



A Comprehensive Analysis of Oil Extraction Technologies for Optimized Biodiesel Production

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

There is a critical need for energy diversification due to over dependence on fossil fuel and its daunting challenges. These impediments linked with fossil fuels have stirred the search for another energy sources and biodiesel is one of the potential alternatives. Biodiesel is renewable, non-toxic, environmental-friendly and an economically viable choice to solve the diminishing fossil fuels and its harmful environmental effect. It can be made from seeds oil plant, vegetable oils, animal fats, waste oils and algae. Here are various means for the production of the biodiesel oil which comprises; mechanical, chemical/solvent and enzymatic oil extraction methods etc. Report from the open literatures revealed that, all the extraction methods have its own advantages and disadvantages but in all, oil expeller machine which is based on mechanical means of extracting oil from the common wastage seeds oil plant prove to be efficient especially for large scale extraction. Thus, for efficient

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oil extraction from wastage seeds oil plant, oil expeller machine is appropriate. This research seeks to discuss an improve ways of maximum oil yield with an expeller machine from the wastage seeds oil plant commonly available in our environment.

Keywords: biodiesel production process; oil extraction methods; seeds oil; screw press oil expeller.

1. INTRODUCTION

Generally, energy is an essential element of industrialization and socio-economic development of any country. The petroleum deposits in certain regions of the world are fast diminishing on daily basis and at the current usage rate, these sources will soon be exhausted. Recently, due to the shortage of fossil fuels throughout the world, crude oil price increase and impact of these fuels in polluting the environment, biodiesel is attracting increasing attention as a potential substitute and renewable fuel for diesel engines worldwide [1].

The choice of biodiesel as an alternative fuel has been getting a lot of attention throughout the world owing to its renewable, biodegradable as well as its environmentally friendly nature. It produces lower pollutant emissions, possesses a high flash point, better qualities of lubrication and high cetane number with very close physical and chemical characteristics to those of conventional diesel fuel. This allows its use either as pure biodiesel (B100) or mixed with petroleum-based diesel fuel at a ratio of between 5 – 20%, (B5–B20) with very few technical adjustments or no modifications. Burning of biodiesel fuel does not contribute to a rise in the level of carbon dioxide in the atmosphere and does not pose a danger to the ozone layer [2].

The biodiesel produced from renewable resources could help to minimize the fossil fuel burning and CO₂ production. Biofuels and bio products produced from plant biomass mitigate global warming. This is as a result of the CO₂ released during combustion being equal to the CO₂ tied up by the plant during photosynthesis and does not add up to the net CO₂ in the atmosphere [3]. Therefore, an increase in biodiesel production by trans-esterification may lead to an excess of glycerol production as a by-product. The glycerol is mostly used in medical, pharmaceutical and personal care applications [4].

Over the years, several review articles have been published by many researchers on the extraction of oil for biodiesel production [5]. However, in this research we shall discuss

efficient ways of maximum oil yield with an expeller machine from the oil seeds. The review paper seeks to present; first, the various ways of oil extraction for biodiesel production. It goes further to compare oil extraction process of automatic screw press oil expeller and the manual oil expeller process. The problem associated with each oil extraction processes were identified and their respective appropriate remedies were proffered in the course of this review. It further considered an overview of biodiesel focusing on the production methods of the biodiesel.

2. FEEDSTOCK PREPARATION

The initial phase of oil extraction commences with seed preparation. This process involves removing the outer layers of the fruit to expose the kernels or seeds, followed by drying to reduce moisture content [6]. The seeds are then separated from the fruits, and for those fruits that do not naturally split open, manual cracking is employed. To achieve the ideal moisture content for optimal oil extraction, the kernels or seeds are predominantly dried either in the sun or in an oven, depending on the prevailing weather conditions. Following the drying process, the separated seeds or kernels undergo sieving, cleaning, and are subsequently stored at room temperature in preparation for the extraction of their oil content, as documented in various literature sources [7-9].

2.1 Oil Extraction from Seeds

One crucial element in biodiesel production is the extraction of oil, and various methods and techniques for oil extraction have been documented in studies such as [10-13]. These methods encompass mechanical, chemical/solvent, enzymatic oil extraction, as well as microwave-assisted extraction, supercritical fluid extraction, and accelerated solvent extraction. This article focuses on the mechanical method, specifically comparing the manual oil extraction machine process with the automatic oil extraction process. Additionally, improvements to the machinery will be explored to address and enhance the oil production process.

2.2 Oil Extraction Methods

This section provides an overview of the prevalent oil extraction techniques. These methods encompass chemical/solvent extraction, enzymatic extraction, microwave-assisted extraction, supercritical fluid extraction, accelerated solvent extraction, and mechanical extraction.

2.2.1 chemical/solvent

Solvent extraction, also known as leaching, is the procedure through which oil is separated from a solid using a liquid solvent, as documented in studies [7,14]. Various factors influence the chemical leaching process, including particle size, the type of liquid solvent employed, temperature, and the mixing speed of the system. In order to increase the interfacial area between the feedstock and the solvent, a tiny particle size is desired. For unrestricted circulation, the solvent should have a low viscosity. Temperature plays an important role as it makes the oil more soluble, which influences the rate of extraction. According to Yusuf et al [15], mixing speed is another crucial component that affects the process by increasing the rate of diffusion, which subsequently facilitates material transfer from the particle surface.

It's interesting to note that the solvent extraction method has its own set of advantages and disadvantages. While it has been proven to be a highly effective process with a high yield and consistent performance, it does come with a relatively higher production cost compared to mechanical press methods due to the expense associated with the solvent, as highlighted by Muzenda et al [16].

2.2.2 Enzymatic extraction

This approach involves the crushing of seeds followed by the utilization of enzymes for oil extraction [17]. There is also the potential to integrate aqueous enzymatic oil extraction with other methods for oil retrieval. Despite the promising aspects of this method, its practical application encounters challenges such as the requirement for de-emulsification in subsequent processing, extended incubation periods, and elevated enzyme expenses [18, 19]. Affinity chromatography and perfusion chromatography are two techniques that can simplify downstream processing, and the immobilization of enzymes helps in reducing overall costs and minimizing

enzyme losses [20]. Nevertheless, the immobilization of enzymes may result in decreased reaction rates due to steric hindrance. Moreover, the utilization of solvents like n-hexane not only amplifies wastewater generation and the emission of volatile organic compounds but also presents hazards owing to the flammability and toxicity of n-hexane [21]. To address these issues, an alternative extraction method, such as an aqueous enzymatic oil system coupled with ultra-sonication pre-treatment, is recommended [18,22]. The principal merits of enzymatic oil extraction are its eco-friendliness and the absence of volatile organic compounds. However, a notable drawback associated with this technique is the prolonged processing time, as highlighted by Mahanta and Shrivastava [17].

2.2.3 Microwave-Assisted

Microwave-assisted extraction, also referred to as microwave extraction in accordance with Hao et al [23], represents a novel extraction method that combines traditional solvent extraction with microwave technology. This technique is acclaimed for its numerous advantages compared to alternative extraction methods. These advantages encompass reduced extraction costs, expedited processing times, diminished solvent usage, heightened extraction efficiency, improved product quality at a reduced expense, decreased energy consumption, and lower CO₂ emissions [24]. The literature showcases numerous instances where successful applications of microwave-assisted extraction, documented by various researchers, have substantiated these advantages [25-28]. However, as noted by Uquiche et al [29], a drawback of microwave-assisted extraction is that certain plants may not be suitable due to the potentially damaging effects of high microwave energy levels on plant structures.

2.2.4 Supercritical fluid extraction

The supercritical fluid extraction method is employed to eliminate the reliance on organic solvents and to enhance the speed of extraction. According to the literature [30], supercritical fluid extraction using CO₂ offers numerous advantages over solvent extraction. This method utilizes CO₂ as a solvent, which is non-toxic, cost-effective, nonflammable, and environmentally friendly, enabling the extraction of almost 100% oil [31]. Nevertheless, the primary drawback of supercritical fluid extraction

lies in the high production costs. This is attributed not only to the use of high-pressure equipment but also to the necessity of freeze-drying raw materials to reduce moisture to values below 20%, as a high concentration of water in the fluid phase adversely affects oil yield [32, 33].

2.2.5 Accelerated solvent extraction

Accelerated solvent extraction, also known as pressurized solvent extraction, represents a contemporary method for oil extraction utilizing organic or aqueous solvents under elevated temperatures and pressures [10]. It has been noted that higher temperatures expedite the extraction rate, while increased pressure prevents boiling beyond the normal boiling point of the solvent.

In accelerated solvent extraction, both time and solvent consumption are significantly reduced compared to other solvent extraction methods [34]. This efficiency is evident in the extraction of various materials, including wheat germ and flaxseed hulls, as indicated in the literature [35].

However, accelerated solvent extraction comes with its own set of drawbacks, including a very high initial cost, extensive preparation requirements, the need for specialized equipment and skills, the potential for solvent contamination, and the limitation to processing only kernels, as reported in Sarip et al [36], Ali and Watson [37].

2.3 Mechanical Screw Press Oil Extraction

The traditional and widely used technique for large-scale oil extraction is mechanical screw press oil extraction. As outlined in the research conducted by Ketan et al [38], this method can be carried out through the utilization of either a manual press or an engine-driven screw press.

2.3.1 Manual oil expeller

Manual oil expeller involves the extraction of oil through manual effort, utilizing human energy. This stands in contrast to the automatic oil expeller process, where oil is pressed out of plant seeds with the assistance of an oil expeller machine. In the manual expeller method, the raw materials (seeds, nuts, and fruits) are crushed into a powder either by manually pounding the feedstock with a mortar and pestle or by using a

grinding machine. Subsequently, water is sprinkled on the powder. The resulting paste is preheated in an oven to facilitate the oil flow from the cake. Following preheating, the paste is placed into a sleeve bag and subjected to a hydraulic press to enhance the extraction of oil from the cake. However, this oil extraction process is recognized as a labor-intensive and cumbersome method.

2.3.2 Automatic screw press oil expeller

The screw press oil expeller stands out as a more efficient method of oil extraction compared to all other techniques. Seeds are introduced through a hopper, crushed, and conveyed by a rotating screw within a press barrel. The continuous movement of the screw shaft transports the feedstock, causing pressure to rise to the necessary level. This heightened pressure increases friction inside the screw press, generating heat that reduces the viscosity of the oil in the crushed seeds, thereby enhancing the oil flow rate. The oil and cake are typically collected at the oil outlet and press cake exit.

Mechanical extraction, specifically through the use of automatic screw press oil expellers, offers several advantages over alternative extraction methods, as emphasized in studies [7, 39]. These advantages are particularly evident in the form of low operating costs and the production of high-quality, light-colored oil with a low concentration of free fatty acids (FFAs), as documented in Carr [40]. Correspondingly, research findings indicate that powered screw presses can extract between 68 and 80 percent of the oil from seed oils [41]. However, it does exhibit a comparatively lower oil yield when compared to solvent extraction, as demonstrated in Buenrostro et al [42], leaving some oil in the cake after the extraction process.

Furthermore, a prior investigation [43] revealed that chemical/solvent approaches result in increased oil yield, albeit with associated drawbacks of higher costs and environmental issues due to the use of hazardous and flammable solvents, restricting its applicability. Hence, there is a necessity for research aimed at refining and bolstering the screw press oil extraction method, given its aforementioned merits over alternative extraction techniques, as outlined in Table 1. This research is crucial to enhance its effective utilization in the biodiesel production sector.

2.4 Summary

2.4.1 Based on analysis above, the following improvement are available

The production of biodiesel oil from seeds can be achieved through either an automatic or manual method. When using the automatic method, the friction inside the screw press generates heat which reduces the viscosity of the oil, increasing the oil flow rate. However, this method lacks a preheater, resulting in lower oil yield and some oil remaining in the cake, which leads to wastage. On the other hand, the manual method involves crushing the feedstock into a powder, sprinkling water to create a paste, and preheating it in an oven for around an hour to reduce the paste's viscosity. After preheating, the paste is taken to a presser to extract oil from the cake. Despite being labor-intensive, the manual method yields more oil compared to the automatic process.

This research aims to bridge the gap between automatic and manual methods by incorporating a heater or heating element in the crushing chamber of the automatic machine. This integration is intended to reduce the viscosity of the paste, resulting in increased oil production, reduced processing time, and a more streamlined oil.

3. OVERVIEW AND HISTORY OF THE USE OF BIODIESEL FUELS

Biodiesel, as per the definition provided by Marchetti [44], refers to the mono-alkyl ester of long-chain fatty acids obtained from renewable lipid sources, such as vegetable oils or animal fats. This fuel is characterized as non-toxic, biodegradable, and renewable, with the capacity to be produced from various organic sources, including both fresh and waste vegetable oils, animal fats, and oilseed plants [45]. The biodiesel formation process, as outlined by Azad et al [46], Krishna et al [47], is as follows:

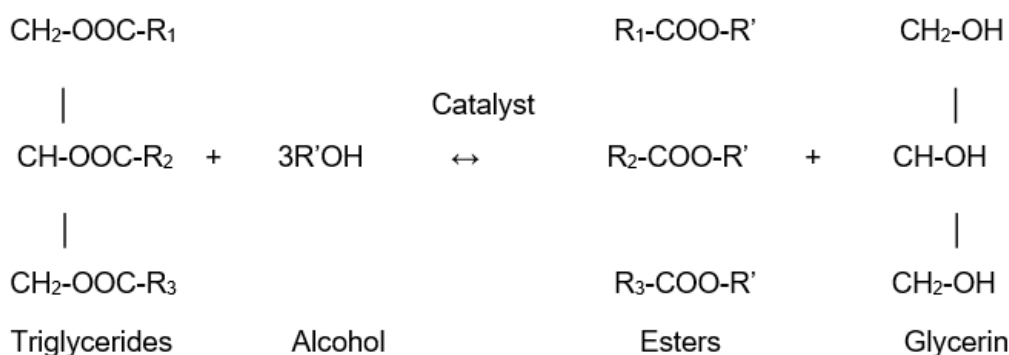


Table 1. Merits and demerits of oil extraction methods [10,6, 43]

Method of Oil Extraction	Merits	Demerits
Mechanical	No environmental problem regarding the use of mechanical method No potential for solvent contamination Relatively inexpensive after initial capital costs Minor consumable costs	Relatively dirty process Oil not completely extracted from the cake Filtration or degumming process of oil is required Operators require experience to achieve best results
chemical/solvent	Repeatable and reproducible results and process High oil yields Relatively simple and quick Hexane can be recovered and reused, reducing cost significantly	Less sought after than virgin oil Potential for solvent contamination Safety issues and environmental concerns regarding the use of hexane Very costly if the hexane cannot be recovered
enzymatic	No negative effect on the environment. The method is sustainable	Requires high cost of enzyme and incubation time. Requires de-emulsification during down-stream operations.

Method of Oil Extraction	Merits	Demerits
microwave-assisted	It eliminates the emission of carbon dioxide (CO ₂). Only a fraction of the energy is needed in comparison to traditional heating methods.	Not suitable for cases where the solvent or desired compound is non-polar or possesses volatility.
supercritical fluid extraction	Supercritical conditions result in increased extraction due to improved solubility with the solvent. Employing CO ₂ as a solvent renders the process more cost-effective, given the readily available and non-flammable nature of CO ₂ .	The elevated temperature and pressure necessary for the supercritical technique contribute to an overall increase in costs.
accelerated solvent extraction	Both time and solvent usage are substantially decreased in comparison to alternative solvent extraction methods.	The initial cost is exceptionally high, and extensive preparation is necessary. Specialized equipment and expertise are necessary. There is a risk of contamination from solvents.

Transesterification reaction for biodiesel production [46,47]

The utilization of biologically derived fuels, such as vegetable oil, traces back to Rudolf Diesel in 1896, who initially employed peanut oil in an Internal Combustion Engine. Another early proponent of biofuels was Henry Ford, a pioneer in automobile manufacturing, who designed his first car model to run on ethanol. Despite the visionary expectations of these inventors that their innovations would be sustained by plant-derived fuels, petroleum gained preference due to its economic advantages and widespread availability. However, the oil crisis of the 1970s, coupled with environmental concerns, reignited interest in biofuels [48].

From the 1980s onward, there was significant discourse on the use of vegetable oil as a fuel [49]. Bartholomew introduced the idea of utilizing food crops for fuel, asserting that petroleum should be viewed as the "alternative" fuel, with vegetable oil and alcohol serving as viable alternatives. He emphasized the necessity for some form of renewable energy to replace non-renewable resources [50].

Vegetable oil, obtained from diverse plants, can be categorized as either suitable for consumption or non-consumable. The exploration of non-edible plant sources is driven by the intention to avoid contributing to the rising costs of edible oils. The conversion of biodiesel from edible seeds has the potential to worsen their scarcity and lead to increased prices, given their dual utilization as both food and fuel. Non-edible plants are notably appealing due to their abundant availability in

various regions and their cost-effectiveness in specific countries [51]. An overview of biodiesel production from non-edible raw materials is outlined in Table 2.

3.1 Methods of Biodiesel Production Process

Numerous researchers have exerted considerable effort to advance biodiesel production methods, with ongoing studies aimed at enhancing product yields, refining fuel properties, and reducing production costs [57-59]. The use of straight vegetable oils in engines presents challenges such as fuel filter clogging, poor atomization, and incomplete combustion due to their high viscosity, density, and inadequate volatility. The conversion of vegetable oils into biodiesel can be achieved through four methods: heating/pyrolysis, dilution/blending, micro-emulsion, and transesterification. Among these approaches, transesterification stands out as an extensive, convenient, and highly promising method for mitigating the issues associated with straight vegetable oils, such as viscosity and density. However, it introduces additional processing costs due to the chemical reactions and process heat inputs involved in the transesterification process [60].

3.1.1 Pyrolysis

"Pyrolysis" denotes a chemical process involving the application of thermal energy in the absence of nitrogen or air. Diesel fuels closely resemble the liquid residues resulting from the thermal decomposition of vegetable oils. The pyrolysis product shares calorific values akin to diesel fuel but exhibits lower viscosity, flash point, and pour

Table 2. Non-edible feedstock for biodiesel synthesis

Feedstock	Catalyst	Temperature (°C)	Time (Min)	Oil to Alcohol Ratio	Yield (%)	References
Mahua Oil	KOH	-	-	6:1	98	[52]
Mahua Oil	KOH	60	30	4:1	-	[53]
Karanja oil	NaOH	50	70	-	84	[54]
Jatropha oil	KOH	55	60	9:1	90-95	[45]
Jatropha oil	H ₂ SO ₄	60	120	9:1	80	[45]
Canola oil	KOH	50	60	9:1	90-95	[45]
Rubberseed oil	NaOH	-	-	9:1	80	[55]
Honne oil	KOH	45-65	30-150	4:1	89	[56]

point. However, the pyrolyzate possesses a diminished cetane number. Although pyrolyzed vegetable oils contain satisfactory levels of water, sedimentation, and sulfur, their ash content, carbon residual, and pour point fall short of desired standards [61]. The pyrolysis procedure can be categorized into three subtypes depending on the operating conditions: flash pyrolysis (1050 - 1300 K), fast pyrolysis (850 - 1250 K), and conventional pyrolysis (550 - 900 K) [62-64]. Due to its energy-intensive nature and associated drawbacks, researchers need to explore more pragmatic and cost-effective approaches for biodiesel production.

3.1.2 Micro-emulsification

The creation of micro-emulsions emerges as a potential remedy for addressing the challenges related to vegetable oil viscosity and certain atomization properties, as documented in the studies by Vivekpantidar et al [65], Yusuf et al [66]. Micro-emulsions exhibit characteristics of being transparent and thermodynamically stable colloidal dispersions, featuring droplet sizes within the range of 100 to 1000 nm. These emulsions may consist of vegetable oils, alcohol, a surfactant, a cetane improver, and/or an ester and a dispersant (co-solvent), with or without the addition of diesel fuel. Microemulsions involving hexanol, octanol, and butanol all meet the maximum viscosity standards for diesel fuel.

Notably, 2-octanol has demonstrated effectiveness as an amphiphile for the micellar solubilization of methanol in triolein and soybean oil [67-70]. Conversely, research conducted by Parawira [71], May and Gazi [72] suggests that the use of micro-emulsified diesel in diesel engines may lead to common issues such as carbon deposits, nozzle failure, and incomplete combustion.

3.1.3 Dilution

Vegetable oils can be thinned by incorporating substances like ethanol, solvents, or diesel fuels,

resulting in reduced density and viscosity. The addition of 4% ethanol to diesel fuel enhances brake power, torque, and thermal efficiency while requiring less fuel, specifically for braking. Due to its lower boiling point compared to diesel fuel, ethanol may aid combustion by generating an unburned mix spray [73]. A published study indicates successful blending of vegetable oils with diesel by researchers. During World War II in Europe, vegetable oil, either in its pure form or combined with diesel, was utilized as fuel [74]. In 1980, Caterpillar Brazil Company achieved full power without modifying the engine by blending 10% vegetable oil with diesel in the pre-combustion chamber. Furthermore, positive results are documented when combining vegetable oil and diesel in a 20:80 ratios. In 1982, a successful test of a diesel engine was conducted using a 5% diesel mixture consisting of 95% spent cooking oil [75]. As per a study [76], operating the engine with a 50% blend of *Jatropha curcas* oil (JCO) did not pose significant operational challenges.

In August 1982, a conference convened in Fargo, North Dakota, aiming to explore the development, methodology, and limitations associated with using vegetable oil as a fuel, notwithstanding ongoing research efforts [72, 77]. Diesel fuels, being mobile and possessing high heat content (approximately 80%), are more suitable for dilution or mixing with liquids. The efficacy of blending is diminished for substances with elevated viscosity, low volatility, and a high unsaturated carbon chain. Running engines exclusively on vegetable oil leads to issues such as coking and trumpet formation, carbon deposition, oil ring sticking, thickening, and gelling of lubricating oil. Future considerations for alternative fuels will predominantly focus on the production of biodiesel while effectively addressing these challenges [75, 78].

3.1.4 Transesterification

Transesterification stands out as one of the most convenient techniques for biodiesel production,

involving the conversion of vegetable oil or any triacylglycerol with alcohol in the presence of a catalyst. This process results in the formation of alkyl esters (biodiesel) and glycerol [79]. Numerous researchers have explored various biodiesel production methods and consistently identified transesterification as the most favorable one [80]. Biodiesel produced through this approach exhibits fuel properties that fall within the specifications of EN 14214 and ASTM D6751 standards. Transesterification has demonstrated fuel properties characterized by higher cetane numbers, reduced emissions, and enhanced combustion efficiency. However, the notable drawback of this method is the requirement for excess methanol [78]. The ongoing quest for optimal conditions for transesterification, along with the pursuit of cost-effective and environmentally friendly catalysts, remains a significant concern for the industrial-scale production of biodiesel.

Transesterification method can be carried out by two ways according to literature [81].

- a) Catalytic transesterification.
- b) Supercritical methanol transesterification.

3.1.4.1 Catalytic transesterification

The process known as "Catalytic Transesterification" involves the reaction of a triglyceride (fat/oil) with an alcohol in the presence of a catalyst, resulting in the formation of esters and glycerol. A triglyceride comprises a glycerin molecule as its base, with three long-chain fatty acids attached. The properties of the oil or fat are dictated by the type of fatty acids linked to the glycerin, and, consequently, the characteristics of the biodiesel can be influenced by the nature of these fatty acids [60, 82-85].

3.1.4.2 Super critical transesterification

The simple transesterification processes mentioned earlier face two challenges, namely, being relatively time-consuming and requiring the separation of the catalyst and saponified impurities from the biodiesel. The first issue arises from the phase separations within the vegetable oil/alcohol mixture, which can be addressed through vigorous stirring. These challenges are not encountered in the supercritical method of transesterification. This lack of issues may be attributed to the absence of a tendency for the two-phase formation of the vegetable oil/alcohol mixture, resulting in a single phase due to the reduction in the dielectric constant of alcohol in the supercritical state (at

340°C and 43 MPa). Consequently, the reaction is completed in a remarkably short time, typically within 2-4 minutes. Moreover, since no catalyst is employed, the purification of biodiesel becomes much simpler, hassle-free, and environmentally friendly [86-90].

3.2 Effect of Reaction Parameters on Transesterification

The production efficiency of biodiesel through the transesterification process is influenced by various operational parameters, encompassing factors such as the presence of moisture and free fatty acids (FFA), reaction time, reaction temperature, catalyst, and the molar ratio of alcohol to oil [48].

The effect of reaction parameters on transesterification are discussed as follows:

3.2.1 Effect of Free Fatty Acid (FFA) and Moisture Content (MC)

The presence of FFAs and water consistently yields detrimental effects, as their presence leads to soap formation, catalyst consumption, and reduced catalyst effectiveness, ultimately resulting in a lower conversion rate. In catalyst-based methods, water's presence adversely affects the yields of methyl esters. In acid-catalyzed transesterification, the formation of fatty acids can occur. These free fatty acids then react with the alkaline catalyst, producing soaps that hinder the separation of biodiesel, glycerin, and wash water. Research findings from [91-93] emphasize that achieving a high-quality biodiesel with a complete base-catalyzed reaction requires a free fatty acid value lower than 2%. As per [94], an increased water content in waste cooking oil accelerates the hydrolysis reaction and simultaneously diminishes ester formation. In response to this issue, the supercritical methanol method was proposed, noting that water has less influence in this approach [91]. Hence, to achieve a 90% biodiesel yield, the water content should not surpass 0.5%, and this factor is more critical in an acid-catalyzed reaction than in a base-catalyzed reaction [95].

3.2.2 The effect of molar ratio and alcohol type

The biodiesel yield percentage increases with a higher alcohol-to-oil molar ratio, reaching an optimal yield of 85% at a ratio of 6.1. However, going beyond this ratio does not necessarily lead to an increase in biodiesel yield; instead, it may

escalate production costs and, consequently, the pump price of biodiesel. While the stoichiometric molar ratio of methanol to triglyceride for transesterification is 3.1, higher molar ratios are employed to enhance solubility and promote increased contact between triglyceride and alcohol molecules. Elevated molar ratios contribute to greater ester conversion within a shorter timeframe. Another crucial factor influencing methyl ester yield is the choice of alcohol-to-triglyceride type. In general, short-chain alcohols such as methanol, ethanol, propanol, and butanol can be utilized in transesterification reactions to achieve high methyl ester yields. Among them, methanol stands out due to its simple chemical structure, resulting in superior yields compared to butanol and ethanol [96-98]. Fig 1 illustrates the impact of the oil-to-alcohol ratio on biodiesel yield.

Fig 1 illustrates the influence of the oil-to-alcohol ratio on supercritical transesterification, where carbon dioxide serves as the solvent and methanol as the co-solvent. The experiment maintained a consistent temperature of 280 °C. Notably, the biodiesel yield exhibits a positive trend for approximately 23 minutes during the experiment. This occurrence is attributed to findings from previous studies [91], indicating that an excessive amount of alcohol leads to product contamination, increases overall process costs, and consequently reduces the total biodiesel production.

3.2.3 The effect of catalyst

Alkali-catalyzed transesterification exhibits significantly higher speed compared to acid-catalyzed transesterification, contributing to its commercial success. The Transmethylation process occurs 4000 times more rapidly with an alkaline catalyst than with an equivalent amount of an acidic catalyst. This heightened efficiency is attributed to the lesser corrosive nature of alkaline catalysts on industrial equipment compared to acid catalysts. The concentration of the catalyst also plays a role in biodiesel yield. However, surpassing an optimal catalyst concentration is not economically advantageous, as it leads to increased residues in the biodiesel, escalating the washing costs [99, 100]. Literature has reported that excessive catalyst usage can result in emulsions, leading to higher viscosity and complicating the biodiesel recovery process [101].

Moreover, research conducted by Madhuvilakku and Piraman [102] revealed that elevating KOH

conversion from 2% to 12% resulted in an increase in biodiesel output from 20% to 95%. Similarly, a study conducted by Vivekpantidar et al [65] determined that a 1 weight percent catalyst yielded the highest production of jatropha biodiesel. Fig 2 depicts the impact of catalyst concentration on biodiesel production. The graph indicates that the biodiesel yield initially increases with the rise in the concentration of alkali catalysts (NaOH and KOH) but subsequently decreases after reaching a peak value.

3.2.4 The effect of reaction temperature and time

Transesterification exhibits variations in reaction temperatures based on the type of oil involved. The reaction temperature significantly impacts the reaction rate, with room temperature allowing completion given sufficient time, while higher temperatures expedite the reaction. Typically, the reaction is carried out at atmospheric pressure around the boiling point of methanol (60 to 70°C). However, a further temperature increase adversely affects the conversion process. Previous studies [106-108] indicate that, at ambient temperatures, the reaction proceeds effectively using an alkaline catalyst, with low temperatures having no impact on conversion but significantly affecting biodiesel recovery. Research by Ishak et al [109] also noted that temperature enhances the reaction rate up to an optimal level.

Fig 3, derived from prior research by Mathiyazhagan and Ganapathi [91], illustrates the impact of temperature on FAMES composition in the presence of a co-solvent (CO₂). The rise in temperature increases the energy of reacting molecules, and as transesterification is inherently endothermic, elevated temperatures favor the reaction. The graph suggests that the optimum temperature range for transesterification lies between 250 and 350 °C. Further temperature escalation may result in the thermal decomposition of the product.

Fig. 4 illustrates a gradual increase in the concentration of fatty acid methyl ester as the reaction progresses over an extended duration. Initially, the reaction proceeds at a relatively slow pace, which can be ascribed to minimal stirring and limited dispersion of oil and solvent. The primary site of the reaction is predominantly the exterior surfaces of the oil and triglycerides.

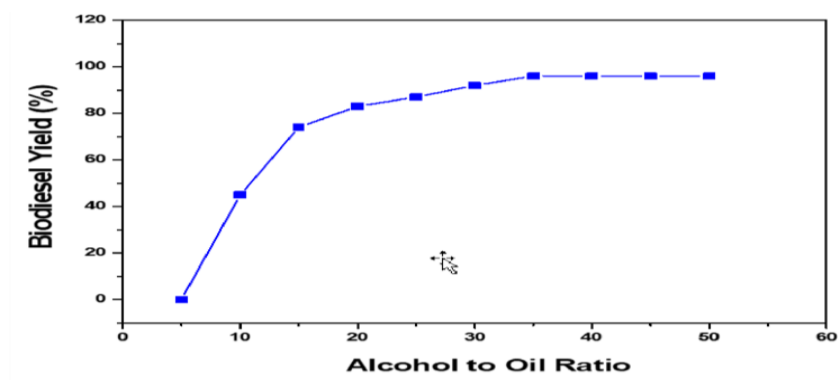


Fig. 1. Oil to alcohol ratio effect on biodiesel yield, Source [91]

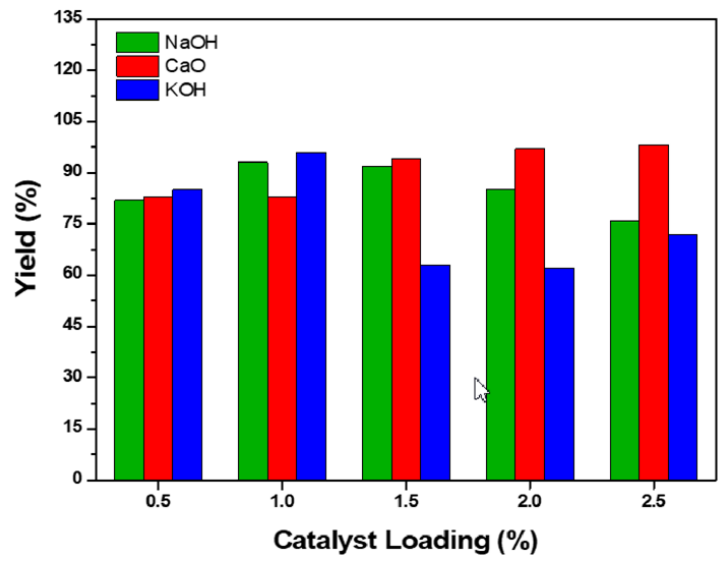


Fig. 2. Influence of catalyst concentration on biodiesel yield [103-105]

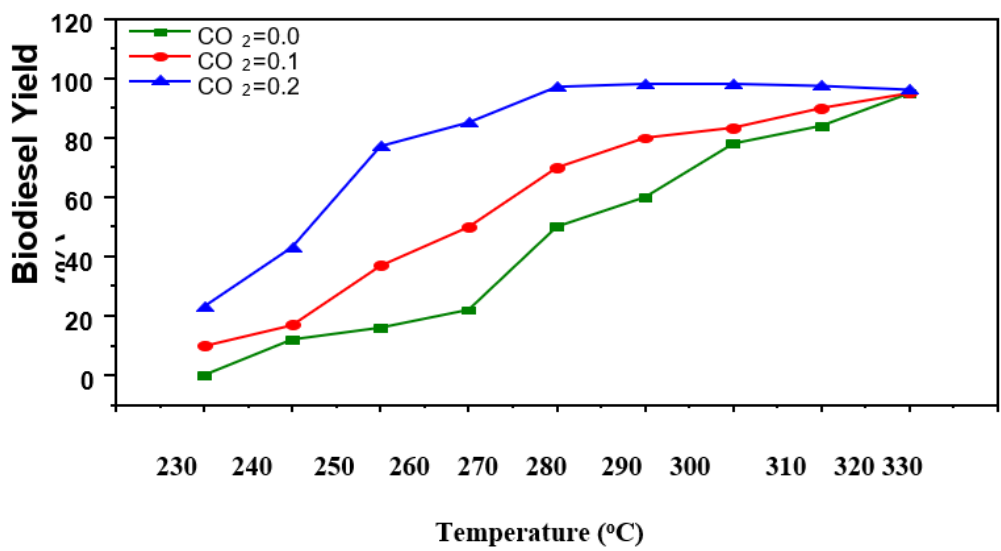


Fig. 3. CO₂ and temperature effect on biodiesel yield [91]

Table 3. Effect of different parameters on biodiesel synthesis

Feedstock	Molar Ratio	Time (min)	Catalyst Loading	Temperature (°C)	Agitation Speed (rpm)	Type of Transesterification	Yield (%)	References
Palm oil	6:1 (methanol)	60	1% KOH	60	600	Homogeneous base	88	[113]
		60	1% NaOH	60	600		93	[113]
	480	8.5% KOH	65–75	-	96.2		[114]	
	9:1	-	0.4% KOH	70–110	-		98	[115]
Jatropha oil	10:1	480	9% KOH	60–80	-	Homogeneous base	96.8	[102]
	4.83:1 to 9.65:1	300–480	1–4%	50–65	-		87.3	[116]
Waste frying Oil	12:1	60	6% CaFeAl	60	270	Heterogeneous transesterification	90	[117]
Jatropha oil	3:7	180	1% H ₂ SO ₄ 1% NaOH	65	400	Homogeneous acid and base	21.2	[118]
	3:7			50	400		90.2	
Waste cooking oil	3:7	180	1% H ₂ SO ₄ 1% NaOH	65	400	Homogeneous acid and base	21.2	[119]
	3:7			50	400		90.6	
Canola oil	3:1 to 8:1	25–75	0.2–1.2% KOH	30–70	100–600	Homogeneous base	-	[120]
Mustard oil	-	30	KOH	40–60	450	Homogeneous base	-	[121]
Sunflower Oil	6:1	90–330	1% CaO	23–60	-	Heterogeneous	91	[122]
	6:1	-	0.06–0.34	23–60	400	Homogeneous base	99	[123]
Peanut oil Waste lard	12:1	30–360	-	250–310	500	Supercritical transesterification	>90	[124]
	24:1						30	
Silybum Marianum seed oil	30:1	20	4–6 wt.% enzyme	50	-	Ultrasound assisted transesterification	96.8	[125]
	6:1						75	
Canola oil Used frying Oil	6:1	-	0.5% KOH	45	-	Homogeneous base	95	[127]
	6.03:1	120	0.55% KOH	60–100	-	Homogeneous base	-	[128]
Rapeseed oil Neem oil	3.5:1 to 42:1	120	-	200–500	-	Supercritical transesterification	95	[129]
	10:1	60	10% CZO	55	-	Heterogeneous transesterification	97.1	[130]

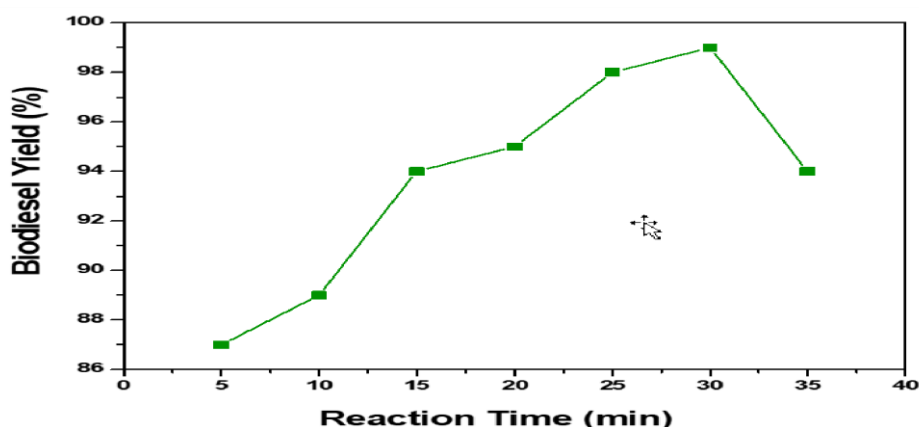


Fig. 4. Influence of reaction time on biodiesel production [109, 110]

As depicted in Fig. 4, the graph indicates that an extended reaction time leads to an augmentation in the concentration of fatty acid alkyl esters in the product. Nevertheless, this impact is noticeable only up to a 30-minute reaction time. Beyond 30 minutes, the reaction yield becomes indifferent to the reaction time. This is attributed to the equilibrium being already attained at the 30-minute mark, as reported by Farobie et al [111], Hossain and Boyce [112]. It is advisable to conduct supercritical transesterification within a reaction time range of 6 to 12 minutes and conventional transesterification within a range of 30 to 60 minutes.

According to literatures report, Table 3 shows the effect of various parameters on biodiesel synthesis.

4. BIODIESEL FUEL SPECIFICATION

The most recent standard for B100 biodiesel is ASTM D6751-078 or D6751, where ASTM

stands for the American Society of Testing and Materials. This organization comprises manufacturers of engines and fuel injection systems, fuel producers, and users, and its standards are officially recognized in the United States by governmental entities, including state agencies, to ensure fuel quality. Biodiesel fuels failing to meet these specifications are deemed unsuitable for use in Internal Combustion Engines (ICE). To ensure quality, Nigeria, through its Nigerian biofuel policy and incentives, has legislatively established the Standard Organization of Nigeria (SON) and the Department of Petroleum Resources (DPR), both of which have subsequently adopted the ASTM standard. Currently, B20 biodiesel blend has received commercial approval for use in ICES, though it is not readily available in the open market. Table 3 demonstrates that biodiesel shares similar physico-chemical properties with conventional diesel fuel and typically does not require engine modification for diesel engines.

Table 4. Specification of biodiesel standard [1],[137-141]

Properties	ASTM D6751	EN 14214
Density (15 °C, g/cm ³)	NS	0.86–0.90
Kinematic viscosity (40 °C, mm ² /s)	1.9 – 6.0	3.5 – 5.0
Cetane number	47 min	51 min
Flash point (°C)	130 min	120 min
Sodium (ppm) Potassium (ppm)	Na & K combined 5 (max)	Na & K combined 5 (max)
Acid value (mg of KOH/g)	0.50 max	0.50 max
Iodine value (g I ₂ /100 g)	NS	120 (max)
Total sulfur (ppm)	15 max	10 max

NS: not specified. Max: maximum. Min: minimum

Top-notch fuel is generated through the correct blending of diesel fuel that meets all specifications with biodiesel that also fulfills those criteria, following appropriate fuel management procedures. The outcome is a superior diesel fuel proven to operate efficiently in nearly any unmodified diesel engine. Nevertheless, the use of substandard fuels, including biodiesel, may lead to performance issues or equipment damage [131-136].

4.1 ASTM and EN Biodiesel Specification

Table 4 presents a comparative examination of the physico-chemical properties of several biodiesel standards utilized in gas turbines across Europe and the American continent. The differences in the values observed for various fuel properties can be largely attributed to the climatic conditions prevalent in each specific country.

5. CONCLUSION

As the demand for energy continues to rise with population growth and economic expansion, the depletion of fossil fuels, the primary energy source, becomes a pressing concern. Given the current consumption rate, these fossil fuel reserves are anticipated to diminish. However, rising crude oil prices and environmental pollution concerns associated with traditional fuels have propelled biodiesel into the spotlight as a promising alternative and renewable fuel for diesel engines worldwide. Consequently, there is an urgent need to enhance the oil extraction process for biodiesel production. Various oil extraction methods are employed to extract oils from seeds, with oil expellers falling into this category. This discussion has covered two types of oil expellers: automatic screw press and manual.

While each oil extraction method discussed has its advantages, this research aims to bridge the gap between automatic and manual methods. The recommendation involves incorporating a heater or heating element into the crushing chamber of automatic expeller machines. This addition aims to reduce oil viscosity in the paste, resulting in increased oil production, reduced processing time, and improved overall production efficiency. The study delineates four methods for biodiesel production: Heating/pyrolysis, dilution/blending, micro-emulsion, and transesterification. Among these approaches, transesterification emerges as one of the most

practical techniques for biodiesel production. This method involves reducing the viscosity of oil or fat using an acid or base catalyst in the presence of methanol or ethanol. However, the biodiesel yield in the transesterification process is influenced by various process parameters, including the presence of moisture and free fatty acids (FFA), reaction time, reaction temperature, catalyst, and the molar ratio of alcohol to oil.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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