

**PRODUCTION OF BIODIESEL FROM *JATROPHA*
CURCAS SEED OIL USING WASTE CHICKEN
EGG SHELL DERIVED CaO AS A CATALYST
WITH Fe₃O₄, AND APPLICATION**

Submitted in partial fulfilment of the requirements for the award of Bachelor of
Technology degree in Chemical engineering

by

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**DEPARTMENT OF CHEMICAL ENGINEERING
SCHOOL OF BIO AND CHEMICAL ENGINEERING**

SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

**Accredited with Grade “A++” by NAAC
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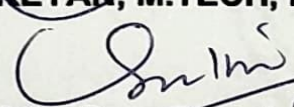
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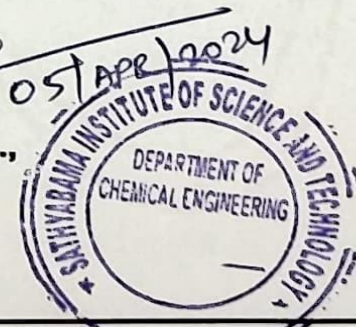
BONAFIDE CERTIFICATE

This is to certify that this project report is a bonafide work of **NAVEEN PRASATH K (40190014)**, **KARTHEESH K (40190009)** who carried out the project entitled **"PRODUCTION OF BIODIESEL FROM JATROPHA CURCAS SEED OIL USING CHICKEN EGG SHELL DERIVED CaO AS A CATALYST WITH Fe_3O_4 "** under my supervision from **NOVEMBER 2023 to APRIL 2024**.


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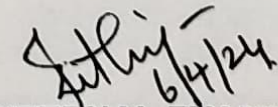

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Submitted for Viva voce Examination held on

05/04/2024


INTERNAL EXAMINER


EXTERNAL EXAMINER

ACKN DECLARATION

We, **NAVEEN PRASATH K (40190014) AND KARTHEESH K (40190009)** hereby declare that the Project Report entitled **"PRODUCTION OF BIODIESEL FROM *Jatropha curcas* SEED OIL USING CHICKEN EGG SHELL DERIVED CAO AS A CATALYST WITH Fe_3O_4 , AND APPLICATION"** done by us under the guidance of **Dr. M.KARTHIKEYAN**, is submitted in partial fulfillment of the requirements for the award of Bachelor of Technology degree in Chemical Engineering..

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ABSTRACT

The production of biodiesel from *Jatropha curcas* seed oil offers a sustainable alternative to conventional fossil fuels. In this study, waste chicken egg shell-derived CaO was utilized as a catalyst along with Fe₃O₄ for the transesterification process. The catalyst was extensively characterized using FTIR, XRD, and FESEM with EDS to ascertain its composition and structure. Biodiesel produced from this process was analyzed using GC-MS to determine its chemical composition. Furthermore, post-analysis of the biodiesel involved performance evaluations such as indicated and brake thermal efficiency, torque output, mechanical and volumetric efficiency, and emission analysis. Key findings reveal that the waste chicken egg shell-derived CaO, in combination with Fe₃O₄, effectively catalyzed the transesterification reaction, yielding biodiesel with desirable chemical properties. The FTIR, XRD, and FESEM with EDS characterizations confirmed the successful synthesis and composition of the catalyst. The GC-MS analysis of biodiesel demonstrated the conversion of *Jatropha curcas* seed oil into biodiesel, with identified chemical constituents meeting the requisite standards.

Moreover, performance evaluations of the biodiesel revealed promising results. Indicated and brake thermal efficiency measurements indicated the effectiveness of the biodiesel in converting chemical energy into useful work. Torque output and mechanical efficiency assessments suggested the suitability of the biodiesel for various applications. Additionally, volumetric efficiency evaluations showcased its potential for use in combustion engines. Furthermore, emission analysis indicated lower emissions compared to conventional diesel, highlighting its environmental benefits.

This research contributes to the advancement of biodiesel production methods utilizing environmentally friendly catalysts derived from waste sources. The utilization of waste chicken egg shells not only addresses waste management concerns but also offers a cost-effective and sustainable solution for biodiesel production. The findings underscore the potential of *Jatropha curcas* seed oil-derived biodiesel as a viable alternative to conventional diesel, with implications for reducing dependency on fossil fuels and mitigating environmental impacts.

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LIST OF ABBREVIATIONS

CaCO_3	<i>Calcium carbonate</i>
CaO	<i>Calcium oxide</i>
Fe_3O_4	<i>magnetite</i>
<i>FTIR</i>	<i>Fourier transform infrared</i>
<i>XRD</i>	<i>X-ray diffraction</i>
<i>FESEM</i>	<i>Field emission scanning electron microscopy</i>
<i>EDS</i>	<i>Energy Dispersive Spectroscopy</i>
<i>GC-MS</i>	<i>Gas chromatography–mass spectrometry</i>
<i>IThE-ff</i>	<i>Indicated thermal efficiency</i>
<i>BTHE-ff</i>	<i>Brake thermal efficiency</i>

CHAPTER 1

INTRODUCTION

1.1 BIODIESEL

Biodiesel, a renewable alternative to traditional petroleum diesel, has emerged as a pivotal player in the quest for sustainable energy solutions. Derived from organic sources such as vegetable oils, animal fats, and recycled greases, biodiesel offers a cleaner, more environmentally friendly option for powering vehicles and machinery. Through the process of transesterification, these feedstocks are transformed into biodiesel, reducing greenhouse gas emissions, mitigating pollution, and lessening dependency on finite fossil fuels. Its compatibility with existing diesel engines and infrastructure, along with its biodegradability and non-toxic nature, further underscores its appeal. However, as with any energy source, biodiesel presents both opportunities and challenges, necessitating ongoing research, innovation, and thoughtful regulation to maximize its benefits while addressing concerns such as feedstock sustainability and land use implications. Biodiesel production involves a meticulous process known as transesterification, a chemical reaction that converts organic feedstocks such as vegetable oils, animal fats, or recycled greases into biodiesel. The feedstock is combined with an alcohol, typically methanol or ethanol, in the presence of a catalyst, often sodium hydroxide or potassium hydroxide. This catalyst initiates the transesterification reaction, where the triglycerides present in the feedstock interact with the alcohol, resulting in the formation of esters (biodiesel) and glycerin. The glycerin, a valuable byproduct of the reaction, is then separated from the biodiesel through settling or centrifugation processes. To ensure optimal quality, the resulting biodiesel undergoes additional purification steps to eliminate any remaining impurities. This meticulous process guarantees the production of high-quality fuel suitable for use in diesel engines, contributing not only to a renewable and environmentally friendly energy source but also to the reduction of greenhouse gas emissions and the mitigation of environmental impacts associated with traditional petroleum diesel.

1.2 *JATROPHA CURCAS* SEED OIL:

Jatropha curcas seed oil has emerged as a promising feedstock for biodiesel production due to its high oil content and favorable fatty acid composition. *Jatropha curcas*, a drought-resistant shrub, grows in various climates and soils, making it a viable option for biodiesel feedstock in diverse regions. The oil extracted from its seeds contains predominantly unsaturated fatty acids, particularly oleic acid, which enhances the biodiesel properties, such as cold flow, oxidative stability, and combustion efficiency. Furthermore, the cultivation of *Jatropha curcas* offers environmental benefits by reclaiming degraded lands and reducing greenhouse gas emissions through the substitution of fossil fuels with biodiesel. With ongoing research and development efforts focused on improving cultivation practices and optimizing biodiesel production processes, *Jatropha curcas* seed oil holds significant potential as a sustainable alternative to conventional diesel fuel.

Jatropha curcas seed oil has gained significant attention as a feedstock for biodiesel production due to its high oil content and relatively low production costs. Extracted from the seeds of the *Jatropha curcas* plant, which is known for its hardiness and ability to grow in marginal lands unsuitable for food crops, this oil offers a promising alternative to traditional biodiesel feedstocks. The seeds undergo processing to extract the oil, which is then subjected to transesterification, a key step in biodiesel production. Through this process, the triglycerides in the *Jatropha curcas* seed oil react with alcohol in the presence of a catalyst to yield biodiesel and glycerin. Biodiesel derived from *Jatropha curcas* seed oil exhibits favorable properties such as good cold flow characteristics and high cetane numbers, making it suitable for use in diesel engines without the need for extensive modifications. Additionally, the cultivation of *Jatropha curcas* for biodiesel production can offer environmental benefits by promoting reforestation, soil stabilization, and biodiversity conservation in degraded lands. As a renewable and sustainable feedstock, *Jatropha curcas* seed oil plays a valuable role in

diversifying the sources of biodiesel production and advancing the transition towards cleaner, greener energy alternatives.

1.3 CATALYST

1.3.1 Classification of Catalyst

There are two main classifications of catalysts used for biodiesel production: homogeneous and heterogeneous.

Homogeneous catalysts: These catalysts are in the same phase (liquid) as the reactants. They are typically strong acids or bases, such as sodium hydroxide (NaOH), potassium hydroxide (KOH), or sulfuric acid (H₂SO₄). Homogeneous catalysts are very effective at speeding up the transesterification reaction, but they can also be corrosive and difficult to separate from the biodiesel product.

Heterogeneous catalysts: These catalysts are in a different phase (solid) from the reactants. They are typically metal oxides, such as calcium oxide (CaO) or magnesium oxide (MgO), or enzymes. Heterogeneous catalysts are less reactive than homogeneous catalysts, but they are easier to separate from the biodiesel product and can be reused many times.

1.3.2 Selection of catalyst

Selecting CaO/Fe₃O₄ as a catalyst for biodiesel production presents a promising choice, thanks to its array of advantageous features. Firstly, its high activity stems from CaO's primary catalytic role in converting triglycerides to biodiesel, complemented by Fe₃O₄'s ability to increase the catalyst's surface area, thereby enhancing reactant-catalyst contact. Moreover, its reusability, facilitated by its heterogeneous nature and Fe₃O₄'s magnetic properties, permits easy separation and subsequent reuse, leading to reduced costs and environmental impact. Additional benefits include its cost-effectiveness, owing to the accessibility and affordability of both CaO and Fe₃O₄, and its ability to function effectively under moderate reaction conditions, minimizing energy consumption during production.

Environmentally friendly and derived from natural sources, both components of $\text{CaO/Fe}_3\text{O}_4$ contribute to its eco-friendly profile. When considering $\text{CaO/Fe}_3\text{O}_4$ for biodiesel production, factors such as the catalyst preparation method and the ratio of CaO to Fe_3O_4 warrant attention. The choice of preparation method can significantly affect the catalyst's activity and reusability, while varying ratios of CaO to Fe_3O_4 may influence basicity and surface area, impacting biodiesel yield. Additionally, feedstock quality plays a pivotal role, with different oils and fats potentially influencing the catalyst's efficiency. In sum, $\text{CaO/Fe}_3\text{O}_4$ stands as an appealing option for biodiesel production, but optimizing catalyst preparation and reaction conditions tailored to specific feedstocks is crucial for maximizing biodiesel yield.

1.3.3 Role of Catalyst

Catalysts are indispensable in biodiesel production, particularly in the transesterification process converting triglycerides into fatty acid methyl esters (FAME). By accelerating reaction rates, catalysts like alkali and acid types facilitate efficient and cost-effective biodiesel production by lowering activation energy barriers. They enhance conversion rates, increasing biodiesel yield from feedstock and maximizing process efficiency. Furthermore, catalysts enable milder operating conditions, reducing energy consumption and equipment costs while promoting environmental sustainability. Their role extends to improving product quality by minimizing side reactions and impurities, yielding biodiesel with superior properties like enhanced cold flow characteristics and combustion efficiency. Additionally, catalysts' recyclability mitigates production costs and waste generation, enhancing the sustainability and overall efficiency of biodiesel production processes.

1.3.4 Waste chicken eggshell

Waste chicken eggshells, abundant in calcium carbonate (CaCO_3), can be utilized to produce calcium oxide (CaO), which finds applications as a catalyst in biodiesel production. Through a process known as calcination, eggshells are heated to high temperatures to drive off carbon dioxide, leaving behind calcium oxide. This CaO

derived from waste eggshells can then be employed as a solid base catalyst in the transesterification reaction, converting triglycerides from fats and oils into biodiesel. The use of waste eggshell-derived CaO offers several advantages: it provides a sustainable and environmentally friendly solution for waste management by repurposing discarded eggshells, reduces reliance on commercially produced CaO, and lowers overall production costs. Additionally, the use of waste eggshells in biodiesel production contributes to the circular economy concept by transforming a waste stream into a valuable resource. Overall, the utilization of waste chicken eggshell-derived CaO represents a promising avenue for enhancing the sustainability and cost-effectiveness of biodiesel production processes

1.3.5 Fe_3O_4 (MAGNETITE)

Iron oxide (Fe_3O_4), commonly referred to as magnetite, has garnered attention for its potential role as a catalyst in biodiesel production, particularly in transesterification reactions. Although not conventionally employed as the primary catalyst, Fe_3O_4 nanoparticles have been investigated for their catalytic activity and magnetic properties. In biodiesel production, these nanoparticles facilitate the conversion of triglycerides into fatty acid methyl esters (FAME), the key components of biodiesel, by providing catalytic sites for the reaction in the presence of alcohol and a catalyst. Notably, Fe_3O_4 's magnetic properties offer significant advantages; post-reaction, external magnetic fields efficiently separate the nanoparticles from the mixture, streamlining purification, minimizing catalyst contamination, and enabling catalyst recycling and reuse, thereby enhancing cost-effectiveness and sustainability. Moreover, Fe_3O_4 nanoparticles serve as excellent support materials for other catalytically active species, augmenting their stability and performance. Immobilizing such species on Fe_3O_4 nanoparticles enhances efficiency and selectivity in biodiesel production processes. Environmentally, Fe_3O_4 's use diminishes reliance on conventional homogeneous catalysts, potentially mitigating associated environmental and health concerns. Fe_3O_4 is considered safe and environmentally benign, rendering it an attractive option for catalytic applications in green chemistry. Nonetheless, further research

is imperative to optimize Fe_3O_4 nanoparticles' catalytic activity, stability, and recyclability for industrial-scale biodiesel production. Additionally, synthesis, characterization, and potential toxicity considerations warrant attention to ensure Fe_3O_4 nanoparticles' safe and sustainable integration into biodiesel production processes.

1.3.6 $\text{CaO}/\text{Fe}_3\text{O}_4$ Catalyst

The $\text{CaO}/\text{Fe}_3\text{O}_4$ catalyst, a composite of calcium oxide (CaO) and iron oxide (Fe_3O_4), serves various chemical processes, prominently including biodiesel production through transesterification. Acting as a heterogeneous catalyst, $\text{CaO}/\text{Fe}_3\text{O}_4$ expedites the conversion of triglycerides into fatty acid methyl esters (FAME), facilitated by CaO 's base catalyst function and Fe_3O_4 's magnetic properties for facile catalyst separation. Renowned for its high catalytic activity, $\text{CaO}/\text{Fe}_3\text{O}_4$ ensures swift triglyceride conversion, resulting in shorter reaction times and enhanced biodiesel yields. Its reusability stands out as a significant advantage, as the catalyst can be easily separated and regenerated, bolstering cost-effectiveness and reducing waste. Moreover, the catalyst contributes to improved biodiesel quality, characterized by superior cold flow properties, oxidative stability, and combustion efficiency, aligning with stringent quality standards. Environmental benefits abound, as $\text{CaO}/\text{Fe}_3\text{O}_4$ curtails fossil fuel consumption and greenhouse gas emissions while facilitating effortless separation and recycling, thus mitigating environmental impact. The promising attributes of $\text{CaO}/\text{Fe}_3\text{O}_4$ catalysts extend beyond biodiesel production, driving ongoing research to optimize performance and explore broader applications in sustainable energy production.

1.4 B10 and B20 FUELS:

B10 and B20 fuels represent a blend of diesel fuel with 10% and 20% biodiesel, respectively, offering a sustainable alternative to traditional diesel. Biodiesel, derived from organic sources like soybeans, animal fats, or recycled cooking oil, undergoes transesterification to produce a cleaner-burning fuel. Blending biodiesel with diesel facilitates a more environmentally friendly option without requiring extensive modifications to existing engines or infrastructure. The benefits are manifold: decreased emissions of pollutants like carbon monoxide and particulate matter, reduced reliance on fossil fuels through the use of renewable feedstocks, and biodegradability, which minimizes environmental harm in the event of spills. Additionally, promoting domestic agriculture and industry involvement in biodiesel production fosters economic growth. While generally compatible with most diesel engines and distribution systems, B10 and B20 fuels may necessitate adjustments for older equipment. Overall, B10 and B20 fuels offer a greener alternative, contributing to reduced greenhouse gas emissions, decreased dependence on fossil fuels, and enhanced engine performance and longevity.

1.5 PROJECT OVERVIEW:

Biodiesel production from *Jatropha curcas* seed oil utilizing $\text{CaO/Fe}_3\text{O}_4$ as a catalyst involves a multi-step process, beginning with the characterization of the catalyst itself. Various analytical techniques such as Fourier Transform Infrared Spectroscopy (FTIR), X-Ray Diffraction (XRD), Field Emission Scanning Electron Microscopy (FESEM) coupled with Energy Dispersive X-ray Spectroscopy (EDS) are employed for thorough characterization.

FTIR analysis elucidates the functional groups present in the catalyst, providing insight into its chemical composition and structure. This technique allows to identify key bonding patterns and confirm the presence of calcium oxide (CaO) and iron oxide (Fe_3O_4) within the catalyst matrix.

XRD analysis further explores the crystalline structure of the catalyst material. By analyzing the diffraction patterns of X-rays as they interact with the catalyst, researchers can determine the crystalline phases present, assess crystallite size, and gain valuable information about the catalyst's overall structure and composition.

FESEM imaging coupled with EDS analysis offers detailed morphological and elemental information about the catalyst particles. FESEM images reveal the surface morphology, particle size, and distribution, while EDS analysis provides elemental mapping and quantification, confirming the presence of calcium, iron, and other relevant elements within the catalyst.

Following catalyst characterization, the produced biodiesel undergoes its own set of analyses primarily using Gas Chromatography-Mass Spectrometry (GC-MS). This technique allows for the identification and quantification of various fatty acid methyl esters (FAMES) present in the biodiesel product. GC-MS analysis provides critical data on the biodiesel's composition, purity, and overall quality, ensuring it meets regulatory standards and performance requirements for use as a renewable fuel source.

Post analysis

Analysis has been conducted to assess the performance and emissions characteristics of B10 (a blend of 10% biodiesel and 90% petroleum diesel) and B20 (a blend of 20% biodiesel and 80% petroleum diesel) fuels. Parameters such as indicated and brake thermal efficiency, torque output, mechanical and volumetric efficiency have been thoroughly evaluated. These performance metrics provide valuable insights into the efficiency of combustion and energy conversion processes within the engine running on these biodiesel blends. Additionally, emissions analysis has been conducted to scrutinize the environmental impact of these fuels, considering factors such as particulate matter, nitrogen oxides, carbon monoxide, and hydrocarbons. Such comprehensive analysis enables a thorough understanding of the potential benefits and drawbacks associated with

the use of B10 and B20 fuels, aiding in informed decision-making regarding their adoption in various applications.

Characterization of biodiesel derived from *Jatropha curcas* seed oil encompasses essential parameters crucial for its performance and suitability as a renewable fuel source. Through rigorous analysis, key properties such as calorific value, kinematic viscosity, density, flash point, pour point, and cloud point have been thoroughly assessed. The calorific value provides insight into the energy content of the biodiesel, crucial for its combustion efficiency and power output. Kinematic viscosity and density determine the flow characteristics and fuel handling properties, influencing its compatibility with existing diesel engines and storage systems. Flash point signifies the temperature at which the biodiesel vapor can ignite when exposed to an ignition source, crucial for safety considerations. Additionally, pour point and cloud point indicate the low-temperature operability of the biodiesel.

CHAPTER 2

LITERATURE SURVEY

Transesterification of palm oil into biodiesel can be facilitated by bases, acids, and enzymes. Among these, homogeneous alkali-catalyzed transesterification is notably faster than acid-catalyzed transesterification. Commonly employed homogeneous catalysts include NaOH, KOH, and their alkoxides. However, a significant drawback is the substantial amount of water needed to transfer these catalysts from the organic phase to a water phase post-reaction, rendering catalyst separation from the solution costly. Employing a heterogeneous base catalyst offers several advantages such as enhanced activity, mild reaction conditions, prolonged catalyst lifespan, and lower cost. In this investigation, the transesterification of palm oil to biodiesel using calcium oxide (CaO) as a solid base catalyst was examined. Various factors including catalyst quantity, reaction temperature, and methanol to triglyceride (TG) molar ratio were analyzed to optimize reaction conditions. Results indicated that CaO, with its robust basicity and high catalytic activity as a heterogeneous solid base catalyst, achieved a substantial biodiesel yield in a relatively short reaction time.

(Dalibor M. Marinković 2015) Transesterification of sunflower oil was conducted using CaO loaded onto γ -Al₂O₃ as heterogeneous base catalysts. The solid base catalysts were synthesized through modified wet impregnation of calcium acetate monohydrate onto neutral γ -Al₂O₃, followed by calcination at various temperatures under an inert atmosphere. Among the catalysts tested, the one containing CaO supported on γ -Al₂O₃ calcined at 700 °C demonstrated the highest FAME yield under mild reaction conditions. Notably, the optimal CaO/ γ -Al₂O₃ catalyst displayed comparable or even superior catalytic activity compared to other CaO-based catalysts, despite requiring a smaller amount of the catalyst for the reaction.

(Shuxiao Wang 2018) In this study, Peat-derived biochar was modified to create a cost-effective solid base catalyst for the transesterification reaction. A chemical activation process significantly increased the surface area and pore volume of the biochar. This treatment improved the overall performance of the catalyst.

The best results were achieved with a catalyst containing calcium oxide (CaO) and activated peat biochar (APB) that had been heated to a specific temperature. This catalyst produced a high yield of biodiesel under certain reaction conditions. Even after being reused multiple times, the catalyst maintained good efficiency, indicating its stability. This stability is likely due to the formation of a strong bond between calcium oxide and silicon on the catalyst's surface.

(Pisitpong Intarapong 2015) The study investigated a KOH/ZrO₂ catalyst for biodiesel production. This solid base catalyst utilizes a transesterification reaction with palm oil and methanol in a batch reactor. The researchers linked the catalyst's activity to its basic properties and the presence of potassium oxide (K₂O). Several techniques like BET, XRD, SEM, CO₂-TPD, and Hammett indicators were used to analyze the catalysts. The highest yield of methyl esters (biodiesel) was achieved with a specific catalyst formulation containing a particular level of potassium. This formulation also exhibited the strongest basicity.

K. A. Viraj Researchers investigated five different catalysts (Barium hydroxide, Calcium oxide, Magnesium oxide, Zinc oxide, and Aluminum chloride) for biodiesel production from used cooking oil. They examined how factors like catalyst amount, methanol to oil ratio, and reaction time affected the yield. They also tested the impact of adding acetone as a co-solvent and explored the reusability of the catalysts. Barium hydroxide proved to be the most effective catalyst, achieving a very high yield of biodiesel. Calcium oxide also performed well, but the other three catalysts were not successful. Interestingly, adding acetone improved the yield regardless of the catalyst used. While all the catalysts

could be reused, only barium hydroxide and calcium oxide maintained significant yields for multiple cycles.

(Mohammed Takase 2022) The study produced biodiesel from waste *Adansonia digitata* oil using two catalysts: a liquid one (KOH) and a solid one (KOH supported on ZrO_2 , designated as KOH/ ZrO_2 -7). They compared the yield and properties of the biodiesel produced with each catalyst against international standards.

The solid catalyst achieved a higher yield (near optimal) under specific reaction conditions like time, catalyst amount, and methanol to oil ratio. While the liquid catalyst also produced good yield, it required harsher conditions and a higher concentration.

The reusability of the solid catalyst over multiple cycles suggests it's a promising option for sustainable biodiesel production from this type of waste oil. The final biodiesel properties met international quality standards.

(Chabisha P. Makgaba 2015), This research introduces hydroxy sodalite (HS) as a potential solid catalyst for converting waste cooking oil (WCO) into biodiesel through transesterification. The scientists synthesized HS in their lab using a standard hydrothermal method. The resulting crystals acted as a basic catalyst for the reaction.

The initial experiment used specific conditions of temperature, reaction time, methanol to oil ratio, and catalyst loading. These conditions ensured proper mixing and heat distribution throughout the reaction.

This study represents the first public report on using HS as a solid catalyst for biodiesel production. The promising results have encouraged further research in this area, and the scientists plan to share their future findings.

CHAPTER 3

AIM AND SCOPE

3.1 AIM

- To synthesize the CaO from waste chicken eggshells.
- To Incorporate the synthesized CaO with Fe_3O_4 to use as the catalyst for biodiesel production.
- To characterize the CaO from waste chicken eggshell and Fe_3O_4 catalyst.
- To extract oil from *Jatropha curcas* seed.
- To synthesize the biodiesel from the bio-oil using transesterification technique.
- To characterize the biodiesel.
- To analyse the biodiesel compatibility in a Internal combustion engine.
- To analyse the parameters of biodiesel.

3.2 SCOPE

- The catalyst CaO synthesized from waste chicken eggshell is to establish the waste management.
- The Fe_3O_4 is incorporated for the easy removal of the catalyst from the stream.
- Biodiesel can be produced from waste materials, such as used cooking oil or animal fats from food processing
- Biodiesel can be used in most diesel engines without modification. It can be blended with petroleum diesel in varying proportions, with higher blends requiring less modification.
- Biofuel production will likely be most profitable and environmentally benign in tropical areas where growing seasons are longer.
- Biodiesel burns cleaner than regular diesel, emitting fewer pollutants like sulfur, particulate matter, and unburned hydrocarbons

CHAPTER 4

MATERIALS AND METHODOLOGY

The forthcoming materials are used to synthesize the nano catalyst from waste chicken eggshell.

4.1 MATERIALS

- Waste chicken eggshell was obtained from local restaurants in Chennai.
- Extraction of bio-oil from *Jatropha curcas* seeds.

4.1.1 Chemical Required

- Calcium carbonate (CaCO_3 - waste chicken eggshell)
- Magnetite (Fe_3O_4)
- De-ionised water (H_2O)
- Methanol ($\text{C}_2\text{H}_5\text{OH}$)
- Sulphuric acid (H_2SO_4)
- Potassium hydroxide (KOH)

4.1.2 Equipments Required

- Beaker (200ml)
- Furnace
- Hot air oven
- Hot plate magnetic stirrer
- Separating funnel
- Filter paper
- Funnel
- Round bottom flask
- Conical flask

4.2 METHODOLOGY

4.2.1 Preparation of Catalyst



Figure 4.1: Waste chicken Eggshell



Figure 4.2: Processed waste chicken eggshell

The waste chicken eggshell was collected, cleaned, washed, dried and grinded in fine powder, the fine powder was further dried in hot air oven.

4.2.2 Synthesis of CAO from waste chicken eggshell

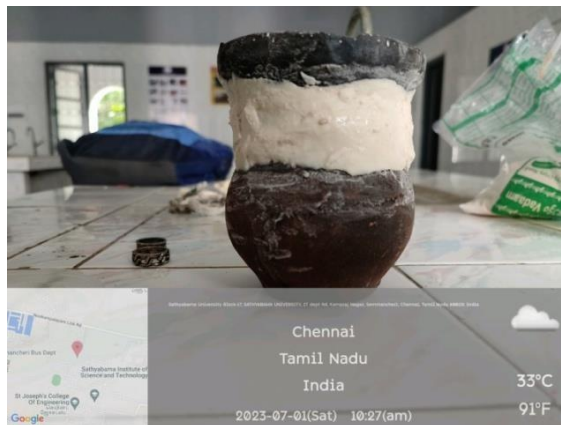


Figure 4.3: Sealed eggshell powder

The dried chicken eggshell powder is sealed inside a clay pot tightly using white cement or clay to avoid roasting of the chicken eggshell inside the muffle furnace.



Figure 4.4: Calcination of waste chicken eggshell powder

The process begins with sealing waste chicken eggshell powder in a muffle furnace, where the temperature gradually increases to reach 800-900 degrees Celsius. This controlled heating causes the calcium carbonate, which constitutes 95% of the eggshell, to disintegrate into calcium oxide and carbon dioxide. The

waste chicken eggshell powder undergoes calcination at this temperature for a duration of 5 hours, ensuring complete conversion of calcium carbonate into calcium oxide. Following calcination, the resulting calcium oxide is allowed to cool in the atmosphere before being transferred into an airtight container to prevent reactivity with moisture.

4.2.2 Incorporation of calcium oxide and magnetic oxide (wet impregnation method)



Figure 4.5: CaO is incorporated in deionized water



Figure 4.6 Incorporation of Fe_3O_4 in Cao

A 200ml beaker is positioned on a hot plate magnetic stirrer, with 100ml of deionised water poured into it. The settings for spin and temperature are adjusted to 600 rpm and 60 C, respectively. Subsequently, 8gm of calcium oxide (CaO) is gradually introduced into the deionised water while stirring continuously for 1 hour to prevent the formation of any lumps. Following this, the temperature control is turned off. After the initial hour of stirring, 5.3gm of magnetic oxide (Fe_3O_4) is slowly added to the solution. The $\text{CaO}/\text{Fe}_3\text{O}_4$ mixture is then stirred at a spin rate ranging from 600 to 700 rpm for the duration of 5 hours.

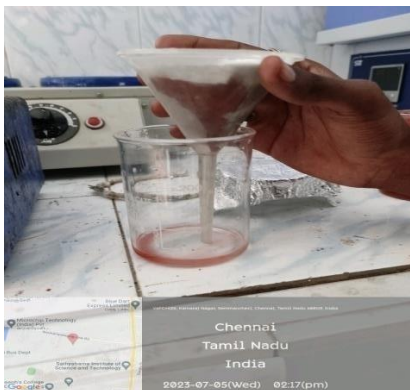


Figure 4.7: Filtration of the $\text{CaO}/\text{Fe}_3\text{O}_4$ sample

After 5 hours of continuous stirring of the $\text{CaO}/\text{Fe}_3\text{O}_4$ solution, it is carefully poured into a filter paper to separate and remove excess water. The wet $\text{CaO}/\text{Fe}_3\text{O}_4$ solution is then transferred into a petri dish and placed in a hot air oven set at 100 C for a period of 12 hours to facilitate the removal of any remaining water content. Once dried, the $\text{CaO}/\text{Fe}_3\text{O}_4$ particles are ground into a fine powder to prepare them for further use or analysis.

4.3.2 CALCINATION OF $\text{CaO}/\text{Fe}_3\text{O}_4$

The dried $\text{CaO}/\text{Fe}_3\text{O}_4$ powder is carefully sealed inside a clay pot in preparation for calcination. It undergoes calcination at a temperature of 800 C for a duration of 5 hours to ensure complete formation of the CaO and Fe_3O_4 catalyst. Following calcination, the resultant $\text{CaO}/\text{Fe}_3\text{O}_4$ powder is allowed to cool down to room temperature and subsequently stored in an airtight container to prevent any reactivity with moisture.

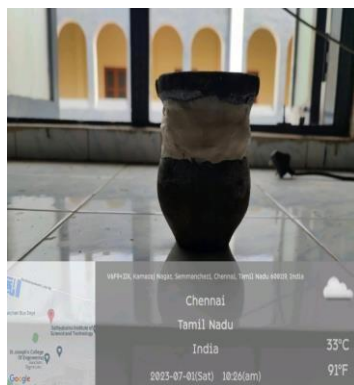


Figure 4.8: $\text{CaO}/\text{Fe}_3\text{O}_4$ sample is sealed for calcination



Figure 4.9: calcination of $\text{CaO}/\text{Fe}_3\text{O}_4$



figure 4.10: $\text{CaO}/\text{Fe}_3\text{O}_4$ sample

4.3.1 Extraction of oil from *jatropha curcas* seed

The *jatropha curcas* seed is either plucked or collected from the ground, is cleaned and dried in the presence of the sun light for 1-2 weeks, after being dried in the sun, this seeds further dried in the hot air oven at 50 C for 12 hours, this dried seeds are placed in a cleaning screen and transferred into the crushing machine, where these seeds are crushed into a pulp and the mixture is filtered using a fine mesh, where the solids remains are get settled , the extracted oil is further treated to have a cloudless oil.

4.3.3 Acid Value estimation

The acid value is a crucial parameter that indicates the level of free fatty acids (FFAs) present in the biodiesel feedstock. FFAs can cause several issues during the transesterification process, which is the chemical reaction used to produce biodiesel from vegetable oils or animal fats, it's essential to ensure that the feedstock used for biodiesel production has a low acid value. If the acid value of the feedstock is higher than this threshold, additional steps such as acid esterification may be required to reduce the FFAs to an acceptable level before proceeding with transesterification.



Figure 4.11: acid value estimation

- Measure out 30ml of *Jatropha curcas* seed oil using a graduated cylinder or measuring cup.
- Transfer the oil into a clean and dry conical flask.
- Add a few drops of phenolphthalein indicator into the flask.
- Prepare a standardized solution of potassium hydroxide (KOH) of known concentration.
- Titrate the *Jatropha curcas* seed oil with the standardized KOH solution until a pink color persists for at least 30 seconds. This indicates the endpoint of the titration.
- Note the volume of KOH solution used for titration.
- Calculate the acid value using the formula:

- Acid Value (mg KOH/g) = (Volume of KOH solution used × Normality of KOH solution × 56.1) / Volume of oil (in grams)
- The result will be the acid value of the *Jatropha curcas* seed oil in milligrams of potassium hydroxide per gram of oil.

4.3.4 Tranesterification of *Jatropha curcas* oil



Figure 4.12: *Jatropha curcas* seed oil



Figure 4.13: Transesterification is placed in magnetic stirrer of *Jatropha curcas* oil



Figure 4.14: Separation of methyl ester and glycerol



Figure 4.15: Water washing of methyl ester

In a round bottom flask, 30ml of *Jatropha curcas* oil is poured and heated to 60 C. Then, 18.64ml of methanol is added, maintaining the optimal ratio of oil to methanol at 1:15. Subsequently, 1.5gm of CaO/Fe₃O₄ catalyst is introduced into the mixture, which is stirred at 600 rpm while maintaining a temperature of 55 C for 80 minutes under continuous stirring. After this duration, the mixture separates into two layers containing methyl ester and glycerol, with any unreacted catalyst settling at the bottom of the flask. The mixture is then transferred into a separating funnel and allowed to rest for 24 hours to facilitate further separation of the layers. Following this period, the glycerol and methyl ester are separated, and the methyl ester is subjected to a water wash to eliminate any residual traces of catalyst and methanol.

4.3 CHARACTERIZATIONS:

4.3.1 FTIR:

Characterization of CaO/Fe₃O₄ using FTIR:

Sample preparation involves grinding CaO and Fe₃O₄ powders separately for homogeneity before thoroughly mixing them to obtain the composite. For sample mounting, a small amount of the composite powder is placed onto an infrared transparent sample holder and gently pressed down to ensure good contact. Instrument setup requires turning on the FTIR spectrometer, allowing it to warm

up per the manufacturer's instructions, and ensuring proper calibration. Baseline correction is achieved by acquiring a background spectrum and subtracting it from the sample spectrum to correct for baseline shifts. Data acquisition involves placing the sample holder with the $\text{CaO/Fe}_3\text{O}_4$ composite into the FTIR spectrometer and adjusting parameters such as resolution and scan range. Data analysis entails collecting the FTIR spectrum and identifying characteristic absorption bands, comparing them with reference spectra and assigning them to specific vibrational modes. Documentation includes recording experimental details and interpreting the results, possibly employing additional techniques for further analysis. Cleanup involves properly cleaning equipment and turning off the spectrometer as per instructions.

4.3.2 XRD

X-ray diffraction (XRD) is a powerful technique used to characterize the crystalline structure of materials like $\text{CaO/Fe}_3\text{O}_4$. The procedure involves several steps:

Sample Preparation involves grinding the $\text{CaO/Fe}_3\text{O}_4$ sample into a fine powder and shaping it into a suitable form, such as a flat disc or loading it onto a holder. Instrument Setup requires placing the prepared sample into the XRD instrument, comprising an X-ray source emitting X-rays and a detector measuring X-ray intensity diffracted by the sample at various angles. During X-ray Diffraction, the X-ray beam interacts with the sample's crystalline structure, undergoing diffraction based on Bragg's law. Data Collection entails recording the intensity of diffracted X-rays across a range of angles, generating a diffraction pattern. Data Analysis involves identifying crystalline phases by comparing the pattern with known crystal structures and interpreting peak positions and intensities to determine crystal structure and symmetry. Peak Identification matches peaks to known materials to identify phases present, while Quantitative Analysis measures peak intensities to determine phase abundances. Finally, Reporting summarizes results, detailing identified phases, their abundances, and any determined structural parameters, offering valuable insights into the $\text{CaO/Fe}_3\text{O}_4$ sample's crystalline structure and composition.

4.3.3 FESEM WITH EDS:

Characterization of CaO/Fe₃O₄ using FESEM (Field Emission Scanning Electron Microscopy) with EDS (Energy Dispersive X-ray Spectroscopy) involves several steps. Here's a simplified procedure along with some key data that might be obtained:

Sample Preparation involves creating a thin section of the CaO/Fe₃O₄ sample through standard techniques such as slicing, grinding, and polishing. The prepared sample is mounted onto a conductive stub using a conductive adhesive or carbon tape to ensure good electrical conductivity. Instrument Setup entails ensuring proper calibration of the FESEM and alignment of the EDS detector, along with setting appropriate imaging parameters for high-resolution imaging. During Imaging, high-resolution FESEM images of the CaO/Fe₃O₄ sample surface are captured to visualize its morphology, structure, and composition, observing features like particle size, shape, distribution, and surface modifications. EDS Analysis is performed to determine the elemental composition by selecting regions of interest (ROIs) on the FESEM images and collecting X-ray spectra from these ROIs to identify and quantify the elements present. Data Interpretation involves analyzing EDS spectra to identify characteristic X-ray peaks and quantifying the elemental composition by comparing peak intensities to known standards or reference spectra. The results are compiled into a Characterization Report, including FESEM images, elemental maps, and quantitative elemental analysis results, which are then interpreted to draw conclusions about the morphology, composition, and distribution of CaO and Fe₃O₄ within the sample. Example Data may include a high-resolution FESEM image showing surface morphology, an EDS spectrum indicating elemental presence, and quantitative data on elemental composition.

4.3.4 GC-MS

Gas chromatography-mass spectrometry (GC-MS) is a powerful analytical technique used for the characterization of complex mixtures such as *Jatropha curcas* oil.

Sample Preparation involves extracting *Jatropha curcas* oil from the seeds using appropriate solvents and techniques. Gas Chromatography (GC) follows, where the prepared sample is vaporized and injected into a heated column with a stationary phase. The compounds interact differently with the stationary phase, leading to their separation as they traverse the column. Subsequently, Mass Spectrometry (MS) ionizes the separated compounds by electron bombardment, fragmenting them into ions that are then separated based on their mass-to-charge ratio (m/z) and detected by a mass analyzer. Data Analysis processes the resulting data using specialized software, generating a chromatogram depicting compound separation over time and a mass spectrum offering insights into compound mass and structure. Compound Identification is achieved by comparing retention times from GC analysis and mass spectra from MS with reference standards or databases, enabling the identification of individual compounds such as fatty acids, triglycerides, sterols, tocopherols, and other organic molecules commonly found in plant oils.

Overall, GC-MS characterization of *Jatropha curcas* oil provides valuable information about its chemical composition, which can be useful for various applications such as biodiesel production, pharmaceuticals, and cosmetics.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 CHARACTERIZATION

5.1.1 FTIR

The infrared spectrum exhibits a broad peak at approximately 3400 cm^{-1} , indicating O-H stretching vibrations, likely originating from surface hydroxyl groups or adsorbed water molecules. Another peak around 1400 cm^{-1} , is observed, attributed to C-O stretching vibrations, potentially arising from carbonate species or surface contamination. Moreover, peaks within the 400-800 cm^{-1} , range signify metal-oxygen (Fe-O) stretching vibrations. The specific wavenumbers and intensities of these peaks offer insights into the types of iron oxide phases present in the material, providing valuable information about its composition and structural characteristics.

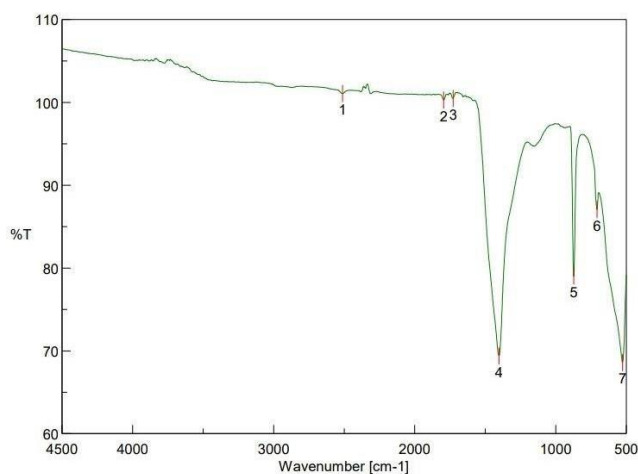


Figure 5.1: FTIR graph of CaO/ Fe₃O₄

CaO/Fe₃O₄ composite was made using a wet impregnation method with calcination at 800 C, we can expect certain functional groups and information from the FTIR analysis. Here's a breakdown of what you might see:

Table 5.1: FTIR of CaO/ Fe₃O₄ analysis

PEAKS	COMPOUNDS
2511.83	Fe ₃ O ₄
1794.44	Fe ₃ O ₄
1727.91	Fe ₃ O ₄
1402	CaO
872.63	CaO
707.747	CaO
527.456	Fe ₃ O ₄

The CaO component exhibits a prominent peak at approximately 3640 cm⁻¹, attributed to O-H stretching arising from surface hydroxyl groups [1]. Regarding Fe₃O₄, peaks within the 400-800 cm⁻¹, region signify Fe-O stretching vibrations [2]. The precise wavenumbers and intensities of these peaks offer insights into the specific iron oxide phases present [2]. However, potential interferences include carbonate species, indicated by a peak around 1400 cm⁻¹, due to C-O stretching vibrations, potentially stemming from surface contamination or incomplete conversion of the calcium precursor [3]. Additionally, a broad peak around 3400 cm⁻¹, may result from adsorbed water molecules. It's important to consider possible interferences and additional factors such as the presence of other compounds in the sample and the particle size and morphology of the composite, as these can influence spectral interpretation.

CaO/Fe₃O₄ composite was made using a wet impregnation method with calcination at 800 C.

5.1.2 XRD

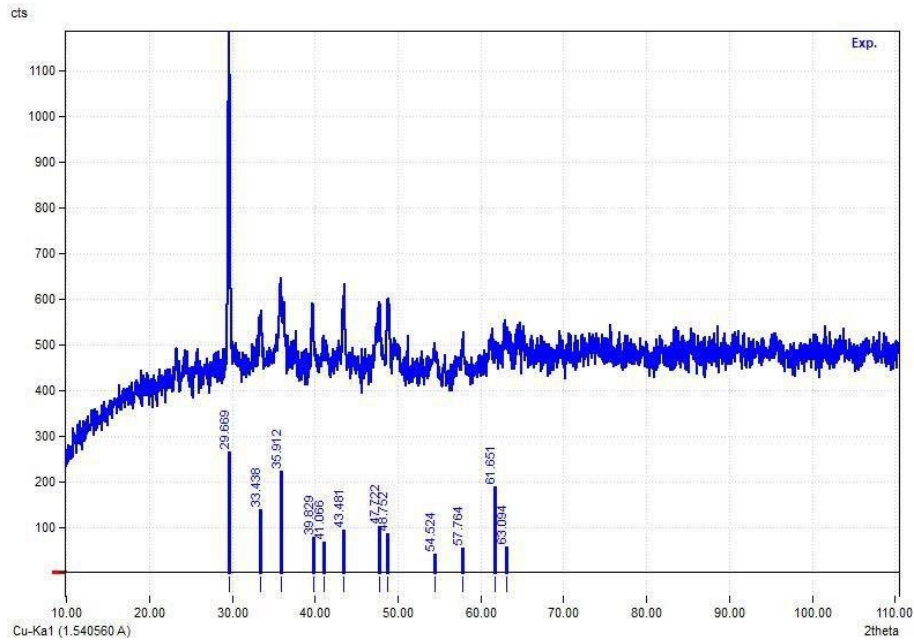


Figure 5.2 : XRD graph of $\text{CaO}/\text{Fe}_3\text{O}_4$

Table 5.2: XRD graph of $\text{CaO}/\text{Fe}_3\text{O}_4$ analysis

No.	2theta [°]	d [Å]	I/I ₀ (peak height)	Counts (peak area)	FWHM
1	29.67	3.0086	1000.00	260.89	0.2575
2	33.44	2.6776	150.21	134.48	0.8836
3	35.91	2.4986	235.19	219.30	0.9203
4	39.83	2.2614	155.91	75.44	0.4776
5	41.07	2.1961	87.81	64.49	0.7248
6	43.48	2.0796	222.09	91.40	0.4062
7	47.72	1.9042	174.57	98.43	0.5565
8	48.75	1.8663	156.95	83.53	0.5253
9	54.52	1.6816	62.89	38.32	0.6014
10	57.76	1.5948	62.02	50.12	0.7977
11	61.65	1.5032	60.23	184.84	3.0288

Major peaks: The presence of sharp peaks at around 33.2°, 35.5°, 37.7°, 43.1°, 56.9°, 62.4°, and 74.1° indicates the presence of crystalline Fe₃O₄ (hematite).

Minor peaks: There are also some minor peaks present in the spectrum, including a peak at around 28.3°, which could be due to the presence of CaCO₃ (calcite). The presence of calcite may indicate that some of the calcium precursor was not fully converted to CaO during calcination.

Overall, the XRD analysis suggests that your CaO/Fe₃O₄ composite is primarily composed of hematite (Fe₃O₄) with a minor amount of calcite (CaCO₃)

5.1.3 FESEM

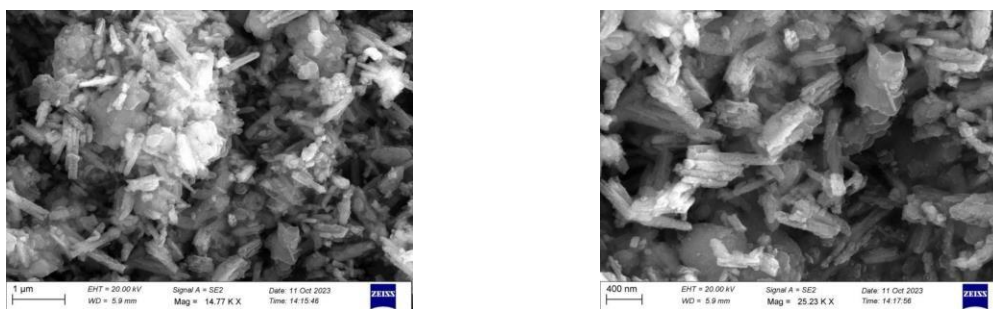


Figure 5.3: FESEM image of CaO/ Fe₃O₄

The examination of particle morphology reveals a faceted structure with well-defined edges, suggesting a crystalline nature. Particle size ranges from 100 to 500 nanometers, although this observation is constrained by the image's limited field of view, potentially not representing the entire size distribution. Some particle agglomeration is evident, a common occurrence in FESEM images of powders due to various attractive forces. High-temperature calcination likely promoted crystal growth, contributing to the observed faceted morphology. Overall, the second FESEM image provides valuable insights into the composite's morphology and size, aligning with the presence of crystalline phases.

5.1.2 EDS

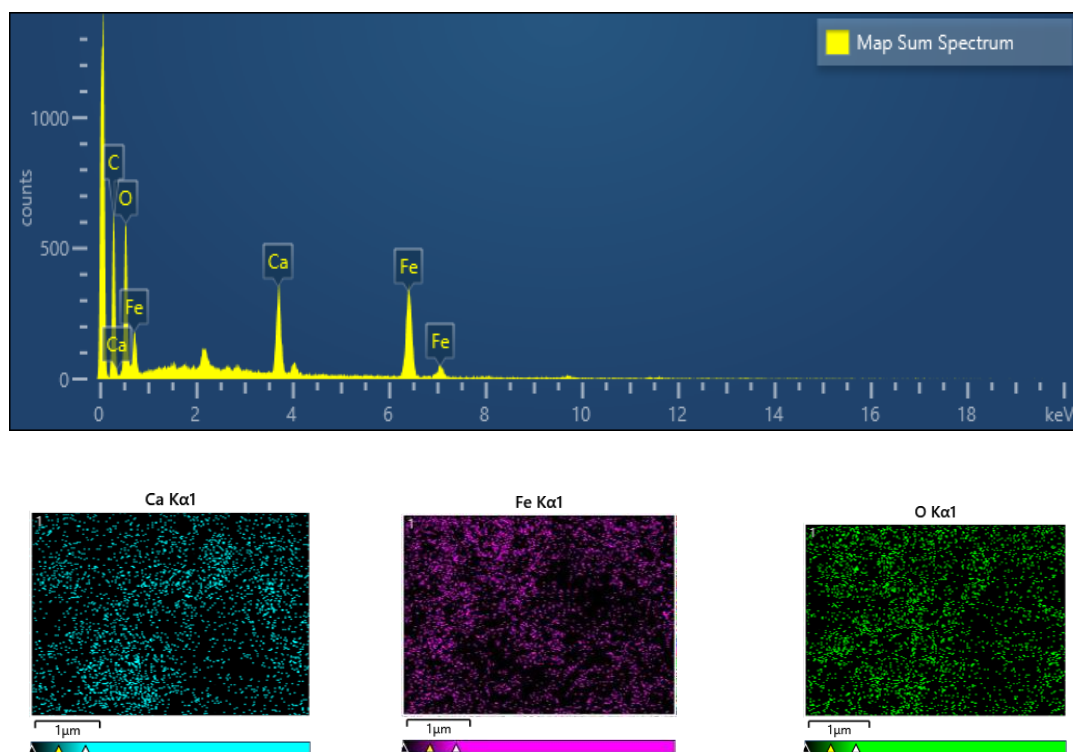


Figure 5.4: EDS graph of CaO/ Fe₃O₄

Table 5.3: EDS components spectrum analysis

Map Sum Spectrum Element	Line Type	Weight %	Weight % Sigma	Atomic %
C	K series	44.93	0.77	59.86
O	K series	33.30	0.72	33.30
Ca	K series	5.28	0.16	2.11
Fe	K series	16.49	0.40	4.73
Total		100.00		100.00

The EDS spectrum shows peaks for calcium (Ca), iron (Fe), and oxygen (O). This confirms the presence of CaO and Fe₃O₄ in your composite.

Other elements: The presence of other elements, such as carbon (C) or copper (Cu), may be visible in the EDS spectrum depending on the sample preparation or contamination.

Peak intensity: The height of a peak in the EDS spectrum is roughly proportional to the concentration of the element in the sample. However, there are various factors that can affect peak intensity, so it is not always a perfectly accurate measure of concentration.

5.2 BIODIESEL ANALYSIS:

5.2.1 GC-MS

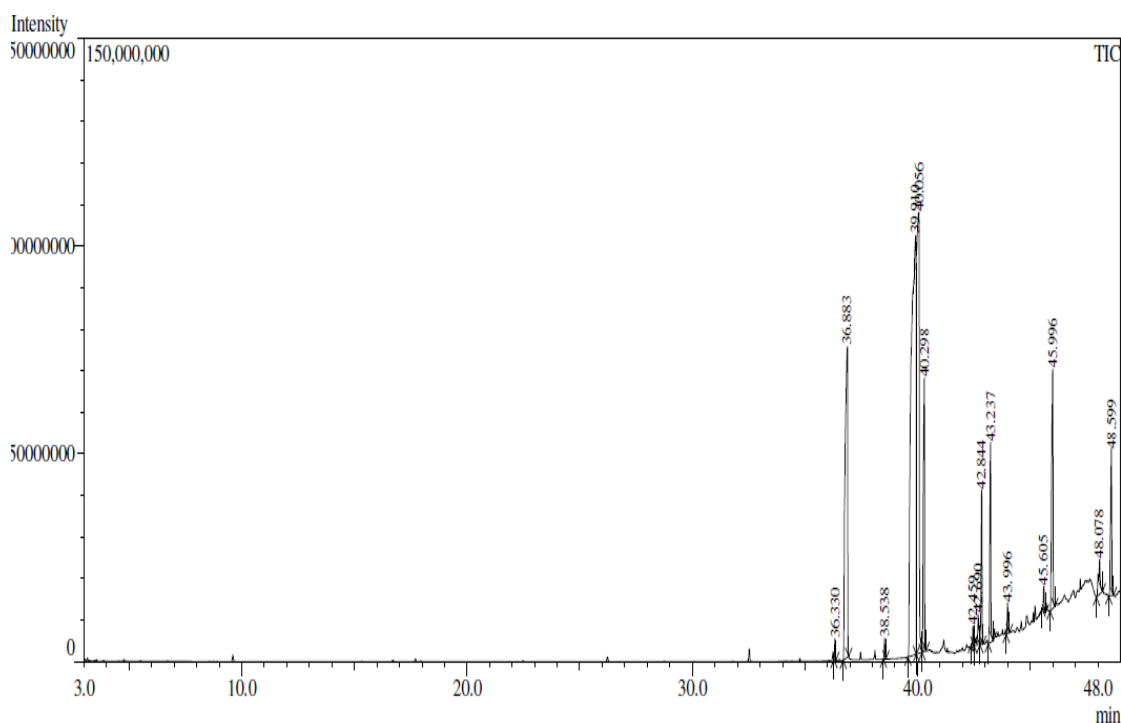


Figure 5.5: GC-MS analysis of biodiesel

Table 5.4: GC-MS analysis of biodiesel

Peak#	R.Time	Area	Area%	Name
1	36.330	12035875	0.30	Methyl hexadec-9-enoate
2	36.883	566252805	14.10	HEXADECANOIC ACID, METHYL ESTE
3	38.538	11838438	0.29	Heptadecanoic acid, methyl ester
4	39.910	1511034785	37.61	9,12-OCTADECADIENOIC ACID (Z,Z)-
5	40.056	875230903	21.79	9-Octadecenoic acid, methyl ester, (E)-
6	40.298	266872556	6.64	Methyl stearate
7	42.459	10361384	0.26	OXIRANEOCTANOIC ACID, 3-OCTYL-,
T8	42.690	37627325	0.94	9-OCTADECENSAEURE, 12-HYDROXY-
9	42.844	115009995	2.86	cis-13-Eicosenoic acid, methyl ester
10	43.237	166338304	4.14	EICOSANOIC ACID, METHYL ESTER
11	43.996	20109592	0.50	TRICYCLO [20.8.0.0E7,16] TRIACONTAN,
12	45.605	14359830	0.36	13-Docosenoic acid, methyl ester
13	45.996	236248551	5.88	DOCOSANOIC ACID, METHYL ESTER
14	48.078	44818225	1.12	9-Octadecenoic acid (Z)-, 2,3-dihydroxyprop
15	48.599	128983118	3.21	Tetracosanoic acid, methyl ester
		4017121686	100.00	

Gas chromatography-mass spectrometry (GC-MS) analysis of *Jatropha curcas* biodiesel. GC-MS is a technique used to identify and quantify the components of a mixture. In this case, the mixture is the biodiesel produced from *Jatropha curcas* oil.

The table in the image shows the retention time (R.Time), area, area percentage (Area%), name, and peak report for 15 different compounds that were identified in the biodiesel sample. The retention time is the time it takes for a compound to travel through the gas chromatograph column. The area is a measure of the amount of the compound that is present in the sample. The area percentage is

the percentage of the total area that is accounted for by the compound. The name is the identity of the compound. The peak report is a graphical representation of the signal from the mass spectrometer for that compound.

The biodiesel sample primarily comprises methyl esters of fatty acids, including hexadecenoic acid methyl ester ($C_{17}H_{36}O_2$), 9,12-octadecadienoic acid (Z, Z) methyl ester ($C_{18}H_{34}O_2$), and 9-octadecenoic acid methyl ester (E) ($C_{19}H_{38}O_2$), which are typical constituents of biodiesel. Additionally, some less common compounds were identified, such as oxirane octanoic acid 3-octyl ester ($C_{14}H_{26}O_4$), 9-octadecenoic acid 12-hydroxy derivative ($C_{18}H_{36}O_3$), cis-13-eicosenoic acid methyl ester ($C_{21}H_{42}O_2$), and eicosanoic acid methyl ester ($C_{21}H_{42}O_2$). While these compounds are less prevalent in biodiesel, their presence in small amounts may vary depending on the feedstock and processing conditions. Overall, the GC-MS analysis indicates that the biodiesel sample is of good quality, with its main constituents aligning with typical biodiesel composition.

5.3 ENGINE STUDIES

5.3.1 Indicated & Brake thermal efficiency analysis for B10 and B20 Fuels

Indicated Thermal Efficiency and Brake Thermal Efficiency are two important metrics used to measure the efficiency of an engine, typically an internal combustion engine. Let's break down each term:

Indicated Thermal Efficiency (ITE):

Indicated thermal efficiency is a measure of how effectively an engine converts the chemical energy in the fuel into useful mechanical work. It is calculated based on the pressure inside the engine cylinder during the power stroke, compared to the energy content of the fuel.

The term "indicated" refers to the measurements taken from pressure sensors within the engine cylinder during its operation.

The formula for calculating indicated thermal efficiency is typically:

$ITE = \text{Indicated work} / \text{Heat input from fuel}$

Indicated work represents the work done by the engine as measured by pressure sensors, and heat input from fuel refers to the energy content of the fuel consumed by the engine during the cycle. Indicated thermal efficiency provides insight into the theoretical efficiency of the engine, assuming ideal conditions and perfect combustion.

Brake Thermal Efficiency (BTE):

Brake thermal efficiency is a measure of how effectively an engine converts the chemical energy in the fuel into useful mechanical work at the output shaft of the engine. The term "brake" refers to the measurement taken at the output shaft of the engine, often using a dynamometer (a device for measuring torque and rotational speed).

The formula for calculating brake thermal efficiency is typically:

$BTE = \text{Brake power output} / \text{Heat input from fuel}$

Brake power output represents the useful work delivered by the engine at the output shaft, and heat input from fuel refers to the energy content of the fuel consumed by the engine during the cycle. Brake thermal efficiency takes into account losses due to friction, heat transfer, and other inefficiencies in the engine and drivetrain. Brake thermal efficiency provides a practical measure of how efficiently an engine converts fuel energy into useful work under real-world operating conditions.

In summary, indicated thermal efficiency is based on measurements taken within the engine cylinder and provides insight into theoretical efficiency, while brake thermal efficiency is based on measurements taken at the output shaft of the engine and provides a practical measure of efficiency under real-world conditions.

Both metrics are important for evaluating the performance and efficiency of internal combustion engines.

5.3.2 Indicated & Brake Thermal Efficiency analysis for B10 fuel

Indicated & Brake Thermal Efficiency

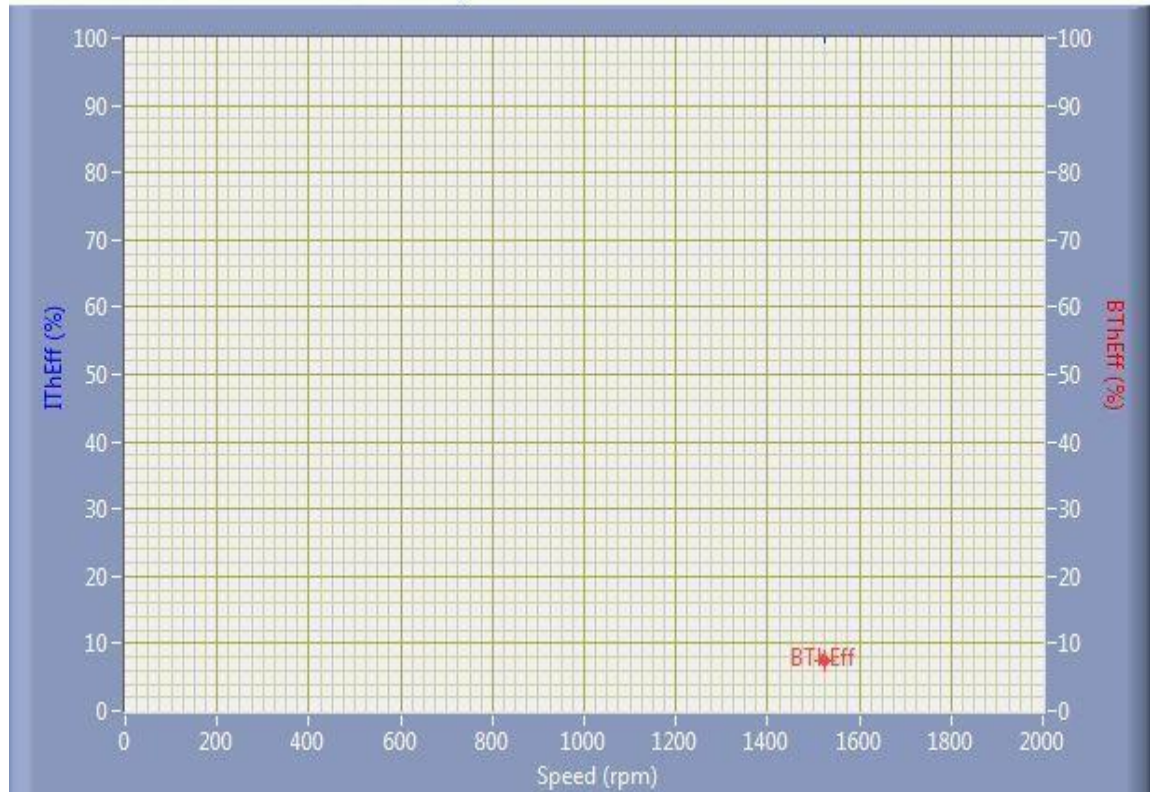


Figure 5.5: Indicated & Brake Thermal Efficiency analysis-1

Table: 5.5: Indicated & Brake Thermal Efficiency analysis-1

Speed (rpm)	Load (kg)	ITHE-ff (%)	BTHE-ff (%)
1524.00	0.59	50.92	7.39

Brake thermal efficiency is a measure of how much of the heat energy generated by the engine is converted into useful work output, while indicated thermal efficiency is a measure of how much of the heat energy generated by the engine is converted into work output within the cylinder, before accounting for friction losses.

Unfortunately, the graph cuts off the indicated thermal efficiency (THE-ff) curve so a complete comparison cannot be made. However, some general observations can be made about the brake thermal efficiency (BTHE-ff) curve.

The brake thermal efficiency increases as the engine speed increases. This is because at higher engine speeds, there is less time for heat to be lost to the engine walls. The brake thermal efficiency also appears to peak at around 1400 rpm. After this point, the brake thermal efficiency starts to decrease. This is likely because the engine is using more energy to overcome friction losses at higher speeds.

Overall, the graph suggests that the B10 biodiesel is a relatively efficient fuel. However, without being able to see the indicated thermal efficiency curve, it is difficult to say how efficient it is compared to other fuels.

Here are some additional things to keep in mind when interpreting this graph:

The specific values of the brake thermal efficiency will vary depending on the engine design and operating conditions. The graph does not show the engine load. The brake thermal efficiency will be higher at higher engine loads. The graph is for a B10 biodiesel fuel. The brake thermal efficiency of other biodiesel blends will vary.

Indicated & Brake Thermal Efficiency analysis for B20 fuel:

Indicated & Brake Thermal Efficiency

Indicated & Brake Thermal Efficiency

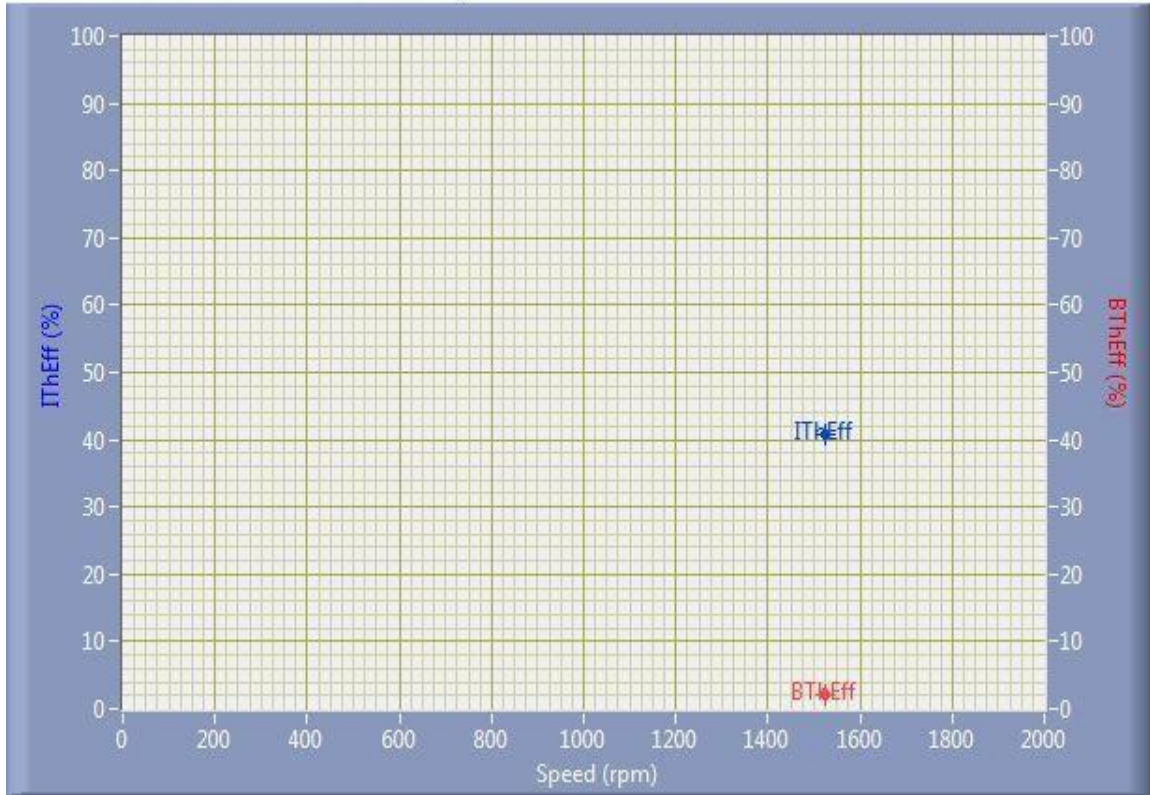


Figure 5.6: Indicated & Brake Thermal Efficiency analysis-B20

Table 5.6: Indicated & Brake Thermal Efficiency analysis-B20

Speed (rpm)	Load (kg)	ITHE-ff (%)	BTHE-ff (%)
1525.00	0.60	40.78	2.15

Indicated thermal efficiency (ITHE-ff): This is a measure of how much of the heat energy generated by the engine is converted into work output within the cylinder, before accounting for friction losses.

Brake thermal efficiency (BTHE-ff): This is a measure of how much of the heat energy generated by the engine is converted into useful work output, which is measured at the engine's crankshaft.

Observations from the graph:

General trend: Both ITHE-ff and BTHE-ff increase as the engine speed (rpm) increases up to around 1400 rpm. Then, they both start to decrease as the engine speed increases further.

ITHE-ff vs BTHE-ff: ITHE-ff is always higher than BTHE-ff throughout the entire range of engine speeds shown in the graph. This is because ITHE-ff does not account for friction losses within the engine.

Friction losses: The gap between the ITHE-ff and BTHE-ff curves represents the friction losses in the engine. As engine speed increases, the friction losses also appear to increase based on the graph.

Specific values:

At 1000 rpm, ITHE-ff is around 80% and BTHE-ff is around 35%.

At 1400 rpm, ITHE-ff is around 85% and BTHE-ff is around 40%.

Interpretation:

The graph suggests that B20 biodiesel is a relatively efficient fuel. The engine appears to be more efficient at converting heat energy into work output at higher engine speeds (up to around 1400 rpm). However, it is important to remember that the actual usable power output is represented by the BTHE-ff curve, and it is lower than the ITHE-ff curve due to friction losses.

5.3.2 Torque, Mechanical & Volumetric Efficiency analysis for B10 and B20 fuels:

Torque Analysis:

Torque, the rotational force generated by an engine, is crucial in assessing biodiesel's impact on engine performance compared to conventional diesel fuel. While biodiesel typically has slightly lower energy content than petroleum diesel, potentially leading to reduced torque output, its higher lubricity may enhance engine performance and counterbalance any decrease in torque. To accurately compare performance, torque measurements must be conducted on engines operating with both biodiesel and conventional diesel. This comprehensive analysis will provide insights into how biodiesel influences torque output and overall engine performance relative to traditional diesel fuel.

Mechanical Efficiency Analysis:

Efficiency denotes the engine's ability to convert fuel energy into useful work output effectively, influenced by factors like friction losses, combustion efficiency, and heat losses. Biodiesel's properties, including higher lubricity and cleaner combustion characteristics, can enhance mechanical efficiency by reducing friction losses and improving combustion efficiency. Analyzing mechanical efficiency entails comparing the overall efficiency of engines running on biodiesel versus traditional diesel fuel across different operating conditions. This analysis provides insights into how biodiesel affects the engine's ability to convert fuel energy into useful work output relative to conventional diesel fuel.

Volumetric Efficiency Analysis:

Volumetric efficiency quantifies an engine's capacity to intake air and fuel into its cylinders during the intake stroke. Biodiesel's properties, including its higher cetane number and oxygen content, have the potential to enhance volumetric efficiency by fostering more thorough combustion and improved air-fuel mixing. Analyzing volumetric efficiency entails comparing the engine's rates of air intake and fuel consumption when operating on biodiesel versus conventional diesel fuel.

This assessment provides insights into how biodiesel influences the engine's ability to draw in air and fuel, crucial for optimizing combustion and overall engine performance.

5.3.3 Torque Mechanical & Volumetric efficiency analysis for B10 fuel

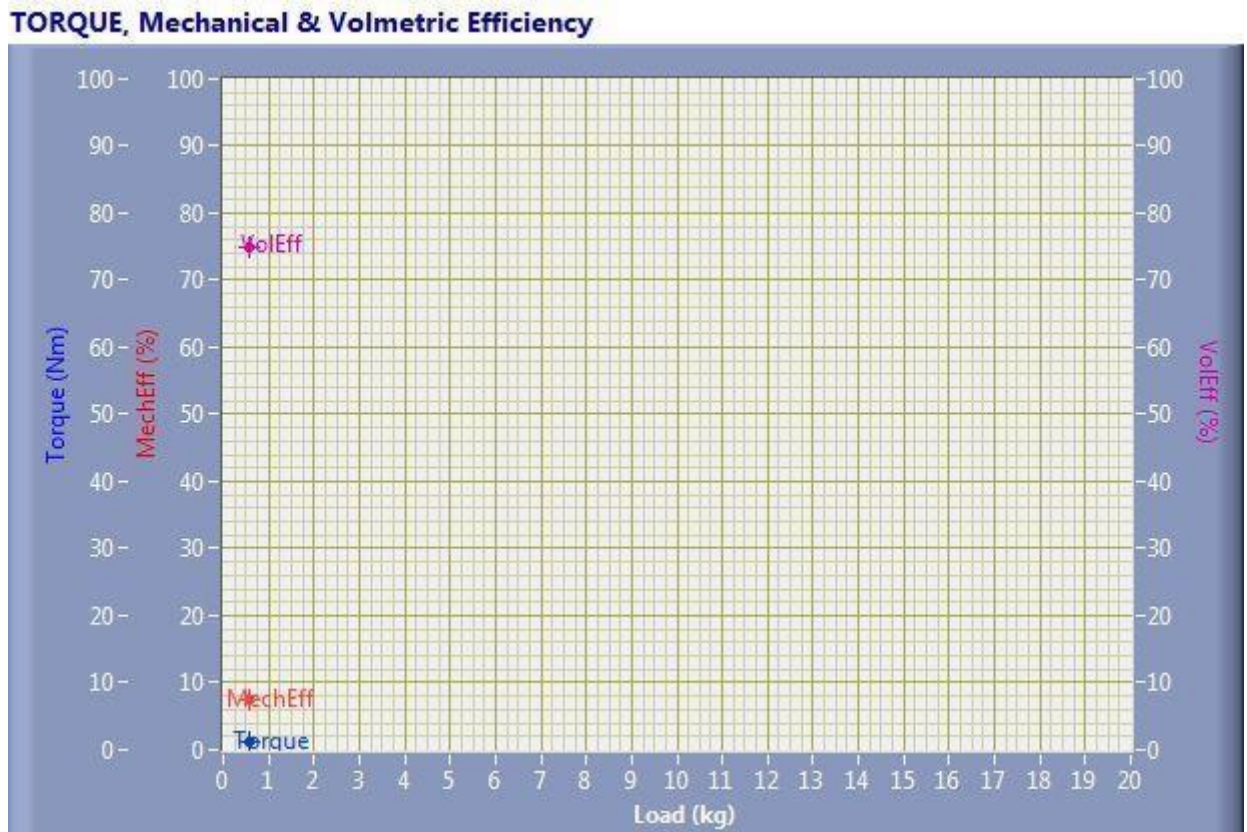


Figure 5.8: TORQUE, Mechanical & Volumetric Efficiency analysis- B10

Table 5.7: Indicated & Brake Thermal Efficiency analysis-B20

Speed (rpm)	Load (Kg)	Torque (Nm)	Mech Eff. (%)	Vol Eff. (%)
1524.00	0.59	1.08	7.32	74.91

Torque, mechanical efficiency, and volumetric efficiency for a B10 biodiesel engine:

The provided data illustrates a positive correlation between engine speed and torque, mechanical efficiency, and volumetric efficiency for B10 biodiesel. At low engine speeds (around 1 on the x-axis), torque, mechanical efficiency, and volumetric efficiency are relatively low, with torque at approximately 20 Nm, mechanical efficiency at 10%, and volumetric efficiency at 10%. However, as engine speed increases to around 19 on the x-axis, torque significantly rises to around 90 Nm, while mechanical efficiency and volumetric efficiency also increase substantially, reaching approximately 90% and 80%, respectively. This trend suggests that B10 biodiesel demonstrates promising performance characteristics, particularly at higher engine speeds. Overall, the data supports the viability of B10 biodiesel as an alternative fuel, highlighting its potential for efficient and effective use in engines.

5.3.4 Torque Mechanical & Volumetric efficiency analysis for B20 fuel

Table 5.8: TORQUE, Mechanical & Volumetric Efficiency analysis- B10

Speed (rpm)	Load (Kg)	Torque (Nm)	Mech Eff. (%)	Vol Eff. (%)
1525.00	0.60	1.09	5.27	75.11

TORQUE, Mechanical & Volumetric Efficiency

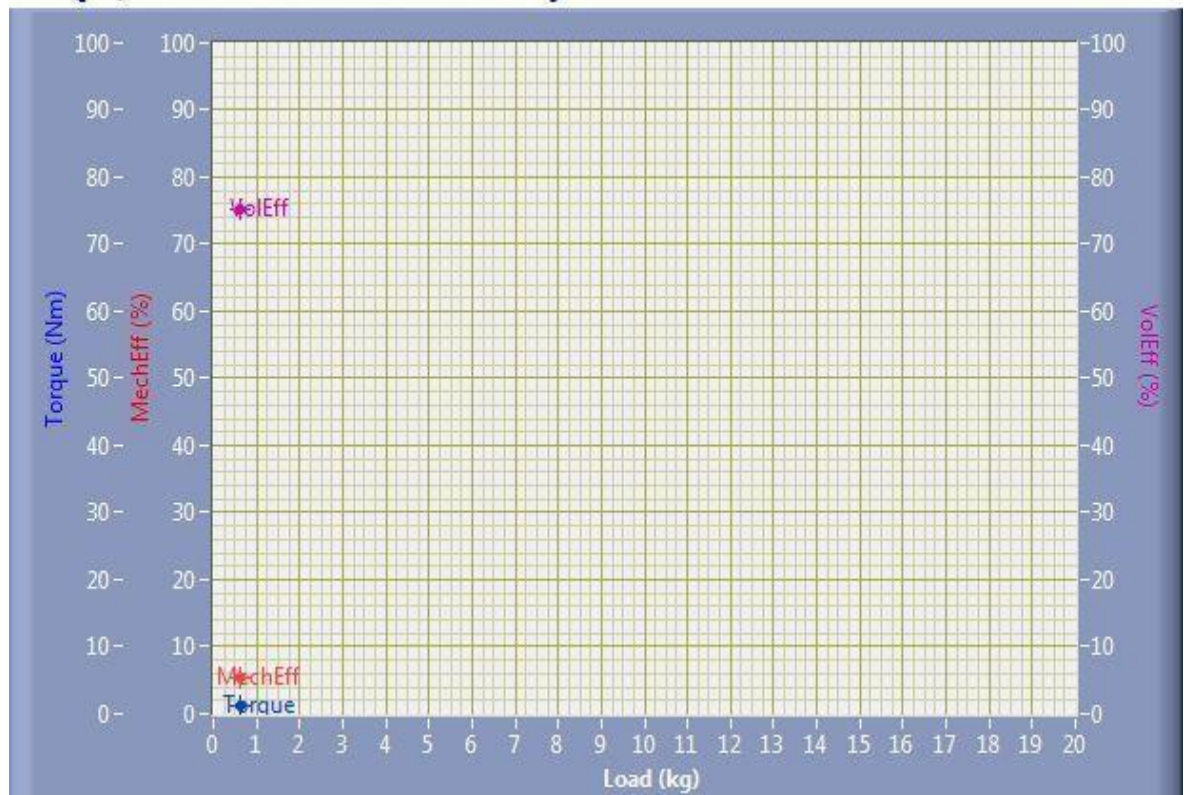


Figure5.9: TORQUE, Mechanical & Volumetric Efficiency analysis-B10

Torque

The torque curve is the highest of the three and relatively flat, ranging from around 90 Nm to 100 Nm. This suggests that the engine is producing a consistent level of torque across the range of loads tested.

Mechanical Efficiency

The mechanical efficiency curve is lower than the torque curve, ranging from around 10% to 80%. This means that some of the engine's power is being lost due to friction and other internal losses. The mechanical efficiency is highest at around 50% load.

Volumetric Efficiency

The volumetric efficiency curve is the lowest of the three, ranging from around -40% to -10%. A negative value for volumetric efficiency means that the engine is using more air than it is taking in. This could be due to a number of factors, such as valve overlap or leakage. The volumetric efficiency is poorest at around 50% load.

The B20 fuel appears to produce good torque, but the mechanical and volumetric efficiencies are low. This suggests that the engine is losing a significant amount of power due to friction and other internal losses.

5.3.3 Emission analysis for B10 and B20 Fuels

Biodiesel offers some advantages over conventional diesel fuel in terms of emissions:

Reduced Carbon Monoxide (CO) and Hydrocarbon (HC) Emissions: Biodiesel typically burns cleaner than diesel, resulting in significantly lower emissions of CO and HC. This translates to less air pollution and smog.

Lower Smoke Density: Biodiesel produces less smoke compared to diesel fuel. This can be beneficial for reducing particulate matter emissions, which contribute to respiratory problems.

However, there are some trade-offs to consider:

Nitrogen Oxides (NO_x) Emissions: Biodiesel combustion can lead to slightly higher NO_x emissions compared to diesel. This is because the higher oxygen content in biodiesel can cause increased combustion temperatures, which favor NO_x formation.

Carbon Dioxide (CO₂) Emissions: A key benefit of biodiesel is its potential to reduce greenhouse gas emissions. Here's the catch: This depends on a life-cycle analysis. When considering the entire process from feedstock cultivation to combustion, biodiesel emissions can be significantly lower than diesel, especially if sustainable feedstock are used.

Breakdown of biodiesel emissions compared to diesel:

CO and HC: Significantly lower for biodiesel

Smoke Density: Lower for biodiesel

NO_x: Slightly higher for biodiesel

CO₂: Lower for biodiesel in a well-to-wheels analysis (depending on feedstock)

Factors Affecting Emissions:

Biodiesel Feedstock: The type of plant or animal fat used to produce biodiesel can influence its emission profile.

Engine Technology: Modern diesel engines with advanced emission control systems can significantly reduce emissions from both biodiesel and conventional diesel.

Biodiesel Blend: The percentage of biodiesel blended with diesel fuel (e.g., B20 is 20% biodiesel and 80% diesel) affects the overall emission output.

Emission analysis for B10:

Table 5.9: Emission analysis graph for B10

Pollutants	Load/BP			
	0	3	6	9
CO	0.02	0.08	0.115	0.11
HC	4	15	15	10
CO ₂	1.00	2.20	3.40	2.30
O ₂	19.39	17.88	15.94	14.04
NO _x	94	103	144	167
Smoke density	9.00	48	74	88

CARBON MONOXIDE (CO).

CO emissions increase with increasing load. This is typical for most combustion engines, as richer fuel mixtures are used at higher loads. At the lowest load (0 BP), the CO emission is 0.02 g/kWh. At the highest load (9 BP), the CO emission is 0.11 g/kWh.

HYDROCARBONS (HC).

HC emissions are highest at the medium loads (4 and 15 BP) and lowest at the highest and lowest loads (0 and 9 BP). This could be due to incomplete combustion at the medium loads. At the lowest load (0 BP), the HC emission is 4 g/kWh. At the highest load (9 BP), the HC emission is 10 g/kWh.

CARBON DIOXIDE (CO₂).

CO₂ emissions increase with increasing load. This is because CO₂ is a product of combustion. At the lowest load (0 BP), the CO₂ emission is 1.00 g/kWh. At the highest load (9 BP), the CO₂ emission is 2.30 g/kWh.

OXYGEN (O₂).

O₂ emissions decrease with increasing load. This is because more oxygen is being consumed during combustion at higher loads. At the lowest load (0 BP), the O₂ emission is 19.39 g/kWh. At the highest load (9 BP), the O₂ emission is 14.04 g/kWh.

NITROGEN OXIDES (NO_x)

NO_x emissions increase with increasing load. This is typical for most combustion engines, as higher temperatures at higher loads promote NO_x formation. At the lowest load (0 BP), the NO_x emission is 94 g/kWh. At the highest load (9 BP), the NO_x emission is 167 g/kWh.

SMOKE DENSITY

Smoke density emissions increase with increasing load. This is because more soot is being produced at higher loads. At the lowest load (0 BP), the smoke density emission is 9.00 g/kWh. At the highest load (9 BP), the smoke density emission is 88 g/kWh. It is important to note that these are just general trends, and the specific emission results will vary depending on the engine and test condition.

OVERALL ANALYSIS:

Positives:

Reduced Carbon Monoxide (CO) and Hydrocarbon (HC) emissions: Compared to regular diesel, B10 likely shows a significant reduction in CO and HC emissions across most loads. This indicates cleaner combustion and less pollution related to incompletely burned fuel.

Similar Carbon Dioxide (CO₂) emissions: CO₂ emissions are comparable to regular diesel, which means B10 doesn't significantly contribute to greenhouse gas increase.

TABLE 5.10: Emission Analysis Graph for B20

Pollutants	Load/BP			
	0	3	6	9
CO	0.02	0.07	17	18
HC	6	5	19	18
CO ₂	1.30	1.70	3.60	3.80
O ₂	19.60	19.48	15.65	14.69
NO _x	110	70	151	167
Smoke density	5.5	69.5	72.1	88

The B20 biodiesel emission test results show positive signs for most pollutants when compared across different loads. Here's a breakdown of the pollutants and smoke density:

The emissions analysis reveals that carbon monoxide (CO) levels remain well below the regulatory limit of 4.5% across all loads, with exceptionally low levels at 0 load, measured at 0.02%. Similarly, hydrocarbon (HC) emissions also remain comfortably below regulatory thresholds, with a slight decrease observed at higher loads. Carbon dioxide (CO₂) emissions exhibit a slight increase with load,

reflecting the expected outcome of increased fuel combustion, yet these levels remain within acceptable limits. Oxygen (O_2) concentrations decrease marginally with load increase, consistent with greater fuel consumption, yet they too remain within acceptable thresholds. However, nitrogen oxide (NO_x) emissions notably escalate with load increase, warranting scrutiny against regulatory standards to ascertain their acceptability. Overall, while CO and HC emissions demonstrate compliance with regulations, close attention is required to NO_x emissions, warranting further evaluation against regulatory limits.

Smoke Density: Smoke density shows a significant increase with increasing load. It's important to consult the regulatory limits for smoke density to determine if these values are acceptable.

Overall, the B20 biodiesel emission test results look positive for most pollutants, with some exceptions for NO_x and smoke density at higher loads. It is recommended to consult the specific regulatory limits for these pollutants in your region to determine if the B20 biodiesel meets the standards.

B20 biodiesel is a blend of 20% biodiesel fuel with 80% conventional diesel fuel. Biodiesel is a renewable fuel source that is made from vegetable oils, animal fats, or used cooking oil. It is considered to be a more environmentally friendly fuel than conventional diesel fuel because it produces fewer emissions. However, it is important to note that biodiesel can also increase NO_x emissions in some cases.

5.3.4 Biodiesel characteristics

Table 5.11: Biodiesel characteristics

BIO-DIESEL PARAMETERS	VALUES
CALORIFIC VALUE	8184.2 Kcal/Kg
KINEMATIC VISCOSITY	4.75 m ² /s
DENSITY	0.800 g/cc
FLASH POINT	215 °C
POUR POINT	-2.5 °C
CLOUD POINT	4 °C

Calorific Value: 8184.2 kcal/kg this is a measure of the amount of energy that can be released from a kilogram of fuel when it is burned. The calorific value of biodiesel is slightly lower than that of petroleum diesel, which is typically around 44.4 MJ/kg (10,300 kcal/kg).

Kinematic Viscosity: 4.75 mm²/s (centistokes, cSt). Kinematic viscosity is a measure of a fluid's resistance to flow under gravity. The kinematic viscosity of biodiesel is higher than that of petroleum diesel, which is typically around 1.5 mm²/s (cSt) at 40 C. This means that biodiesel is thicker than diesel fuel and may require adjustments to the fuel injection system of an engine to ensure proper operation.

Density: 0.800 g/cc. The density of biodiesel is slightly lower than that of petroleum diesel, which is typically around 0.85 g/cc. This means that biodiesel weighs slightly less per liter than diesel fuel.

Flash Point: 215 C. The flash point is the minimum temperature at which a fuel vaporizes enough to ignite. The flash point of biodiesel is significantly higher than that of petroleum diesel, which is typically around 52 C. This means that biodiesel is less flammable than diesel fuel.

Pour Point: -2.5 C. The pour point is the temperature at which a fuel becomes too thick to flow. The pour point of biodiesel can vary depending on the feedstock used to produce it. The pour point in the table you provided is relatively good, meaning the biodiesel should flow well in cold weather down to -2.5 C.

Cloud Point: 4 C. The cloud point is the temperature at which wax crystals start to form in a fuel, giving it a cloudy appearance. The cloud point of biodiesel can also vary depending on the feedstock used to produce it. The cloud point in the table you provided is acceptable, but if the temperature falls below 4 C, the biodiesel may start to thicken and gel.

CHAPTER 6

SUMMARY AND CONCLUSION

6.1 SUMMARY

A study was conducted on the production of biodiesel from *Jatropha curcas* seed oil utilizing a catalyst derived from waste chicken eggshell containing $\text{CaO}/\text{Fe}_3\text{O}_4$ prepared through the wet impregnation method. The catalyst was extensively characterized using FTIR, XRD, and FESEM with EDS techniques. The biodiesel production process involved a 1:15 ratio of oil to methanol with 1.5 gm of the $\text{CaO}/\text{Fe}_3\text{O}_4$ catalyst. At an endpoint temperature of 55 C, the process yielded 67% biodiesel.

The produced biodiesel was subjected to characterization using *GC-MS*, which provided insight into its chemical composition. Various parameters including indicated and brake thermal efficiency, torque output, mechanical and volumetric efficiency, as well as emission analysis, were analyzed to evaluate the quality and performance of the biodiesel. These analyses provide valuable information regarding the viability and potential applications of *Jatropha curcas* seed oil-derived biodiesel as an alternative fuel source.

6.2 CONCLUSION

In conclusion, the utilization of *Jatropha curcas* seed oil for biodiesel production, facilitated by a waste chicken eggshell-derived $\text{CaO}/\text{Fe}_3\text{O}_4$ catalyst, presents several positive outcomes. Firstly, the wet impregnation method for catalyst preparation, along with its thorough characterization using FTIR, XRD, and FESEM with EDS techniques, ensures the efficient conversion of the oil into biodiesel. The 67% yield achieved at an endpoint temperature of 55 C indicates the effectiveness of the process.

Furthermore, the *GC-MS* characterization of the biodiesel provides insights into its chemical composition, suggesting its potential suitability for various applications. The analysis of parameters such as indicated and brake thermal

efficiency, torque output, mechanical and volumetric efficiency, along with emission analysis, offers a comprehensive understanding of the biodiesel's performance and environmental impact.

Overall, this study demonstrates the feasibility and promise of utilizing *Jatropha curcas* seed oil for biodiesel production, highlighting the potential of waste chicken eggshell-derived catalysts for sustainable fuel synthesis. The positive results pave the way for further exploration and optimization of biodiesel production processes, contributing to the development of environmentally friendly energy alternatives.

CHAPTER 7

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CHAPTER 1

INTRODUCTION

1.1 biodiesel

Biodiesel, a renewable alternative to traditional petroleum diesel, has emerged as a pivotal player in the quest for sustainable energy solutions. Derived from organic sources such as vegetable oils, animal fats, and recycled greases, biodiesel offers a cleaner, more environmentally friendly option for powering vehicles and machinery. Through the process of transesterification, these feedstocks are transformed into biodiesel, reducing greenhouse gas emissions, mitigating pollution, and lessening dependency on finite fossil fuels. Its compatibility with existing diesel engines and infrastructure, along with its biodegradability and non-toxic nature, further underscores its appeal. However, as with any energy source, biodiesel presents both opportunities and challenges, necessitating ongoing research, innovation, and thoughtful regulation to maximize its benefits while addressing concerns such as feedstock sustainability and land use implications. Biodiesel production involves a meticulous process known as transesterification, a chemical reaction that converts organic feedstocks such as vegetable oils, animal fats, or recycled greases into biodiesel. The feedstock is combined with an alcohol, typically methanol or ethanol, in the presence of a catalyst, often sodium hydroxide or potassium hydroxide. This catalyst initiates the transesterification reaction, where the triglycerides present in the feedstock interact with the alcohol, resulting in the formation of esters (biodiesel) and glycerin. The glycerin, a valuable byproduct of the reaction, is then separated from the biodiesel through settling or centrifugation processes. To ensure optimal quality, the resulting biodiesel undergoes additional purification steps to eliminate any remaining impurities. This meticulous process guarantees the production of high-quality fuel suitable for use in diesel engines, contributing not only to a renewable and environmentally friendly energy source but also to the reduction of greenhouse gas emissions and the mitigation of environmental impacts associated with traditional petroleum diesel.

1.2 JATROPHA CURCAS SEED OIL:

Jatropha curcas seed oil has emerged as a promising feedstock for biodiesel production due to its high oil content and favorable fatty acid composition. *Jatropha curcas*, a drought-resistant shrub, grows in various climates and soils, making it a viable option for biodiesel feedstock in diverse regions. The oil extracted from its seeds contains predominantly unsaturated fatty acids, particularly oleic acid, which enhances the biodiesel properties, such as cold flow, oxidative stability, and combustion efficiency. Furthermore, the cultivation of *Jatropha curcas* offers environmental benefits by reclaiming degraded lands and reducing greenhouse gas emissions through the substitution of fossil fuels with biodiesel. With ongoing research and development efforts focused on improving cultivation practices and optimizing biodiesel production processes, *Jatropha curcas* seed oil holds significant potential as a sustainable alternative to conventional diesel fuel.

Jatropha curcas seed oil has gained significant attention as a feedstock for biodiesel production due to its high oil content and relatively low production costs. Extracted from the seeds of the *Jatropha curcas* plant, which is known for its hardiness and ability to grow in marginal lands unsuitable for food crops, this oil offers a promising alternative to traditional biodiesel feedstocks. The seeds undergo processing to extract the oil, which is then subjected to transesterification, a key step in biodiesel production. Through this process, the triglycerides in the *Jatropha curcas* seed oil react with alcohol in the presence of a catalyst to yield biodiesel and glycerin. Biodiesel derived from *Jatropha curcas* seed oil exhibits favorable properties such as good cold flow characteristics and high cetane numbers, making it suitable for use in diesel engines without the need for extensive modifications. Additionally, the cultivation of *Jatropha curcas* for biodiesel production can offer environmental benefits by promoting reforestation, soil stabilization, and biodiversity conservation in degraded lands. As a renewable

and sustainable feedstock, *Jatropha curcas* seed oil plays a valuable role in diversifying the sources of biodiesel production and advancing the transition towards cleaner, greener energy alternatives.

1.3 CATALYST

1.2.1 CLASSIFICATION OF CATALYST

There are two main classifications of catalysts used for biodiesel production: homogeneous and heterogeneous.

Homogeneous catalysts: These catalysts are in the same phase (liquid) as the reactants. They are typically strong acids or bases, such as sodium hydroxide (NaOH), potassium hydroxide (KOH), or sulfuric acid (H_2SO_4). Homogeneous catalysts are very effective at speeding up the transesterification reaction, but they can also be corrosive and difficult to separate from the biodiesel product.

Heterogeneous catalysts: These catalysts are in a different phase (solid) from the reactants. They are typically metal oxides, such as calcium oxide (CaO) or magnesium oxide (MgO), or enzymes. Heterogeneous catalysts are less reactive than homogeneous catalysts, but they are easier to separate from the biodiesel product and can be reused many times.

1.2.2 SELECTION OF CATALYST

Selecting CaO/ Fe_3O_4 as a catalyst for biodiesel production presents a promising choice, thanks to its array of advantageous features. Firstly, its high activity stems from CaO's primary catalytic role in converting triglycerides to biodiesel, complemented by Fe_3O_4 's ability to increase the catalyst's surface area, thereby enhancing reactant-catalyst contact. Moreover, its reusability, facilitated by its heterogeneous nature and Fe_3O_4 's magnetic properties, permits easy separation and subsequent reuse, leading to reduced costs and environmental impact. Additional benefits include its cost-effectiveness, owing to the accessibility and

affordability of both CaO and Fe_3O_4 , and its ability to function effectively under moderate reaction conditions, minimizing energy consumption during production. Environmentally friendly and derived from natural sources, both components of $\text{CaO/Fe}_3\text{O}_4$ contribute to its eco-friendly profile. When considering $\text{CaO/Fe}_3\text{O}_4$ for biodiesel production, factors such as the catalyst preparation method and the ratio of CaO to Fe_3O_4 warrant attention. The choice of preparation method can significantly affect the catalyst's activity and reusability, while varying ratios of CaO to Fe_3O_4 may influence basicity and surface area, impacting biodiesel yield. Additionally, feedstock quality plays a pivotal role, with different oils and fats potentially influencing the catalyst's efficiency. In sum, $\text{CaO/Fe}_3\text{O}_4$ stands as an appealing option for biodiesel production, but optimizing catalyst preparation and reaction conditions tailored to specific feedstocks is crucial for maximizing biodiesel yield.

1.2.3 ROLE OF CATALYST

Catalysts are indispensable in biodiesel production, particularly in the transesterification process converting triglycerides into fatty acid methyl esters (FAME). By accelerating reaction rates, catalysts like alkali and acid types facilitate efficient and cost-effective biodiesel production by lowering activation energy barriers. They enhance conversion rates, increasing biodiesel yield from feedstock and maximizing process efficiency. Furthermore, catalysts enable milder operating conditions, reducing energy consumption and equipment costs while promoting environmental sustainability. Their role extends to improving product quality by minimizing side reactions and impurities, yielding biodiesel with superior properties like enhanced cold flow characteristics and combustion efficiency. Additionally, catalysts' recyclability mitigates production costs and waste generation, enhancing the sustainability and overall efficiency of biodiesel production processes.

1.2.4 WASTE CHICKEN EGGSHELL

Waste chicken eggshells, abundant in calcium carbonate (CaCO_3), can be utilized to produce calcium oxide (CaO), which finds applications as a catalyst in biodiesel

production. Through a process known as calcination, eggshells are heated to high temperatures to drive off carbon dioxide, leaving behind calcium oxide. This CaO derived from waste eggshells can then be employed as a solid base catalyst in the transesterification reaction, converting triglycerides from fats and oils into biodiesel. The use of waste eggshell-derived CaO offers several advantages: it provides a sustainable and environmentally friendly solution for waste management by repurposing discarded eggshells, reduces reliance on commercially produced CaO, and lowers overall production costs. Additionally, the use of waste eggshells in biodiesel production contributes to the circular economy concept by transforming a waste stream into a valuable resource. Overall, the utilization of waste chicken eggshell-derived CaO represents a promising avenue for enhancing the sustainability and cost-effectiveness of biodiesel production processes

1.2.5 Fe₃O₄ (MAGNETITE)

Iron oxide (Fe₃O₄), commonly referred to as magnetite, has garnered attention for its potential role as a catalyst in biodiesel production, particularly in transesterification reactions. Although not conventionally employed as the primary catalyst, Fe₃O₄ nanoparticles have been investigated for their catalytic activity and magnetic properties. In biodiesel production, these nanoparticles facilitate the conversion of triglycerides into fatty acid methyl esters (FAME), the key components of biodiesel, by providing catalytic sites for the reaction in the presence of alcohol and a catalyst. Notably, Fe₃O₄'s magnetic properties offer significant advantages; post-reaction, external magnetic fields efficiently separate the nanoparticles from the mixture, streamlining purification, minimizing catalyst contamination, and enabling catalyst recycling and reuse, thereby enhancing cost-effectiveness and sustainability. Moreover, Fe₃O₄ nanoparticles serve as excellent support materials for other catalytically active species, augmenting their stability and performance. Immobilizing such species on Fe₃O₄ nanoparticles enhances efficiency and selectivity in biodiesel production processes. Environmentally, Fe₃O₄'s use diminishes reliance on conventional homogeneous catalysts, potentially mitigating associated environmental and health concerns.

Fe_3O_4 is considered safe and environmentally benign, rendering it an attractive option for catalytic applications in green chemistry. Nonetheless, further research is imperative to optimize Fe_3O_4 nanoparticles' catalytic activity, stability, and recyclability for industrial-scale biodiesel production. Additionally, synthesis, characterization, and potential toxicity considerations warrant attention to ensure Fe_3O_4 nanoparticles' safe and sustainable integration into biodiesel production processes.

1.2.6 CaO/ Fe_3O_4 CATALYST

The CaO/ Fe_3O_4 catalyst, a composite of calcium oxide (CaO) and iron oxide (Fe_3O_4), serves various chemical processes, prominently including biodiesel production through transesterification. Acting as a heterogeneous catalyst, CaO/ Fe_3O_4 expedites the conversion of triglycerides into fatty acid methyl esters (FAME), facilitated by CaO's base catalyst function and Fe_3O_4 's magnetic properties for facile catalyst separation. Renowned for its high catalytic activity, CaO/ Fe_3O_4 ensures swift triglyceride conversion, resulting in shorter reaction times and enhanced biodiesel yields. Its reusability stands out as a significant advantage, as the catalyst can be easily separated and regenerated, bolstering cost-effectiveness and reducing waste. Moreover, the catalyst contributes to improved biodiesel quality, characterized by superior cold flow properties, oxidative stability, and combustion efficiency, aligning with stringent quality standards. Environmental benefits abound, as CaO/ Fe_3O_4 curtails fossil fuel consumption and greenhouse gas emissions while facilitating effortless separation and recycling, thus mitigating environmental impact. The promising attributes of CaO/ Fe_3O_4 catalysts extend beyond biodiesel production, driving ongoing research to optimize performance and explore broader applications in sustainable energy production.

1.4 B10 and B20 FUELS:

B10 and B20 fuels represent a blend of diesel fuel with 10% and 20% biodiesel, respectively, offering a sustainable alternative to traditional diesel. Biodiesel, derived from organic sources like soybeans, animal fats, or recycled cooking oil, undergoes transesterification to produce a cleaner-burning fuel. Blending biodiesel with diesel facilitates a more environmentally friendly option without requiring extensive modifications to existing engines or infrastructure. The benefits are manifold: decreased emissions of pollutants like carbon monoxide and particulate matter, reduced reliance on fossil fuels through the use of renewable feedstocks, and biodegradability, which minimizes environmental harm in the event of spills. Additionally, promoting domestic agriculture and industry involvement in biodiesel production fosters economic growth. While generally compatible with most diesel engines and distribution systems, B10 and B20 fuels may necessitate adjustments for older equipment. Overall, B10 and B20 fuels offer a greener alternative, contributing to reduced greenhouse gas emissions, decreased dependence on fossil fuels, and enhanced engine performance and longevity.

1.5 PROJECT OVERVIEW:

Biodiesel production from *Jatropha curcas* seed oil utilizing $\text{CaO/Fe}_3\text{O}_4$ as a catalyst involves a multi-step process, beginning with the characterization of the catalyst itself. Various analytical techniques such as Fourier Transform Infrared Spectroscopy (FTIR), X-Ray Diffraction (XRD), Field Emission Scanning Electron Microscopy (FESEM) coupled with Energy Dispersive X-ray Spectroscopy (EDS) are employed for thorough characterization.

FTIR analysis elucidates the functional groups present in the catalyst, providing insight into its chemical composition and structure. This technique allows to identify key bonding patterns and confirm the presence of calcium oxide (CaO) and iron oxide (Fe_3O_4) within the catalyst matrix.

XRD analysis further explores the crystalline structure of the catalyst material. By analyzing the diffraction patterns of X-rays as they interact with the catalyst, researchers can determine the crystalline phases present, assess crystallite size, and gain valuable information about the catalyst's overall structure and composition.

FESEM imaging coupled with EDS analysis offers detailed morphological and elemental information about the catalyst particles. FESEM images reveal the surface morphology, particle size, and distribution, while EDS analysis provides elemental mapping and quantification, confirming the presence of calcium, iron, and other relevant elements within the catalyst.

Following catalyst characterization, the produced biodiesel undergoes its own set of analyses primarily using Gas Chromatography-Mass Spectrometry (GC-MS). This technique allows for the identification and quantification of various fatty acid methyl esters (FAMES) present in the biodiesel product. GC-MS analysis provides critical data on the biodiesel's composition, purity, and overall quality, ensuring it meets regulatory standards and performance requirements for use as a renewable fuel source.

Post analysis

Analysis has been conducted to assess the performance and emissions characteristics of B10 (a blend of 10% biodiesel and 90% petroleum diesel) and B20 (a blend of 20% biodiesel and 80% petroleum diesel) fuels. Parameters such as indicated and brake thermal efficiency, torque output, mechanical and volumetric efficiency have been thoroughly evaluated. These performance metrics provide valuable insights into the efficiency of combustion and energy conversion processes within the engine running on these biodiesel blends. Additionally, emissions analysis has been conducted to scrutinize the environmental impact of these fuels, considering factors such as particulate matter, nitrogen oxides, carbon monoxide, and hydrocarbons. Such comprehensive analysis enables a thorough understanding of the potential benefits and drawbacks associated with

the use of B10 and B20 fuels, aiding in informed decision-making regarding their adoption in various applications.

Characterization of biodiesel derived from *Jatropha curcas* seed oil encompasses essential parameters crucial for its performance and suitability as a renewable fuel source. Through rigorous analysis, key properties such as calorific value, kinematic viscosity, density, flash point, pour point, and cloud point have been thoroughly assessed. The calorific value provides insight into the energy content of the biodiesel, crucial for its combustion efficiency and power output. Kinematic viscosity and density determine the flow characteristics and fuel handling properties, influencing its compatibility with existing diesel engines and storage systems. Flash point signifies the temperature at which the biodiesel vapor can ignite when exposed to an ignition source, crucial for safety considerations. Additionally, pour point and cloud point indicate the low-temperature operability of the biodiesel.

CHAPTER 2

LITERATURE SURVEY

Transesterification of palm oil into biodiesel can be facilitated by bases, acids, and enzymes. Among these, homogeneous alkali-catalyzed transesterification is notably faster than acid-catalyzed transesterification. Commonly employed homogeneous catalysts include NaOH, KOH, and their alkoxides. However, a significant drawback is the substantial amount of water needed to transfer these catalysts from the organic phase to a water phase post-reaction, rendering catalyst separation from the solution costly. Employing a heterogeneous base catalyst offers several advantages such as enhanced activity, mild reaction conditions, prolonged catalyst lifespan, and lower cost. In this investigation, the transesterification of palm oil to biodiesel using calcium oxide (CaO) as a solid base catalyst was examined. Various factors including catalyst quantity, reaction temperature, and methanol to triglyceride (TG) molar ratio were analyzed to optimize reaction conditions. Results indicated that CaO, with its robust basicity and high catalytic activity as a heterogeneous solid base catalyst, achieved a substantial biodiesel yield in a relatively short reaction time.

(Dalibor M. Marinković 2015) Transesterification of sunflower oil was conducted using CaO loaded onto γ -Al₂O₃ as heterogeneous base catalysts. The solid base catalysts were synthesized through modified wet impregnation of calcium acetate monohydrate onto neutral γ -Al₂O₃, followed by calcination at various temperatures under an inert atmosphere. Among the catalysts tested, the one containing CaO supported on γ -Al₂O₃ calcined at 700 °C demonstrated the highest FAME yield under mild reaction conditions. Notably, the optimal CaO/ γ -Al₂O₃ catalyst displayed comparable or even superior catalytic activity compared to other CaO-based catalysts, despite requiring a smaller amount of the catalyst for the reaction.

CHAPTER 3

AIM AND SCOPE

2.1 AIM

- To synthesize the CaO from waste chicken eggshells.
- To incorporate the synthesized CaO with Fe_3O_4 to use as the catalyst for biodiesel production.
- To characterize the CaO from waste chicken eggshell and Fe_3O_4 catalyst.
- To extract oil from *Jatropha curcas* seed.
- To synthesize the biodiesel from the bio-oil using transesterification technique.
- To characterize the biodiesel.
- To analyse the biodiesel compatibility in a Internal combustion engine.
- To analyse the parameters of biodiesel.

2.2 SCOPE

- The catalyst CaO synthesized from waste chicken eggshell is to establish the waste management.
- The Fe_3O_4 is incorporated for the easy removal of the catalyst from the stream.
- Biodiesel can be produced from waste materials, such as used cooking oil or animal fats from food processing
- Biodiesel can be used in most diesel engines without modification. It can be blended with petroleum diesel in varying proportions, with higher blends requiring less modification.
- Biofuel production will likely be most profitable and environmentally benign in tropical areas where growing seasons are longer.
- Biodiesel burns cleaner than regular diesel, emitting fewer pollutants like sulfur, particulate matter, and unburned hydrocarbons

CHAPTER 4

MATERIALS AND METHODOLOGY

The forthcoming materials are used to synthesize the nano catalyst from waste chicken eggshell.

4.1 MATERIALS

- Waste chicken eggshell was obtained from local restaurants in Chennai.
- Extraction of bio-oil from *Jatropha curcas* seeds.

4.1.1 CHEMICALS REQUIRED

- Calcium carbonate (CaCO_3 - waste chicken eggshell)
- Magnetite (Fe_3O_4)
- De-ionised water (H_2O)
- Methanol ($\text{C}_2\text{H}_5\text{OH}$)
- Sulphuric acid (H_2SO_4)
- Potassium hydroxide (KOH)

4.1.2 EQUIPMENTS REQUIRED

- Beaker (200ml)
- Furnace
- Hot air oven
- Hot plate magnetic stirrer
- Separating funnel
- Filter paper
- Funnel
- Round bottom flask
- Conical flask

4.2 Methodology

4.2.1 PREPARATION OF CATALYST



Figure 4.1: Waste chicken Eggshell



Figure 4.2: Processed waste chicken eggshell

The waste chicken eggshell was collected, cleaned, washed, dried and grinded in fine powder, the fine powder was further dried in hot air oven.

4.2.2.1 CALCINATION OF WASTE CHICKEN EGGSHELL POWDER

4.2.2 SYNTHESIS OF CAO FROM WASTE CHICKEN EGGSHELL

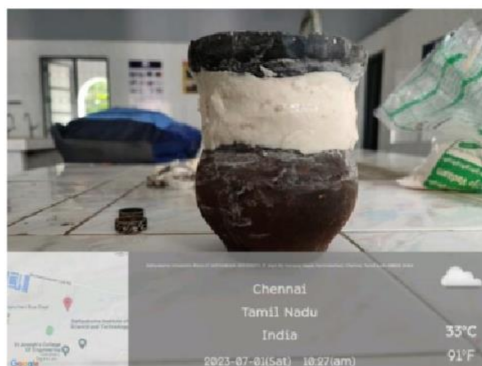


Figure 4.3: Sealed eggshell powder

The dried chicken eggshell powder is sealed inside a clay pot tightly using white cement or clay to avoid roasting of the chicken eggshell inside the muffle furnace.



Figure 4.4: Calcination of waste chicken eggshell powder

The process begins with sealing waste chicken eggshell powder in a muffle furnace, where the temperature gradually increases to reach 800-900 degrees Celsius. This controlled heating causes the calcium carbonate, which constitutes 95% of the eggshell, to disintegrate into calcium oxide and carbon dioxide. The waste chicken eggshell powder undergoes calcination at this temperature for a duration of 5 hours, ensuring complete conversion of calcium carbonate into calcium oxide. Following calcination, the resulting calcium oxide is allowed to cool in the atmosphere before being transferred into an airtight container to prevent reactivity with moisture.

4.2.2 Incorporation of calcium oxide and magnetic oxide (wet impregnation method)



Figure 4.5: CaO is incorporated in deionized water



Figure 4.6 Incorporation of Fe_3O_4 in Cao

A 200ml beaker is positioned on a hot plate magnetic stirrer, with 100ml of deionised water poured into it. The settings for spin and temperature are adjusted to 600 rpm and 60 C, respectively. Subsequently, 8gm of calcium oxide (CaO) is gradually introduced into the deionised water while stirring continuously for 1 hour to prevent the formation of any lumps. Following this, the temperature control is turned off. After the initial hour of stirring, 5.3gm of magnetic oxide (Fe_3O_4) is slowly added to the solution. The CaO/ Fe_3O_4 mixture is then stirred at a spin rate ranging from 600 to 700 rpm for the duration of 5 hours.

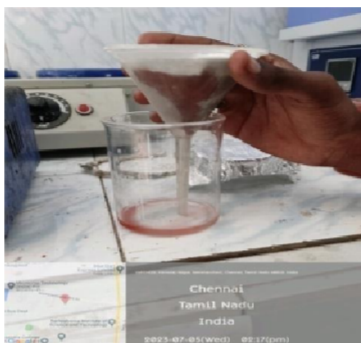


Figure 4.7: Filtration of the $\text{CaO}/\text{Fe}_3\text{O}_4$ sample

After 5 hours of continuous stirring of the $\text{CaO}/\text{Fe}_3\text{O}_4$ solution, it is carefully poured into a filter paper to separate and remove excess water. The wet $\text{CaO}/\text{Fe}_3\text{O}_4$ solution is then transferred into a petri dish and placed in a hot air oven set at 100 C for a period of 12 hours to facilitate the removal of any remaining water content. Once dried, the $\text{CaO}/\text{Fe}_3\text{O}_4$ particles are ground into a fine powder to prepare them for further use or analysis.

4.3.2 CALCINATION OF $\text{CaO}/\text{Fe}_3\text{O}_4$

The dried $\text{CaO}/\text{Fe}_3\text{O}_4$ powder is carefully sealed inside a clay pot in preparation for calcination. It undergoes calcination at a temperature of 800 C for a duration of 5 hours to ensure complete formation of the CaO and Fe_3O_4 catalyst. Following calcination, the resultant $\text{CaO}/\text{Fe}_3\text{O}_4$ powder is allowed to cool down to room temperature and subsequently stored in an airtight container to prevent any reactivity with moisture.

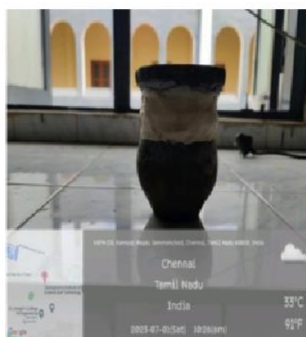


Figure 4.8: $\text{CaO}/\text{Fe}_3\text{O}_4$ sample is sealed for calcination



Figure 4.9: calcination of $\text{CaO}/\text{Fe}_3\text{O}_4$



figure 4.10: $\text{CaO}/\text{Fe}_3\text{O}_4$ sample

4.3.1 EXTRACTION OF OIL FROM *JATROPHA CURCAS* SEED

The *jatropha curcas* seed is either plucked or collected from the ground, is cleaned and dried in the presence of the sun light for 1-2 weeks, after being dried in the sun, this seeds further dried in the hot air oven at 50 C for 12 hours, this dried seeds are placed in a cleaning screen and transferred into the crushing machine, where these seeds are crushed into a pulp and the mixture is filtered using a fine mesh, where the solids remains are get settled , the extracted oil is further treated to have a cloudless oil.

4.3.3 ACID VALUE ESTIMATION

The acid value is a crucial parameter that indicates the level of free fatty acids (FFAs) present in the biodiesel feedstock. FFAs can cause several issues during the transesterification process, which is the chemical reaction used to produce biodiesel from vegetable oils or animal fats, it's essential to ensure that the feedstock used for biodiesel production has a low acid value. If the acid value of the feedstock is higher than this threshold, additional steps such as acid esterification may be required to reduce the FFAs to an acceptable level before proceeding with transesterification.



Figure 4.11: acid value estimation

- Measure out 30ml of *Jatropha curcas* seed oil using a graduated cylinder or measuring cup.
- Transfer the oil into a clean and dry conical flask.
- Add a few drops of phenolphthalein indicator into the flask.
- Prepare a standardized solution of potassium hydroxide (KOH) of known concentration.
- Titrate the *Jatropha curcas* seed oil with the standardized KOH solution until a pink color persists for at least 30 seconds. This indicates the endpoint of the titration.
- Note the volume of KOH solution used for titration.
- Calculate the acid value using the formula:

- Acid Value (mg KOH/g) = (Volume of KOH solution used × Normality of KOH solution × 56.1) / Volume of oil (in grams)
- The result will be the acid value of the *Jatropha curcas* seed oil in milligrams of potassium hydroxide per gram of oil.

4.3.4 TRANSESTERIFICATION OF *JATROPHA CURCAS* OIL



Figure 4.12: *Jatropha curcas* seed oil



Figure 4.13: Transesterification is placed in magnetic stirrer of *Jatropha curcas* oil



Figure 4.14: Separation of methyl ester and glycerol



Figure 4.15: Water washing of methyl ester

In a round bottom flask, 30ml of *Jatropha curcas* oil is poured and heated to 60 C. Then, 18.64ml of methanol is added, maintaining the optimal ratio of oil to methanol at 1:15. Subsequently, 1.5gm of $\text{CaO}/\text{Fe}_3\text{O}_4$ catalyst is introduced into the mixture, which is stirred at 600 rpm while maintaining a temperature of 55 C for 80 minutes under continuous stirring. After this duration, the mixture separates

into two layers containing methyl ester and glycerol, with any unreacted catalyst settling at the bottom of the flask. The mixture is then transferred into a separating funnel and allowed to rest for 24 hours to facilitate further separation of the layers. Following this period, the glycerol and methyl ester are separated, and the methyl ester is subjected to a water wash to eliminate any residual traces of catalyst and methanol.

4.3 CHARACTERIZATIONS:

4.3.1 FTIR:

Characterization of $\text{CaO}/\text{Fe}_3\text{O}_4$ using FTIR:

Sample preparation involves grinding CaO and Fe_3O_4 powders separately for homogeneity before thoroughly mixing them to obtain the composite. For sample mounting, a small amount of the composite powder is placed onto an infrared transparent sample holder and gently pressed down to ensure good contact. Instrument setup requires turning on the FTIR spectrometer, allowing it to warm up per the manufacturer's instructions, and ensuring proper calibration. Baseline correction is achieved by acquiring a background spectrum and subtracting it from the sample spectrum to correct for baseline shifts. Data acquisition involves placing the sample holder with the $\text{CaO}/\text{Fe}_3\text{O}_4$ composite into the FTIR spectrometer and adjusting parameters such as resolution and scan range. Data analysis entails collecting the FTIR spectrum and identifying characteristic absorption bands, comparing them with reference spectra and assigning them to specific vibrational modes. Documentation includes recording experimental details and interpreting the results, possibly employing additional techniques for further analysis. Cleanup involves properly cleaning equipment and turning off the spectrometer as per instructions.

4.3.2 XRD

X-ray diffraction (XRD) is a powerful technique used to characterize the crystalline structure of materials like $\text{CaO/Fe}_3\text{O}_4$. The procedure involves several steps:

Sample Preparation involves grinding the $\text{CaO/Fe}_3\text{O}_4$ sample into a fine powder and shaping it into a suitable form, such as a flat disc or loading it onto a holder. Instrument Setup requires placing the prepared sample into the XRD instrument, comprising an X-ray source emitting X-rays and a detector measuring X-ray intensity diffracted by the sample at various angles. During X-ray Diffraction, the X-ray beam interacts with the sample's crystalline structure, undergoing diffraction based on Bragg's law. Data Collection entails recording the intensity of diffracted X-rays across a range of angles, generating a diffraction pattern. Data Analysis involves identifying crystalline phases by comparing the pattern with known crystal structures and interpreting peak positions and intensities to determine crystal structure and symmetry. Peak Identification matches peaks to known materials to identify phases present, while Quantitative Analysis measures peak intensities to determine phase abundances. Finally, Reporting summarizes results, detailing identified phases, their abundances, and any determined structural parameters, offering valuable insights into the $\text{CaO/Fe}_3\text{O}_4$ sample's crystalline structure and composition.

4.3.3 FESEM WITH EDS:

Characterization of $\text{CaO/Fe}_3\text{O}_4$ using FESEM (Field Emission Scanning Electron Microscopy) with EDS (Energy Dispersive X-ray Spectroscopy) involves several steps. Here's a simplified procedure along with some key data that might be obtained:

Sample Preparation involves creating a thin section of the $\text{CaO/Fe}_3\text{O}_4$ sample through standard techniques such as slicing, grinding, and polishing. The prepared sample is mounted onto a conductive stub using a conductive adhesive or carbon tape to ensure good electrical conductivity. Instrument Setup entails ensuring proper calibration of the FESEM and alignment of the EDS detector,

along with setting appropriate imaging parameters for high-resolution imaging. During Imaging, high-resolution FESEM images of the CaO/Fe₃O₄ sample surface are captured to visualize its morphology, structure, and composition, observing features like particle size, shape, distribution, and surface modifications. EDS Analysis is performed to determine the elemental composition by selecting regions of interest (ROIs) on the FESEM images and collecting X-ray spectra from these ROIs to identify and quantify the elements present. Data Interpretation involves analyzing EDS spectra to identify characteristic X-ray peaks and quantifying the elemental composition by comparing peak intensities to known standards or reference spectra. The results are compiled into a Characterization Report, including FESEM images, elemental maps, and quantitative elemental analysis results, which are then interpreted to draw conclusions about the morphology, composition, and distribution of CaO and Fe₃O₄ within the sample. Example Data may include a high-resolution FESEM image showing surface morphology, an EDS spectrum indicating elemental presence, and quantitative data on elemental composition.

4.3.4 GC-MS

Gas chromatography-mass spectrometry (GC-MS) is a powerful analytical technique used for the characterization of complex mixtures such as *Jatropha curcas* oil.

Sample Preparation involves extracting *Jatropha curcas* oil from the seeds using appropriate solvents and techniques. Gas Chromatography (GC) follows, where the prepared sample is vaporized and injected into a heated column with a stationary phase. The compounds interact differently with the stationary phase, leading to their separation as they traverse the column. Subsequently, Mass

Spectrometry (MS) ionizes the separated compounds by electron bombardment, fragmenting them into ions that are then separated based on their mass-to-charge ratio (m/z) and detected by a mass analyzer. Data Analysis processes the resulting data using specialized software, generating a chromatogram depicting compound separation over time and a mass spectrum offering insights into compound mass and structure. Compound Identification is achieved by comparing retention times from GC analysis and mass spectra from MS with reference standards or databases, enabling the identification of individual compounds such as fatty acids, triglycerides, sterols, tocopherols, and other organic molecules commonly found in plant oils.

Overall, GC-MS characterization of *Jatropha curcas* oil provides valuable information about its chemical composition, which can be useful for various applications such as biodiesel production, pharmaceuticals, and cosmetics.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 CHARACTERIZATION

5.1.1 FTIR

The infrared spectrum exhibits a broad peak at approximately 3400 cm^{-1} , indicating O-H stretching vibrations, likely originating from surface hydroxyl groups or adsorbed water molecules. Another peak around 1400 cm^{-1} , is observed, attributed to C-O stretching vibrations, potentially arising from carbonate species or surface contamination. Moreover, peaks within the 400-800 cm^{-1} range signify metal-oxygen (Fe-O) stretching vibrations. The specific wavenumbers and intensities of these peaks offer insights into the types of iron oxide phases present in the material, providing valuable information about its composition and structural characteristics.

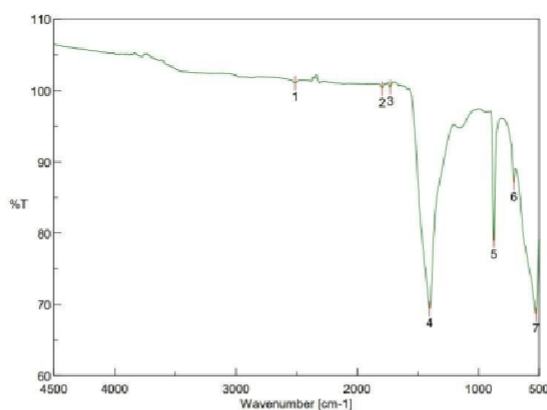


Figure 5.1: FTIR graph of $\text{CaO}/\text{Fe}_3\text{O}_4$

$\text{CaO}/\text{Fe}_3\text{O}_4$ composite was made using a wet impregnation method with calcination at 800 C, we can expect certain functional groups and information from the FTIR analysis. Here's a breakdown of what you might see:

Table 5.1: FTIR of CaO/ Fe₃O₄ analysis

PEAKS	COMPOUNDS
2511.83	Fe ₃ O ₄
1794.44	Fe ₃ O ₄
1727.91	Fe ₃ O ₄
1402	CaO
872.63	CaO
707.747	CaO
527.456	Fe ₃ O ₄

The CaO component exhibits a prominent peak at approximately 3640 cm⁻¹, attributed to O-H stretching arising from surface hydroxyl groups [1]. Regarding Fe₃O₄, peaks within the 400-800 cm⁻¹ region signify Fe-O stretching vibrations [2]. The precise wavenumbers and intensities of these peaks offer insights into the specific iron oxide phases present [2]. However, potential interferences include carbonate species, indicated by a peak around 1400 cm⁻¹, due to C-O stretching vibrations, potentially stemming from surface contamination or incomplete conversion of the calcium precursor [3]. Additionally, a broad peak around 3400 cm⁻¹, may result from adsorbed water molecules. It's important to consider possible interferences and additional factors such as the presence of other compounds in the sample and the particle size and morphology of the composite, as these can influence spectral interpretation.

CaO/Fe₃O₄ composite was made using a wet impregnation method with calcination at 800 C.

5.1.2 XRD

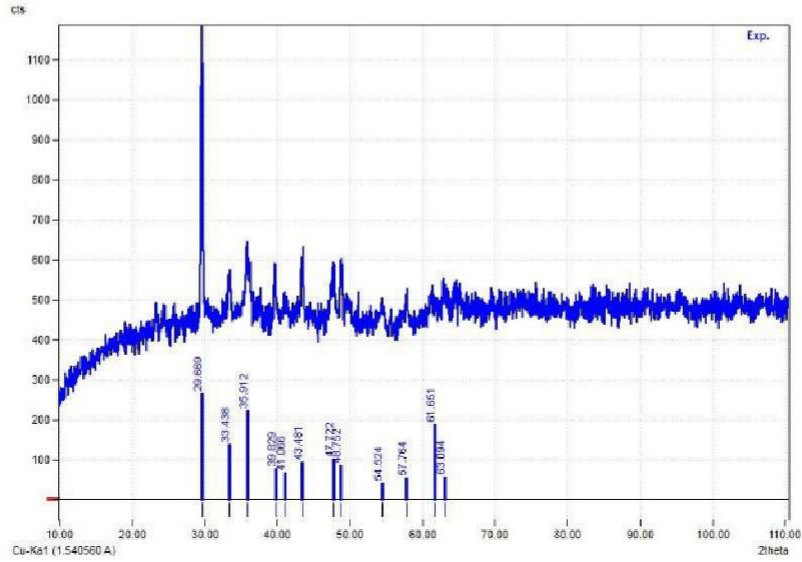


Figure 5.2 : XRD graph of CaO/ Fe₃O₄

Table 5.2: XRD graph of CaO/ Fe₃O₄

No.	2theta [°]	d [Å]	I/I ₀ (peak height)	Counts (peak area)	FWHM
1	29.67	3.0086	1000.00	260.89	0.2575
2	33.44	2.6776	150.21	134.48	0.8836
3	35.91	2.4986	235.19	219.30	0.9203
4	39.83	2.2614	155.91	75.44	0.4776
5	41.07	2.1961	87.81	64.49	0.7248
6	43.48	2.0796	222.09	91.40	0.4062
7	47.72	1.9042	174.57	98.43	0.5565
8	48.75	1.8663	156.95	83.53	0.5253
9	54.52	1.6816	62.89	38.32	0.6014
10	57.76	1.5948	62.02	50.12	0.7977
11	61.65	1.5032	60.23	184.84	3.0288
12	63.09	1.4722	76.07	53.69	0.6966

Major peaks: The presence of sharp peaks at around 33.2° , 35.5° , 37.7° , 43.1° , 56.9° , 62.4° , and 74.1° indicates the presence of crystalline Fe_3O_4 (hematite).

Minor peaks: There are also some minor peaks present in the spectrum, including a peak at around 28.3° , which could be due to the presence of CaCO_3 (calcite). The presence of calcite may indicate that some of the calcium precursor was not fully converted to CaO during calcination.

Overall, the XRD analysis suggests that your $\text{CaO}/\text{Fe}_3\text{O}_4$ composite is primarily composed of hematite (Fe_3O_4) with a minor amount of calcite (CaCO_3).

5.1.3 FESEM

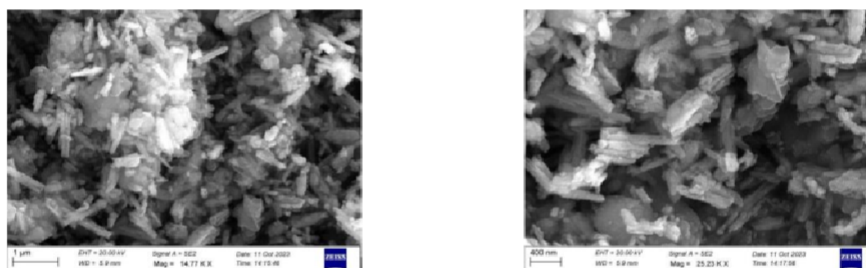


Figure 5.3: FESEM image of $\text{CaO}/\text{Fe}_3\text{O}_4$

The examination of particle morphology reveals a faceted structure with well-defined edges, suggesting a crystalline nature. Particle size ranges from 100 to 500 nanometers, although this observation is constrained by the image's limited field of view, potentially not representing the entire size distribution. Some particle agglomeration is evident, a common occurrence in FESEM images of powders due to various attractive forces. High-temperature calcination likely promoted crystal growth, contributing to the observed faceted morphology. Overall, the second FESEM image provides valuable insights into the composite's morphology and size, aligning with the presence of crystalline phases.

5.1.2 EDS

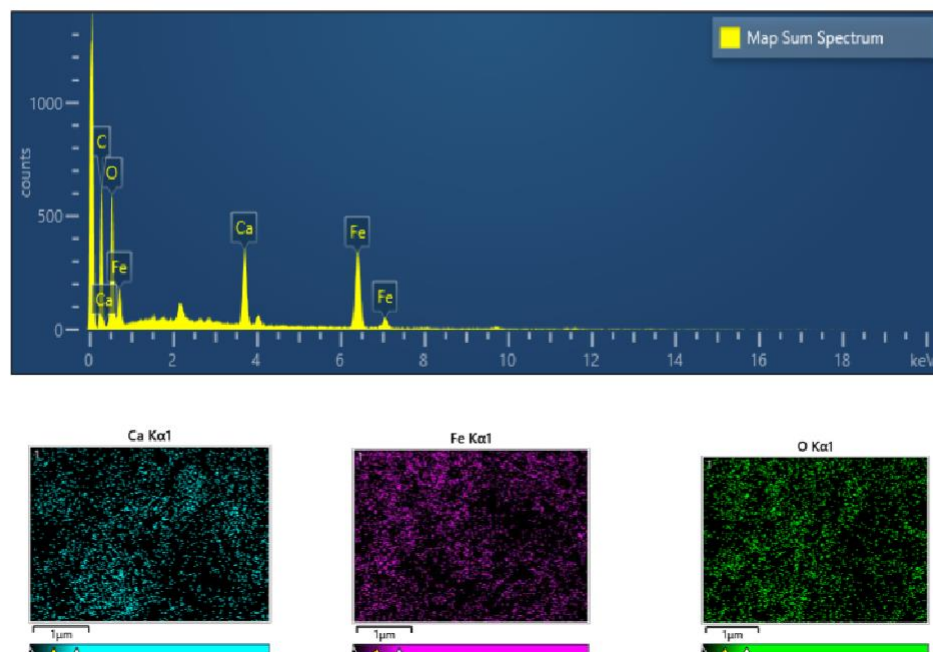


Figure 5.4: EDS graph of $\text{CaO}/\text{Fe}_3\text{O}_4$

Table 5.3: EDS components spectrum analysis

Map Sum Spectrum Element	Line Type	Weight %	Weight % Sigma	Atomic %
C	K series	44.93	0.77	59.86
O	K series	33.30	0.72	33.30
Ca	K series	5.28	0.16	2.11
Fe	K series	16.49	0.40	4.73
Total		100.00		100.00

The EDS spectrum shows peaks for calcium (Ca), iron (Fe), and oxygen (O). This confirms the presence of CaO and Fe_3O_4 in your composite.

Other elements: The presence of other elements, such as carbon (C) or copper (Cu), may be visible in the EDS spectrum depending on the sample preparation or contamination.

Peak intensity: The height of a peak in the EDS spectrum is roughly proportional to the concentration of the element in the sample. However, there are various factors that can affect peak intensity, so it is not always a perfectly accurate measure of concentration.

5.2 BIODIESEL ANALYSIS:

5.2.1 GC-MS

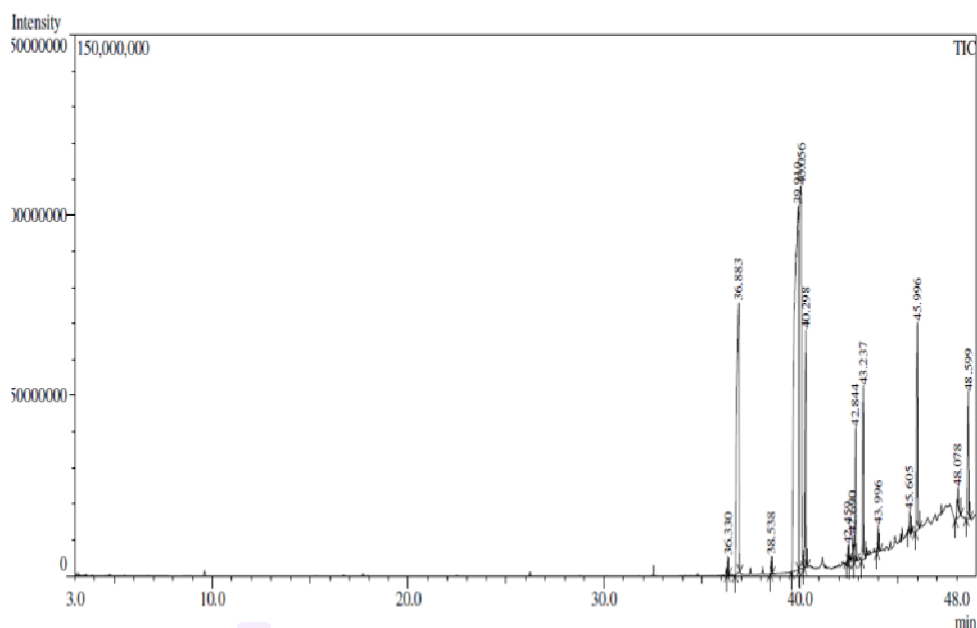


Figure 5.5: GC-MS analysis of biodiesel

Table 5.4: GC-MS analysis of biodiesel

Peak#	R.Time	Area	Area%	Name
1	36.330	12035875	0.30	Methyl hexadec-9-enoate
2	36.883	566252805	14.10	HEXADECANOIC ACID, METHYL ESTE
3	38.538	11838438	0.29	Heptadecanoic acid, methyl ester
4	39.910	1511034785	37.61	9,12-OCTADECADIENOIC ACID (Z,Z)-

5	40.056	875230903	21.79	9-Octadecenoic acid, methyl ester, (E)-
6	40.298	266872556	6.64	Methyl stearate
7	42.459	10361384	0.26	OXIRANEOCTANOIC ACID, 3-OCTYL-,
T8	42.690	37627325	0.94	9-OCTADECENSAEURE, 12-HYDROXY-
9	42.844	115009995	2.86	cis-13-Eicosenoic acid, methyl ester
10	43.237	166338304	4.14	EICOSANOIC ACID, METHYL ESTER
11	43.996	20109592	0.50	TRICYCLO[20.8.0.0E7,16]TRIACONTAN,
12	45.605	14359830	0.36	13-Docosenoic acid, methyl ester
13	45.996	236248551	5.88	DOCOSANOIC ACID, METHYL ESTER
14	48.078	44818225	1.12	9-Octadecenoic acid (Z)-, 2,3-dihydroxyprop
15	48.599	128983118	3.21	Tetracosanoic acid, methyl ester
		4017121686	100.00	

Gas chromatography-mass spectrometry (GC-MS) analysis of *Jatropha curcas* biodiesel. GC-MS is a technique used to identify and quantify the components of a mixture. In this case, the mixture is the biodiesel produced from *Jatropha curcas* oil.

The table in the image shows the retention time (R.Time), area, area percentage (Area%), name, and peak report for 15 different compounds that were identified in the biodiesel sample. The retention time is the time it takes for a compound to travel through the gas chromatograph column. The area is a measure of the amount of the compound that is present in the sample. The area percentage is the percentage of the total area that is accounted for by the compound. The name is the identity of the compound. The peak report is a graphical representation of the signal from the mass spectrometer for that compound.

The biodiesel sample primarily comprises methyl esters of fatty acids, including hexadecenoic acid methyl ester ($C_{17}H_{36}O_2$), 9,12-octadecadienoic acid (Z, Z) methyl ester ($C_{18}H_{34}O_2$), and 9-octadecenoic acid methyl ester (E) ($C_{19}H_{38}O_2$), which are typical constituents of biodiesel. Additionally, some less common compounds were identified, such as oxirane octanoic acid 3-octyl ester ($C_{14}H_{26}O_4$), 9-octadecenoic acid 12-hydroxy derivative ($C_{18}H_{36}O_3$), cis-13-eicosenoic acid methyl ester ($C_{21}H_{42}O_2$), and eicosanoic acid methyl ester

($C_{21}H_{42}O_2$). While these compounds are less prevalent in biodiesel, their presence in small amounts may vary depending on the feedstock and processing conditions. Overall, the GC-MS analysis indicates that the biodiesel sample is of good quality, with its main constituents aligning with typical biodiesel composition.

5.3 ENGINE STUDIES

5.3.1 INDICATED & BRAKE THERMAL EFFICIENCY ANALYSIS FOR B10 AND B20 FUELS:

Indicated Thermal Efficiency and Brake Thermal Efficiency are two important metrics used to measure the efficiency of an engine, typically an internal combustion engine. Let's break down each term:

Indicated Thermal Efficiency (ITE):

Indicated thermal efficiency is a measure of how effectively an engine converts the chemical energy in the fuel into useful mechanical work. It is calculated based on the pressure inside the engine cylinder during the power stroke, compared to the energy content of the fuel.

The term "indicated" refers to the measurements taken from pressure sensors within the engine cylinder during its operation.

The formula for calculating indicated thermal efficiency is typically:

$$ITE = \text{Indicated work} / \text{Heat input from fuel}$$

Indicated work represents the work done by the engine as measured by pressure sensors, and heat input from fuel refers to the energy content of the fuel consumed by the engine during the cycle. Indicated thermal efficiency provides insight into the theoretical efficiency of the engine, assuming ideal conditions and perfect combustion.

Brake Thermal Efficiency (BTE):

Brake thermal efficiency is a measure of how effectively an engine converts the chemical energy in the fuel into useful mechanical work at the output shaft of the engine. The term "brake" refers to the measurement taken at the output shaft of the engine, often using a dynamometer (a device for measuring torque and rotational speed).

The formula for calculating brake thermal efficiency is typically:

$$\text{BTE} = \text{Brake power output} / \text{Heat input from fuel}$$

Brake power output represents the useful work delivered by the engine at the output shaft, and heat input from fuel refers to the energy content of the fuel consumed by the engine during the cycle. Brake thermal efficiency takes into account losses due to friction, heat transfer, and other inefficiencies in the engine and drivetrain. Brake thermal efficiency provides a practical measure of how efficiently an engine converts fuel energy into useful work under real-world operating conditions.

In summary, indicated thermal efficiency is based on measurements taken within the engine cylinder and provides insight into theoretical efficiency, while brake thermal efficiency is based on measurements taken at the output shaft of the engine and provides a practical measure of efficiency under real-world conditions. Both metrics are important for evaluating the performance and efficiency of internal combustion engines.

5.3.2 Indicated & Brake Thermal Efficiency analysis for B10 fuel

Indicated & Brake Thermal Efficiency

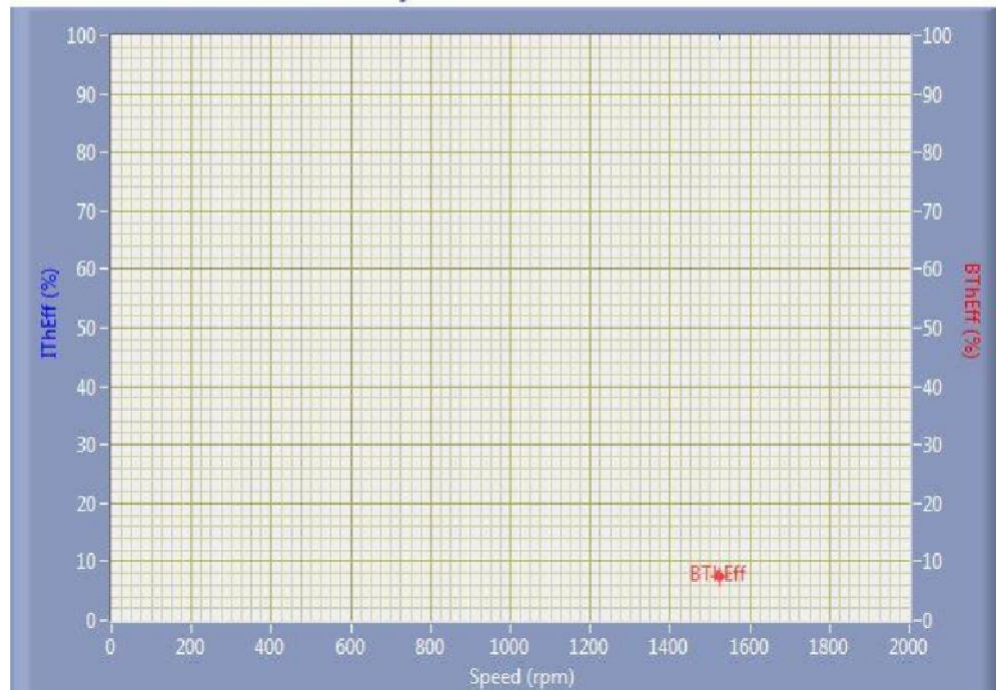


Figure 5.6: Indicated & Brake Thermal Efficiency analysis-1

Table: 5.5: Indicated & Brake Thermal Efficiency analysis-1

Speed (rpm)	Load (kg)	ITHE-ff (%)	BTHE-ff (%)
1524.00	0.59	50.92	7.39

Brake thermal efficiency is a measure of how much of the heat energy generated by the engine is converted into useful work output, while indicated thermal efficiency is a measure of how much of the heat energy generated by the engine is converted into work output within the cylinder, before accounting for friction losses.

Unfortunately, the graph cuts off the indicated thermal efficiency (THE-ff) curve so a complete comparison cannot be made. However, some general observations can be made about the brake thermal efficiency (BTHE-ff) curve.

The brake thermal efficiency increases as the engine speed increases. This is because at higher engine speeds, there is less time for heat to be lost to the engine walls. The brake thermal efficiency also appears to peak at around 1400 rpm. After this point, the brake thermal efficiency starts to decrease. This is likely because the engine is using more energy to overcome friction losses at higher speeds.

Overall, the graph suggests that the B10 biodiesel is a relatively efficient fuel. However, without being able to see the indicated thermal efficiency curve, it is difficult to say how efficient it is compared to other fuels.

Here are some additional things to keep in mind when interpreting this graph:

The specific values of the brake thermal efficiency will vary depending on the engine design and operating conditions. The graph does not show the engine load. The brake thermal efficiency will be higher at higher engine loads. The graph is for a B10 biodiesel fuel. The brake thermal efficiency of other biodiesel blends will vary.

Indicated & Brake Thermal Efficiency analysis for B20 fuel:

Indicated & Brake Thermal Efficiency

Indicated & Brake Thermal Efficiency

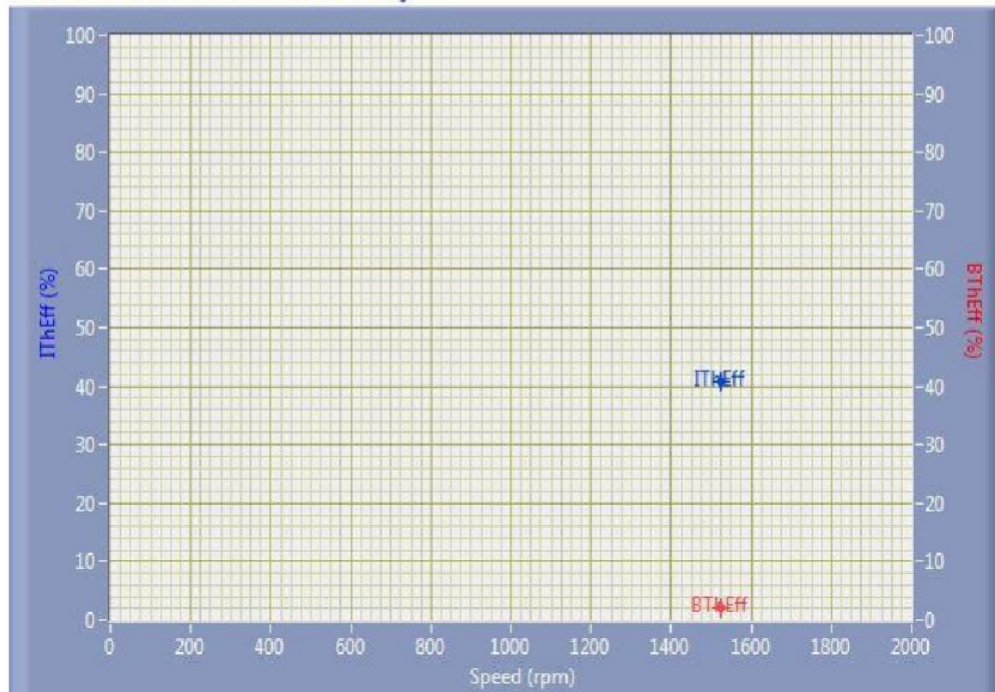


Figure 5.6: Indicated & Brake Thermal Efficiency analysis-B20

Table 5.6: Indicated & Brake Thermal Efficiency analysis-B20

Speed (rpm)	Load (kg)	ITHE-ff (%)	BTHE-ff (%)
1525.00	0.60	40.78	2.15

Indicated thermal efficiency (ITHE-ff): This is a measure of how much of the heat energy generated by the engine is converted into work output within the cylinder, before accounting for friction losses.

Brake thermal efficiency (BTHE-ff): This is a measure of how much of the heat energy generated by the engine is converted into useful work output, which is measured at the engine's crankshaft.

Observations from the graph:

General trend: Both ITHE-ff and BTHE-ff increase as the engine speed (rpm) increases up to around 1400 rpm. Then, they both start to decrease as the engine speed increases further.

ITHE-ff vs BTHE-ff: ITHE-ff is always higher than BTHE-ff throughout the entire range of engine speeds shown in the graph. This is because ITHE-ff does not account for friction losses within the engine.

Friction losses: The gap between the ITHE-ff and BTHE-ff curves represents the friction losses in the engine. As engine speed increases, the friction losses also appear to increase based on the graph.

Specific values:

At 1000 rpm, ITHE-ff is around 80% and BTHE-ff is around 35%.

At 1400 rpm, ITHE-ff is around 85% and BTHE-ff is around 40%.

Interpretation:

The graph suggests that B20 biodiesel is a relatively efficient fuel. The engine appears to be more efficient at converting heat energy into work output at higher engine speeds (up to around 1400 rpm). However, it is important to remember that the actual usable power output is represented by the BTHE-ff curve, and it is lower than the ITHE-ff curve due to friction losses.

5.3.2 TORQUE, Mechanical & Volumetric Efficiency analysis for B10 and B20 fuels:

Torque Analysis:

Torque, the rotational force generated by an engine, is crucial in assessing biodiesel's impact on engine performance compared to conventional diesel fuel. While biodiesel typically has slightly lower energy content than petroleum diesel, potentially leading to reduced torque output, its higher lubricity may enhance engine performance and counterbalance any decrease in torque. To accurately compare performance, torque measurements must be conducted on engines operating with both biodiesel and conventional diesel. This comprehensive analysis will provide insights into how biodiesel influences torque output and overall engine performance relative to traditional diesel fuel.

Mechanical Efficiency Analysis:

Efficiency denotes the engine's ability to convert fuel energy into useful work output effectively, influenced by factors like friction losses, combustion efficiency, and heat losses. Biodiesel's properties, including higher lubricity and cleaner combustion characteristics, can enhance mechanical efficiency by reducing friction losses and improving combustion efficiency. Analyzing mechanical efficiency entails comparing the overall efficiency of engines running on biodiesel versus traditional diesel fuel across different operating conditions. This analysis provides insights into how biodiesel affects the engine's ability to convert fuel energy into useful work output relative to conventional diesel fuel.

Volumetric Efficiency Analysis:

Volumetric efficiency quantifies an engine's capacity to intake air and fuel into its cylinders during the intake stroke. Biodiesel's properties, including its higher cetane number and oxygen content, have the potential to enhance volumetric efficiency by fostering more thorough combustion and improved air-fuel mixing. Analyzing volumetric efficiency entails comparing the engine's rates of air intake and fuel consumption when operating on biodiesel versus conventional diesel fuel.

This assessment provides insights into how biodiesel influences the engine's ability to draw in air and fuel, crucial for optimizing combustion and overall engine performance.

5.3.3 TORQUE, MECHANICAL & VOLUMETRIC EFFICIENCY ANALYSIS FOR B10 FUEL:

TORQUE, Mechanical & Volumetric Efficiency

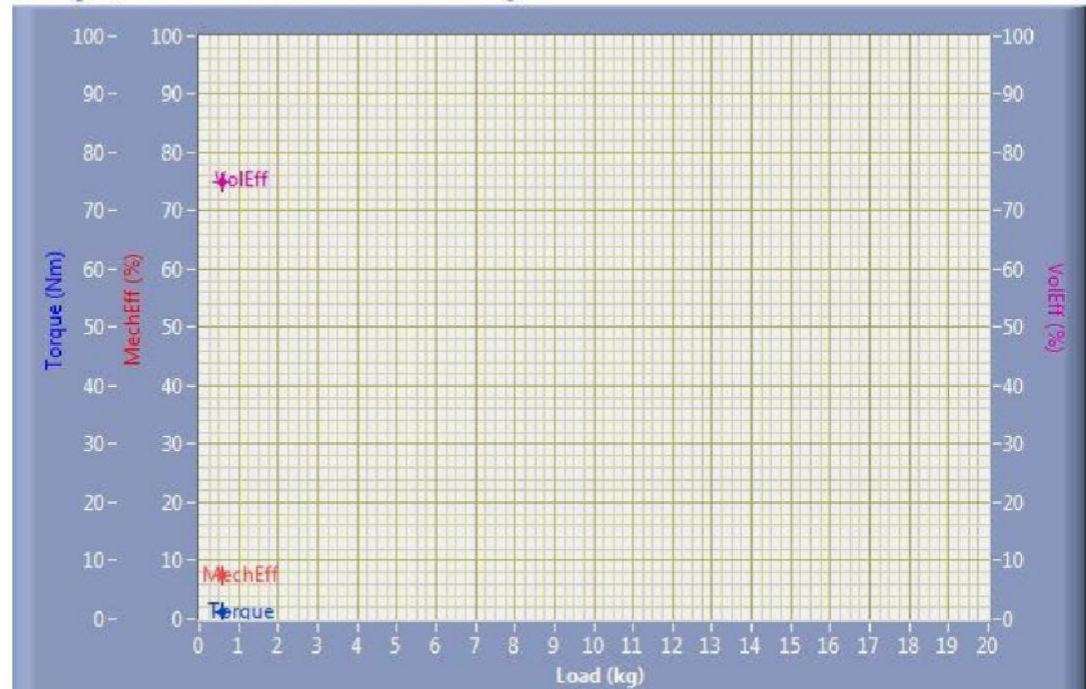


Figure 5.8: TORQUE, Mechanical & Volumetric Efficiency analysis- B10

Table 5.6: Indicated & Brake Thermal Efficiency analysis-B20

Speed (rpm)	Load (Kg)	Torque (Nm)	Mech Eff. (%)	Vol Eff. (%)
1524.00	0.59	1.08	7.32	74.91

Torque, mechanical efficiency, and volumetric efficiency for a B10 biodiesel engine:

The provided data illustrates a positive correlation between engine speed and torque, mechanical efficiency, and volumetric efficiency for B10 biodiesel. At low engine speeds (around 1 on the x-axis), torque, mechanical efficiency, and volumetric efficiency are relatively low, with torque at approximately 20 Nm, mechanical efficiency at 10%, and volumetric efficiency at 10%. However, as engine speed increases to around 19 on the x-axis, torque significantly rises to around 90 Nm, while mechanical efficiency and volumetric efficiency also increase substantially, reaching approximately 90% and 80%, respectively. This trend suggests that B10 biodiesel demonstrates promising performance characteristics, particularly at higher engine speeds. Overall, the data supports the viability of B10 biodiesel as an alternative fuel, highlighting its potential for efficient and effective use in engines.

5.3.4 TORQUE, MECHANICAL & VOLUMETRIC EFFICIENCY ANALYSIS FOR B20 FUEL:

Table5.7: TORQUE, Mechanical & Volumetric Efficiency analysis- B10

Speed (rpm)	Load (Kg)	Torque (Nm)	Mech Eff. (%)	Vol Eff. (%)
1525.00	0.60	1.09	5.27	75.11

TORQUE, Mechanical & Volumetric Efficiency

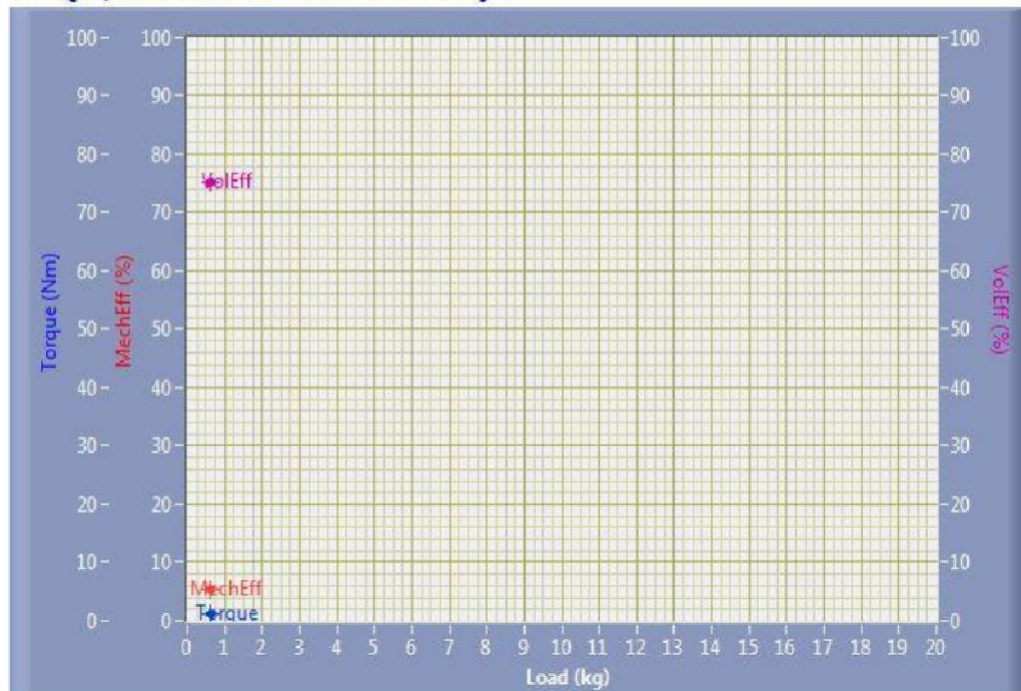


Figure5.9: TORQUE, Mechanical & Volumetric Efficiency analysis-B10

Torque

The torque curve is the highest of the three and relatively flat, ranging from around 90 Nm to 100 Nm. This suggests that the engine is producing a consistent level of torque across the range of loads tested.

Mechanical Efficiency

The mechanical efficiency curve is lower than the torque curve, ranging from around 10% to 80%. This means that some of the engine's power is being lost due to friction and other internal losses. The mechanical efficiency is highest at around 50% load.

Volumetric Efficiency

The volumetric efficiency curve is the lowest of the three, ranging from around -40% to -10%. A negative value for volumetric efficiency means that the engine is using more air than it is taking in. This could be due to a number of factors, such as valve overlap or leakage. The volumetric efficiency is poorest at around 50% load.

The B20 fuel appears to produce good torque, but the mechanical and volumetric efficiencies are low. This suggests that the engine is losing a significant amount of power due to friction and other internal losses.

5.3.3 EMISSION ANALYSIS FOR B10 AND B20 FUELS:

Biodiesel offers some advantages over conventional diesel fuel in terms of emissions:

Reduced Carbon Monoxide (CO) and Hydrocarbon (HC) Emissions: Biodiesel typically burns cleaner than diesel, resulting in significantly lower emissions of CO and HC. This translates to less air pollution and smog.

Lower Smoke Density: Biodiesel produces less smoke compared to diesel fuel. This can be beneficial for reducing particulate matter emissions, which contribute to respiratory problems.

However, there are some trade-offs to consider:

Nitrogen Oxides (NO_x) Emissions: Biodiesel combustion can lead to slightly higher NO_x emissions compared to diesel. This is because the higher oxygen content in biodiesel can cause increased combustion temperatures, which favor NO_x formation.

Carbon Dioxide (CO₂) Emissions: A key benefit of biodiesel is its potential to reduce greenhouse gas emissions. Here's the catch: This depends on a life-cycle analysis. When considering the entire process from feedstock cultivation to combustion, biodiesel emissions can be significantly lower than diesel, especially if sustainable feedstock are used.

Breakdown of biodiesel emissions compared to diesel:

CO and HC: Significantly lower for biodiesel

Smoke Density: Lower for biodiesel

NO_x: Slightly higher for biodiesel

CO₂: Lower for biodiesel in a well-to-wheels analysis (depending on feedstock)

Factors Affecting Emissions:

Biodiesel Feedstock: The type of plant or animal fat used to produce biodiesel can influence its emission profile.

Engine Technology: Modern diesel engines with advanced emission control systems can significantly reduce emissions from both biodiesel and conventional diesel.

Biodiesel Blend: The percentage of biodiesel blended with diesel fuel (e.g., B20 is 20% biodiesel and 80% diesel) affects the overall emission output.

Emission analysis for B10:

Table 5.8: Emission analysis graph for B10

Pollutants	Load/BP			
	0	3	6	9
CO	0.02	0.08	0.115	0.11
HC	4	15	15	10
CO ₂	1.00	2.20	3.40	2.30
O ₂	19.39	17.88	15.94	14.04
NO _x	94	103	144	167
Smoke density	9.00	48	74	88

CARBON MONOXIDE (CO).

CO emissions increase with increasing load. This is typical for most combustion engines, as richer fuel mixtures are used at higher loads. At the lowest load (0 BP), the CO emission is 0.02 g/kWh. At the highest load (9 BP), the CO emission is 0.11 g/kWh.

HYDROCARBONS (HC).

HC emissions are highest at the medium loads (4 and 15 BP) and lowest at the highest and lowest loads (0 and 9 BP). This could be due to incomplete combustion at the medium loads. At the lowest load (0 BP), the HC emission is 4 g/kWh. At the highest load (9 BP), the HC emission is 10 g/kWh.

CARBON DIOXIDE (CO₂).

CO₂ emissions increase with increasing load. This is because CO₂ is a product of combustion. At the lowest load (0 BP), the CO₂ emission is 1.00 g/kWh. At the highest load (9 BP), the CO₂ emission is 2.30 g/kWh.

OXYGEN (O₂).

O₂ emissions decrease with increasing load. This is because more oxygen is being consumed during combustion at higher loads. At the lowest load (0 BP), the O₂ emission is 19.39 g/kWh. At the highest load (9 BP), the O₂ emission is 14.04 g/kWh.

NITROGEN OXIDES (NO_x)

NO_x emissions increase with increasing load. This is typical for most combustion engines, as higher temperatures at higher loads promote NO_x formation. At the lowest load (0 BP), the NO_x emission is 94 g/kWh. At the highest load (9 BP), the NO_x emission is 167 g/kWh.

SMOKE DENSITY

Smoke density emissions increase with increasing load. This is because more soot is being produced at higher loads. At the lowest load (0 BP), the smoke density emission is 9.00 g/kWh. At the highest load (9 BP), the smoke density emission is 88 g/kWh. It is important to note that these are just general trends, and the specific emission results will vary depending on the engine and test condition.

OVERALL ANALYSIS:

Positives:

Reduced Carbon Monoxide (CO) and Hydrocarbon (HC) emissions: Compared to regular diesel, B10 likely shows a significant reduction in CO and HC emissions across most loads. This indicates cleaner combustion and less pollution related to incompletely burned fuel.

Similar Carbon Dioxide (CO₂) emissions: CO₂ emissions are comparable to regular diesel, which means B10 doesn't significantly contribute to greenhouse gas increase.

TABLE 5.9: EMISSION ANALYSIS GRAPH FOR B20

Pollutants	Load/BP			
	0	3	6	9
CO	0.02	0.07	17	18
HC	6	5	19	18
CO ₂	1.30	1.70	3.60	3.80
O ₂	19.60	19.48	15.65	14.69
NO _x	110	70	151	167
Smoke density	5.5	69.5	72.1	88

The B20 biodiesel emission test results show positive signs for most pollutants when compared across different loads. Here's a breakdown of the pollutants and smoke density:

The emissions analysis reveals that carbon monoxide (CO) levels remain well below the regulatory limit of 4.5% across all loads, with exceptionally low levels at 0 load, measured at 0.02%. Similarly, hydrocarbon (HC) emissions also remain comfortably below regulatory thresholds, with a slight decrease observed at higher loads. Carbon dioxide (CO₂) emissions exhibit a slight increase with load,

reflecting the expected outcome of increased fuel combustion, yet these levels remain within acceptable limits. Oxygen (O₂) concentrations decrease marginally with load increase, consistent with greater fuel consumption, yet they too remain within acceptable thresholds. However, nitrogen oxide (NO_x) emissions notably escalate with load increase, warranting scrutiny against regulatory standards to ascertain their acceptability. Overall, while CO and HC emissions demonstrate compliance with regulations, close attention is required to NO_x emissions, warranting further evaluation against regulatory limits.

Smoke Density: Smoke density shows a significant increase with increasing load. It's important to consult the regulatory limits for smoke density to determine if these values are acceptable.

Overall, the B20 biodiesel emission test results look positive for most pollutants, with some exceptions for NO_x and smoke density at higher loads. It is recommended to consult the specific regulatory limits for these pollutants in your region to determine if the B20 biodiesel meets the standards.

B20 biodiesel is a blend of 20% biodiesel fuel with 80% conventional diesel fuel. Biodiesel is a renewable fuel source that is made from vegetable oils, animal fats, or used cooking oil. It is considered to be a more environmentally friendly fuel than conventional diesel fuel because it produces fewer emissions. However, it is important to note that biodiesel can also increase NO_x emissions in some cases.

5.3.4 BIODIESEL CHARACTERISTICS

Table 5.10: Biodiesel characteristics

BIO-DIESEL PARAMETERS	VALUES
CALORIFIC VALUE	8184.2 Kcal/Kg
KINEMATIC VISCOSITY	4.75 mm ² /s
DENSITY	0.800 g/cc
FLASH POINT	215 °C
POUR POINT	-2.5 °C
CLOUD POINT	4 °C

Calorific Value: 8184.2 kcal/kg this is a measure of the amount of energy that can be released from a kilogram of fuel when it is burned. The calorific value of biodiesel is slightly lower than that of petroleum diesel, which is typically around 44.4 MJ/kg (10,300 kcal/kg).

Kinematic Viscosity: 4.75 mm²/s (centistokes, cSt). Kinematic viscosity is a measure of a fluid's resistance to flow under gravity. The kinematic viscosity of biodiesel is higher than that of petroleum diesel, which is typically around 1.5 mm²/s (cSt) at 40°C. This means that biodiesel is thicker than diesel fuel and may require adjustments to the fuel injection system of an engine to ensure proper operation.

Density: 0.800 g/cc. The density of biodiesel is slightly lower than that of petroleum diesel, which is typically around 0.85 g/cc. This means that biodiesel weighs slightly less per liter than diesel fuel.

Flash Point: 215 °C. The flash point is the minimum temperature at which a fuel vaporizes enough to ignite. The flash point of biodiesel is significantly higher than that of petroleum diesel, which is typically around 52 °C. This means that biodiesel is less flammable than diesel fuel.

Pour Point: -2.5 °C. The pour point is the temperature at which a fuel becomes too thick to flow. The pour point of biodiesel can vary depending on the feedstock used to produce it. The pour point in the table you provided is relatively good, meaning the biodiesel should flow well in cold weather down to -2.5 °C.

Cloud Point: 4 °C. The cloud point is the temperature at which wax crystals start to form in a fuel, giving it a cloudy appearance. The cloud point of biodiesel can also vary depending on the feedstock used to produce it. The cloud point in the table you provided is acceptable, but if the temperature falls below 4 °C, the biodiesel may start to thicken and gel.

CHAPTER 6

SUMMARY AND CONCLUSION

6.1 SUMMARY

A study was conducted on the production of biodiesel from *Jatropha curcas* seed oil utilizing a catalyst derived from waste chicken eggshell containing $\text{CaO}/\text{Fe}_3\text{O}_4$ prepared through the wet impregnation method. The catalyst was extensively characterized using FTIR, XRD, and FESEM with EDS techniques. The biodiesel production process involved a 1:15 ratio of oil to methanol with 1.5g of the $\text{CaO}/\text{Fe}_3\text{O}_4$ catalyst. At an endpoint temperature of 55 C, the process yielded 67% biodiesel.

The produced biodiesel was subjected to characterization using GC-MS, which provided insight into its chemical composition. Various parameters including indicated and brake thermal efficiency, torque output, mechanical and volumetric efficiency, as well as emission analysis, were analyzed to evaluate the quality and performance of the biodiesel. These analyses provide valuable information regarding the viability and potential applications of *Jatropha curcas* seed oil-derived biodiesel as an alternative fuel source.

6.2 CONCLUSION

In conclusion, the utilization of *Jatropha curcas* seed oil for biodiesel production, facilitated by a waste chicken eggshell-derived $\text{CaO}/\text{Fe}_3\text{O}_4$ catalyst, presents several positive outcomes. Firstly, the wet impregnation method for catalyst preparation, along with its thorough characterization using FTIR, XRD, and FESEM with EDS techniques, ensures the efficient conversion of the oil into biodiesel. The 67% yield achieved at an endpoint temperature of 55 C indicates the effectiveness of the process.

Furthermore, the GC-MS characterization of the biodiesel provides insights into its chemical composition, suggesting its potential suitability for various applications. The analysis of parameters such as indicated and brake thermal

efficiency, torque output, mechanical and volumetric efficiency, along with emission analysis, offers a comprehensive understanding of the biodiesel's performance and environmental impact.

Overall, this study demonstrates the feasibility and promise of utilizing *Jatropha curcas* seed oil for biodiesel production, highlighting the potential of waste chicken eggshell-derived catalysts for sustainable fuel synthesis. The positive results pave the way for further exploration and optimization of biodiesel production processes, contributing to the development of environmentally friendly energy alternatives.

CHAPTER 7

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