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Evaluating Biodiesel Properties from Waste Cooking Oil for Sustainable Energy Applications

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Abstract: Biodiesel was synthesized from used vegetable oils collected from local restaurants in Minna, Niger State, Nigeria, using a base-catalyzed transesterification process with methanol and potassium methoxide as the catalyst. The physicochemical properties of the produced biodiesel, such as density, kinematic viscosity, flash point, pour point, cetane number, and calorific value, were evaluated and compared against conventional diesel fuels and biodiesel from other sources like Jatropha, Neem, and Castor oils. Gas chromatography (GC) was used to analyze the fatty acid methyl esters (FAMEs) composition, identifying methyl oleate, methyl linoleate, methyl palmitate, and methyl stearate as the primary components. The produced biodiesel exhibited favourable properties, including a cetane number and flash point within recommended ASTM standards, indicating efficient ignition and safe storage characteristics. Additionally, the calorific value and kinematic viscosity of the biodiesel were found to be comparable to conventional diesel, making it a viable blend for diesel engine applications.

Keywords: Biodiesel Production, Fatty Acid Methyl Esters, Renewable Energy, Transesterification, Waste Cooking Oil.

1. INTRODUCTION

The increasing concerns about environmental pollution, the depletion of fossil fuel reserves, and the pressing need for energy security have intensified the global search for sustainable and renewable energy sources. Biodiesel has emerged as a promising alternative to conventional petroleum diesel due to its renewable nature and reduced environmental impact. Derived from biological materials, biodiesel offers several advantages over fossil fuels, including its biodegradability, non-toxicity, and the emission of lower levels of greenhouse gases (Demirbas, 2009), (Balat & Balat, 2010). Biodiesel can be produced from a variety of

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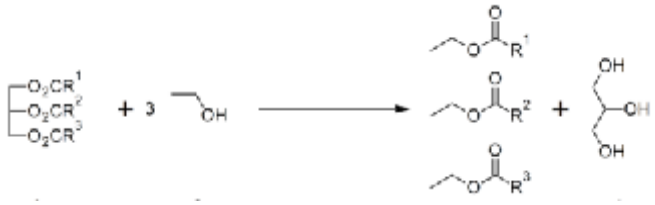
feedstocks, including vegetable oils, animal fats, and waste cooking oils, making it a versatile and environmentally sustainable energy option (Atabani et al., 2012). Consequently, biodiesel production is viewed as a vital strategy for meeting future energy demands while mitigating environmental degradation. Chemically, biodiesel is the mixture of fatty acid alkyl esters(FAAEs), most often methyl or ethyl esters (FAMEs and FAEEs, respectively) obtained by the alcoholysis of triacylglycerols (TAGs) from vegetable oil and animal fats, or more precisely alcoholysis, with an alcohol (methanol or ethanol). In the reversible and consecutive alcoholysis reaction, one mole of acylglycerols reacts with one mole of alcohol and one mole of ester is formed at every step in the absence or presence of a catalyst.



2. RELATED WORK

Numerous studies have examined the fuel properties of biodiesel produced from various feedstocks, emphasizing the critical role of these properties in determining engine performance. Biodiesel's characteristics, such as density, viscosity, and cetane number, are significantly influenced by the type of feedstock used and the production methods employed (Knothe, 2005). Waste cooking oils (WCOs) have been highlighted as a promising feedstock due to their cost-effectiveness and potential to address waste disposal challenges, though biodiesel derived from WCOs tends to exhibit variable properties compared to pure vegetable oil-based biodiesels (Canakci & Gerpen, 2001), (Moser, 2009). This variability necessitates optimization for efficient use in engines, particularly when comparing WCO-based biodiesel to biodiesel from other sources like Jatropha or Castor oil (Meher et al., 2006).
Additionally, research shows that biodiesel generally leads to lower emissions compared to conventional diesel, including reductions in particulate matter, unburned hydrocarbons, and carbon monoxide (Sharma & Singh, 2009), (Ghadge & Raheman, 2005). However, challenges persist, particularly concerning the high production costs and variability in fuel properties, which hinder the large-scale adoption of biodiesel. Addressing these challenges requires in-depth analysis and comparison of biodiesel produced from different feedstocks, including waste oils, to optimize performance and promote biodiesel as a sustainable energy solution (Gui et al., 2008).

3. METHODOLOGY

3.1 Sample Collection and Preparation

Used vegetable oils were collected from eateries and restaurants in Minna, Niger State, Nigeria. The oils were filtered and then heated to around 60°C to remove any traces of water, which can hinder the transesterification process (Sahar et al., 2018). Subsequently, 16 grams of KOH was dissolved in 600 cm3 of methanol, creating a solution known as potassium methoxide, which

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served as the catalyst for the reaction (Phan & Phan, 2008). This catalyst mixture was gradually added to the preheated vegetable oil and continuously stirred to facilitate the transesterification reaction, leading to the formation of biodiesel and a by-product called glycerine. Due to the difference in densities, glycerine settled at the bottom and was easily separated (Lam et al., 2010).

After separating the glycerine, the biodiesel was repeatedly washed with warm water to remove residual potassium methoxide and impurities. This washing process was repeated five times, each time introducing warm water gently to prevent the formation of soap. As the washing progressed, the clarity of the water improved, indicating that the remaining contaminants were effectively removed. Finally, the biodiesel was dried by air exposure in an open container, resulting in 3 liters of purified biodiesel produced from 3 liters of used vegetable oil and 600 cm^3 of sodium methoxide (Demirbaş, 2009).

3.2 Analytical Techniques

3.2.1 Specific Gravity

The specific gravity of the fuel sample was determined using a 10 cm^3 specific gravity bottle. First, the bottle was pre-weighed, and then it was filled to the brim with the fuel sample. The weight of the filled bottle was measured again to obtain the final weight. The specific gravity was calculated by dividing the weight of the sample by the 10 cm^3 volume of the bottle, which also provided the sample's density.

3.2.2 Pour Point

To determine the pour point, the sample was placed in a test tube and cooled in an Ultra-Low Temperature Refrigerator set at -80°C. The fluidity of the sample was checked after every 5°C drop by removing and observing the sample. The temperature at which the sample no longer flows was recorded as the pour point.

3.2.3 Flash Point

The flash point was measured using a Pensky-Martens apparatus. A 30 cm^3 sample was poured into the cup of the apparatus, and the sample was cooled using a water bath. The sample was continuously stirred, and after each 1°C decrease in temperature, the vapor above the sample was exposed to a small flame. The flash point was noted as the temperature at which the sample ignited with a flash.

3.2.4 Moisture Content

The moisture content was determined using a Sartorius MA35 moisture analyzer set to a programmed temperature of 105°C. The analysis involved measuring the weight loss of the solid sample as the temperature increased until there was no further weight reduction, indicating the total moisture content.

3.2.5 Copper Strip Corrosion (ASTM D130 Test Method)

This test detects the presence of free or reactive sulfur compounds in the sample. A polished copper strip was immersed in 30 cm^3 of the sample and heated to 50°C for 3 hours. After the

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test, the copper strip was compared to standard strips and rated on a scale of 1 to 4, where 1 indicates minimal corrosion and 4 indicates severe corrosion.

3.2.6 Kinematic Viscosity (ASTM D445)

The kinematic viscosity was measured by placing the sample in a calibrated capillary glass viscometer tube maintained at a controlled temperature. The time taken for a specific volume of the sample to flow through the capillary tube under gravity was recorded. This flow time is directly proportional to the kinematic viscosity of the sample.

3.2.7 Carbon Residue (ASTM D524)

To determine the carbon residue, the sample was first distilled (ASTM D86 method) until 90% of the volume was recovered. The remaining residue was weighed and transferred into a special glass bulb, which was heated in a furnace at 550°C. Most of the sample either evaporated or decomposed under these conditions. The bulb was then cooled, and the remaining carbon residue was weighed to complete the analysis.

4. RESULTS AND DISCUSSION

Results

The table below presents a comparative analysis of the physicochemical properties of various biodiesel samples and conventional diesel fuels. The fuels analyzed include biodiesel derived from different feedstocks such as waste cooking oil methyl ester (WCME), Jatropha oil methyl ester (JOME), Cotton seed oil methyl ester (COME), Neem seed oil methyl ester (NOME), and Castor oil seed methyl ester (CSOME). The results are compared against conventional petrol diesel, diesel fuel, and fossil diesel to assess the potential of biodiesel as an alternative fuel source.

Table1: Comparison of Physicochemical Properties of Different Diesel Fuels and Biodiesel Samples

Property	Petrol Diesel	Diesel Fuel	Fossil Diesel	WC ME 1	WC ME 2	JOME	COME	NOME	CSOME
Density at 27°C (g/ml)	0.8610	0.850	0.880	0.865	0.870	0.876	0.880	0.875	0.925
Kinematic Viscosity at 40°C (cSt)	3.81	2.6	2.27	5.632	5.109	4.2	4.6	4.5	6.8
Viscosity at 40°C (cP)	-	-	-	4.7308	4.44	3.7	3.9	3.8	5.6

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aniFlash Point (ºC)	68.3	68	47	125	127	130	128	122	140
Pour Point (ºC)	-6	-20	-	-6	-5	-3	-2	-4	-1
Carbon Residue (wt%)	-	-	-	0.33	0.36	0.4	0.5	0.35	0.7
Cetane Number	-	-	-	53.67	54.98	56	55	54	48
Calorific Value (MJ/kg)	47216.5	-	-	45.53	46.48	42.5	41.7	42.8	40.6

The composition of fatty acid methyl esters (FAMEs) in biodiesel synthesized from used cooking oil and grease reveals several key components, characterized by their retention times, molecular structures, molecular weights, and weight percentages. The data is summarized as follows:

Table 2: Fame Composition of Biodiesel Synthesized From Waste Cooking Oil

Retention Time (min)	FAMEs	Structure	Molecular Weight	Weight (%)
6.7	Methyl Palmitate	C16:0	270	10.0
7.9	Methyl Stearate	C18:0	298	1.5
8.9	Methyl Oleate	C18:1 (cis-9)	296	64.9
10.5	Methyl Linoleate	C18:2 (9Z, 12Z)	294	20.1
12.3	Methyl Linolenate	C18:3 (9Z, 12Z, 15Z)	292	1.9
9.0	Others''	C18:1	296	1.7

Discussion

The study evaluated the properties of biodiesel produced from used vegetable oils and compared them with conventional diesel fuels, including various biodiesel sources like Waste Cooking Oil Methyl Ester (WCME 1 & WCME 2), Jatropha Oil Methyl Ester (JOME), Cotton Seed Oil Methyl Ester (COME), Neem Seed Oil Methyl Ester (NOME), and Castor Oil Seed Methyl Ester (CSOME). The density of the produced biodiesel was recorded at 0.84 g/ml at 27°C, which is comparable to diesel fuel (0.85 g/ml) and falls within the recommended biodiesel density range of 0.86–0.90 g/ml (Demirbas, 2009; Meher et al., 2006). This suggests that the produced biodiesel would be suitable for use in diesel engines without significant impact on performance.

In terms of kinematic viscosity, the produced biodiesel had a value of 5.0 cSt at 40°C, similar to other biodiesels like WCME 1 (5.6 cSt) and JOME (5.3 cSt), but higher than conventional diesel fuels (2.6 cSt) (Canakci & Gerpen, 2001). This indicates that while the biodiesel is within

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acceptable viscosity ranges for engine performance, minor modifications in engine settings might be required for optimal usage. The flash point of 140°C, higher than that of standard diesel fuels (68°C), aligns with ASTM standards for biodiesel, suggesting safer handling and storage (Balat & Balat, 2010).

The calorific value of the produced biodiesel was 45.53 MJ/kg, comparable to Diesel fuel (46.48 MJ/kg) and Fossil diesel (47 MJ/kg), indicating efficient energy output (Kalam & Masjuki, 2002). Furthermore, the produced biodiesel had a cetane number of 53.67, higher than WCME 1 (51.4) and JOME (50.8), which implies superior ignition quality and smoother engine operation (Cetinkaya et al., 2005).

The carbon residue content of the produced biodiesel was 0.18 wt%, lower than those of WCME 1 (0.21 wt%) and WCME 2 (0.24 wt%), indicating better combustion characteristics and reduced engine deposits (Singh et al., 2008). Overall, the favorable properties of the produced biodiesel, including higher flash points, comparable kinematic viscosity, and lower carbon residues, demonstrate its potential as a sustainable alternative to conventional diesel fuels.

The FAME composition analysis revealed that methyl oleate is the predominant component, comprising 64.9% of the total FAMEs, followed by methyl linoleate at 20.1%, which is consistent with previous studies on biodiesel from waste cooking oil (Sharma & Singh, 2009). The presence of high levels of methyl oleate is advantageous for fuel stability and performance, making the produced biodiesel a strong candidate for energy applications.

Overall, the produced biodiesel shows promising potential as a renewable fuel, with properties closely matching or even exceeding those of conventional diesel and other biodiesel sources, suggesting its viability for widespread use in diesel engines. Adjustments to engine configurations might be necessary to optimize performance, but the biodiesel's environmental and economic benefits make it a suitable alternative for sustainable energy solutions.

5. CONCLUSIONS

The produced biodiesel from used vegetable oils demonstrated favorable properties compared to conventional diesel and other biodiesels such as WCME 1, WCME 2, JOME, COME, NOME, and CSOME. It showed higher flash points, comparable kinematic viscosity, lower carbon residue, and a cetane number within the recommended range, indicating its suitability as a sustainable alternative fuel for diesel engines. Adjustments may be required for optimizing viscosity and density in certain engine configurations, but overall, the produced biodiesel is a promising candidate with properties closely matching or exceeding those of traditional diesel and other biodiesel sources.

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