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Jatropha Oil Biodiesel: Production Process, Fuel Characterization and Engine Efficiency Evaluation

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A B S T R A C T

This study explores the potential of Jatropha oil methyl ester as an alternative fuel for diesel engines. The oil was extracted using a Soxhlet extractor with normal hexane as the solvent. To address the high kinematic viscosity of the raw oil, a transesterification process with a high molar ratio of alcohol to oil, specifically 6:1, was employed to produce the methyl ester. Although the viscosity of the resulting ester was initially high, it was effectively reduced by blending with diesel fuel, bringing it within the ASTM standards for biodiesel. The produced biodiesel was then characterized and tested in a single-cylinder diesel engine, yielding torque output and specific fuel consumption values comparable to conventional diesel fuel, thereby confirming its viability as an alternative. Jatropha curcas is identified as a promising feedstock for biodiesel due to its high oil yield and adaptability to arid conditions. The study also highlights biodiesel's compliance with standard specifications and potential environmental and performance advantages over traditional diesel. Chromatography analysis revealed that the methyl ester is composed of 92% ricinoleic acid, a monounsaturated 18-carbon fatty acid with a hydroxyl group at C12 and ester linkages, contributing to the fuel's unsaturated nature. This composition, along with its high oil yield and adaptability to arid conditions, underscores the potential of Jatropha oil biodiesel for a wide range of industrial applications, making it a versatile and intriguing alternative fuel.

Keywords: Jatropha curcas, Biodiesel, Transesterification, Fuel Properties, Emissions, Performance Evaluation.

1.0 Introduction

The growing demand for fossil fuels and their environmental impact has spurred research into alternative energy sources. Biodiesel, derived from vegetable oils and animal fats, offers a renewable and less polluting alternative to diesel fuel. Jatropha curcas, a drought-resistant plant, is a promising feedstock for biodiesel production due to its high oil content and ease of cultivation [2,3] .

Biodiesel, a monoalkyl ester of vegetable oils or animal fats, shares physical properties with diesel fuel, with an even higher cetane number. This similarity allows it to be used directly as a substitute for diesel fuel without modifications or as a blending agent for diesel. Because biodiesel is produced from renewable, domestically grown feedstocks, it can reduce dependence on petroleum-based fuels and potentially lower the overall cost of diesel. Furthermore, biodiesel typically contains little to no sulphur, making it a promising option for reducing particulate and toxic emissions, a significant concern with diesel engines. The environmental benefits of Jatropha oil biodiesel are particularly inspiring, as it offers a renewable and less polluting alternative to diesel fuel, inspiring the audience about its potential impact on the environment.

Although Jatropha curcas seeds contain toxins that make the oil and cake inedible, jatropha oil was selected for this study due to its widespread availability and lack of competition with other commercial uses, such as food production. The plant thrives on marginal land, is drought and pest-resistant, and yields approximately 1,413 litres per hectare. High-yield breeds of jatropha contain 3555% oil by weight and have one of the highest viscosities among vegetable oils, with a molecular weight of 298.[20].

Jatropha oil is a non-drying oil that maintains its consistency across a range of temperatures, making it suitable as a lubricant for cars and racing car engines[14]. It is the only 18-carbon hydroxylated fatty acid source with one double bond in each fatty acid chain. Ricinoleic acid, which constitutes about 89% of the fatty acid composition, contains a hydroxyl group at C12, along with ester linkages and double bonds. These features make it unusually polar and provide multiple reaction sites for producing a wide range of natural and synthetic resins, waxes, polymers, and elastomers. Additionally, jatropha oil has excellent emollient and lubricating properties, a notable ability to wet and disperse dyes, pigments, and fillers [8,10], and various medicinal uses [7,13] . This versatility of Jatropha oil biodiesel in various applications is intriguing and can inspire the audience about its potential applications.

The growth in the world's population has resulted in a surge in energy demand. The world's energy supply has relied heavily on nonrenewable crude oil derived from fossil fuels for over two centuries. About 90% of crude oil is estimated to be consumed for energy generation and transportation [18]. This reliance has led to the dual crises of fossil fuel depletion and environmental degradation. [18] predicted that before the end of the 21st century, the world's reserves of fossil fuels would be exhausted. [23] also confirmed that these known crude oil reserves could be depleted at the present consumption rate in less than 50 years.

Horn revealed that in 2010, between 95 and 99.1 million barrels of crude oil were consumed per day [16], according to calculations by OPEC and the Energy Information Administration (EIA). This implies that by 2010, the world had consumed only 35 billion barrels of oil annually, but new field discoveries yielded less than 6 billion barrels annually. As a result, countries like Nigeria, Canada, and Venezuela, known for their oil production peaks, are under increasing pressure. These realities have driven the search for renewable and sustainable alternatives to fossil fuels. One of these alternatives is biodiesel (BD). Biodiesel is a clear amber-yellow liquid from vegetable oils, animal fats, or grease. Its non-flammability, biodegradability, nontoxicity, and non-explosiveness make it more environmentally friendly than petroleum diesel (PD) [6,15].

Several vegetable oils have been used as raw materials for biodiesel production. Vegetable oils such as palm, castor, rubber, coconut, rapeseed, and tung oils have been explored. Even algae, microalgae, bacteria, and fungi oils have been investigated [11,26]. Some of these feedstocks are abundant in Nigeria and could be either edible or nonedible. The edible oil seeds in Nigeria include soybean, groundnut, palm kernel oils, and coconut oil.

In contrast, the most commonly found nonedible ones are Jatropha curcas and Neem (Azadirachta indica). Vegetable oils as diesel fuel compared to diesel from fossil fuels include high heat content, ready availability, liquid nature, lower sulphur content, lower aromatic content, biodegradability, and renewability [28]. However, the drawbacks of these oils include higher viscosity, lower volatility, and the reactivity of the unsaturated hydrocarbon chains present in the oils [6,15].

According to [6], 95% of biodiesel is still made from edible oils, which compete with food consumption. Jatropha curcas plants are usually considered economically unuseful and invaluable among Nigeria's two non-edible oils. These plants are mostly used as fences for houses and are present in abundant quantities on abandoned lands, while the usefulness of neem plants is felt across the nation. Jatropha curcas is a drought-resistant, oil-bearing multipurpose shrub or small tree belonging to the family Euphorbiaceae [9]. It originates from Central America and is widely grown in Mexico, China, northeast Thailand, India, Nepal, Brazil, Ghana, Mali, Zimbabwe, Nigeria, Malawi, Zambia, and other countries [1,9]. The Jatropha curcas plant, which cuttings can easily propagate, is widely planted as a hedge to protect fields, as cattle or other animals do not browse it. It is well adapted to arid and semiarid conditions and is often used to prevent soil erosion [27] . Also, it grows in a wide range of rainfall regimes, from 200 to 1500 mm per annum [9]. The plants grow quickly, forming a thick, bushy fence in a short period of 6–9 months and growing to heights of 4 meters with thick branches in 2–3 years[27]. It has a lifespan of 50 years [28] Seeds of Jatropha curcas resemble castor seeds in shape but are smaller and brown. Jatropha curcas can tolerate high temperatures and grow well under low fertility and moisture conditions (Baroi et al., 2023). It can survive in poor, stony soils [6]. Due to its leaf-shedding activity, the jatropha plant becomes highly adaptable in harsh environments because the decomposition of the shed leaves provides nutrients for the plant and reduces water loss during the dry season. Thus, it is well adapted to various types of soil, including soils that are poor in nutrition, such as sandy, saline, and stony soils [27]. Jatropha cultivation in wastelands would help the soil regain nutrients and assist in carbon restoration and sequestration [6,28].

Comparision of selected studies on biodiesel production from Jatropha curcas oil in different countries like China and India in 2023. [6] studied biodiesel production from Jatropha curcas oil obtained in China, while [9] investigated biodiesel production from Indian Jatropha curcas oil. Studies on the use of Jatropha curcas plants revealed that they have an oil yield of 47.5% [11] and 49.1% [9,29] compared to an oil yield of 39.7% from neem (Mansir et al., 2024). In their review works, [7,17] also reported on research focused on transesterifying jatropha oil with methanol and ethanol using alkaline catalysts such as KOH and NaOH. Furthermore, comparing the fatty acid composition of Jatropha curcas oil with that of other common vegetable oils. Results from these research efforts suggest that Jatropha curcas oil could be a useful feedstock for biodiesel production, significantly reducing production costs. Additionally, using Jatropha curcas oil could promote global acceptance and commercialization of biodiesel as an alternative energy source [7].

Various techniques have been employed for biodiesel production, namely direct use and blending, microemulsions, thermal cracking (pyrolysis), and transesterification [2]. However, due to its simplicity, the most commonly used method is transesterifying vegetable oils and animal fats ([2,24]. These methods have been reported for biodiesel production from Jatropha curcas oil [6,7,11]

2.0 Materials and Methods

2.1 Materials

Oil Extraction Jatropha seeds were harvested from the wild, dried, crushed and separated into seeds and shells. The seeds were packed into the extraction chamber, and normal hexane was poured into the round-bottom flask of a Soxhlet extractor. The mantle heater was set at 60, and the oil in the seeds was leached for 8 hours, after which the N-hexane was distilled from the jatropha. The eight of the oil produced, and the residue was measured.

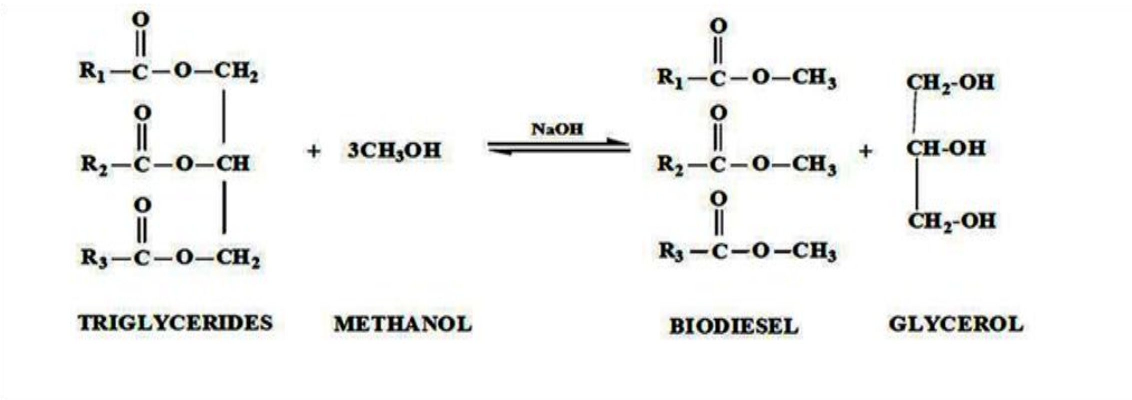

Fig.1 Esterification Process

2.2 Esterification Process

Determination of Optimum Conditions for Transesterification

An iterative experimental design determined the optimal conditions for transesterifying Nigerian specification on jatropha oil regarding molar ratio and the amount of catalyst required. The mass of sodium hydroxide was varied from 2.5 to 5 g in steps of 0.5 g. Each mass was dissolved in 1 litre of methanol to form sodium methoxide. The resulting methoxide was mixed with jatropha oil in molar ratios of 1:1, 4:1, and 6:1, yielding 18 samples. The amounts of methyl ester and glycerol produced were separated and measured for each sample as in Figure 1.

2.2.1 Trans esterification Process

Sodium hydroxide (3 g/L) was dissolved in methanol at 350 rpm until completely dissolved. The mixture was combined with jatropha oil in a 250 mL reactor equipped with a heater and magnetic stirrer at a molar ratio of 6:1 to bias the reaction towards higher yields due to the oil's high viscosity. The mixture was stirred at 1000 rpm for 3 hours at 60°C. After allowing the mixture to settle for 8 hours, it separated into two layers: biodiesel (upper layer) and glycerol (denser, lower layer). The biodiesel was then separated using a separating funnel. Tannic acid was added to neutralize any remaining base catalyst, followed by washing with distilled water to remove impurities such as glycerine, monoglyceride, catalyst, soap, and excess methanol. The washing process involved mixing the biodiesel with 20 vol.% distilled water and stirring gently for 10 minutes. After settling, the biodiesel and hydrated methanol layers were separated using a separatory funnel. The washing procedure was repeated three times before the biodiesel was heated to 120°C to remove any residual water vapour (Dorado et al., 2002).

2.2.2 Characteristics of Jatropha Oil

Jatropha oil, extracted from the seeds of the Jatropha curcas plant, is a rich source of triglycerides, making it suitable for biodiesel production. The following indices were used in the characterization of Jatropha oil values such as Specific gravity, Saponification, Iodine, Cetane number, phosphorus content to mention a few.

2.3 Determination of Specific Gravity

Specific gravity is a measure of a substance's density compared to the density of water. In biodiesel production, specific gravity is used to test the purity of biodiesel. B100 should have a specific gravity between 0.86-0.90.

2.4 Saponification Value Determination

The British standard method was used to determine the saponification value of the extracted oil. Based on the method, 2.0g of the oil was placed in a 250ml conical flask and 25ml of 0.5 Nethanolic potassium hydroxide solution was added. A reflux condenser was attached, and the flask content refluxed for 30 min in a water bath with continuous swirling until it simmered. The excess potassium hydroxide was titrated against 0.5N hydrochloric acid using a phenolphthalein indicator while still hot. A blank determination was carried out under the same conditions.

2.5 Iodine Value Determination

Hanus method was used to determine the iodine value of the oil. This was done by placing 0.1 g of the oil in a 250 ml conical flask, adding 10 ml of anhydrous chloroform and 30 ml of Hanus solution. The content was mixed and placed in a drawer for exactly 30 min. After that, potassium iodide solution (10ml of 15% weight volume) was added to the flask to wash down any iodide at the stopper used for the flask. The entire content was titrated against 0.14 M Na2SO3 until the solution turned light yellow. After that, 2 ml of 1% starch indicator was added and the titration continued until the blue colour formed finally disappeared. A blank determination was carried out under the same condition, and the titre values were recorded.

2.6 Phosphorus Content

Phosphorus content in Jatropha oil indicates potential contaminants that can poison catalysts during biodiesel production. However, its value is expected below 10 ppm (parts per million). A lower phosphorus content is crucial for preventing catalyst deactivation during transesterification.

2.7 Cetane Number

The cetane number measures the ignition quality of diesel fuel. However, the expected range from research studies is 48-65. A higher cetane number in biodiesel leads to better ignition properties, resulting in smoother engine operation and lower emissions.

2.8 Kinematics Viscosity

The viscosity of biodiesel affects its flow and atomization in the engine. It is expected to range between 4-6 mm^2/s at 40°C. However, a lower viscosity after transesterification makes biodiesel more compatible with diesel engines without extensive modifications.

2.9 Acid Number and Free Fatty Acid Value

This is the quantity of base required to titrate a sample to a specified endpoint. It is a measure of free fatty acid in biodiesel. Excessive free fatty acid in the fuel can be corrosive and may be a symptom of water in the fuel or poor production or subjected to oxidative degradation. Excessive free fatty acid in the fuel can inhibit transesterification and lead to soap formation. The acid values of the oil and FAME are 15.37 mg KOH/gm and 3.37 mg KOH/gm, respectively.

2.10 Engine Testing

The test engine is a Lister 8/1 VA low-speed single-cylinder diesel engine connected to an electrical dynamometer. The specifications of the engine are:

Nominal power output: 6 kw @ 850 rev/min, 4.5 kW @ 650 rev /min

Bore: 114.3 mm

Stroke: 139.7 mm

Swept volume: 1.433 litres

Current from the mains excites the field independently, and a rheostat regulates its intensity. Switching in the eight electrical components loads the engine. They can take in the entire production of the dynamometer and are chosen using a selection. Flip. The current generated is sent to the load—the generator circuit's resistance. The motor was when the throttle was fully opened and the load progressively raised by turning on the load components one by one until the pace drops to the the lowest number at which the engine will only operate seamlessly. The plant fuel gauge, which measures fuel consumption, is made out of a glass tube with four spacers with knife edges positioned such that the volume of gasoline between them is precisely calibrated. The engine speed, revolution counter, amount of gasoline used, time, and spring balance reading were recorded and utilized to calculate the engine performance metrics during each test run. The B100 and diesel fuels were tested.

3.0 Results and discussion

Jatropha biodiesel exhibits robust characteristics, making it a viable alternative to conventional diesel. The fuel's specific gravity of 0.88 is within the international standards (EN 14214 and ASTM D6751), ensuring that it has a density comparable to traditional diesel, which is critical for efficient fuel injection and engine performance.

The kinematic viscosity of 4.8 mm^2/s at 40°C falls comfortably within the required range, indicating that the fuel has the right flow properties for proper atomization in diesel engines. This is important for ensuring smooth combustion and efficient engine operation. The flash point of 135°C is well above the minimum requirements, making Jatropha biodiesel safe for storage and handling, as it has a low risk of igniting at lower temperatures.

However, the cloud point (10°C) and pour point (5°C) reveal that Jatropha biodiesel may face challenges in colder climates. These values suggest that the fuel could begin to gel and become less fluid at lower temperatures, limiting its usability in regions with cold weather unless additives or modifications are applied to improve its cold flow properties.

The fuel's density (880 kg/m^3) is within the acceptable range, indicating that it has a similar energy content and combustion characteristics to conventional diesel. This is crucial for maintaining the performance and efficiency of diesel engines when using biodiesel.

Jatropha biodiesel's chemical properties, such as a low acid value (0.4 mg KOH/g) and phosphorus content (8 ppm), indicate that it has low impurities, which is beneficial for reducing the risk of engine corrosion and deposits. The sulphur content is 20 ppm, while slightly above the EN 14214 standard, is still relatively low, helping to minimize sulphur oxide emissions and engine wear.

The 39 MJ/kg heating value is comparable to conventional diesel, ensuring the fuel can deliver similar engine performance. The cetane number of 55 exceeds the minimum requirements, a positive indicator of good combustion quality and efficient ignition in the engine.

4.0 Conclusion

Conclusively, Jatropha biodiesel demonstrates several favorable attributes that make it a promising alternative to conventional diesel. Its adherence to international standards for specific gravity, viscosity, flash point, and density suggests that it can perform well in diesel engines while maintaining safety in storage and handling as correlated by [6,17] . Although challenges arise in colder climates due to its higher cloud and pour points, these issues can be mitigated through additives or further refining processes. The fuel's low impurity levels, including acid value, phosphorus, and sulfur content, are advantageous in terms of minimizing engine wear and emissions. With a heating value and cetane number comparable to or exceeding those of traditional diesel, Jatropha biodiesel offers comparable performance in terms of combustion efficiency and power output. Overall, despite some limitations, especially in cold environments, Jatropha biodiesel stands as a viable, environmentally friendly fuel option with the potential for widespread use. The primary areas for improvement lie in enhancing its cold flow properties and slightly reducing its sulphur content to meet stricter environmental regulations. These adjustments could help Jatropha biodiesel become even more competitive with traditional diesel, offering a cleaner, renewable energy source with comparable performance.

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