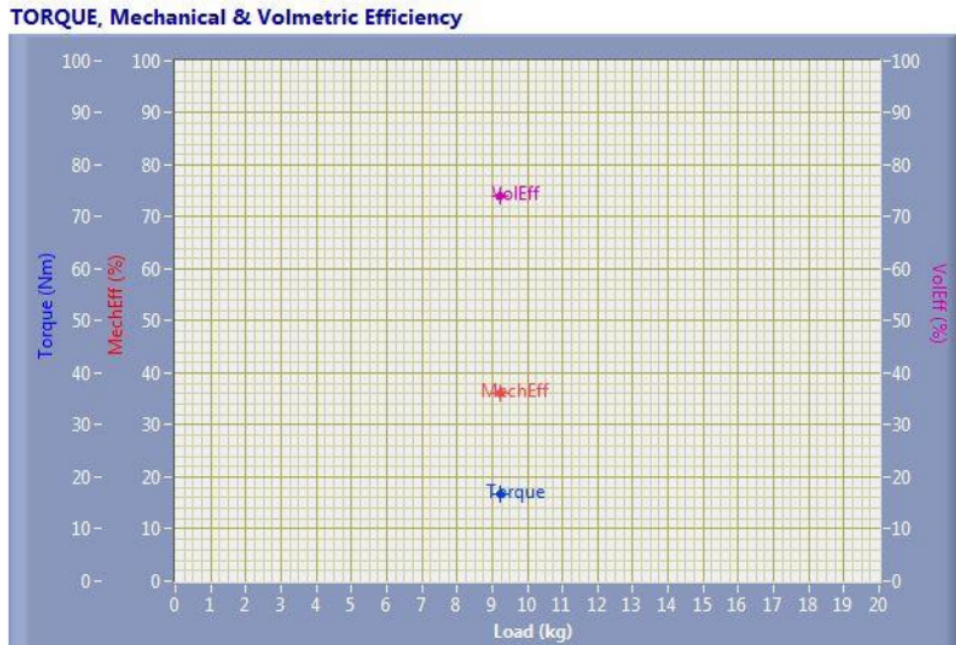


Fig 5.19: IC ENGINE STUDY FOR B20

Speed (rpm)	Load (Kg)	Torque (Nm)	<u>Mech</u> Eff. (%)	Vol Eff. (%)
1518.00	9.23	16.74	36.09	74.18

Table 5.9: IC Engine Study Data for B20

5.5 EMISSION ANALYSIS FOR VARIOUS BLENDS:

Emissions from internal combustion engines using biodiesel are essential for assessing the fuel's environmental impact and contrasting it with regular diesel. It describes the steps taken to assess emissions while using biodiesel fuel in an engine. It indicates the parameters of the emissions that were measured, such as hydrocarbons (HC), carbon monoxide (CO), particulate matter (PM), nitrogen oxides

(NO_x), and other pollutants. Give specifics about the test parameters, such as the load, engine speed, and composition of the biodiesel blend.

Name of the gas	Load	Load	Load	Load
	0	3	6	9
CO	0.01	0.04	0.05	0.06
HC	1	2	2	3
CO ₂	0.30	1.10	1	1.10
O ₂	20.64	19.41	19.61	19.30
NOX	23	52	61	68
SMOKE DENSITY	3.5	43.6	55.03	62.5

TABLE 5.10: EMISSION ANALYSIS FOR B10

Name of the gas	Load	Load	Load	Load
	0	3	6	9
CO	0.01	0.03	0.04	0.04
HC	1	2	3	4
CO ₂	0.50	0.70	0.80	1
O ₂	2.333	19.65	19.83	19.57
NOX	32	35	34	41
SMOKE DENSITY	3.8	58.2	62.8	67.8

TABLE 5.11: EMISSION ANALYSIS FOR B20

The above tables show the amount of gas emitted for different loads of biodiesel input. It is done for two blends of B10 and B20. The emission values of various gases were studied through the fine gas detector. As the emission range meets the standards it can be used as an alternative eco-friendly source.

CHAPTER 6

SUMMARY AND CONCLUSIONS

6.1 SUMMARY:

We have done the biodiesel using pongamia pinnata oil. The oil is extracted from pongamia seeds by using oil expeller naturally the pongamia seed has the best oil yield compare to other nonedible oil. We have planned to do the biodiesel with heterogeneous catalyst. The seaweed, which was collected from rameshwaram, which is cleaned, washed and dried. After dried the seaweed is sealed and kept in furnace for 1hr with 210C for convert into biochar. The biochar was further dried in hot air oven to remove excess moisture. We take zinc oxide which is doped with seaweed and stir for 3hrs to make it as a heterogeneous catalyst. we have tested the acid value for pongamia oil is contain high FFA value. so we have decided to go for two step process which is esterification and transesterification. Esterification process is done with oil, methanol and sulfuric acid with 60C and 45 min stirring. after esterification process the oil will reduce the FFA value less than 1 .Now transesterification process takes place for 1hr with the heterogeneous catalyst we prepared by using magnetic stirrer. After the reaction over the solution is poured into separating funnel after 6hrs the biodiesel is transfer to the container and is used for internal combustion engine study to know the engine performance and also emission. The biodiesel helps to reduce the greenhouse has emission and also it is eco-friendly. By using pongamia oil with is easily available, renewable source and also cost effective.

6.2 CONCLUSION:

Pongamia oil turned into clean fuel using seaweed charcoal (biochar) and zinc oxide! This eco-friendly biodiesel ran well in an engine, reducing emissions.

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