

INVESTIGATION ON PERFORMANCE OF BIODIESEL MADE FROM OILS OF DIFFERENT FREE FATTY ACID CONTENT

Submitted in partial fulfilment of the requirements for the award of

Bachelor of Engineering degree in
Mechanical Engineering

By

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(DEEMED TO BE UNIVERSITY)

Accredited with grade "A++" by NAAC

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of Prasanth A (Reg. No. 40150034) and Ragul G (Reg. No. 40150035) who carried out the project entitled "INVESTIGATION ON PERFORMANCE OF BIODIESEL MADE FROM OILS OF DIFFERENT FREE FATTY ACID CONTENT" under our supervision from December 2023 to April 2024.

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We PRASANTH A (Reg. No. 40150034) and RAGUL G (Reg. No. 40150035) hereby declare that the Project Report entitled **"INVESTIGATION ON PERFORMANCE OF BIODIESEL MADE FROM OILS OF DIFFERENT FREE FATTY ACID CONTENT"** done by us under the guidance of Dr. J JAYAPRABHAKAR., M.E., Ph.D., is submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering degree in Mechanical Engineering..

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ABSTRACT

This investigation delves into the performance analysis of biodiesel produced from oils with varying high free fatty acid (FFA) content, focusing on pongamia oil (5.6), iluppai oil (11.5), and neem oil (33.5). The study evaluates key parameters including density on pongamia oil (0.9424 g/cc), iluppai oil (0.102g/cc), neem oil(0.9172g/cc), viscosity on pongamia oil(39.55cst), iluppai oil (36.96cst), neem oil(37.03cst), moisture content on pongamia oil (0.0751%), iluppai oil (0.332%), neem oil (0.531%), and transesterification efficiency. Through systematic experimentation and analysis, the influence of elevated FFA levels on biodiesel properties and conversion efficiency is examined. Results indicate significant variations in density, viscosity, and moisture content among the biodiesels derived from different oils. Moreover, transesterification efficiency is observed to be affected by the FFA content of the oils. These findings offer valuable insights into optimizing biodiesel production processes and selecting suitable feedstocks for sustainable energy generation.

The spray characteristics test method used in the present study is Mei Scattering Technique. The biodiesel made from illupai oil and pongamia oil are tested in this study to find the spray characterization behaviour. A halogen white light is positioned on one side of the glass to illuminate the spray inside the cylinder's combustion chamber. On the opposite side, a high-resolution camera has been installed to capture the spray created by the end injector's double-hole nozzle at 50 frames per minute within the cylinder. After analysing each frame of the recorded video, the best image is selected and used for the analysis. The software called "ImageJ v1.47h" is used to analyse the image. Spray tip penetration length, spray angle, and spray area were calculated for both illupai oil and pongamia oil biodiesels by adjusting the threshold using the software. The results found that spray penetration and spray area of Biofuel made from illupai oil is more than biofuel made from pongamia oil. This is because the viscosity and density of the biodiesel made from illupai oil is less. It results in proper combustion, increased engine efficiency, reduced emissions. The spray angle of Biofuel made from illupai oil is more than biofuel made from pongamia oil. This is because the density and viscosity of the biofuel is less.

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LIST OF ABBREVIATIONS

FFA - free fatty acid
GC - Gas chromatography
Naoh - Sodium hydroxide
C 3 H 8 O - isopropyl alcohol
G / cc - gram per cubic centimetre
cst- Central Standard Time
CH₃OH - methanol
H₂SO₄ - sulfuric acid
G / ml - gram and molecular weight
GL - Greaves model
Pufa - polyunsaturated fatty acid
Di - diesel engine
Co - Cooking oil
Pi - phenolphthalein indicator
Cf - conical flask
P - pycnometer
Wm - weighing machine
Mm - Millimetre

CHAPTER-1

INTRODUCTION

Biodiesel, a renewable alternative to conventional fossil fuels, has garnered significant attention in recent years due to its potential to mitigate environmental concerns and reduce dependence on finite resources. Derived from a variety of feedstocks such as vegetable oils, animal fats, and waste oils, biodiesel offers a promising avenue for sustainable energy production [1-5]. This investigation focuses on the performance of biodiesel produced from oils with varying levels of free fatty acids (FFA). Free fatty acids are natural components of oils and fats that can significantly impact the quality and efficiency of biodiesel production. High FFA content in feedstocks poses challenges during the transesterification process, the primary method for biodiesel production, leading to reduced conversion efficiency and lower biodiesel yields [6-8]. Understanding the influence of FFA content on biodiesel properties and performance is essential for optimizing production processes and enhancing the overall sustainability of biodiesel production. By systematically evaluating biodiesel derived from oils with different FFA contents, this study aims to uncover insights into the following key aspects:

- **Background and Significance:** Biodiesel serves as a renewable and environmentally friendly alternative to conventional diesel fuels. Its production and utilization offer numerous benefits, including reduced greenhouse gas emissions and decreased reliance on non-renewable resources.
- **Biodiesel Production Methods:** The transesterification process, which involves the reaction of oils or fats with alcohol in the presence of a catalyst, is the most common method for biodiesel production. However, the presence of high levels of FFA in feedstock can hinder the efficiency of this process, leading to lower biodiesel yields and increased production costs.
- **Importance of Free Fatty Acid Content:** The free fatty acid content in feedstocks significantly influences the quality and properties of biodiesel. High FFA levels can result in the formation of soap during the transesterification process, leading to difficulties in separation and purification. Therefore, minimizing FFA content

in feedstocks or developing efficient methods for FFA removal is crucial for enhancing biodiesel production efficiency and product quality [9-12].

Biodiesel has emerged as a promising alternative to conventional fossil fuels, offering potential environmental and economic benefits. Produced from renewable feedstocks such as vegetable oils and animal fats, biodiesel represents a sustainable energy option with reduced greenhouse gas emissions compared to petroleum-based diesel. However, the performance and quality of biodiesel can vary significantly based on factors such as feedstock composition, production methods, and chemical properties. One critical aspect influencing biodiesel performance is the free fatty acid (FFA) content of the feedstock. FFAs can adversely affect the transesterification process, leading to soap formation, reduced yield, and altered fuel properties. Despite advancements in biodiesel production technology, understanding the impact of FFA content on biodiesel properties remains essential for optimizing production processes and ensuring product quality[13]. This investigation aims to comprehensively evaluate the performance of biodiesel derived from oils with varying FFA levels. By systematically analyzing key biodiesel characteristics such as cetane number, viscosity, oxidative stability, and emissions profile, this study seeks to elucidate the influence of FFA content on fuel quality and engine compatibility. Additionally, the findings will contribute to enhancing our understanding of biodiesel's role in sustainable energy strategies and inform decision-making processes for stakeholders across the energy sector. Through rigorous experimentation and analysis, this research endeavors to provide valuable insights into the feasibility, challenges, and potential benefits of utilizing different feedstocks for biodiesel production. Ultimately, the outcomes of this study have implications for promoting the adoption of biodiesel as a renewable, low-carbon transportation fuel, thereby advancing efforts to mitigate climate change and enhance energy security.

A comprehensive investigation into the performance of biodiesel derived from oils with varying FFA contents, this study aims to contribute valuable insights to the field of biodiesel production and utilization. Through experimental analysis and comparative studies, the aim is to identify optimal feedstock compositions and production processes that maximize biodiesel yield, quality, and overall performance [14-15].

CHAPTER 2

LITERATURE SURVEY

This chapter describes the literature survey and explores the Performance of Biodiesel Made from oils of different Free Fatty Acid content.

E. Monroe et al. Superior performance biodiesel from biomass-derived fuel alcohols and low grade oils: Fatty acid fusel esters (FAFE) Fuel(2020)-We demonstrated production of a superior performance biodiesel referred to here as fatty acid fusel alcohol esters (FAFE) – by reacting fusel alcohols (isobutanol, 3-methyl-1-butanol, and (S)-(-)-2-methyl-1-butanol) with oil (glyceryl trioleate) using lipase from *Aspergillus oryzae*. Reaction conditions corresponding to a molar ratio of 5:1 (fusel alcohols to oil), enzyme loading of 2% w/w, reaction temperature of 35 °C, shaking speed of 250 rpm, and reaction time of 24 h achieved >97% conversion to FAFE. Further, FAFE obtained from reacting a fusel alcohol mixture with corn oil were evaluated for use as a fuel for diesel engines. FAFE mixtures showed superior combustion and cold-flow properties, with the derived cetane numbers up to 4.8 points higher, cloud points up to –6 °C lower, and the heat of combustion up to 2.1% higher than the corresponding FAME samples, depending on the fusel mixture used. This represents a significant improvement for all three metrics, which are typically anti-correlated. FAFE provides a new opportunity for expanded usage of biodiesel by addressing feedstock limitations, fuel performance, and low temperature tolerance [16].

Gokul Raghavendra Srinivasan, Vijayalakshmi Shankar, Sreekanth Chandra Sekharan, Mamoon Munir, Deepanraj Balakrishnan, Anand Mohanam, Ranjitha Jambulingam Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 1-19, 2020-This present study focus on the process optimization and characteristic assessment of waste animal fat (WAF) biodiesel based on the influence of fatty acids characterized in it. WAFs were rendered from leather fleshing (subcutaneous fat, 85.64%) and slaughterhouse (intramuscular fat, 8.46%) wastes using dry rendering technique, wherein the maximum renderable fat content was

found to be 75.77% and 5.89%, respectively. Ethyl esters of oleic acid, palmitic acid, and stearic acid were characterized as dominant fatty acid esters (FAEs) in WAF biodiesel. Optimized transesterification on waste fats using ethanol and synthesized D-valine amido ethyl methyl imidazolium chloride ([D-Vaemim] Cl) as novel ionic liquid (IL) catalyst yielded 97.36% of biodiesel. High molar ratio (WAF to ethanol:6) and reaction temperature (75°C) were accounted by the long-chain fatty acids in triglyceride molecules and their higher degree of saturation, respectively, meanwhile, [D-Vaemim] Cl exhibited high conversion yield beyond 10% and was effective up to 10 cycles. Similarly, biodiesel properties were evaluated as per ASTM D6751 standards, were found to be in acceptable range, and were deeply influenced by carbon chain length and degree of unsaturation in FAE molecules. Also, the presence of long-chain saturated FAEs along with fuel bound oxygen induced superior combustion characteristics and controlled emission concentrations. However, slight reduction in engine performance was due to high viscosity and reduced calorific value of biodiesel which was reflected from its FAE molecules [17].

Fadilla Noor Rahma, ArifHidayatInt J Technol 14, 206-218, 2023- This study utilizes ZrO₂/Bagasse Fly Ash as a solid catalyst to convert Free Fatty Acid (FFA) from Palm Fatty Acid Distillate (PFAD) into biodiesel. The ZrO₂/Bagasse fly ash catalyst was characterized by several physicochemical techniques, i.e., N₂ adsorption-desorption, X-ray diffraction (XRD), and X-ray fluorescent (XRF). The catalyst was then applied for FFA esterification under different conditions. The highest FFA esterification conversion was 90.6%, which was reached at the optimal reaction condition as follows: methanol/PFAD mass ratio of 10:1; catalyst amount of 10 wt%; and reaction temperature of 60°C. It was also found that the catalyst could be reused up to four times by an activation process. This study presented the Eley-Rideal kinetic model to describe the reaction mechanism. The model demonstrated an excellent fit to the experimental result with an R² value of 0.99, showing that Eley-Rideal is a valid model to describe the reaction and that the surface reaction step acts as the rate-determining step. Additionally, the reaction kinetics and adsorption equilibrium parameters were determined using non-linear regression. The correlation between the parameters with temperature was evaluated using Arrhenius and van't Hoff equations [18].

Nattee Akkarawatkhoosith, Thapanee Bangjang, Amaraporn Kaewchada, Attasak Jaree Energy Reports 9, 5299-5305, 2023-Rice bran oil fatty acid distillate (RBOFAD), a by-product from rice bran oil production, was used as feedstock for the production of biodiesel. The hydrolysis–esterification–transesterification of RBOFAD with ethanol was performed in a microreactor under supercritical conditions. The biodiesel product in the form of fatty acid ethyl ester (FAEE) was obtained. The operating conditions, including the sulfuric acid content (0.2–0.6%), water content (0–7.5%), ethanol-to-oil molar ratio (5:1–16:1), and reaction temperature (260–320 °C), were optimized. The water content could affect the reaction system via both hydrolysis of triglycerides and reverse esterification of fatty acids. Biodiesel with the FAEE content of 93% was obtained at the optimal conditions (sulfuric acid content of 0.4%, water content of 2.5%, ethanol-to-oil molar ratio of 7:1, residence time of 19 min, and reaction temperature of 280 °C). The properties of the biodiesel, including density, viscosity, acidity, oxidation stability, freezing point, and pour point, were compared with standards. The properties such as viscosity, acid value, heating value, and oxidation stability were suitable as biodiesel according to EN14213, except for the contents of ester, monoglyceride, and diglyceride [19].

Yanxia Zhou, Kaiyue Li, Shangde Sun Biomass and Bioenergy 144, 105930, 2021-Biodiesel is a typical renewable and green energy, that is usually produced by the transesterification of edible vegetable oils. However, the cost of edible vegetable oils as feedstock accounts for 60%–80% of the total cost of biodiesel production. To overcome these issues, in this work, a low-cost feedstock, waste phoenix seed oil (PSO) with a high free fatty acid (FFA) content ($30.1 \pm 0.6\%$), consisting of the main fatty acid, linoleic acid (30.2%), oleic acid (22.2%), and palmitic acid (17.4%), was developed as a new feedstock to prepare biodiesel. A novel one-step method including simultaneous esterification of FFAs and transesterification of the PSO to prepare biodiesel was developed. Free lipase was used as catalyst. The influences of the reaction parameters were explored and optimized by response surface methodology. The results showed that the free lipase Lipozyme TL100L from *Thermomyces lanuginosus* can simultaneously catalyze esterification and transesterification. Under the optimum conditions (enzyme load 9.7%, reaction time 6.9 h, reaction temperature 31 °C and substrate ratio (methanol/PSO) 4.3: 1

(mol/mol)), the maximum biodiesel yield ($93.8 \pm 0.5\%$) was achieved. The activation energy from biodiesel preparation using PSO with a high FFA content was 39.7 kJ/mol. Furthermore, the kinetic values for K_m and V_{max} were 0.18 mol/L and 0.043 mol/(L·min), respectively. The reaction mechanism of the simultaneous esterification and transesterification was also proposed. These results indicate that PSO with a high FFA content can be used as a potential feedstock for biodiesel production [20].

ObieFarobie, E HartulistiyosoInt. J. Renew. Energy Res 11 (4), 1590-1596, 2021- Low-cost yet viable feedstock, i.e., crude palm oil (CPO) is one of the potential sources to be utilized in the biodiesel industry. However, CPO mainly contains a high free fatty acid (FFA) content. One of the promising methods to treat feedstock containing high FFA such as CPO is an enzyme-catalyzed transesterification owing to no sensitivity to the presence of FFA. Hence, this study aims to investigate biodiesel production from CPO under different FFA content using enzyme-catalyzed transesterification. Eversa® Transform 2.0 lipase which is a low-cost enzyme was used as a liquid enzyme. Experiments were conducted by changing the temperature (30–60 °C), the methanol-to-CPO molar ratio (3:1–8:1), and enzyme concentration (0.1–0.4 wt%). Intriguingly, the higher the FFA content of CPO, the higher the biodiesel yield. The result showed that biodiesel yield as high as 97.91% could be attained at a milder temperature of 40 °C, CPO with FFA content of 19.33%, and a methanol-to-CPO molar ratio of 7:1 [21].

Maria Cristina Macawile, Armando T Quitain, Tetsuya Kida, Raymond Tan, Joseph AureseniaJournal of cleaner production 275, 123146, 2020- An environmentally friendly surface modification method was applied to synthesize solid acid catalyst suitable for biodiesel production. The catalyst was prepared from multiwalled carbon nanotube (MWCNT) and 3-mercaptopropyltrimethoxysilane (3-MPTMS) oxidized in hydrogen peroxide under supercritical carbon dioxide (scCO₂). The carbon dioxide under supercritical condition with ethanol as cosolvent allows swift transportation and promotes uniform distribution of organosilane groups on randomly entangled and layered orientation of MWCNT. The catalyst was characterized by using Field emission scanning electron microscopy–energy dispersive x-ray (FESEM-EDX), Thermogravimetric analysis (TGA), Fourier transform infrared (FTIR) spectroscopy,

X-ray powder diffraction (XRD), Brunauer–Emmett-Teller (BET) analysis and Time-of-Flight secondary ion mass spectrometry (TOF-SIMS). The catalytic activity of the catalyst was tested using a high free fatty acid (FFA)-containing Hibiscus cannabinus (kenaf) oil, and the fatty acid methyl esters (FAME) products from simultaneous esterification and transesterification reactions were quantified. To compare with scCO₂ method, an acid catalyst was also prepared using liquid chemical deposition that resulted in only 45.11% biodiesel conversion. On the other hand, the optimum conversion of 93.10% was obtained using a scCO₂ synthesized catalyst at the following transesterification conditions: temperature = 63 °C, methanol:oil ratio = 14:1, 10 wt % catalyst and time = 240 min [22].

Bambang Irawan, Abu Hasan International Journal of Research in Vocational Studies (IJRVOCAS) 1 (2), 01-10, 202-Biodiesel is a biomass fuel that can replace petroleum diesel fuel. One of the advantages of biodiesel fuel as renewable energy source that it is more environmentally friendly than fossil fuels because biodiesel significantly reduces greenhouse gas emissions compared to fossil fuels. FAME (fatty acid methyl ester) is a derivative product of CPO (crude palm oil) that has been treated both physically and chemically. The main advantage of FAME lies in the low content of impurities, especially sulphure and metal content. FAME comes from vegetable oil raw materials, which contain high enough fatty acids, around 61-62%, and nowadays, it is used as a mixture with petroleum diesel. The characteristics of biodiesel obtained from the conversion of FAME into biodiesel by pyrolysis at a temperature range of 160 – 200 oC indicate that the biodiesel produced is density 0.8475 kg/m³, viscosity 3.053 cSt, calculated cetane index (CCI) 48.5, flash point 59oC, moisture content 223 ppm, and sulphure content of 0.07% m/m. The results obtained are below the maximum limit of the specified biodiesel quality requirements [23].

CHAPTER 3

AIM AND SCOPE

3.1 AIM

The aim of the investigation is to assess and compare the performance of biodiesel produced from oils with varying free fatty acid (FFA) content. This involves analyzing factors such as fuel efficiency, emissions, engine wear, and overall compatibility with existing diesel engines.

3.2 SCOPE

- The study will involve the selection and analysis of various feedstocks with differing FFA contents. Understanding the properties of these feedstocks is crucial for assessing their suitability for biodiesel production.
- Transesterification, the process by which biodiesel is produced from feedstock oils, will be examined in detail. The efficiency and yield of this process when using oils with varying FFA levels will be investigated.
- The biodiesel produced from different feedstocks will be analyzed to determine its key properties, including viscosity, density, cetane number, and oxidative stability. These properties play a significant role in determining the fuel's suitability for use in diesel engines.
- The performance of biodiesel blends, formulated from oils with varying FFA contents, will be evaluated in a suitable test engine. Parameters such as power output, fuel consumption, and emissions will be measured to assess the impact of FFA content on engine performance.
- The study will include an analysis of the emissions produced by engines running on biodiesel blends with different FFA levels. This will provide insights into the environmental implications of using feedstocks with varying FFA contents for biodiesel production.

CHAPTER 4

MATERIALS AND METHODS

4.1 MATERIALS AND METHODOLOGY USED

In this investigation, biodiesel was produced from oils with varying free fatty acid (FFA) content. The oils selected for this study included pongamia oil, iluppai oil, and neem oil. The FFA content of each oil was determined using the titration method outlined in ASTM D664. Biodiesel was synthesized via a two-step transesterification process. First, the oils were pretreated to reduce FFA levels using an acid-catalyzed esterification reaction. Sulfuric acid was employed as the catalyst at a concentration of 1% by weight of the oil, and the reaction was carried out at 60°C for 1 hour with constant stirring. Following pretreatment, the transesterification reaction was conducted using sodium methoxide as the catalyst at a concentration of 0.5% by weight of the oil. The reaction mixture was heated to 65°C and maintained at this temperature for 1.5 hours with continuous agitation. After completion of the reaction, the biodiesel was separated from the glycerol phase through centrifugation. The produced biodiesel samples were characterized for their physicochemical properties, including density, viscosity, acid value, and ester content, following standard methods outlined in ASTM D6751 [24]. Engine performance testing was conducted using a single-cylinder, direct-injection diesel engine. The engine was operated under steady-state conditions at various loads and speeds to evaluate the combustion efficiency and emissions characteristics of the biodiesel fuels. Additionally, the oxidative stability of the biodiesel samples was assessed using the Rancimat method. Data analysis was performed using statistical software to determine any significant differences in the performance of biodiesel derived from oils with different FFA content. All experiments were conducted in triplicate to ensure reproducibility, and safety precautions were followed throughout the experimental procedures [25].

4.2 OIL SAMPLE COLLECTION:

4.2.1 Pongamia oil:

Investigating the performance of biodiesel derived from Pongamia oil encompasses a comprehensive analysis of its properties and suitability as a renewable fuel source. Pongamia oil, extracted from the seeds of the Pongamiapinnata tree, presents a promising alternative for biodiesel production due to its high triglyceride

content [26]. The transesterification process, which converts triglycerides into biodiesel, is a key step in production. However, variations in the free fatty acid (FFA) content of Pongamia oil can impact the efficiency of the process. High FFA levels can lead to soap formation, reducing biodiesel yield and complicating purification. Before production, it's crucial to assess FFA content using methods like acid-base titration or chromatography. Evaluating biodiesel properties such as viscosity, density, and oxidative stability, as well as engine performance, provides insights into its viability as a fuel. By understanding these factors, researchers strive to optimize Pongamia oil-derived biodiesel production, contributing to sustainable energy solutions and environmental conservation efforts [27-28].

4.2.2 Iluppai oil:

Iluppai oil, derived from the seeds of the *Madhucalongifolia* tree, is a promising feedstock for biodiesel production due to its abundant availability and high oil content. This oil contains varying levels of free fatty acids (FFAs), which significantly impact the biodiesel production process and its performance. Investigating the performance of biodiesel produced from Iluppai oil with different FFA contents is crucial for optimizing its utilization. Higher FFA levels can lead to increased acidity and viscosity, affecting the biodiesel's quality and engine performance[29]. Research into the biodiesel derived from Iluppai oil with varying FFA contents involves studying its physicochemical properties, combustion characteristics, emissions, and engine performance parameters. Understanding how different FFA levels influence biodiesel properties and performance enables the development of efficient production processes and ensures the optimal utilization of Iluppai oil as a sustainable alternative fuel source [30].

4.2.3 Neem oil:

Investigating the performance of biodiesel derived from Neem oil with varying free fatty acid (FFA) contents is integral to optimizing its utilization as a renewable fuel source. Neem oil, extracted from the seeds of the *Azadirachta indica* tree, possesses properties conducive to biodiesel production, such as high viscosity, density, and calorific value. However, the FFA content in Neem oil can significantly impact the biodiesel production process and its performance characteristics. Higher FFA levels contribute to increased acidity, which may affect biodiesel quality, engine

combustion, and emissions. Research endeavors focus on analyzing the physicochemical properties, combustion efficiency, emission levels, and engine performance parameters of biodiesel produced from Neem oil with varying FFA contents. Understanding the relationship between FFA levels and biodiesel properties aids in refining production techniques and optimizing Neem oil's utilization as a sustainable alternative to conventional fossil fuels, fostering advancements in renewable energy technology and environmental sustainability [31-33].

4.3 PRELIMINARY PROPERTY ANALYSIS OF OIL SAMPLES:

The initial characteristics of the gathered oil samples, such as the density, kinematic viscosity, free fatty acid (FFA) percentages and moisture content, were evaluated in a laboratory setting in accordance with the relevant ASTM standards.

4.4 Materials and chemicals required:

To measure density: pycnometer, weighing machine to weigh the sample.

To measure kinematic viscosity: kinematic viscometer

To measure FFA percentage: 0.1 Normality Sodium hydroxide, thermometer, Iso propyl alcohol, 250 mL conical flask, phenolphthalein indicator

To measure moisture content: Crucible, Hot air oven.

4.5 Free fatty acid value:

The production of biodiesel from various feedstocks has gained considerable attention as a renewable and sustainable alternative to conventional diesel fuels. Central to the efficiency and quality of biodiesel production is the content of free fatty acids (FFA) present in the feedstock oils. This investigation aims to provide a comprehensive analysis of the role of FFA content in biodiesel production, its impact on process efficiency, product quality, and strategies for mitigating its adverse effects [34]. Free fatty acid (FFA) content in the oils is the measurement of the acidity of the oil and is frequently used as an index of the quality of the oil. A procedure known as acid value (AV) determination, which includes titration with a standard solution of sodium hydroxide (NaOH), can be used to determine the FFA level of an oil. For this titration process, a burette solution of sodium hydroxide with a normality of 0.1 N must first be made. A 5 gramme sample of oil is weighed inside a conical

flask. In addition, 25 mL of isopropyl alcohol are added to a conical flask that contains the sample of oil. The mixture is then given four drops of the 0.1 normality NaOH solution in the burette. The mixture is then heated to a temperature of 60 °C. It is then allowed to cool until the sample touches to room temperature. Once the solution has warmed to room temperature, phenolphthalein indicator is applied. The outcome of the titration of the solution is then recorded by noting down and calculating the reading in the burette [35].

Titration of FFA is done over the following steps.

Take 5 gm of oil (waste cooking oil sample)

Add 25 ml isopropyl alcohol and drops of 0.1 normality NaOH.

After that heat the sample at 60 degrees Celsius.

After that let it cool down to room temperature.

After that add 2 drops of phenolphthalein indicator, titrate against 0.1 normality NaOH,

At the end pink colour will be appearing.

FFA (%) = Normality [0.1] x Volume of NaOH(ml) x 28.2/sample of weight (g) Above mentioned is the formula for FFA. It is measured in percentage (%).

Calculation:

Pongamia oil sample value:

$$\begin{aligned} \text{FFA} &= 28.2 \times 0.1 \times 0.1 \div 5 \\ &= 5.6 \end{aligned}$$

Iluppai oil sample value:

$$\begin{aligned} \text{FFA} &= 28 \times 59.5 \times 0.1 \div 5 \\ &= 33.5 \end{aligned}$$

Neem oil sample Value:

$$\begin{aligned} \text{FFA} &= 28 \times 29.1 \times 0.1 \div 5 \\ &= 11.5 \end{aligned}$$

4.6 Density:

Density is measured using the standard of ASTM D 1298. Using a pycnometer, the density of the oil sample can be calculated. A glass container with a stopper and a

known volume is called a pycnometer. At first the empty weight of the pycnometer is weighed using a weighing machine. Then the oil sampled is poured in the pycnometer and the weight of the pycnometer along with the oil sample is weighed using the weighing machine. By dividing the mass by the volume of the pycnometer, the density was obtained. The pycnometer has a volume of 25ml. Then the density is measured using the below mentioned formula that is based on the basic principle of density formula mass divided by volume. The unit of density measured is g/cm³.

Calculation:

Sample pongamia oil:

$$= 46.64 - 23.08 \div 25$$

$$= 0.9424 \text{ g/cc}$$

Sample Neem oil:

$$= 23.16 - 46.09 \div 25$$

$$= 0.9172 \text{ g / cc}$$

Sample iluppaioil:

$$= 46.12 - 23.09 \div 25$$

$$= 0.102 \text{ g /cc}$$





Figure 1: Properties of density in bio diesel for FFA

4.7 Kinematic viscosity:

The ASTM D 445 standard is used to determine viscosity. This is a common test procedure for determining the kinematic viscosity of clear and opaque liquids. In order to conduct the test, a predetermined volume of oil sample must pass through a capillary tube at a temperature of 40 degrees Celsius and maintain the heat during the entire process. Then, using the time duration taken and the size of the capillary tube, the kinematic viscosity is determined. The kinematic viscosity of the oil is crucial for determining the biofuel's properties since it affects how the biofuel burns. The resistance of a fluid (liquid or gas) to a change in shape or movement of adjacent sections relative to one another is known as kinematic viscosity. Viscosity is a sign of flow resistance. It is measured in the units of cSt (Centistoke). The kinematic viscometer bath machine is used to measure kinematic viscosity. Oil is placed in a glass flask tube and heated to 40°C, using a sucker oil is expanded and it is being allowed to settle. The time it takes for the oil to settle is then recorded for calculation of kinematic viscosity. The formula for viscosity is,

$$\text{Viscosity} = \text{Time taken (in seconds)} \times 0.014$$

Calaulation:

Sample for all oil:

- Pongamia oil:
 $T = 40^{\circ} \text{C}$
 $= 47.05 \times 0.014$
 $= 39.55 \text{ cst}$
- Iluppai oil:
 $T = 40^{\circ} \text{C}$
 $= 44.10 \times 0.014$
 $= 36.96 \text{ cst}$
- Neem oil:
 $T = 40^{\circ} \text{C}$
 $= 44.05 \times 0.014$
 $= 37.03 \text{ cst}$



Figure 2: Properties of viscosity in Bio diesel

4.8 Moisture content:

At first, the entire weight of the crucible as well as the weight of the 5gm oil sample were both measured and recorded using a weighing machine. The sample was then placed inside a hot air oven that is set to a temperature of 110 degrees Celsius and the sample is heated for three hours. Then the sample is taken out of the oven, and

it is allowed to reach to the room temperature. The total sample weight was then calculated. Figuring out the difference in weight estimation of the sample's moisture content can be found. The moisture content is measured in percentage (%). The formula for finding the moisture content is mentioned below.

Moisture content = $\frac{\text{Initial weight of sample} - \text{dry weight of sample}}{\text{Initial weight of sample}} \times 100$

Calculation:

Sample for pongamiaoil:

$$M = \frac{74.75 - 12.05}{12.05} \times 100$$

$$= 0.0751\%$$

Sample for iluppai oil:

$$M = \frac{27.19 - 27.10}{27.10} \times 100$$

$$= 0.332 \%$$

Sample for Neem Oil:

$$M = \frac{21.20 - 26.34}{26.34} \times 100$$

$$= 0.531 \%$$



Figure 3: Properties of moisture content in bio diesel

4.9 Gas chromatography for biodiesel:

Biodiesel is frequently analyzed using gas chromatography (GC) to ascertain its composition and purity. The main component of biodiesel, fatty acid methyl esters

(FAMES), are separated and quantified using gas chromatography (GC) in biodiesel analysis. This method makes it possible to identify and measure each FAME that is present in the biodiesel sample, which is essential for regulatory compliance and quality control. Furthermore, GC can be used to find pollutants and impurities in biodiesel to guarantee its effectiveness and safety [36].

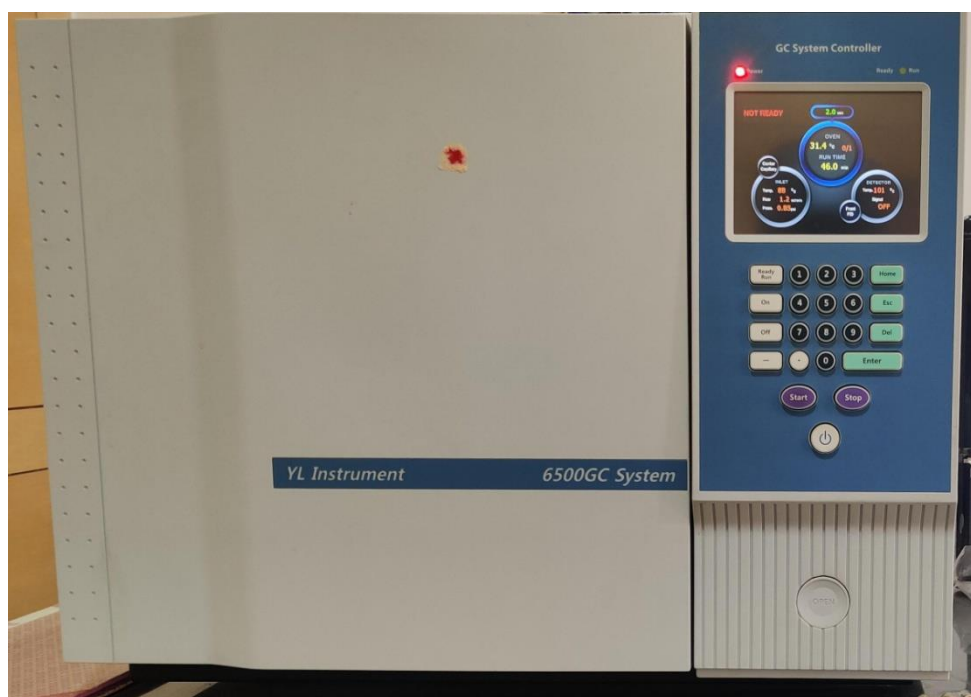


Figure 4: Gas chromatography for bio diesel

List out of sample Oil

- Pongamia oil
- Iluppai oil
- Neem oil

4.9.1 Pongamia oil for Gas chromatography:

One popular analytical method for examining the contents of biodiesel, including pongamia oil, is gas chromatography (GC). When using GC to examine pongamia oil in biodiesel, you would normally:

Preparing the Sample: Extract the biodiesel sample and follow normal procedures to get it ready for analysis. This includes doing any necessary derivatization steps to change fatty acids into more volatile derivatives.

Instrument Setup: To separate and identify the components of interest in the biodiesel sample, set up the GC instrument with the proper column and detector.

Calibration: To guarantee precise quantification of the components of pongamia oil, calibrate the GC apparatus using standards of known concentrations.

Injection: Use a syringe or an autosampler to inject the prepared sample into the GC apparatus.

Separation: Use the gas chromatography (GC) method, which entails running the sample through a chromatographic column to separate the constituents according to their chemical and physical characteristics.

Identification: Employ an appropriate detector, such as a mass spectrometer (MS) or a flame ionization detector (FID), to identify the separated components.

Analysis: To identify and measure the components in the biodiesel sample, including any chemicals unique to pongamia oil, examine the chromatogram produced by the GC apparatus.

Interpretation: Use the results to calculate the pongamia concentration.

Evaluate the amount of oil in the biodiesel sample and determine whether it complies with any rules or regulations.

All things considered, gas chromatography is a flexible and popular method for examining the contents of biodiesel, including the existence of pongamia oil and its constituents.

4.9.2 Iluppai oil for gas Gas chromatography:

Mahua oil, sometimes called iluppai oil, is occasionally utilized in the manufacturing of biodiesel. Its usefulness for gas chromatography (GC) analysis in biodiesel, however, may vary depending on the components you are attempting to test and the makeup of the mixture. It's critical to confirm that it is compatible with GC analysis and that it won't obstruct target compound separation and detection. Gas chromatography for biodiesel analysis would need to be tested using standards, and the method would need to be validated.

4.9.3 Neem oil for gas chromatography:

Neem oil can be used as a feedstock for making biodiesel. However, depending on a number of circumstances, including the components you're interested in evaluating and the content of the neem oil, it may not be suitable for gas chromatography (GC) analysis in biodiesel. Numerous substances included in neem oil, such as fatty acids, triglycerides, and trace amounts of tocopherols and

sterols, can influence the results of a GC analysis. Make sure neem oil satisfies the purity and compatibility requirements for your particular analytical method before utilizing it for GC analysis in biodiesel.

4.10 Bio diesel for production in FFA

List out of sample Oil

- Pongamia oil
- Iluppai oil
- Neem oil

Pongamia oil for production:

There are various stages involved in turning pongamia oil into biodiesel, such as extraction, transesterification, and purification. Because of its high fatty acid content, pongamia oil is a good feedstock. Oil from pongamia seeds is usually extracted, transesterification is used to turn the oil into biodiesel, and the biodiesel is then purified to get rid of contaminants. Compared to conventional fossil fuels, it is a more environmentally friendly fuel.

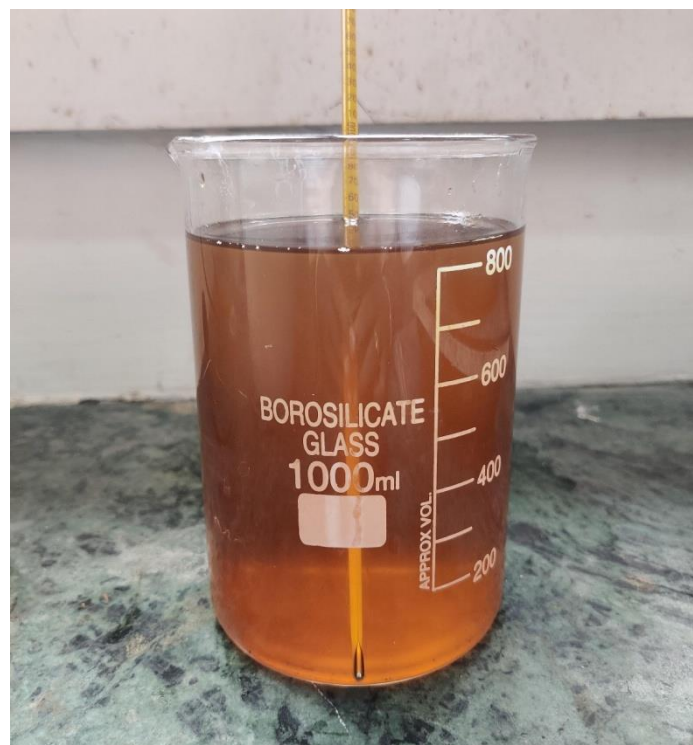


Figure 5: Process for pongamia oil in bio diesel

Iluppai oil for production :



Figure 6: Initial stage process of iluppai oil

Madhucalongifolia oil, sometimes referred to as iluppai oil, is a possible feedstock for the manufacturing of biodiesel. It is taken out of the seeds of the native Indian Iluppai tree. Iluppai seeds have a 50% oil content, which makes them perfect for producing biodiesel. Before employing Iluppai oil for large-scale biodiesel synthesis, however, issues like availability, extraction efficiency, and economic viability need to be taken into account, just like with any other feedstock. Aspects of social and environmental sustainability should also be considered.

Neem oil for production:

It is possible to use neem oil as a feedstock to make biodiesel. Neem oil is extracted from the seeds of the *Azadirachta indica* neem tree. Because of its high fatty acid content, it can be used in the transesterification process to produce biodiesel. To maximize the generation of biodiesel, neem oil may have particular characteristics, such as strong acidity or viscosity, which may call for further processing or blending with other feedstocks. For large-scale production, neem oil sustainability and availability as a feedstock should also be taken into account.

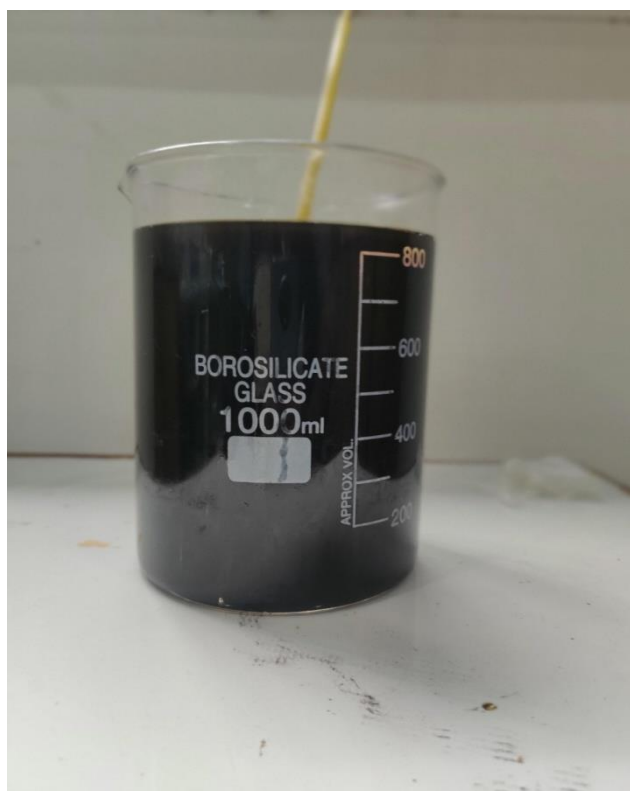


Figure7: Initial stage process for Neem oil.

Second stage process:

In order to lower viscosity and improve the effectiveness of future processes like neutralization or degumming, the crude oil is normally heated to a specific temperature range (generally between 60 and 70°C) during the preheating process for Free Fatty Acids (FFA) in the manufacturing of all sample oil. This preheating process enhances the oil's overall quality by removing contaminants.

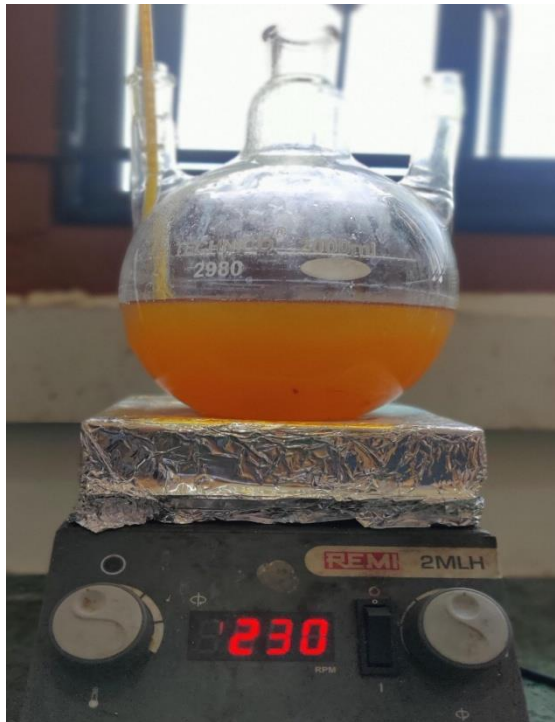


Figure 8: Preheat process for FFA in all sample of oil

Third stage process in FFA of bio diesel:



Figure 9: Get the all oil of two layers of process

You seem to be talking about the procedure where large concentrations of free fatty acids (FFA) are encountered when making biodiesel from all sample oil. Because high FFA level might induce soap formation and other problems during the transesterification process, it can complicate the synthesis of biodiesel. To remedy this, you might need to use extra pre-treatment procedures to lower the FFA content before turning the oil into biodiesel, such as acid esterification or alkaline esterification (Pongamia oil, Iluppa oil, Neem oil).

Transfication of FFA in bio diesel:

- Pongamia oil is usually transesterified into biodiesel by reacting it with an alcohol, like methanol or ethanol, in the presence of a catalyst, most frequently potassium hydroxide or sodium hydroxide. This process yields glycerol as a byproduct and changes the triglycerides in the oil into fatty acid methyl or ethyl esters, which are the primary ingredients in biodiesel. Depending on variables including the oil composition, catalyst concentration, reaction temperature, and reaction time, the transesterification reaction's particular parameters and conditions may change.
- Mahua oil is in fact utilized as a feedstock for the transesterification process, which produces biodiesel. Transesterification is the process of combining oil with an alcohol, usually methanol or ethanol, in the presence of a catalyst to create glycerol as a byproduct and biodiesel (methyl or ethyl esters). Mahua oil's high oil content and advantageous fatty acid composition make it appealing for the generation of biodiesel. However, while using any feedstock for the manufacturing of biodiesel, it is imperative to maintain sustainability and take environmental factors into consideration.
- It is possible to use neem oil in the transesterification process to make biodiesel. Triglycerides, like those in vegetable oils like neem oil, react chemically with an alcohol (usually methanol or ethanol) in the presence of a catalyst to form glycerol and biodiesel. This process is known as transesterification. Neem oil is appealing for the production of biodiesel because of its high lipid content and accessibility. When using neem oil as a feedstock for biodiesel production, it's crucial to take sustainability, quality, and purity into account



Figure 10: Transesterification of FFA in bio diesel

Catalyst preparation of bio diesel in FFA :

- Pongamia Oil
- Iluppai oil
- Neem oil

FFA Determination: Calculate the extracted oil's FFA content. Titration techniques like acid-base titration and enzymatic techniques can be used for this

Acid Pre-treatment: You must pretreat the oil to lower the FFA level if it is excessive. One popular technique is acid-catalyzed etherification, which turns FFAs into biodiesel by using a catalyst like sulfuric acid or methane sulfonic acid.

Esterification Reaction: Combine the acid catalyst, appropriate alcohol (often methanol), and all sample oil. To speed up the esterification reaction, heat the mixture and stir it.

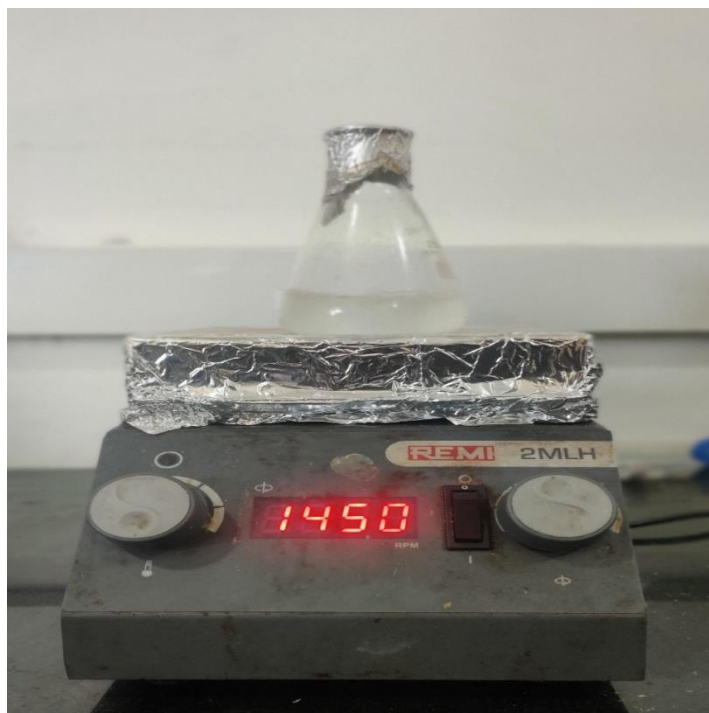


Figure 11: Catalyst preparation for allsample oil .

Neutralization: To get rid of any leftover acid catalyst, neutralize the mixture following the esterification reaction. Adding a basic, such as potassium or sodium hydroxide, is often how this is accomplished. Glycerol and biodiesel layers should separate after letting the mixture settle. Next, scrape off the bottom layer of glycerol [37-39].

Crude oil for FFA in Bio diesel of production:

Crude oil, sometimes called cruise oil, is made from pig oil and has a variable amount of free fatty acids (FFA) depending on how it is extracted and refined. Usually, the goal for making biodiesel from all sample oil is to lower the FFA content by neutralization or esterification before turning the oil into biodiesel. Both the finished product's quality and the biodiesel conversion process are impacted by the FFA

It like we get samples of all oil



Figure 12: Crude oil for FFA in Bio diesel of production

Water wash for bio diesel of production in FFA:

One popular technique for eliminating free fatty acids (FFA) from sample all oil used in the biodiesel synthesis process is water washing. This is a basic flowchart of the procedure:

Reaction: To produce biodiesel and glycerol, the oil is transesterified with an alcohol (commonly methanol or ethanol) in the presence of a catalyst (usually sodium hydroxide or potassium hydroxide).

Following the reaction, the mixture is allowed to settle and separates into two layers: glycerol on the bottom and biodiesel on top.

Washing: Next, the biodiesel layer is wetted with water. Water aids in the elimination of contaminants, such as soap and leftover catalyst from the process. By creating a water phase with contaminants that are soluble in water, the water wash also aids in lowering the FFA concentration.

Setting and Separation: After allowing the mixture to settle once more, the water and other contaminants are able to separate from the biodiesel. Cleaner biodiesel is produced once the water phase is removed.

Drying: After being cleaned, the biodiesel is dried to get rid of any leftover water. Techniques like heating the biodiesel or putting it through a desiccant substance can be used to accomplish this.

Final Quality Check: Before being utilized or sold, the biodiesel is tested for quality factors such moisture content, FFA content, and purity.

This water wash procedure lowers the biodiesel's FFA content and contaminants, improving its quality and suitability for fuel use.



Figure 13. Water wash for bio diesel of production in FFA



Figure 14: Iluppai oil water wash



Figure 15: Neem oil water wash

CHAPTER-5

RESULTS AND DISCUSSION

5.1 TESTING SAMPLE OF GC:

An extra step known as acid esterification is usually required to lower the Free Fatty Acid (FFA) level prior to transesterification in the synthesis of biodiesel from any sample oils with a high FFA content. The production and quality of biodiesel are enhanced by this procedure.

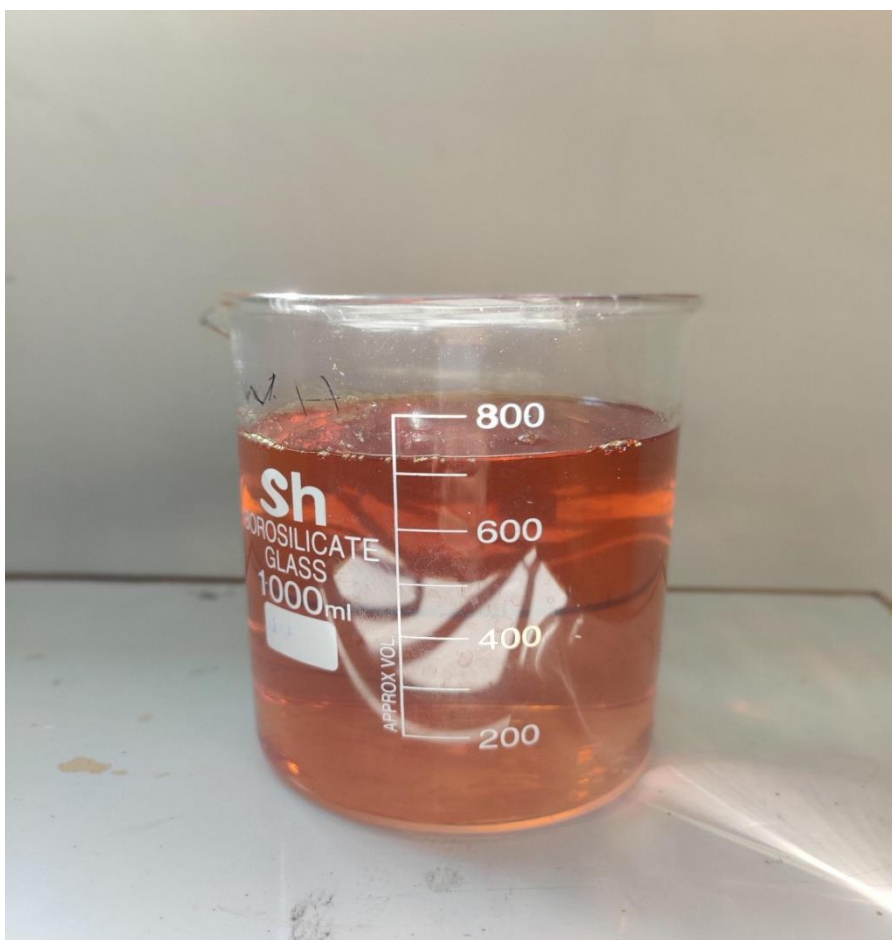


Figure 16: Pure Biodiesel

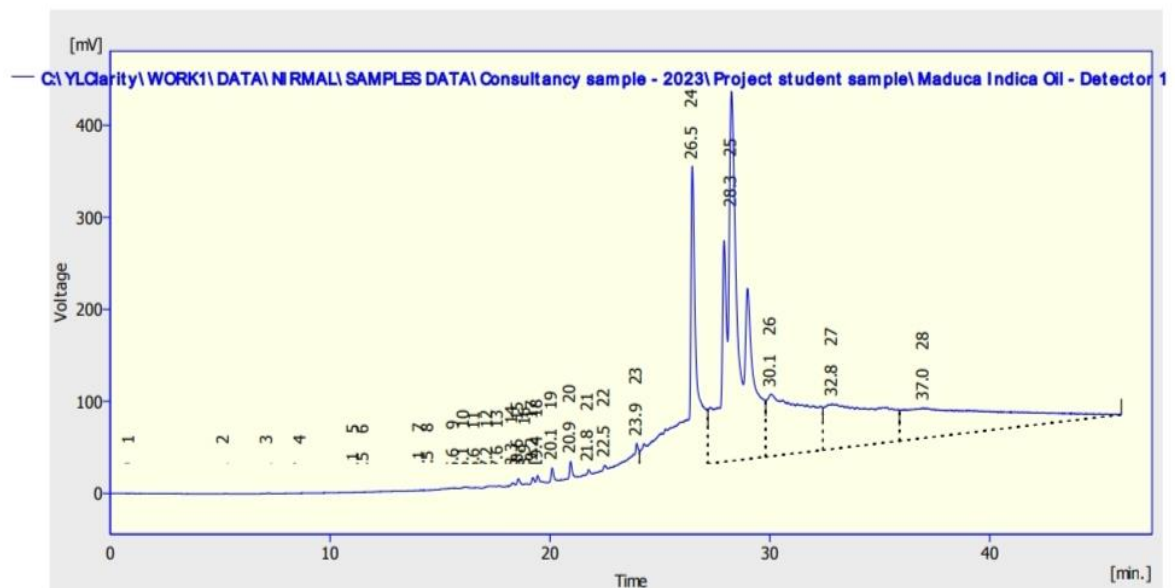
5.1.1 TESTING SAMPLE OF GC FOR PONGAMIA OIL:

SNO.	Rete time [min]	Area [mv.s]	Height [mv]	Area [%]	Height [%]	Acid name	Molecular weight
1.	1.080	31.501	0.298	0.0	0.0	Myristic acid	228.37 g/ ml
2	5.200	5.528	0.596	0.0	0.1	Eicosatrienoic acid	306.482 g /ml
3.	6.707	12.934	0.317	0.0	0.0	Lauric acid	200.3178 g/ml
4.	6.930	4.642	0.555	0.0	0.1	Lauric acid	200.3178 g / ml
5.	8.083	25.854	1.075	0.0	0.1	Palmitic acid	256 .43 g/ml
6	8.460	5.886	0.559	0.0	0.1	Palmitic acid	256.43 g/ml
7	10.460	28.394	0.385	0.0	0.0	Oleic acid	282 .46 g/ ml
8	11.467	3.710	0.498	0.0	0.1	Linolenic acid	278.43 g/ml
9	11.710	5.782	0.566	0.0	0.1	Linolenic acid	278.43 g/ml
10	11.993	5.722	0.602	0.0	0.1	Linolenic acid	278.43 g/ml
11	13.190	16.026	0.379	0.0	0.0	Butyric acid	88.11 g/ml
12	13.757	6.020	0.356	0.0	0.0	Butyric acid	88.11 g/ ml
13	14.003	4.798	0.493	0.0	0.1	Palmitic acid	256.43 g/ml
14	14.997	35.740	1.546	0.1	0.2	Palmitic acid	256.43 g /ml
15	15.467	75.839	3.561	0.1	0.4	Palmitoleic acid	254.414g /ml
16	15.970	77.218	4.031	0.1	0.5	Palmitoleic acid	254 .414 g/ml
17	16.527	41.954	2.393	0.1	0.3	Margaric acid	270.45 g /ml
18	16.967	17.568	2.058	0.0	0.2	Margaric acid	270 .45g/ml
19	17.520	57.161	2.327	0.1	0.3	Margaric acid	270 .45 g/ml
20	18.203	22.776	3.114	0.0	0.4	Oleic acid	282.46g/ml
21	18.420	146.672	14.724	0.2	1.7	Oleic acid	282.46g/ml
22	18.797	29.609	2.645	0.0	0.3	Oleic acid	282.46g/ml
23	19.307	228.621	17.035	0.3	1.9	linoleic acid	280.4472g/ml

5.1.2 ILUPPAI oil for test sample of GC:

SNO	Reten .time [min]	Area[mv.s]	Height [mv]	Area [%]	Height[%]	Acid name	Molecular weight
1	0.887	2.995	0.298	0.0	0.0	Decanoic acid	172.26g/ml
2	5.183	2.354	0.298	0.0	0.0	Decanoic acid	172.26g/ml
3	7.150	8.404	0.774	0.0	0.1	Caproic acid	116.1583g/ml
4	8.673	6.795	0.314	0.0	0.0	Palmitic acid	256.43g/ml
5	11.083	0.626	0.298	0.0	0.0	Linolenic acid	278.43g/ml
6	11.530	4.172	0.316	0.0	0.0	Linolenic acid	278.43g/ml
7	14.087	10.356	0.436	0.0	0.0	Palmitic acid	256.43g/ml
8	14.870	3.248	0.415	0.0	0.0	Palmitic acid	256.43g/ml
9	15.637	53.778	1.529	0.1	0.2	Palmitic acid	256.43g/ml
10	16.097	46.209	1.961	0.1	0.2	Margaric acid	270.45g/ml
11	16.587	18.895	0.853	0.0	0.1	Margaric acid	270.45g/ml
12	17.167	40.829	1.714	0.1	0.2	Margaric acid	270.45g/ml
13	17.640	14.789	1.205	0.0	0.1	Margaric acid	270.45g/ml
14	18.297	34.072	3.348	0.1	0.3	Oleic acid	282.46g/ml

15	18.553	67.413	7.221	0.1	0.7	Oleic acid	282.46g/ml
16	18.880	11.638	1.110	0.0	0.1	Oleic acid	282.46g/ml
17	19.210	53.078	6.898	0.1	0.7	inoleic acid	280.4472g/ml
18	19.437	87.939	8.754	0.1	0.9	Inoleic acid	280.4472g/ml
19	20.097	134.602	15.611	0.2	1.6	Arachidic acid	312.5304g/ml
20	20.933	218.533	20.110	0.4	2.0	Arachidic acid	312.5304g/ml
21	21.750	174.284	9.168	0.3	0.9	Eicosenoic acid	310.51g/ml
22	22.487	283.308	11.508	0.5	1.1	Adrenic acid	332.5g/ml
23	23.947	1245.946	31.187	2.0	3.1	Linoleic acid	280.4472g/ml
24	26.473	11254.847	325.127	18.3	32.5	Linoleic acid	280.4472g/ml
25	28.253	20074.651	401.522	32.7	40.1	Arachidic acid	312.5304g/ml
26	30.060	8520.342	67.455	13.9	6.7	Margaric acid	270.45g/ml
27	32.847	8590.095	48.826	14.0	4.9	Linoleic acid	280.4472g/ml
28	37.00	10419.652	32.626	17.0	3.3	Linoleic acid	280.4472g/ml
	Total	61383.851	1000.882	100.0	100.0		



ILUPPAI oil Sample of GC Graph

5.1.3 Neem oil for sample test of GC:

SN O.	Reten- tion time [Min]	Area[MV .S]	Height[mv]	Area[%]	Height[%]	Acid name	Molecular weight
1.	5.16 0	2.310	0.298	0.0	0.0	Decanoic acid	172.26g/ml
2.	6.32 0	46.708	130.844	0.1	8.6	Palmitonic acid	256.43g/ml
3.	6.40 0	2.384	0.456	0.0	0.0	Lauric acid	200.3178g/ ml
4.	8.46 7	9.418	0.315	0.0	0.0	Myristic acid	228.37g/ml
5.	9.28 3	8..196	0.330	0.0	0.0	oleic acid	282.46g/ml
6.	9.74 3	4.321	0.334	0.0	0.0	Oleic acid	282.46g/ml
7.	11.3 10	15.005	25.567	0.0	1.7	Linolenic acid	278.43g/ml

8.	12.7 17	23.410	0.414	0.0	0.0	Linolenic acid	278.43g/ml
9.	14.7 10	51.960	1.678	0.1	0.1	Palmitic acid	256.43g/ml
10.	15.3 93	86.926	2.001	0.1	0.1	Palmitic acid	256.43g/ml
11.	17.1 43	61.035	1.526	0.1	0.1	Arachidonic acid	304.47g/ml
12.	18.1 27	77.918	3.664	0.1	0.2	Stearic acid	284.48g/ml
13.	18.8 50	175.655	12.512	0.2	0.8	Oleic acid	282.46g/ml
14.	20.6 23	433.132	26.262	0.5	1.7	Arachidic acid	312.5304g/ml
15.	21.4 60	97.945	9.934	0.1	0.6	Eicosenoic acid	310.51g/ml
16.	24.0 07	1291.05 2	22.887	1.6	1.5	Pentadecen oic acid	242.3875g/ml
17.	25.0 23	1762.65 8	40.598	2.2	2.7	Docosahexa noic acid	328.49g/ml
18.	27.9 33	31768.6 80	800.986	40.3	52.4	Palmitoleic acid	254.4082g/ml
19.	28.6 93	19762.2 03	332.820	25.0	21.8	Palmitoleic acid	254.4082g/ml
20.	32.4 37	4336.59 6	55.800	5.5	3.6	Elaidic acid	1282.46g/ml
21.	34.7 23	6088.45 1	57.850	7.7	3.8	Linolenic acid	280.4472g/ml
22.	45.8 73	12805.9 54	2.593	16.2	0.2	Enoic acid	1142.1956 g/ml
	Total	78911.9 15	1529.66 9	100.0	100.0		



Figure 17: Diesel engine



Figure 18: Fuel Injector

Specifications of Diesel Engine used for the experimentation:

Model	GREAVES MODEL GL-400
Type of Engine	Diesel Engine
No. of Cylinders	Single Cylinder
No. of Strokes	4
Type of Cooling System	Air Cooled
Speed	1500RPM
Power	7.5 hp
Bore Diameter	85mm
Stroke Length	127mm
Hole Diameter	10mm

Selection of Illupai Oil:

Illupai oil, obtained from the seeds of the *Madhucalongifolia* tree, is a potential biodiesel source. <https://doi.org/10.1016/j.rse1r.2023.11381> With an oil concentration ranging between 50-60%, Illupai oil is a valuable feedstock for biodiesel production. Its fatty acid composition is significant for a high amount of monounsaturated fatty acids (MUFA), particularly oleic acid. This mixture is favorable because it improves biodiesel's oxidative stability and cold flow qualities. One of the primary reasons for using Illupai oil for biodiesel production is its widespread availability. *Madhucalongifolia* trees are native to India and are extensively spread across the tropical and subtropical areas. This accessibility assures a steady supply of feedstock for biodiesel manufacturing. Because of its high oleic acid content, illupai oil requires only a few simple transesterification procedures where transesterification is a chemical process that convert triglycerides into biodiesel and glycerol using alcohol and a catalyst. This can result in reduced production costs and energy needs than feedstocks with complex fatty acid compositions. Utilizing Illupai oil for biodiesel production can have an environmental impact by reducing dependency on fossil fuels and lowering greenhouse gas emissions.

Selection of Pongamia Oil:

Pongamia oil, produced from *Pongamiapinnata* seeds, is a promising option for biodiesel production. With an oil concentration of 30-40%, Pongamia oil is an important feedstock for biodiesel production.[doi:10.4236/sgre.2011.23022](https://doi.org/10.4236/sgre.2011.23022) Its fatty acid composition stands out for its high polyunsaturated fatty acid (PUFA) content, notably linoleic acid. PUFA-rich oils, such as Pongamia oil, may require additional refining stages due to their sensitivity to oxidative deterioration, although they may still be successfully turned into biodiesel by transesterification. Furthermore, Pongamia trees can survive in a variety of tropical climates, which improves the feedstock's accessibility and sustainability. [doi:10.4236/sgre.2011.23022](https://doi.org/10.4236/sgre.2011.23022) To ensure sustainability for large-scale biodiesel production, Pongamia oil should be selected based on characteristics such as availability, processing efficiency, and environmental sustainability. This is how the biodiesel is produced. Firstly, the oil is heated to 110⁰c. A new layer is formed on the top of the oil. Then the oil is again heated to 60⁰c for production of biodiesel. After heating to 60⁰c, adding sodium

hydroxide and methyl oxide catalysts will result in cruise oil. Then after the water wash the biodiesel is ready.

The physical properties of both the biodiesel made from illupai oil and pongamia oil are shown in the below table.

Properties of Biodiesel made from illupai oil and pongamia oil:

Properties	Illupai Oil	Pongamia Oil
Free Fatty Acid content	33.5	5.6
Moisture Content (%)	0.332	0.0751
Viscosity (cst)(At 40°C)	36.96	39.55
Density (g/cc)	0.102	0.9424

5.2.1 Spray Test Result and Discussion:

The biofuels produced by pongamia oil and illupai oil are taken to visualize the spray structure in a direct injection diesel engine. The same injection pressure taken throughout the experiment i.e., 230 bar with nozzle hole diameter of 0.23mm. And the fuel tank capacity is half litre. The chamber dimensions are 20 x 10 x 22cm. VLC Media Player is used to capture the best image by playing the video frame by frame. The best image is captured for every injection for both the biofuels made from pongamia oil and illupai oil. Each image is uploaded to the 'ImageJ v1.47k' program, which analyses the spray angle, spray tip penetration, and spray area. Experiments were conducted on both pongamia oil and illupai oil biofuels to determine the spray angle, spray tip penetration, and spray area values.

Spray tip penetration length in ImageJ software can be determined by measuring the distance between the spray tip and the point where the spray enters an object with the measurement tools. The spray angle is determined in ImageJ software, by drawing a line in the direction of the spray, and the software will calculate the angle. Spray area can be estimated in ImageJ software by selecting the spray location using the "Freehand Selection Tool" and then using the "Analyze" tool to measure the area.

Image Processing System. The captured video is the analysed frame by frame to get the best output from the image. Using VLC Media Player, we have analysed the video frame by frame and captured the best image. The best image is captured and converted into jpeg format. Four different photos were taken, to find spray tip

penetration, spray angle and spray area. Using 'ImageJ v1.47k' software, value for the spray tip penetration, spray angle and spray area are calculated.

Image taken for analysing in Image software:



Illupai Oil



Pongamia Oil

Spray Tip Penetration:

Spray tip penetration refers to the length obtained by the spray tip after injection. Spray tip penetration length was tested for biofuels made from illupai and Pongamia oils. The results revealed significant differences in penetration lengths between the two biofuels. The average spray penetration length taken from best images of illupai

oil-based biofuel was found to be 324.52 mm, whereas that of Pongamia oil-based biofuel was 295.67 mm. The spray penetration of Biofuel made from illupai oil is less than biofuel made from pongamia oil. The findings imply that biofuels derived from various feedstocks may have variable spray properties, which might affect combustion efficiency and emissions. The spray tip penetration for biofuel made from Illuppai and Pongamia oils.

Spray Angle

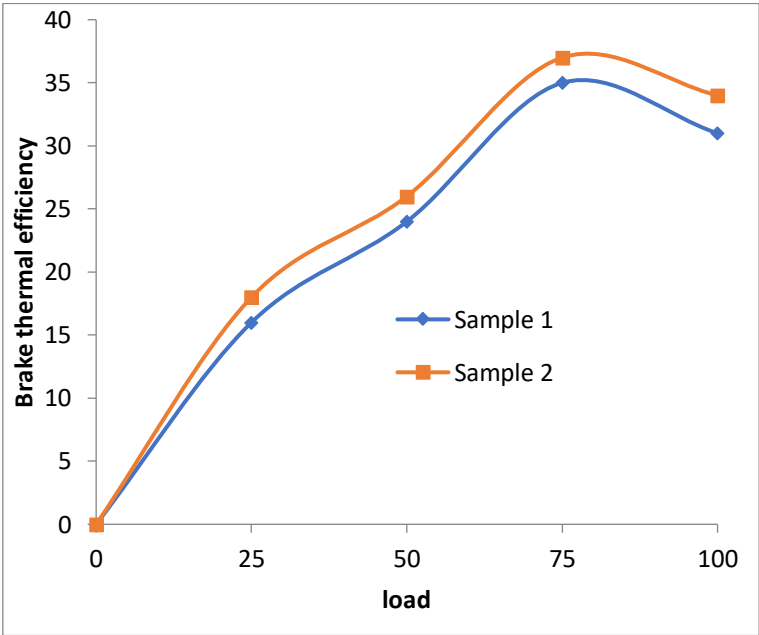
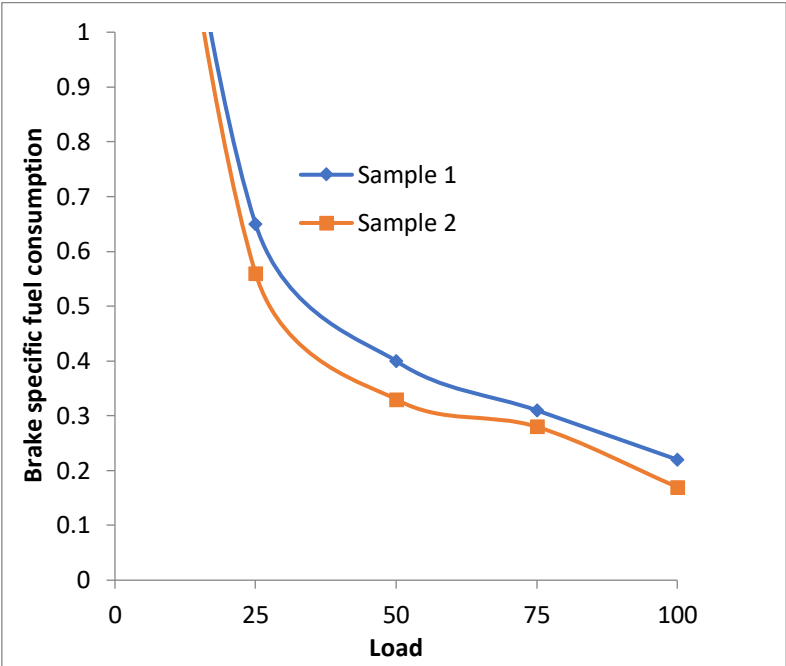
The spray cone angle refers to the angle formed by straight lines from the nozzle tip to the spray boundary. The average spray angle illupai oil-based biofuel was found to be 21.12° , whereas that of Pongamia oil-based biofuel was 25.19° . The spray angle of Biofuel made from illuppai oil is more than biofuel made from pongamia oil. The evolution of spray angle with time is shown in Fig.6 for biofuels made from illupai and Pongamia oils. A higher spray angle for Illuppai oil-based biofuel than Pongamia oil-based biofuel indicates that fuel droplets are dispersed more widely. This may result in uneven combustion, greater fuel consumption, and potentially higher emissions, highlighting the importance of exact control and optimization of combustion characteristics for various biofuel compositions.

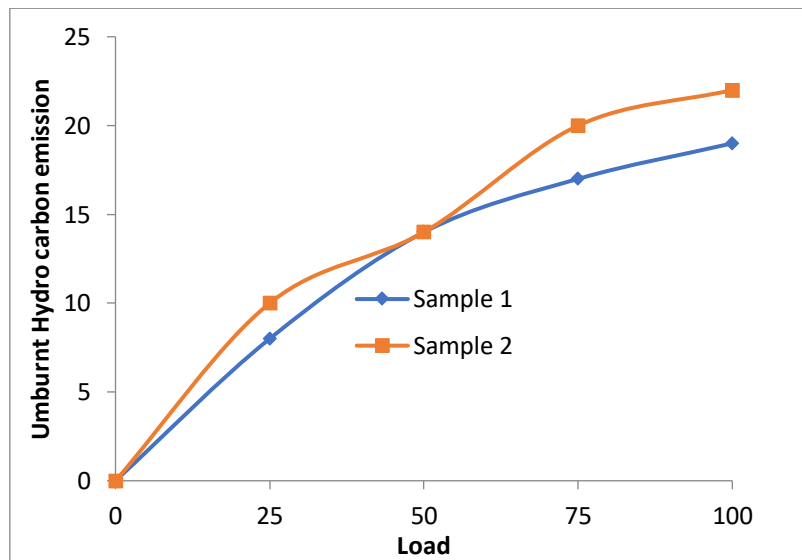
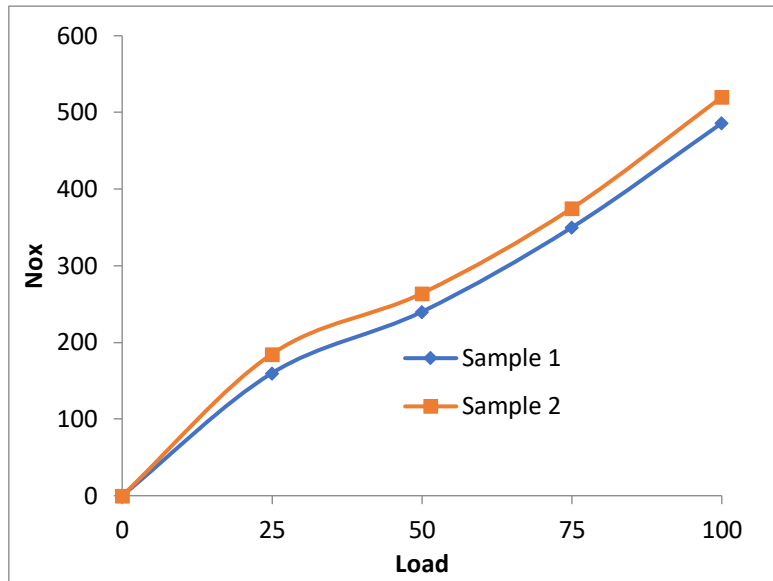
Spray Area

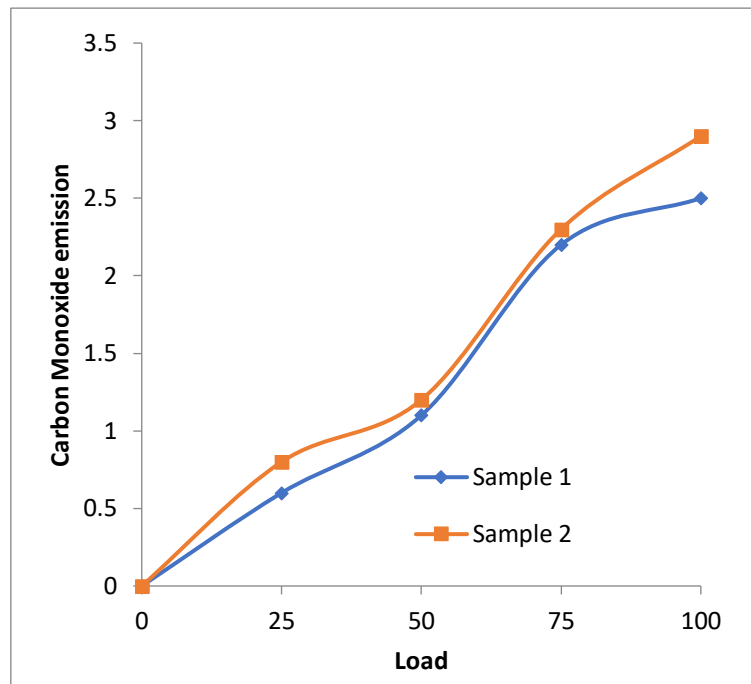
The spray area analysis revealed distinct characteristics between biofuels derived from Illuppai and Pongamia oils. Illuppai oil-based biofuel exhibited a spray area of 17945 square millimeters, while Pongamia oil-based biofuel showed a spray area of 14227 square millimeters. Illuppai oil-based biofuel has a smaller spray area than Pongamia oil-based biofuel, indicating less effective atomization and dispersion. This might result in incomplete combustion, decreased engine efficiency, and perhaps greater emissions, emphasizing the significance of optimizing fuel characteristics and combustion procedures for each biofuel type.

Spray Characteristics	Illuppai Oil	Pongamia Oil
Spray Tip Penetration	324.52mm	295.67mm
Spray Angle	21.12°	19.83°
Spray Area	17945mm ²	14227mm ²

Engine Studies







The Engine Characterisation results of ilupai oil biodiesel and pongamia oil biodiesel samples of B20 blends are depicted in the above figures. The engine results show that, both biodiesel samples have performed well in the engine study and the results are comparable to regular diesel

CHAPTER-6

SUMMARY AND CONCLUSION

The present experimental investigations are carried out in DI Diesel engine by using high-definition video camera and image processing techniques. Important spray characteristics namely spray tip penetration, spray angle and spray area were investigated. It was concluded that spray penetration is more for biofuel made from pongamia oil than biofuel made from illupai oil and spray cone angle for illupai oil is more than biofuel made from pongamia oil. The density and viscosity of illupai oil is low when compared to the pongamia oil. The illupai oil has lesser density and viscosity than Pongamia oil, it may result in longer spray penetration lengths, broader spray angles, and bigger spray areas. This might lead to more effective atomization, greater fuel dispersion, and improved combustion performance, potentially increasing engine efficiency and lowering emissions.

It is observed that the spray tip penetration length, spray cone angle and spray area of illupai oil are more than the pongamia oil. In spray characteristic testing, illupai oil had a longer spray tip penetration length, a higher spray cone angle, and a larger spray area than Pongamia oil, implying that illupai oil has a more expansive and penetrating spray pattern. This suggests enhanced atomization, which results in higher fuel-air mixing and combustion efficiency. As a result, engines fuelled with illupai oil may operate better and emit less than engines fuelled with Pongamia oil, emphasizing the potential benefits of employing illupai oil-based biofuels.

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