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Sustainable Production and Characterization of Biodiesel from Kitchen Waste

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ABSTRACT
This study demonstrates the sustainable production of biodiesel from waste palm oil through alkaline transesterification, utilizing methanol and sodium hydroxide (NaOH) as catalyst. Under optimal conditions (200 ml methanol and 16 g NaOH per liter of waste oil), an 85% biodiesel yield was achieved. The physicochemical properties of the biodiesel, including density (0.87 g/cm³), viscosity (4.5 mm²/s), flash point (160 °C), cetane number (52), and acid value (0.45 mg KOH/g), meet international standards (ASTM D6751, EN 14214). The results show that waste palm oil is a viable, low-cost, and environmentally friendly feedstock, offering a promising alternative to fossil diesel. The study employed a combination of transesterification, settling, and washing processes to produce high-quality biodiesel. This research contributes to sustainable urban waste management and highlights the potential for biodiesel production from waste oils in developing countries, providing a pathway towards renewable energy and reduced environmental impact.

Keywords:
Sustainable, Kitchen, Waste, Biodiesel, Production.

INTRODUCTION

The global demand for energy has been growing rapidly as a result of industrialization, urbanization, and population growth. Fossil fuels—primarily petroleum, natural gas, and coal—have remained the dominant sources of energy for decades. However, their extensive use has led to two critical global challenges: depletion of finite resources and environmental degradation caused by greenhouse gas emissions. These challenges have intensified the need for renewable, sustainable, and environmentally friendly energy sources. Among the alternatives, biodiesel has emerged as a promising renewable fuel due to its biodegradability, low sulfur content, reduced emissions, and compatibility with existing diesel engines (Demirbas, 2009). Biodiesel is typically produced through transesterification of oils or fats with alcohol (commonly methanol), in the presence of a catalyst such as sodium hydroxide or potassium hydroxide. While edible oils such as soybean, sunflower, and palm oil have historically been used as biodiesel feedstocks, reliance on these oils raises serious concerns regarding the "food versus fuel" conflict. Using edible oils for biodiesel production can contribute to increased food insecurity, higher market prices, and social inequality, particularly in developing countries where edible oils are a major food source (Knothe, 2010).

To overcome this limitation, research has shifted towards non-edible oils and urban/domestic waste oils as alternative feedstocks for biodiesel production. These oils include waste non-edible palm oil, neem oil, castor oil, rubber seed oil, jatropha oil, animal fats (tallow, lard, poultry fat), and trap grease collected from domestic and urban waste streams. Such oils are often underutilized, discarded, or considered unsuitable for human consumption. Their conversion into biodiesel provides a dual environmental benefit: waste reduction and renewable energy generation.

In Nigeria and many other developing nations, palm oil waste represents one of the largest sources of non-edible oils from urban and domestic activities. After multiple uses or poor storage, palm oil often becomes degraded, unsuitable for cooking, and is discarded as waste. Instead of polluting the environment through improper disposal, this waste oil can serve as a sustainable and low-cost feedstock for biodiesel production.

Although soybean and sunflower oils are commonly used as feedstocks in biodiesel research globally, they remain edible oils and are not suitable for large-scale adoption in countries where food supply is a priority. For this reason, the present study focuses primarily on non-edible palm oil waste, while also considering other domestic/urban waste oils and comparing them with edible oils (soybean, sunflower) where relevant.

Thus, the production of biodiesel from urban/domestic wastes using non-edible oils not only provides a viable alternative to fossil fuels but also contributes to environmental protection, resource efficiency, and sustainable development. The increasing demand for energy and environmental concerns in Nigeria and other developing countries necessitate the exploration of sustainable energy sources. Kitchen waste, particularly waste cooking oil, poses significant environmental challenges due to indiscriminate disposal, clogging sewage systems, polluting waterways, and contributing to environmental hazards.

Research Question

1. How can kitchen waste, specifically waste cooking oil, be effectively converted into biodiesel using sustainable and affordable methods?
2. What quality of biodiesel can be obtained from kitchen waste, and how does it compare to conventional biodiesel?
3. To what extent can sustainable biodiesel production from kitchen waste address environmental challenges while contributing to energy security

Aim & objectives

The aim of this study is to investigate the sustainable production and characterization of biodiesel from kitchen waste, specifically waste cooking oil, with a focus on waste palm oil.

The specific objectives of the study are to:

1. Collect and Characterize Kitchen Waste: Identify and collect waste cooking oil from kitchen waste and characterize its physicochemical properties.
2. Produce Biodiesel: Produce biodiesel from kitchen waste through the transesterification process using environmentally friendly methods.
3. Characterize Biodiesel Properties: Determine the properties of the produced biodiesel, such as density, viscosity, flash point, and acid value, according to ASTM/EN standards.

4. Evaluate Sustainability Benefits: Assess the environmental and economic implications of utilizing kitchen waste for biodiesel production, including waste reduction, greenhouse gas emissions, and energy security.
5. Promote Sustainable Energy: Contribute to the development of sustainable energy solutions by exploring the potential of kitchen waste as a feedstock for biodiesel production

Significant

This study is significant for several reasons:

Environmental Benefits

1. Reduced Pollution: Recycling kitchen waste, specifically waste cooking oil, into biodiesel helps reduce pollution, sewage blockage, and improper waste disposal.
2. Waste Management: The study promotes sustainable waste management practices, contributing to a cleaner environment.

Energy Security

1. Renewable Energy Source: Biodiesel from kitchen waste offers a renewable, local alternative to imported diesel, reducing dependence on fossil fuels.
2. Energy Independence: The study contributes to energy security by exploring local energy sources.

Economic Benefits

1. Income Generation: Adoption of waste-to-energy biodiesel production can generate income for households and small industries.
2. Job Creation: The study's findings can create employment opportunities in the biodiesel industry.

Scientific Contribution

1. Alternative Feedstocks: The study contributes to research on alternative feedstocks for biodiesel production.
2. Case Study: The research provides a case study for biodiesel production from kitchen waste in Nigeria, promoting sustainable energy solutions.

Social Benefits

1. Food Security: By focusing on waste oils, the study avoids the food-versus-fuel debate associated with edible oils.
2. Sustainable Development: The research promotes sustainable development by exploring environmentally friendly energy solutions

SCOPE & LIMITATION

This research focuses on:

1. Sustainable Production: Producing biodiesel from kitchen waste, specifically palm oil waste, using the transesterification method.
2. Characterization: Analyzing the properties of the produced biodiesel according to ASTM and EN standards.
3. Comparative Analysis: Comparing the properties of biodiesel from kitchen waste with other waste oils and conventional biodiesel.

Limitations

1. Feedstock Availability: Availability and quality variation of kitchen waste may affect the study's outcomes.

2. Laboratory Scale: The study will be conducted on a laboratory scale, producing biodiesel in 1-liter batches, which may not be representative of industrial-scale production.
3. Specificity to Kitchen Waste: The study's findings may be specific to kitchen waste and may not be generalizable to other types of waste oils.

Research Focus

The study will focus on:

1. Kitchen Waste: Utilizing kitchen waste as a feedstock for biodiesel production.
2. Sustainable Energy: Exploring the potential of kitchen waste as a sustainable energy source.

The research on sustainable production and characterization of biodiesel from kitchen waste aligns with several United Nations Sustainable Development Goals (SDGs), including.

a. SDG 7: Affordable and Clean Energy: By exploring alternative energy sources like biodiesel from kitchen waste, this research contributes to increasing the share of renewable energy in the global energy mix.
b. SDG 9: Industry, Innovation, and Infrastructure: The development of sustainable biodiesel production processes and supply chains can foster innovation and build resilient infrastructure.
c. SDG 12: Responsible Consumption and Production: The study's focus on waste reduction, efficient resource utilization, and environmentally friendly production practices promotes responsible consumption and production patterns.
d. SDG 13: Climate Action: By reducing greenhouse gas emissions through the use of biodiesel, this research helps mitigate climate change.
e. SDG 14: Life Below Water and SDG 15: Life on Land: Proper disposal and utilization of kitchen waste can prevent environmental pollution, protecting both aquatic and terrestrial ecosystems.

Biodiesel Production from Waste Cooking Oil and Palm Oil

Numerous studies have investigated the production of biodiesel from waste cooking oil and palm oil using different catalysts and techniques. For instance, Abdulla et al. (2022) used immobilized Candida rugosa lipase to produce biodiesel from waste palm cooking oil, achieving promising results. Similarly, Zahan and Badrul (2018) reviewed biodiesel production from palm oil, its by-products, and mill effluent, highlighting the potential of these feedstocks.

Recent Advances and Challenges

Recent studies have focused on optimizing biodiesel production from waste cooking oil and palm oil using different catalysts and techniques. For example, Degfie et al. (2019) used nano-CaO as a heterogeneous catalyst to optimize biodiesel production from waste cooking oil. However, the high cost of catalysts and the complexity of the production process remain significant challenges in the widespread adoption of biodiesel.

MATERIAL AND METHOD

This chapter outlines the methods and procedures used in the sustainable production and characterization of biodiesel from kitchen waste, specifically focusing on palm oil waste and other selected urban/domestic waste oils. The methodology is designed to be scientifically reproducible, cost-effective, and adaptable for both laboratory-scale and community-scale biodiesel production.

Sources of Raw Materials

The primary raw material used in this study is kitchen waste, specifically palm oil waste, obtained from households, restaurants, and local food establishments. The waste oil is collected, filtered, and processed for biodiesel production.

Experimental Design

The study employs an experimental research design approach, involving systematic laboratory experimentation under controlled conditions. This design allows for the determination of the yield, quality, and performance characteristics of biodiesel obtained from kitchen waste.

Materials and Equipment

The materials and equipment used in this study include:

a. Kitchen waste (palm oil waste and other selected urban/domestic waste oils)
b. Laboratory-scale biodiesel production equipment
c. Chemicals and catalysts for transesterification and esterification reactions
d. Analytical instruments for characterizing biodiesel properties

Raw Materials

a. Kitchen waste: Palm oil waste (1 liter per batch)
b. Methanol (CH_3OH)
c. Sodium hydroxide (NaOH, caustic soda pellets)

Laboratory Equipment:

a. Conical flasks (250 ml, 500 ml, 1 L)
b. Beakers (100 ml - 1000 ml)
c. Measuring cylinders
d. Separating funnel (500 ml - 1 L)
e. Thermometer (0-200 °C)
f. Weighing balance
g. Filtration setup (Whatman filter paper)
h. Storage containers for biodiesel and glycerol

Analytical Equipment

a. pH meter
b. Viscometer (for viscosity measurement)

These materials and equipment were used to produce and characterize biodiesel from kitchen waste, specifically palm oil waste, through transesterification and other relevant processes

Biodiesel Production Process

The biodiesel production process involves:

a. Collection and processing of kitchen waste
b. Transesterification and esterification reactions to produce biodiesel

c. Purification and characterization of biodiesel

Characterization of Biodiesel

The produced biodiesel is characterized according to international standards, including:

a. Density
b. Viscosity
c. Flash point
d. Acid value
e. Other relevant properties

Experimental Procedure

The production of biodiesel from kitchen waste, specifically palm oil waste, was carried out using the alkali-catalyzed transesterification method.

Step 1: Pretreatment of Waste Oils

1. Filtration: Waste oils were filtered to remove food particles, dirt, and water.
2. Heating: Oil was heated at 60 °C for 1 hour with continuous stirring.
3. FFA measurement: Oil was cooled and re-measured for FFA using titration.

Step 2: Catalyst Preparation

1. NaOH pellets (16g) were weighed and dissolved in 200 ml of methanol.
2. Sodium methoxide solution was prepared in a closed container.

Step 3: Transesterification Reaction1. 1 liter of pretreated palm oil waste was reacted with sodium methoxide solution.

Green Chemistry Principles in Biodiesel Production

Transesterification ReactionThe transesterification reaction is a crucial step in biodiesel production, where triglycerides react with an alcohol (such as methanol) to produce biodiesel and glycerol.

Chemical Equation

Triglyceride + $3CH_3OH \rightarrow 3RCOOCH_3 + C_3H_8O_3$

Where:

a. Triglyceride: CH_2-O-CO-R_1 | CH-O-CO-R_2 | CH_2-O-CO-R_3
b. $RCOOCH_3$: Biodiesel (fatty acid methyl esters)
c. $C_3H_8O_3$: Glycerol

Green Chemistry Principles

a. Catalysis: Using heterogeneous catalysts (e.g., CaO, MgO) or enzymes (e.g., lipases) to improve efficiency and reduce waste.
b. Atom Economy: Maximizing the incorporation of all materials used in the process into the final product.
c. E-factor: Minimizing waste generation by optimizing reaction conditions and catalysts.

Benefits

By applying green chemistry principles, biodiesel production can become more sustainable, environmentally friendly, and economically viable

a. Mixture was stirred continuously for 1 hour at 60 °C.
b. Triglycerides were converted into methyl esters (biodiesel) and glycerol.

Step 4: Separation of Biodiesel and Glycerol

1. Reaction mixture was transferred to a separating funnel.

2. Allowed to stand for 12 hours for phase separation.
3. Biodiesel (upper layer) was decanted, and glycerol (lower layer) was drained off.

Step 5: Washing of Biodiesel

1. Crude biodiesel was washed with warm distilled water (10% of biodiesel volume).
2. Washing was repeated until wash water turned neutral (pH ≈ 7).

Step 6: Drying of Biodiesel

1. Washed biodiesel was dried by gentle heating at 105 °C for 30 minutes.
2. Final biodiesel product was stored in airtight containers for characterization.

This experimental procedure outlines the steps involved in producing biodiesel from kitchen waste, specifically palm oil waste, using the alkali-catalyzed transesterification method.

Experimental Design Parameters

The experiment was designed to optimize biodiesel production from kitchen waste, specifically palm oil waste, by controlling key variables. The parameters were chosen based on previous studies and calculations to achieve high biodiesel yield.

1. Catalyst Concentration- NaOH: 16g per liter of oil
   Calculation: Based on previous studies, this concentration was chosen to ensure efficient transesterification reaction.
2. Methanol-to-Oil Molar Ratio- Molar ratio: 6:1
   Methanol volume: 200 ml per liter of oil, Calculation: This ratio was chosen to ensure sufficient methanol for the reaction, driving the equilibrium towards biodiesel production.
3. Reaction Time and Temperature- Reaction time: 60 minutes
   Temperature: 60 °C, Calculation: These conditions were chosen to optimize reaction kinetics and yield, based on previous studies.

Optimization Calculations

1. Catalyst concentration: 16g NaOH/L oil = 1.6% (w/w)
2. Methanol-to-oil molar ratio: 6:1 (excess methanol ensures complete reaction)
3. Reaction time and temperature: 60 minutes at 60 °C (optimal for reaction kinetics)

Analytical Methods for Biodiesel Characterization

To evaluate the quality of the produced biodiesel from kitchen waste, the following tests were conducted in line with ASTM and EN standards.

Biodiesel Yield Model

The biodiesel yield can be modeled as a function of reaction conditions:

$$Y = (m_{biodiesel} / m_{oil}) \times 100\%$$

where:
Y = biodiesel yield (%)
$m_{biodiesel}$ = mass of biodiesel produced (kg)
m_{oil} = mass of oil used (kg)

This model calculates the percentage of biodiesel yield based on the mass of biodiesel produced relative to the mass of oil used in the transesterification reaction

Energy Balance Model

$$\Delta H_{reaction} = \Delta H_{biodiesel} + \Delta H_{glycerol} - \Delta H_{oil} - \Delta H_{alcohol}$$

where:
$\Delta H_{reaction}$ = enthalpy change of reaction
$\Delta H_{biodiesel}$ = enthalpy of biodiesel

$\Delta H\_glycerol$ = enthalpy of glycerol
ΔH_oil = enthalpy of oil
$\Delta H\_alcohol$ = enthalpy of alcohol

This model represents the energy balance for the transesterification reaction, accounting for the enthalpy changes of the reactants and products.

Density and Specific Gravity

Measured using a hydrometer at 15 °C

Density (ρ) = mass / volume (kg/m^3)

Specific Gravity = ρbiodiesel / ρwater

Kinematic Viscosity

Measured using a viscometer at 40 °C

Kinematic Viscosity (ν) = dynamic viscosity / density (mm^2/s)

Flash Poin

t- Determined using a Pensky-Martens closed cup apparatus

- Flash Point: lowest temperature at which biodiesel ignites

Acid Value

1. Determined through titration with potassium hydroxide (KOH)
2. Acid Value (AV) = (volume of KOH × normality of KOH × 56.1) / mass of biodiesel mg KOH/g)

These analytical methods ensure the produced biodiesel meets international standards for quality and performance, making it a viable alternative to fossil fuels

Data Collection and Analysis Data Collection

Volume of biodiesel produced per liter of waste oil

Yield percentage (% yield)

Physicochemical properties of biodiesel

1. Density
2. Kinematic viscosity
3. Flash point
4. Acid value

Data Analysis:

1. Statistical analysis of experimental results
2. Comparison with international standards for biodiesel (ASTM D6751, EN 14214)

Calculations:

1. Yield percentage (% yield) = (volume of biodiesel produced / volume of waste oil) × 100
2. Physicochemical properties were evaluated against standard limit

Characterization and Sustainability Benefits Characterization:

Biodiesel yield: calculation of biodiesel produced from kitchen waste, Yield (%) = (volume of biodiesel / volume of waste oil) × 100. Physicochemical properties: evaluation of biodiesel quality, Density, kinematic viscosity, flash point, acid value

Density

1. Density (ρ) = mass / volume (kg/m^3)
2. Equation: $\rho = m / V$

Kinematic Viscosity

1. Kinematic Viscosity (ν) = dynamic viscosity / density (mm^2/s)

2. Equation: $\nu = \mu / \rho$

Flash Point

1. Flash Point: lowest temperature at which biodiesel ignites (°C)
2. Equation: FP = temperature at which vapor pressure equals lower flammability limit

Acid Value

1. Acid Value (AV) = (volume of KOH × normality of KOH × 56.1) / mass of biodiesel (mg KOH/g)
2. Equation: $AV = (V \times N \times 56.1) / m$

These physicochemical properties are crucial in determining the quality and performance of biodiesel produced from kitchen waste, aligning with the research topic on Sustainable Production and Characterization of Biodiesel from Kitchen Waste.

Sustainability Benefits:

1. Renewable energy source: biodiesel from kitchen waste reduces dependence on fossil fuels
2. Waste reduction: utilization of kitchen waste as a feedstock reduces waste disposal issues
3. Greenhouse gas reduction: biodiesel production from kitchen waste can reduce net CO_2 emissions. CO_2 reduction = (amount of biodiesel produced) × (CO_2 emission factor)

Equations:

1. Energy balance: energy output from biodiesel production vs. energy input
   Energy balance = (energy output - energy input) / energy input
2. Carbon footprint: calculation of CO_2 emissions from biodiesel production
   Carbon footprint = (CO_2 emissions from production) / (amount of biodiesel produced)

Sustainable Biodiesel Production Model

The sustainable biodiesel production model can be represented as:

Sustainability Index (SI) = (Energy Output - Energy Input) / (Environmental Impact + Social Impact + Economic Cost)

Where:

Energy Output = Energy content of biodiesel produced
Energy Input = Energy required for production (feedstock, processing, transportation)
Environmental Impact = GHG emissions, water pollution, land use changes
Social Impact = Job creation, community development, food security concerns
Economic Cost = Production costs, market price, government incentives

This model aims to balance the energy, environmental, social, and economic aspects of biodiesel production to ensure sustainability.

RESULTS AND DISCUSSION

This chapter presents the results of biodiesel production from palm oil waste through alkaline transesterification. The experiment used 1 liter of palm oil waste, 16g of NaOH as catalyst, and 200 ml of methanol. The main objective was to investigate the feasibility of converting waste oils into biodiesel fuel and compare the results with international biodiesel standards (ASTM D6751 and EN 14214).

Experimental Observations

During the production of biodiesel from kitchen waste (waste palm oil), several key observations were made:

Initial Oil Characteristics

1. The waste palm oil had a dark yellow to reddish color with a faint rancid odor, typical of non-edible and discarded cooking oils.
2. High viscosity, making it unsuitable for direct use in diesel engines without modification.

Reaction Mixture

1. Upon mixing the heated oil with methanol and sodium hydroxide (NaOH), the solution appeared cloudy.
2. Vigorous stirring was necessary to ensure proper contact between the immiscible oil and methanol phases.

Separation Process

After the reaction, the mixture was transferred into a separating funnel.

Within 12-24 hours of settling, two distinct layers were observed:

1. Top layer: clear, light-yellow biodiesel (methyl esters)
2. Bottom layer: dark brown, viscous glycerol, containing impurities and excess catalyst

Washing and Drying

1. The biodiesel was washed multiple times with warm distilled water until a clear wash water was observed.
2. After washing, the biodiesel was dried at about 105 °C to remove residual moisture.
3. The final biodiesel was light yellow, clearer than the original oil, and had a reduced odor.

Biodiesel Yield Analysis

The volume of biodiesel obtained after transesterification was measured. The yield percentage was calculated using the formula:

Calculation:Yield (%) = (Volume of biodiesel produced ÷ Volume of oil used) × 100

Given values:

Volume of biodiesel produced = 850 ml = 0.85 liters

Volume of oil used = 1 liter

Step-by-Step Calculation

1. Divide the volume of biodiesel produced by the volume of oil used:
   0.85 liters (biodiesel) ÷ 1 liter (oil) = 0.85
2. Multiply by 100 to convert to percentage: 0.85 × 100 = 85%

The biodiesel yield was approximately 85%, which is consistent with results reported in similar studies using waste oils (range: 80-90%)

Table 3.1: Yield of Biodiesel from Waste Palm Oil

Parameter	Value	Remark
Intial oil volume	1.0L	Palm oil waste
Methanol used200 mlCatalyst	NaOH, 20 g	
Biodiesel recovered	0.85 L (850 ml)	After washing & drying
Glycerol layer recovered	0.12 L (120 ml)	Containing methanol & catalyst
Yield (%)	85%	Good conversion achieved

Analysis of Table 3.1: Yield of Biodiesel from Waste Palm Oil The table presents the results of biodiesel production from waste palm oil through transesterification. Key observations:

1. Biodiesel Yield: 85% yield indicates efficient conversion of waste palm oil to biodiesel.
2. Methanol and Catalyst: 200 ml of methanol and 20g of NaOH catalyst were effective in achieving transesterification.
3. Glycerol Recovery: 0.12 L (120 ml) of glycerol was recovered, containing methanol and catalyst.

Implications:

1. Sustainable Production: Utilizing waste palm oil as feedstock reduces waste disposal issues and promotes sustainable biodiesel production.
2. Efficient Process: The high biodiesel yield suggests optimal reaction conditions and catalyst usage.
3. Potential for Scalability: These results can inform larger-scale biodiesel production from waste palm oil.

The analysis supports the topic of Sustainable Production and Characterization of Biodiesel from Kitchen Waste, highlighting the potential for efficient and environmentally friendly biodiesel production from waste oils

Physicochemical Properties of Produced Biodiesel

The produced biodiesel underwent physicochemical analysis to determine its quality and suitability as a fuel. The properties evaluated included:

Key Properties:

1. Density: Measured to ensure compliance with standards.
2. Viscosity: Assessed to determine flow characteristics.
3. Flash Point: Evaluated to determine ignition temperature.
4. Acid Value: Measured to assess free fatty acid content.

Comparison with Standards

The results were compared with international biodiesel standards, such as ASTM D6751 or EN 14214, to ensure the produced biodiesel meets the required specifications.

Significance.

The physicochemical properties of the biodiesel are crucial in determining its performance, stability, and environmental impact as a fuel

Table 3.2: Physicochemical Properties of Produced Biodiesel Compared to Standards

Property	Produced Biodiesel		ASTM D6751 Standard		EN 14214 Standard Remarks
Density@15 °C (g/cm³) 0.87	0.86–0.90		0.86–0.90		Within standard range
Kinematic Viscosity @ 40°C (mm²/s)	4.5		1.9–6.0	3.5–5.0	Acceptable range
Flash Point (°C) 160	160		>130	>120	Safe for storage & handling
Acid Value (mg KOH/g)		0.45	<0.50	<0.50	Acceptable
Iodine Value (g I_2/100 g)	45	-	<120		Acceptable
Cetane Number	52		>47	>51	Meets ignition quality standard

Pour Point (°C)	-1	-15 to 10		-	Acceptable in tropical climates
Cloud Point (°C)	3	-3 to 12	-	-	Acceptable

Analysis of Table 3.2: Physicochemical Properties of Produced Biodiesel

The table presents the physicochemical properties of the produced biodiesel, compared to ASTM D6751 and EN 14214 standards. Key observations:

Compliance with Standards

1. Density: Within standard range (0.86-0.90 g/cm³).
2. Kinematic Viscosity: Acceptable range (1.9-6.0 mm²/s for ASTM, 3.5-5.0 mm²/s for EN).
3. Flash Point: Meets standard requirements (>130°C for ASTM, >120°C for EN)

Other Properties:

1. Cetane Number: Meets ignition quality standard (>47 for ASTM, >51 for EN).
2. Pour Point and Cloud Point: Acceptable in tropical climates.

Implications:

The produced biodiesel meets the required standards for physicochemical properties, indicating its potential as a viable alternative fuel. These results support the sustainable production and characterization of biodiesel from kitchen waste.

Effect of Catalyst and Methanol Ratio on Biodiesel Production from Kitchen Waste

The production of biodiesel from kitchen waste oil involves a transesterification reaction, which requires a catalyst and methanol. The ratio of methanol to oil and the concentration of the catalyst significantly impact the yield and quality of biodiesel.

Methanol to Oil Ratio

1. The stoichiometric requirement for transesterification is a 3:1 molar ratio of methanol to oil. However, a higher ratio of 6:1 or more is commonly used to drive the reaction to completion.
2. In this study, a methanol volume corresponding to a molar ratio of approximately 6.5:1 was used, which is above the stoichiometric requirement, enhancing conversion efficiency.
3. Excess methanol ensures the reaction proceeds towards the forward direction but increases the need for recovery during purification.

Catalyst Concentration (NaOH) in Biodiesel Production from Waste Palm Oil

The concentration of the alkaline catalyst, sodium hydroxide (NaOH), plays a crucial role in the transesterification reaction of waste palm oil to biodiesel. Here's a summary of the findings:

1. Optimum Catalyst Concentration- The ideal range for NaOH concentration is typically between 0.5% and 1.5% (w/v) of oil.
2. In this experiment, a higher concentration of 2% (w/v) NaOH was used.
3. Effects of Higher Catalyst Concentration- The higher catalyst concentration enhanced the reaction rate, leading to a relatively high biodiesel yield of 85%.
4. However, the higher concentration also led to minor soap formation due to the reaction between NaOH and free fatty acids (FFAs) present in the waste palm oil.
5. Implications for Waste Oil with Moderate FFA Content- The experiment suggests that the waste palm oil used had a moderate free fatty acid content, which affected the reaction but still resulted in a high yield.

Table 3.3: Effect of Methanol and Catalyst on Biodiesel Yield

Condition	Observed Effect
Methanol: Oil ratio (6.5:1)	High conversion, but excess methanol recovery required
Catalyst (0.04% NaOH)	Faster reaction, slight soap formation

Analysis of Table Results Methanol to Oil Ratio (6.5:1)- High conversion efficiency:

The chosen ratio of 6.5:1 methanol to oil resulted in a high biodiesel yield, indicating effective transesterification.

1. Excess methanol recovery required: The excess methanol used in the reaction needs to be recovered, which may add to the production costs and energy requirements.
2. Catalyst Concentration (0.04% NaOH)- Faster reaction rate: The use of NaOH as a catalyst accelerated the transesterification reaction, contributing to a high yield.
3. Slight soap formation: The presence of free fatty acids in the oil led to minor soap formation, which may affect the overall yield and quality of the biodiesel.

The trade-off between reaction rate and soap formation highlights the need for careful control of catalyst concentration and methanol to oil ratio

Table 3.4. Comparative Analysis With Other Feedstocks

Feedstock Type	Reported Yield (%)	Catalyst & Methanol Conditions	Reference (Literature)
Waste palm oil	85	16 g NaOH, 200 ml methanol, 1 L oil	Present study
Used soybean oil	80–90	1% NaOH, 6:1 methanol:oil ratio	Literature reports
Sunflower oil	82–87	1% KOH, 6:1 methanol:oil ratio	Literature reports
Jatropha oil (non-edible)	75–85	1.25% NaOH, 7:1 methanol:oil ratio	Literature reports
Rubber seed oil	70–80	Acid esterification + base tra	Literature reports
Animal tallow	65–75	1% NaOH, 7:1 methanol:oil ratio	Literature reports

Comparative Analysis- Waste palm oil shows a competitive yield of 85%, comparable to edible oils like soybean and sunflower oil.

1. Waste palm oil outperforms some non-edible oils, such as jatropha and rubber seed oil, in terms of biodiesel yield.
2. Animal tallow has a relatively lower yield, likely due to its higher saturated fatty acid content.

Implications- Waste palm oil demonstrates potential as a sustainable biodiesel feedstock, offering a competitive yield and reducing waste. The comparison highlights the importance of feedstock selection and optimization of reaction conditions to achieve high biodiesel yields.

Challenges in Sustainable Production of Biodiesel from Kitchen Waste Challenges

Soap Formation:

1. Presence of free fatty acids (FFA) in kitchen waste oil led to soap formation during transesterification.
2. Soap formation hindered the separation of biodiesel and glycerol layers, requiring additional washing steps.

Separation and Purification:

1. The settling process took 12-24 hours, which is time-consuming and may impact production efficiency.
2. Multiple washes with warm water were needed to remove residual methanol and catalyst, adding to the production time and cost.

Odour of Waste Oil:

1. The initial odour of kitchen waste oil carried over into the crude biodiesel, although it reduced after washing and drying.
2. This highlights the need for effective pre-treatment and refining processes to improve biodiesel quality.

Implications for Sustainable Production-

These challenges are consistent with those reported in literature, emphasizing the importance of:

1. Pre-treatment: Effective removal of impurities and FFA to minimize soap formation and improve biodiesel quality.
2. Optimized Process Design: Streamlining the production process to reduce time and costs associated with separation and purification.
3. Addressing these challenges is crucial for the sustainable production of biodiesel from kitchen waste, ensuring a high-quality product with minimal environmental impact.

Environmental and Economic Implications of Biodiesel from Kitchen Waste

Reduction of Environmental Pollution:

1. Converting kitchen waste oils into biodiesel reduces pollution caused by indiscriminate disposal.
2. Biodiesel is biodegradable and produces fewer greenhouse gas emissions compared to petroleum diesel.

Sustainable Urban Waste Management

The process contributes to sustainable urban waste management by utilizing waste oils

Economic Implications

Reduced Feedstock Cost:

1. Utilizing waste oil reduces the feedstock cost, which accounts for 70-80% of biodiesel production expenses.
2. This makes biodiesel production more economically viable

Affordable Alternative: Biodiesel from waste oils could provide an affordable alternative to fossil diesel in developing countries like Nigeria.

Recovery of Glycerol:

Glycerol, a by-product of biodiesel production, has potential economic value in the:

1. Soap industry
2. Cosmetics industry
3. Pharmaceutical industry

Relation to Literature Comparison with Previous Studies

1. The 85% yield obtained in this experiment aligns with previous studies on waste oil biodiesel production using alkaline transesterification, which reported yields between 80-90% (Demirbas, 2009; Atabani et al., 2012).
2. The physicochemical properties of the biodiesel, such as density, viscosity, and cetane number, are within the ranges reported for palm oil biodiesel in previous studies.

Fuel Properties-

1. Density (0.87 g/cm³): Within the standard range for biodiesel.
2. Viscosity (4.5 mm²/s): Suitable for engine performance.
3. Cetane number (52): Indicates good ignition quality.

Flash point (160 °C): Higher than the minimum standard, ensuring safe handling characteristics.

1. Acid value (0.45 mg KOH/g): Confirms adequate neutralization, crucial for engine performance.
2. The production of biodiesel from waste oils can contribute to sustainable energy production and waste management.

Summary of Key Findings.

1. Biodiesel Yield: An 85% yield was achieved using 1 liter of palm oil waste, 200 ml methanol, and 16 g NaOH.
2. Physicochemical Properties: The biodiesel met international standards (ASTM D6751, EN 14214) for density, viscosity, flash point, cetane number, and acid value.
3. Catalyst and Methanol Ratios: The ratios used were effective, but optimization could reduce soap formation.
4. Comparison with Other Feedstocks: Biodiesel from waste palm oil compared favorably with edible oils (soybean, sunflower) and non-edible oils (jatropha, rubber seed).
5. Challenges: Soap formation and purification time were notable challenges.
6. Sustainability: The study demonstrates that waste oils are a viable, low-cost, and environmentally friendly feedstock for biodiesel production

CONCLUSION

This study successfully demonstrates the production of high-quality biodiesel from waste palm oil through alkaline transesterification, achieving an 85% yield and meeting international standards (ASTM D6751, EN 14214). The findings highlight the potential of waste palm oil as a sustainable, low-cost, and environmentally friendly feedstock for biodiesel production. By utilizing waste oils, this research contributes to urban waste management and promotes a circular economy approach. The produced biodiesel offers a promising alternative to fossil diesel, supporting the transition towards renewable energy and reduced greenhouse gas emissions. Overall, this study provides valuable insights into the feasibility and benefits of converting waste palm oil into a valuable energy resource, paving the way for further research and development in sustainable biodiesel production

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