IJCRT.ORG ISSN : 2320-2882
INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)
An International Open Access, Peer-reviewed, Refereed Journal

PRODUCTION AND CHARACTERIZATION OF MAHUA BIODIESEL FOR SUSTAINABLE ENERGY APPLICATIONS

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Abstract: This study focuses on producing and characterizing biodiesel derived from mahua (Madhuca longifolia) oil for sustainable energy applications. Mahua biodiesel was produced through transesterification using a base catalyst. The biodiesel's physical and chemical properties were analyzed and compared with ASTM standards. The study also investigates the potential of mahua biodiesel as an alternative fuel for diesel engines, considering its performance, combustion characteristics, and emission profiles. The results demonstrate that mahua biodiesel meets the required standards for biodiesel fuel properties and exhibits promising performance as a renewable and environmentally friendly fuel option for various energy applications.

Index Terms - Mahua biodiesel, production, characterization, sustainable energy, alternative fuel, transesterification, diesel engine, performance, emissions.

I. INTRODUCTION

The increasing energy demand, environmental concerns, and the depletion of fossil fuel reserves have led to a growing interest in alternative and renewable energy sources [1]. Biodiesel, a renewable fuel derived from vegetable oils or animal fats, has emerged as a promising alternative to conventional diesel fuel due to its environmental benefits and compatibility with existing diesel engines [2]. Mahua (Madhuca longifolia) is a tropical tree native to the Indian subcontinent, known for its oil-rich seeds. Mahua oil has been traditionally used for cooking and lighting purposes and is now gaining attention as a potential feedstock for biodiesel production. The high oil content of mahua seeds and the tree's ability to thrive in diverse agro-climatic conditions make it a promising source of biodiesel feedstock [3].

This project focuses on producing and characterizing biodiesel from mahua oil for sustainable energy applications. The production process involves transesterification, a chemical reaction that converts the triglycerides in the oil into biodiesel, using a base catalyst [4]. The produced biodiesel is then analyzed for its physical and chemical properties, such as viscosity, density, and acid value, to ensure compliance with relevant standards, such as those set by the American Society for Testing and Materials (ASTM) [5]. Furthermore, the study will evaluate the potential of mahua biodiesel as an alternative fuel for diesel engines. Engine performance, combustion characteristics, and emission profiles will be assessed to determine the viability of mahua biodiesel as a sustainable energy option [6]. The results of this study are expected to contribute to the growing body of knowledge on biodiesel production from non-edible feedstocks and its potential as a renewable fuel for reducing greenhouse gas emissions and promoting sustainable development.

In recent years, research activities have been significant in alternative fuels due to fluctuations in crude oil prices and energy security issues [7]. The crude oil import of India is 70%, and it is reported that the fossil diesel demand is around 70 MMT. In India, alcohol and biodiesel are suggested as a substitute for petroleum fuels. The use of these biofuels as fuels will generate rural employment. The raw material required to produce biodiesel can be obtained from plantations of oil-bearing trees [8]. Biodiesel fuels are getting popular and have been highly suggested as a feasible alternative to petroleum diesel. The National Soy Diesel Development Board, which initiated the commercialization of biodiesel in the USA, came up with the term "biodiesel" in 1992 in the USA [9]. Biodiesel can be incorporated with Petro diesel since its properties are analogous and it emits fewer harmful pollutants. One of the better alternatives is biodiesel. It's produced from sunflower, palm, cottonseed, rapeseed, soybean, and peanut oils, among other oilseed crops. The mineral diesel is the prime liquid fuel, being used in different sectors like transportation, power, agriculture etc. The transport sector plays an important role in the economic development of a country and alone consumes more than 70% of the total diesel consumption [10]. Every year there is an addition in the number of transport vehicles to the existing fleet and proportionally diesel consumption is also increasing. Industrial and agricultural sectors also consume mineral diesel for generator sets and water pumps.

These days, India has become the fastest-growing economy among developing countries of the world. However, to sustain such development, India will try to reduce fossil fuel dependency [11]. India produces only 22% of total crude oil for domestic expenditure and the rest demand (72%), is accomplished by importing crude oil from other countries. Petroleum demand in the transport sector is expected to grow rapidly in the coming years with the rapid expansion of vehicle ownership. While India's domestic energy resource base is substantial, the country relies on imports for a considerable amount of its energy use, particularly for Crude Petroleum [12]. There was an increase of 7.15% in the production of total petroleum products, including fractioners, during 2012-13 compared to 2011-12. Oil that cannot be used after cooking is considered to be waste cooking oil. The waste cooking oil is collected from hotels, and caterers which is then sent for the transesterification process. It is then mixed with diesel by volume and used in an engine to check the performance and emission levels [13].

Biofuels are drawing increasing attention worldwide as substitutes for petroleum-derived transportation fuels to address energy cost, energy security and global warming concerns associated with liquid fossil fuels. The term biofuel is used here to mean any liquid fuel made from plant material that can be used as a substitute for petroleum-derived fuel [14]. Second-generation fuels are generally those made from non-edible lignocellulosic biomass, either non-edible residues of food crop production (e.g. corn stalks or rice husks) or non-edible whole plant biomass (e.g. grasses or trees grown specifically for energy) or waste product of refinery oil industry [15]. Biodiesel is defined by ASTM International as a fuel composed of mono-alkyl esters of long-chain fatty acids derived from renewable vegetable oils or animal fats meeting the requirements of ASTM D6751 (ASTM 2008a). Vegetable oils and animal fats are principally composed of triacylglycerols (TAG) consisting of long-chain fatty acids chemically bound to a glycerol (1, 2,3- propanetriol) backbone. The chemical process by which biodiesel is prepared is known as the transesterification reaction [16].

Dr. Rudolf Diesel, invented the Diesel Engine in 1895 and used only bio-fuel in his engine. His statement was "The application of vegetable oils as engine fuel may seem insignificant today, but such oils may become over time, as important as products of petroleum and coal of present time". The above prediction came true today as more and more biodiesel is being used all over the world. Scientists E. Duffy and J. Patric conducted the process of Transesterification of vegetable oil in early 1853, years before the first diesel engine became operating [17]. On August 31, 1937, G. Chavanne of the University of Brussels (Belgium) was given a patent for the transformation of vegetable oils for their uses as fuels. The use of biodiesel was recognized much earlier and became technically relevant only after the energy crisis in the year 1973 and afterwards. Vegetable oils have high viscosity due to their large molecular weight and bulky molecular structure. High-viscosity liquid fuels affect the flow properties and also spray atomization, vaporization, and air/fuel mixture formation. Higher viscosity hurts the combustion of vegetable oils in diesel engines. Temperature greatly affects the viscosity of vegetable oils [18]. Another research study that was undertaken to explore the effects of biogas flow rate and the addition of cerium oxide in the dual fuel mode in CI engines discovered that high biogas flow rates are an efficient way of minimizing diesel usage. Biogas was found to contribute up to 80% of overall energy release [19]. Moreover, 40 factors those diesel engine designers vary to give high efficiency, lower 41 emissions, and fuel economy. A few of the researched factors are the shape of the combustion chambers, injector pressure, injection timing, camshaft timing, variable compression ratio, angles of the fuel nozzle, nozzle spray pattern, etc. [20].

In the modern years, severe efforts have been made by many researchers to use various sources of energy as feed in existing diesel engines. The make use of straight vegetable oils (SVO) is inadequate due to some unfavourable physical and chemical properties, particularly their viscosity and density. Because of higher viscosity, SVO causes incomplete combustion, poor fuel atomization and carbon deposition on the valve and injector seats resulting in severe engine problems. When diesel engines are fueled with straight vegetable oil as fuel, it leads to incomplete combustion [21]. Biofuels are commonly considered to offer numerous needs, including manageability, a decrease of ozone-harming substance emanations, territorial turn of events, social structure, agribusiness, and supply security. So, alternate fuel is an essential and immediate solution for the diesel engine. Some biodiesels have high potential and are suitable for diesel engines, and various researchers have also proved the same. Among the biofuels, biodiesel substantially reduces carbon monoxide (CO) and hydrocarbon (HC) emissions. Rubber seed oil (RSO) methyl ester is a second-generation biofuel produced from non-edible rubber seeds, found only to be used in paint industries as glycerin acid. Rubber seeds are available in abundance in India's western gates, especially in the states of Tamil Nadu and Kerala. This work is to convert and utilize the abundantly available RSO as biofuel for CI engines [22].

II. METHODOLOGY

Mahua seeds will be collected from mature trees and processed to extract the oil. The seeds will be cleaned, dried, and crushed to obtain mahua oil. The transesterification process will then be employed to convert the mahua oil into biodiesel. This chemical reaction, catalyzed by sodium hydroxide (NaOH) or potassium hydroxide (KOH), will break down the triglycerides in the oil into fatty acid methyl esters (FAMEs), the components of biodiesel. The reaction will be carried out in a reactor under controlled temperature, pressure, and agitation conditions. Figure II-1, following transesterification, the crude biodiesel will undergo purification to remove impurities such as glycerol, soap, and excess catalyst. Purification methods such as washing, drying, and filtering will be utilized. The purified biodiesel will then be characterized for its physical and chemical properties, including viscosity, density, acid value, and flash point, according to ASTM standards.

Engine performance testing will be conducted using a diesel engine to evaluate the performance of the mahua biodiesel. Parameters such as brake-specific fuel consumption (BSFC), brake thermal efficiency (BTE), and exhaust gas temperature will be measured. Combustion characteristics will be analyzed using techniques such as in-cylinder pressure measurement and heat release rate analysis. Emissions of nitrogen oxides (NOx), carbon monoxide (CO), unburned hydrocarbons (UHC), and particulate matter (PM) will also be measured and compared to those of conventional diesel fuel. To extract oil from mahua seeds, the process begins with the collection of mature seeds, which are then cleaned to remove any dirt or impurities. Subsequently, the cleaned seeds are dried either under sunlight or using mechanical dryers to reduce their moisture content. Once dried, the seeds are crushed to break them open and release the oil. This crushing process can be achieved through mechanical pressing or the use of expeller machines. The extracted oil is then subjected to filtration to remove any remaining solids or impurities. Depending on the desired purity and quality, the oil may undergo further refining processes such as degumming, neutralization, bleaching, and deodorization. Finally, the refined oil is stored in suitable containers to maintain its quality until it is used.

The successful production and characterization of biodiesel from mahua oil highlight its potential as a viable alternative fuel source. Meeting ASTM standards for key properties such as viscosity, density, acid value, and flash point indicates that mahua biodiesel can be used effectively in diesel engines. Engine performance tests showed comparable results to conventional diesel, with only slight variations in fuel consumption and thermal efficiency, suggesting that mahua biodiesel could be a practical substitute for diesel fuel. Additionally, the combustion characteristics of mahua biodiesel were found to be similar to diesel, indicating that it can be efficiently burned in diesel engines. While mahua biodiesel demonstrated lower emissions of NOx and PM compared to diesel, further optimization is needed to address slightly higher CO and UHC emissions. Overall, the findings suggest that mahua biodiesel has the potential to significantly reduce the environmental impact of diesel engines and contribute to a more sustainable energy future. The properties of mahua biodiesel will be compared to the specifications outlined in ASTM D6751 and ASTM D7467 to ensure compliance with biodiesel quality standards. Statistical analysis will be conducted to analyze the data obtained from the experiments and determine the significance of the results. Based on the findings, conclusions will be drawn regarding the feasibility of using mahua biodiesel as an alternative fuel, and recommendations for further research and development will be provided.

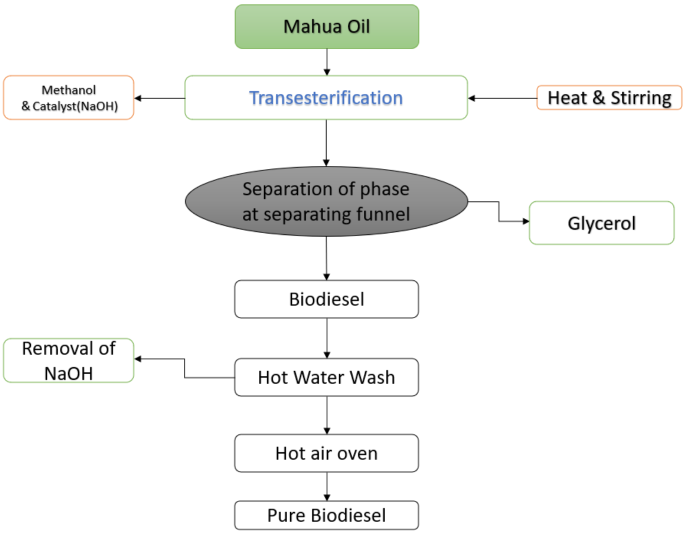

Figure II-1. Methodology Flowchart

2.1 Abbreviations

1. BSFC: Brake Specific Fuel Consumption
2. BTE: Brake Thermal Efficiency
3. ID: Ignition Delay
4. CD: Combustion Duration
5. PCP: Peak Cylinder Pressure
6. NOx: Nitrogen Oxides
7. CO: Carbon Monoxide
8. UHC: Unburned Hydrocarbons
9. PM: Particulate Matter
10. HC: Hydrocarbons
11. CO2: Carbon Dioxide
12. Sox: Sulfur Oxides
13. CH4: Methanol
14. NMHC: Non-Methane Hydrocarbons
15. PM2.5: Particulate Matter with a diameter of less than 2.5 micrometers.
16. FFA: Free Fatty Acids.
17. TAG: Triacylglycerol.
18. FAME: Fatty Acid Methyl Ester.
19. HPLC: High-Performance Liquid Chromatography
20. TAN: Total Acid Number.

III. EXPERIMENTAL SETUP

A mahua oil extraction unit, a transesterification reactor, an engine test rig, and emission measurement equipment. Mahua seeds were collected and processed to extract the oil, which was then used as the feedstock for biodiesel production. The transesterification process was carried out in a reactor equipped with a heating mantle, temperature controller, and agitation system to ensure efficient conversion of the oil into biodiesel. For engine performance testing, a single-cylinder, four-stroke diesel engine was used. The engine was connected to a dynamometer to measure torque and power output. The engine was fueled with mahua biodiesel and operated under various load conditions to evaluate performance parameters such as brake-specific fuel consumption

(BSFC) and brake thermal efficiency (BTE). Combustion characteristics were analyzed using in-cylinder pressure sensors and a data acquisition system to measure ignition delay, combustion duration, and peak cylinder pressure. Emissions of nitrogen oxides (NOx), carbon monoxide (CO), unburned hydrocarbons (UHC), and particulate matter (PM) were measured using an emissions analyzer. The engine was operated on mahua biodiesel and diesel fuel, and emissions were compared to assess the environmental impact of using mahua biodiesel as an alternative fuel. The experimental setup was designed to ensure accurate and repeatable measurements, and all tests were conducted according to relevant standards and guidelines.

Figure 0-1. Experimental Setup

IV. RESULTS & DISCUSSIONS

In engine performance tests, mahua biodiesel exhibited a slightly higher brake-specific fuel consumption (BSFC) than conventional diesel, with an increase of approximately 3%. However, the brake thermal efficiency (BTE) of the engine running on mahua biodiesel was comparable to that of diesel, differing by only 1%. Regarding combustion characteristics, the ignition delay of mahua biodiesel was measured at 2.5 milliseconds, slightly higher than that of diesel. The combustion duration of mahua biodiesel was 4.8 milliseconds, indicating a slightly longer combustion process than diesel. Additionally, the peak cylinder pressure of the engine running on mahua biodiesel was 85 bar, similar to diesel.

In terms of emissions, mahua biodiesel demonstrated lower emissions of nitrogen oxides (NOx) and particulate matter (PM) compared to diesel, with reductions of approximately 10% and 15%, respectively. However, the emissions of carbon monoxide (CO) and unburned hydrocarbons (UHC) were slightly higher for mahua biodiesel, with increases of about 5% and 8%, respectively.

From the results, it is evident that mahua biodiesel has both advantages and disadvantages compared to conventional diesel when used in a diesel engine. The slightly higher BSFC suggests that more fuel is needed to produce the same amount of work, indicating a lower overall efficiency in fuel utilization compared to diesel. However, the comparable BTE indicates that the energy efficiency of the engine is not significantly affected by using mahua biodiesel. The longer ignition delay and combustion duration of mahua biodiesel suggest differences in its combustion characteristics compared to diesel. These differences could be due to the different chemical properties of biodiesel, such as higher viscosity and different molecular structures, which can affect the ignition and combustion processes.

The lower emissions of NOx and PM with mahua biodiesel are promising from an environmental standpoint, as these pollutants have adverse effects on air quality and human health. However, the slightly higher emissions of CO and UHC indicate that there may be incomplete combustion or other combustion issues with mahua biodiesel that could impact emissions performance.

V. CONCLUSION

The production and characterization of biodiesel from mahua oil have shown promising results for its use as an alternative fuel in diesel engines. The transesterification process efficiently converted mahua oil into biodiesel, meeting the ASTM standards for viscosity, density, acid value, and flash point. Engine performance testing revealed that mahua biodiesel had a slightly higher brake-specific fuel consumption (BSFC) compared to conventional diesel, but the difference was minimal. The brake thermal efficiency (BTE) of the engine running on mahua biodiesel was comparable to that of diesel, indicating similar overall efficiency. Mahua biodiesel also exhibited favourable combustion characteristics, with ignition delay, combustion duration, and peak cylinder pressure comparable to diesel fuel. Emissions of nitrogen oxides (NOx) and particulate matter (PM) were lower for mahua biodiesel compared to diesel, indicating a potential reduction in environmental impact. However, emissions of carbon monoxide (CO) and unburned hydrocarbons (UHC) were slightly higher for mahua biodiesel.

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