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# TRANSFORMING WASTE TO WEALTH: BIODIESEL PRODUCTION FROM WASTE PALM OLEIN USING RICE HUSK ASH ADSORBENT

**Emmanuel C. N.*[1], Onoh M.I.[1]**
**1 Department of Chemical Engineering, Enugu State University of Science and Technology**
**Author for Correspondence**: Emmanuel C. N.; **Email:** emmanuelchukwudi223@gmail.com

**Abstract -** This study explores the regeneration of waste palm olein vegetable oil (WVO) using rice husk ash, an agro-waste material, for biodiesel production. The regeneration process was optimized through batch adsorption experiments, which investigated the effects of temperature, contact time, and adsorbent dosage on oil purification. Results indicated that optimal regeneration occurred at a low dosage, atmospheric temperature, and 20 minutes of contact time, achieving a free fatty acid (FFA) reduction of 28.3%. Kinetic analysis revealed that the regeneration process adheres to a pseudo-second-order kinetic model, suggesting chemisorption as the primary mechanism. Characterization of the waste vegetable oil, regenerated oil, and resulting biodiesel samples was conducted to evaluate their physicochemical properties, such as flash point, specific gravity, and viscosity. Sodium hydroxide (NaOH) and methanol were employed as the catalyst and alcohol, respectively, in the transesterification process. Comparative analysis showed that the properties of biodiesel produced from regenerated WVO met international standards, with only a 2% difference in FFA reduction, validating the effectiveness of the regeneration process. The use of rice husk ash, a low-cost and abundant material, as an adsorbent, underscores the potential of converting agricultural waste into valuable products for renewable energy applications. This study not only demonstrates a sustainable approach to waste management but also contributes to the development of alternative feedstocks for biodiesel production, supporting the transition to greener energy solutions.

**Keywords: Biodiesel Production, Waste Palm Olein, Rice Husk Ash, Regeneration Kinetics, Sustainable Energy.**

## 1 Introduction

The global reliance on petroleum-based energy is becoming increasingly unsustainable as the world confronts the negative environmental and economic impacts associated with fossil fuel consumption. Petroleum-based products are integral to the production of plastics, apparel, fertilizers, and pharmaceuticals, effectively defining the modern "Petroleum Civilization" (Demirbas, 2009). However, the environmental damage from fossil fuels, their finite reserves, and their increasing costs have driven interest in alternative energy sources, particularly for diesel engines. The combustion of fossil fuels releases significant amounts of greenhouse gases, which contribute to global warming and climate change (Leung *et al.*, 2010). This growing awareness of environmental degradation, coupled with the urgent need for energy security, has fueled research into renewable, sustainable alternatives to petroleum-based fuels.

Simultaneously, the issue of food waste has emerged as a critical concern. A substantial portion of this waste comes from the disposal of edible vegetable oils used for frying foods, which is often discharged directly into the environment, causing harm to ecosystems (Murugesan *et al.*, 2009). Approximately 60 million tons of edible vegetable oil are discarded annually, with minimal recycling or repurposing efforts currently in place (Idris, 2018). One promising use for waste vegetable oil (WVO) is in the production of biodiesel, a renewable and biodegradable fuel that can replace conventional diesel in compression ignition engines (Gui *et al.*, 2008).

Biodiesel is defined as a monoalkyl ester derived from long-chain fatty acids, which are obtained from renewable sources like vegetable oils or animal fats through a transesterification process (Gui *et al*., 2008). Biodiesel has been recognized for its lower emissions profile compared to petroleum diesel, reducing pollutants such as carbon monoxide, sulfur oxides, and particulates (Demirbas, 2009). However, the quality of waste vegetable oil is often compromised due to repeated use, leading to increased acid numbers and the formation of free fatty acids (FFAs) caused by hydrolysis during frying (Murugesan *et al*., 2009). High levels of FFAs are detrimental to the biodiesel production process, as they can lead to soap formation and reduce biodiesel yield. Thus, treating or regenerating WVO to reduce its FFA content is essential for efficient biodiesel production.

Rice husk ash (RHA), a byproduct of rice milling, has emerged as a sustainable adsorbent for regenerating waste vegetable oil. Rich in silica and possessing a large surface area, RHA offers excellent adsorption properties that can effectively reduce impurities and FFAs in WVO (Ghorbani *et al*., 2017). Utilizing rice husk ash not only provides an eco-friendly solution for waste management but also leverages an abundant, low-cost agricultural byproduct for biodiesel production. This dual-purpose approach addresses both waste reduction and renewable energy needs, aligning with the principles of a circular economy and sustainable development (Dutta *et al*., 2020).

The regeneration process, using RHA, typically involves batch adsorption experiments that explore the impact of variables such as temperature, contact time, and adsorbent dosage on the oil's FFA reduction (Idris, 2018). Recent studies have demonstrated that RHA is highly effective in regenerating waste oils, achieving significant FFA reductions under optimal conditions (Ghorbani *et al*., 2017). This process is governed by adsorption kinetics, which describe the rate at which the adsorbent removes FFAs from the oil. The pseudo-second-order kinetic model is particularly suited to describe the adsorption behaviour observed in regenerating waste palm olein, suggesting that chemisorption, involving valence forces through sharing or exchange of electrons, plays a significant role in the process (Ho and McKay, 1999).

This research aims to explore the regeneration of waste palm olein vegetable oil using rice husk ash as an adsorbent for biodiesel production. By investigating the optimal conditions for maximizing FFA reduction and assessing the quality of the regenerated oil, this study contributes to the development of sustainable, cost-effective methods for producing biodiesel from waste oils. Moreover, it highlights the potential of rice husk ash as an innovative and environmentally friendly material for supporting the transition from a "Petroleum Civilization" to a more sustainable, bio-based economy (Demirbas, 2009; Dutta *et al*., 2020).

## 2. Materials and Method

### 2.1 Materials

Materials used for this study included waste palm olein vegetable oil which was obtained from a road side trader selling fried beans cake and potatoes at Emene, Enugu. The rice husk sample was obtained from a local farm in Abakaliki, while sodium hydroxide, methanol, distilled water were purchased from Centrifuge Laboratory, Enugu. Other equipment used for the study were electric weighing balance (YP502N No: SHP1100313200), laboratory drying oven (DHG-9101-ISA), Specific gravity meter (DA- 130N; Kyoto Electronics) stopwatch, water bath (DK600 Gallenkomp England) measuring cylinders, beakers, electric heater (EW– 04805 series), magnetic stirrer (Benchmark H4000-S), reflux condenser (Allihn 1168G84), conical flasks, Fourier transform Infrared Spectrometer (lambdasys FTIR-7600).

### 2.2 Method

#### 2.2.1 Production and Characterization of rice husk ash

Rice husk was obtained from a local farm in Abakaliki, Ebonyi State, Nigeria. It was sun-dried for 3 days, sieved to remove debris and burned in a muffle furnace at 600 $^{o}$C for 4 h. Subsequently the ash was allowed to cool in a desiccator. Rice husk ash (RHA) was characterized for particle size which was determined via sieve analysis using a sieve shaker and standard sieves with various mesh sizes of 75 µm, 250 µm and 500 µm. The specific surface area was measured using the Brunauer-Emmett-Teller (BET) method. Its bulk density was calculated by weighing known volumes of RHA, typically using a pycnometer, and the color was evaluated visually. Fourier transform Infrared Spectrometer was also used to determine the functional groups present in the RHA.

### 2.2.2 Regeneration and Characterization of the oil and waste vegetable oil

Filtered waste palm olein vegetable oil was used. The particles and other contaminants were eliminated during the filtration process. The regeneration of waste vegetable oil was achieved through a batch adsorption method using rice husk ash. The study investigated the effects of contact time, temperature, and ash dosage on the free fatty acid (FFA) content of the used oil. Typically, 1 gram of ash was weighed into a 100 ml beaker, and 10 ml of oil was added. The mixture was stirred on a temperature-controlled hot plate, filtered, and the FFA of the filtrate was measured as the experimental response. Equations 1, 2 and 3 were used to calculate the FFA, acid value reduction and reduction per weight of ash of virgin, waste, and regenerated vegetable oils (Goncalves, and Meirelles, 2004).

$$FFA\left(mg\frac{KOH}{g}\right) = \frac{N\times V\times 56.1}{m} \qquad (1)$$

Where: N= Normality of the KOH titrant, V = Titer value of the KOH against the oil
M = weight of the oil, 56.1= the equivalent weight of the KOH, m = oil mass (g).

$$\%\mathrm{R}_{\mathrm{AV}} = \frac{\mathrm{Initial}_{\mathrm{AV}} - \mathrm{Final}_{\mathrm{AV}}}{\mathrm{Initial}_{\mathrm{AV}}} \times 100 \qquad (2)$$

Where: % $R_{AV}$ = acid value reduction; Initial $_{AV}$ = acid value of untreated sample (blank) (mg KOH $g^{-1}$); Final $_{AV}$ = sample acid value after treatment (mg KOH $g^{-1}$).

$$\text{Reduction per weight of ash} = \frac{\%\,R_{av}}{M_{ash}} \qquad (3)$$

Where: %$R_{AV}$ = acid value reduction; $M_{ash}$ = weight of ash

### 2.2.3 Characterization of virgin oil, waste vegetable oil, regenerated oil and produced biodiesels.

The physicochemical parameters of both unregenerated and regenerated palm olein oils were assessed using official methods and practices suggested by the Association of Official Analytical Collaboration International (AOAC). These physicochemical parameters were determined according to the procedures given in the A.O.A.C. 21st edition (2011). They consist of iodine value, its acidic content, peroxide values, saponification number, kinematic viscosity, index of refraction specific gravity, and density. Fourier transform Infrared Spectrometer was the tool utilized to identify the functional groups in these oils.

### 2.3 Kinetics of free fatty acid removal

Adsorption kinetics means the rate at which a substance called adsorbate (free fatty acid) remains trapped or released from a water-based solution to the adsorbent. Adsorption uses linear or non-linear kinetic analysis to determine the goodness of fit of the adsorption process (Musah *et al*., 2018).The subsequent models can be used for calculating the kinetics of the adsorption on the outer layers of rice husk ash:

i. **Pseudo first order (Largergren model)**

The pseudo-first-order model represents kinetics, with the rate of adsorption equivalent to the number of available adsorption sites. This model was evaluated using equations 4 (Edet and Ifelebuegu, 2020; Santuraki and Muazu, 2015):

$$\frac{dq_t}{d_t} = k_t(q_e - q_t) \qquad (4)$$

After integration with boundary conditions $t$ = 0 to $t = t$ and $q_t$= 0 to $q_t = q_e$, equation (4) becomes:

$$\log(q_e - q_t) = \log(q_e) - \frac{k_1}{2.303}\,t \qquad (5)$$

where:
$q_e$= adsorption capacity in equilibrium (mg/g)
$q_t$= adsorption capacity with time (mg/g)
$k_1$ = rate constant for pseudo-first-order adsorption ($min^{-1}$).

When values of log $(q_e - q_t)$were correlated linearly with t. The plot of log $(q_e - q_t)$ vs t produces a linear connection, which may be established using the plot's slope and intercept.

ii. **Pseudo second order**

The adsorption kinetics rate equation for pseudo second order model stated in equation (6) and the integrated version of the rate law that specifies a pseudo second order reaction in a linear form, which was reconstructed and stated in equation 7 (Ebelegi *et al.*, 2020; Ademoluyi and Nze, 2016).

$$\frac{dq_t}{d_t} = k_2 \, (q_e - q_t)^2 \qquad (6)$$

where: $K_2$ is the rate constant of the pseudo second order adsorption ($g.mg^{-1}.min^{-1}$). The integral form of the mathematical formula for the boundary conditions $t$ = 0 to $t$ = $t$ and $q_t$ = 0 to $q_t$ =$q_e$, becomes:

$$\frac{1}{(q_e - q_t)} = \frac{1}{q_e} + kt \qquad (7)$$

Regrouping equation (7) gives equation (8)

$$\left[\frac{t}{q_t}\right] = \frac{1}{k_2 q_e^2} + \frac{1}{q_e}\,(t) \qquad (8)$$

The plot of $\left[\frac{t}{q_t}\right]$ and $t$ in equation (8) will produce a linear connection whose slope and intercept may be used for determining the values of $q_e$ and $k_2$ respectively (Edet and Ifelebuegu, 2020).

### 2.4 Production of biodiesel using the un-regenerated and regenerated vegetable oil

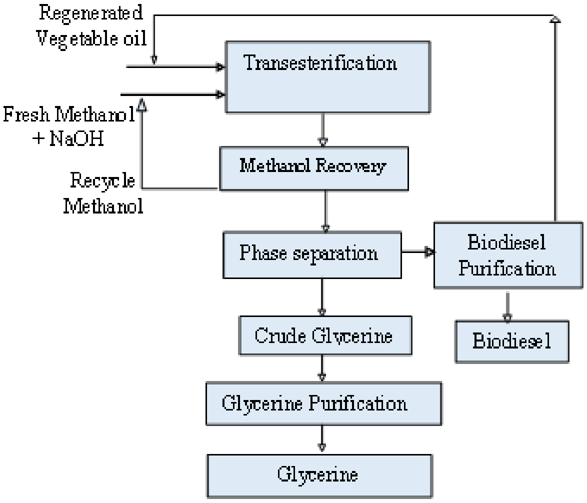

**Figure 1. Base catalyzed transesterification**

Biodiesel was produced from both unregenerated and regenerated vegetable oil. The production was carried out using sodium methoxide as the catalyst and methanol as the solvent. In a 250 ml-flask, 40ml of methanol was combined with 0.5g of sodium hydroxide, which was then agitated by hand. The mixture was shaken manually for about 20 minutes to achieve a complete dissolution of the sodium hydroxide. At the same time, 100 ml of used vegetable oil was put into a beaker and dried in an oven at 100°C for about an hour. Then, the oil was moved to a two-neck flask. Next, the mixture of methanol and sodium hydroxide was added to the oil, and the flask was set up on a magnetic stirrer with a cooling condenser attached. After stirring continuously at 55°C for an hour, the mixture was poured into a separating funnel and left to sit overnight to separate. The bottom layer was discarded, while the upper layer was collected as the crude biodiesel. The biodiesel was washed with 17 ml of distilled water.

## 3.0 Result and Discussion

### 3.1 Characterization of the Rice Husk Ash

The physico-chemical qualities of rice husk ash, also known as RHA, were determined in order to better understand its structure, content, and efficiency as a potential adsorbent for FFA removal. These properties of RHA, shown in Figure 2, were analyzed and compared to those regarding activated carbon. Figure 2 showed that RHA has a pH of 12 indicating its alkalinity which is useful in reducing the FFA in the waste palm olein vegetable oil.

RHA content and activated carbon showed various properties that influenced their applicability. RHA's bigger sized particles and alkaline pH demonstrated its applicability to certain environmental applications (Moghadam and Fadaei, 2021), notably those where alkalinity is favorable. Activated carbon, on the other hand, is commonly utilized for water and air purification due to its greater adsorption properties. It has lesser particle size, higher density, and a neutral pH. Each material has distinct characteristics, making it useful in various distinct characteristics, making it useful in various situations of environmental cleanup along with purification (Asuquo *et al.*, 2017).

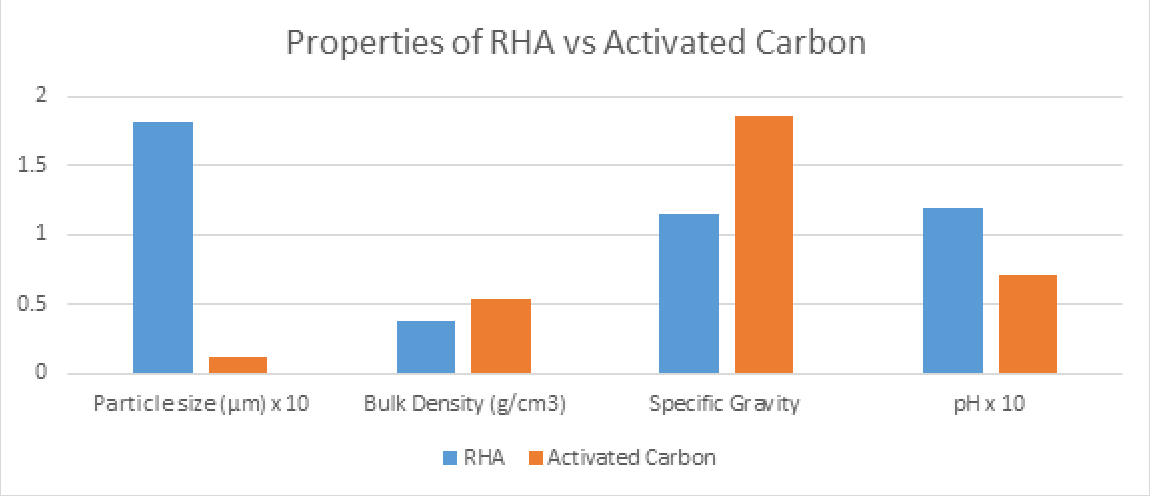

**Figure 2. Physico-chemical properties of RHA vs Activated Carbon**

### 3.2 Characterization of oil and biodiesel

**Table 1. Physiochemical properties of oil and biodiesel**

| Sample | Flash point (°C) | Specific Gravity (@25 °C) | Density (kg/m$^3$) | Kinematic Viscosity (40 °C) (mm$^2$/s) | Acid Value (mg KOH/g) | Saponification Value (mgKOH/g) | Peroxide Value (MeqO$_2$/kg) | Iodine Value (gI$_2$/100g) | Refractive Index ($n_D$ 25 °C) |
|---|---|---|---|---|---|---|---|---|---|
| Virgin Palm Olein VO | 220 | 0.9172 | 917.20 | 34.75 | 1.62 ± 0.00 | 198 ± 1.50 | 4.36 ±0.56 | 59 ±0.40 | 1.4581±0.00 |
| WVO | 162.5 | 0.9237 | 923.70 | 43.90 | 2.92 ± 0.11 | 232 ± 12.30 | 0.86 ±0.15 | 53 ± 0.50 | 1.472±0.00 |
| RegeneratedWVO | 163.5 | 0.9214 | 921.40 | 33.14 | 1.97 ± 0.06 | 195 ± 1.60 | 4.12±0.28 | 76.5±0.11 | 1.462 ±0.00 |
| Un-Regenerated Biodiesel | 151.5 | 0.9145 | 914.50 | 7.53 | 1.56 ± 0.00 | 164 ± 0.00 | 5.84 ±0.35 | 62.1±0.54 | 1.4588±0.00 |
| Regenerated Biodiesel | 152.5 | 0.9147 | 914.70 | 6.38 | 0.27 ± 0.00 | 142 ± 2.45 | 8.14 ±0.00 | 60.8±0.35 | 1.466±0.00 |
| ASTM D6751 | 93 (min) | 0.88 | 880 | 1.9 – 6 | 0.25 ± 0.00 (max) | 500 ± 0.00 (max) | 10 ± 0.00 (max) | 120±0.00 (max) | -- |

The qualities of the regenerated biodiesel shown on Table 1. was studied and compared with that of the standard biodiesel. Kinematic viscosity influences fuel atomization. Similarly, lower viscosity in regenerated biodiesel enhances combustion efficiency (Belewu *et al.*, 2010). Furthermore, lowered acid levels in regenerated biodiesel increase quality while lowering corrosion risk (Robertson, 2005). The lower its saponification and iodine values imply improved stability and resistance to oxidation, making regenerated biodiesel appropriate for diesel-powered vehicles (Shahidi, 2005; Masudi *et al.*, 2022).

### 3.2.1 Fourier Transform Infrared (FTIR) spectrometer

FTIR spectroscopy identifies functional groups in unknown substances by analyzing absorption of infrared energy. The mid-IR region (4000-400 cm$^{-1}$) is most effective for determining organic functional groups (Asuquo *et al*., 2017).

**Table 2. FTIR functional groups of R1, R2, R3 and R4**

| Functional group | R1 cm$^{-1}$ | R2 cm$^{-1}$ | R3 cm$^{-1}$ | R4 cm$^{-1}$ |
|---|---|---|---|---|
| C-$CH_3$ | 2762.19, 2932.64 | 2705.31, 2853.48 | 3000–3500 | 3044.44, 3255.18 |
| C-O | 1170-1200, 1166 | 1247.271, 1392.24 | 1284.48, 1070.68, 1000−1300 | 1184.93, 1012.55, 1278.77, 1366.23, 1473.90 |
| C=O | 1750 | | 1913.38 | 1991.73 |
| C=C | 1925.18 | 1901.21 | 1620.22 | 1610.205, 1737.63, |
| C≡N | | 2206.98 | 2023.63, 2128.56 | 2137.40, 2270.74, 2347.55 |
| -OH | 3000−3400 | 3000−3400 | 3186.57, 3298.92 | 3000−3400 |
| H-H | 2500−3000 | 2500−3000 | 2636.99, 2789.89, 2980.64 | 2616.95, 2700.96, 2886.15 |
| $NH_2$ | 3425.25 | | | |
| C-$CH_2$ | 813.788 | 874.06 | 837.88 | 899.60 |
| –C=H-(cis) | | 760.61 | 713.28 | 788.64 |
| O-H | 3597.17, 3801.98, 3901.15 | 3588.91, 3693.89, 3817.72 | 3673.97, 3777.75 | 3609.02, 3753.49, 3810.92 |

where: R1: Biodiesel from regenerated WVO, R2: Biodiesel from unregenerated WVO, R3: Regenerated WVO, R4: Unregenerated WVO

**The FTIR spectrum for R1, R2,R3 and R4 are as follows:**

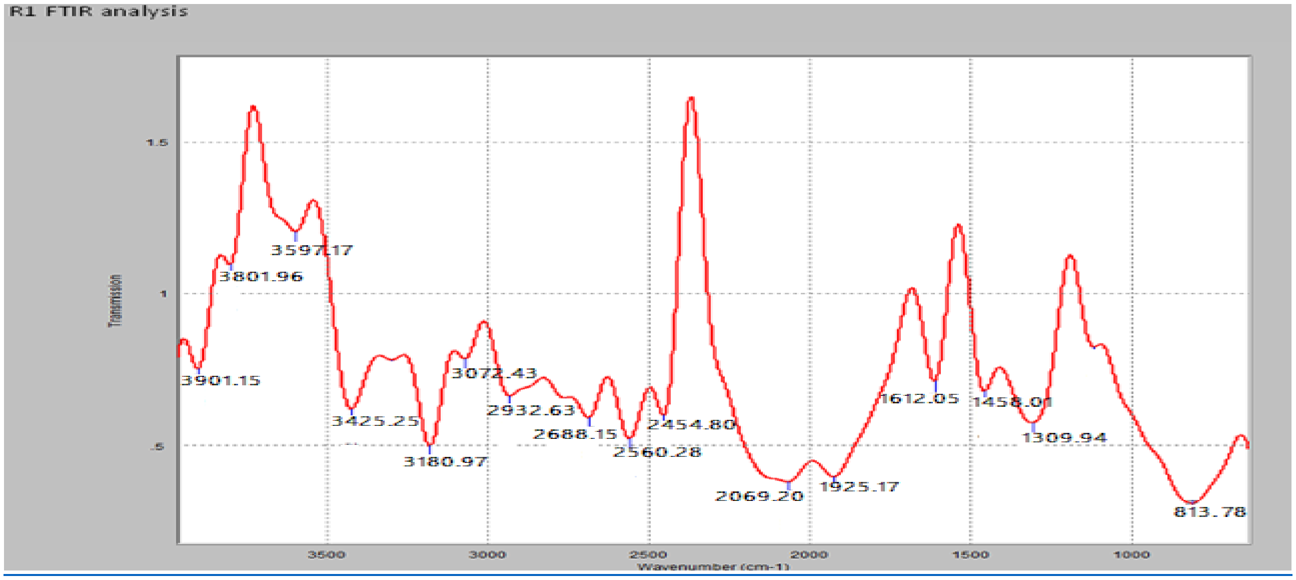

Figure 3. FTIR of Regenerated Biodiesel (R1)

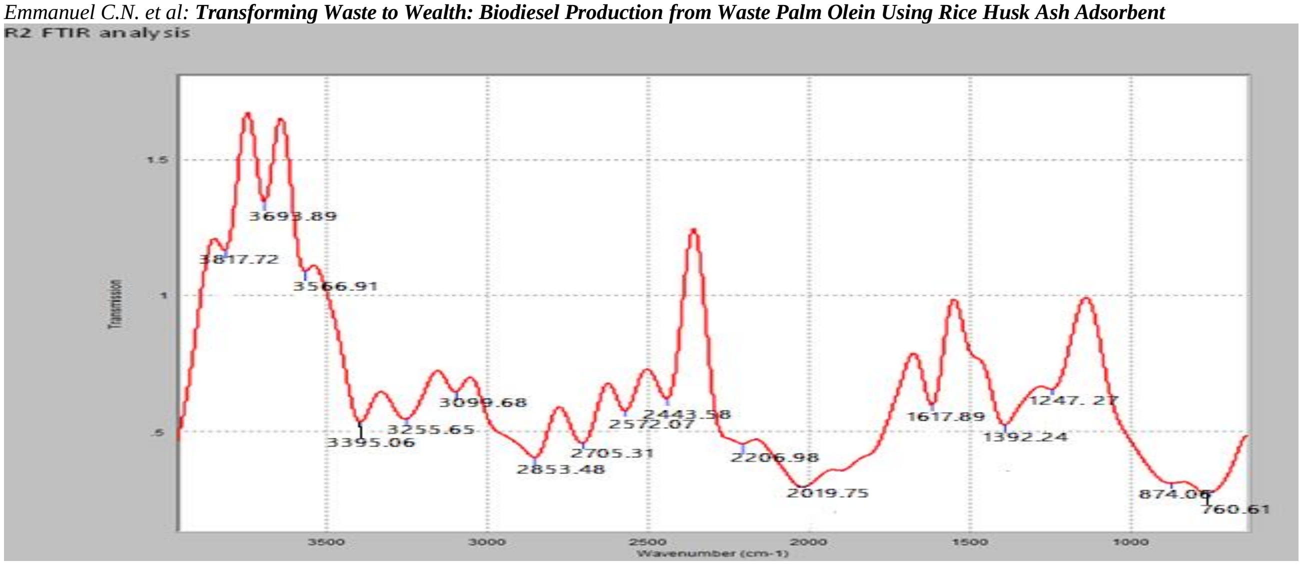

Figure 4. FTIR of Un-regenerated Biodiesel (R2)

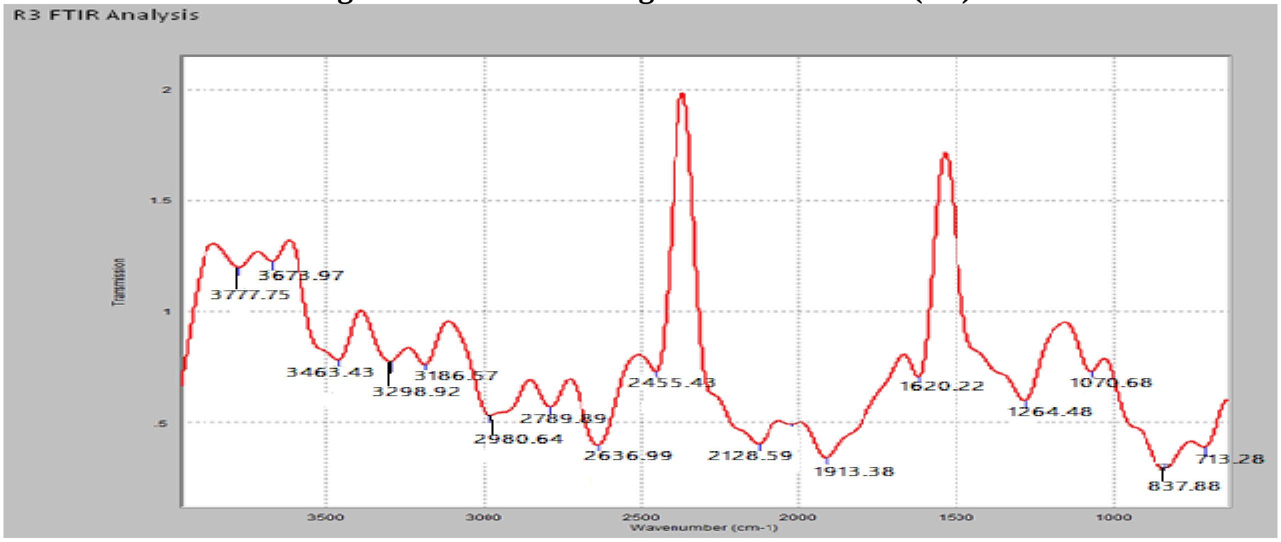

Figure 5. FTIR of Regenerated waste vegetable oil (R3)

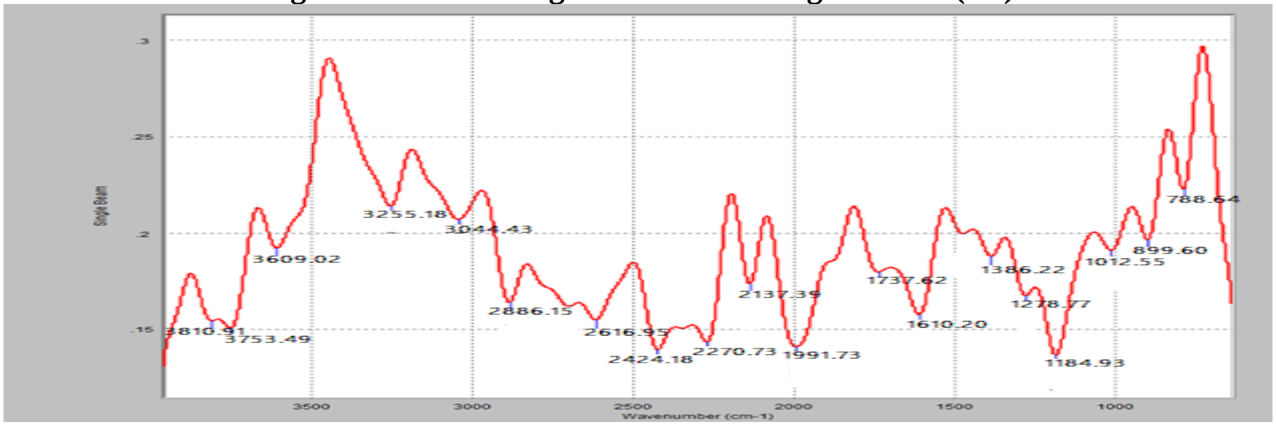

Figure 6. FTIR of Un-regenerated waste vegetable oil (R4)

## 3.3 Regeneration Studies

### 3.3.1 Effect of dosage on the FFA removal

The impact of the adsorbent dose on the acid value reduction show that lower doses are more effective. Acid value rapidly decreases through 0.0g to 0.1g, whereas greater dosages yield diminishing returns. Amorim *et al*. (2006) discovered that lower dosages improve contact with free fatty acids (FFA), optimising adsorbent utilisation and corroborated

Barauna's (2006) observations on dosage impact.

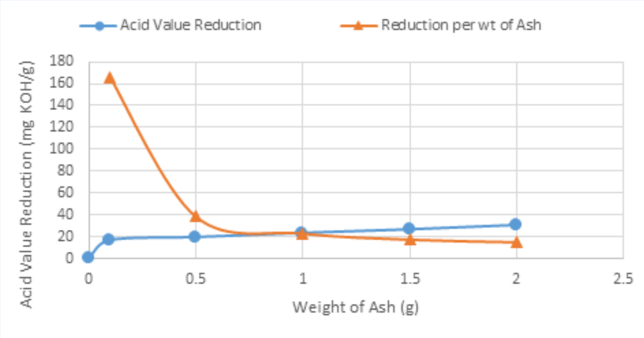

**Figure 7. The effect of ash dosage on the acid value reduction of the WVO**

### 3.3.2 Effect of time and temperature on the FFA removal

The effects of time and temperature on free fatty acid (FFA) levels reveal that acid value reduction varies significantly. At 70 °C, the reduction is minimal at 5 minutes but increases steadily until 30 minutes. Conversely, at 30 °C, the highest reduction occurs. Studies indicate that increasing temperature from 40 °C to 60 °C decreases FFA content, but excessive heating can reduce yields (Lara *et al.*, 2022; Suzihaque *et al.*, 2022). Thus, optimal conditions are 20 minutes at 30 °C for effective reduction.

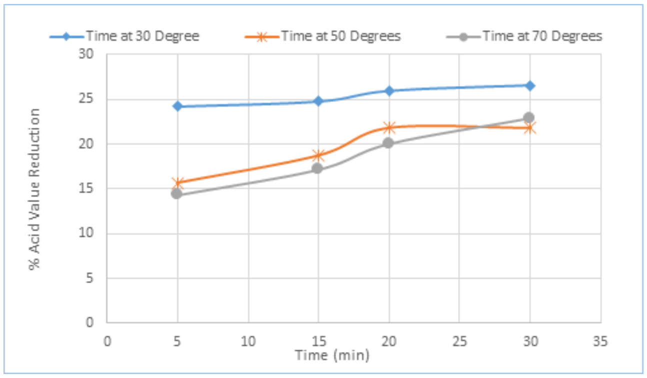

**Figure 8. The effect of time and temperature on the acid value reduction of the WVO**

## 3.4 Adsorption Kinetics

### 3.4.1 Pseudo first order kinetic model

The kinetics associated with waste palm Olein vegetable oil regeneration using rice husk ash (RHA) at 30 °C were studied using the pseudo-first-order kinetic model. Table 3.4 displays the following data:

**Table 3. Pseudo first order kinetic model**

| Kinetic parameters | 30 °C | 70 °C |
|---|---|---|
| $q_e$ Calculated | 2.9026856 | 16.188254 |
| $q_e$ actual | 26.54363 | 22.85714 |
| % difference | 89.064474 | 29.176382 |
| $k_1$ | 0.06149 | 0.0893564 |
| $R^2$ | 0.4447 | 0.954 |

The calculated equilibrium adsorption capacity ($q_e$) was 2.90268 mg/g, while the actual $q_e$ was 26.544 mg/g, resulting in a percentage difference of 0.06149 %. The low $R^2$ value of 0.4447 suggests that the pseudo-first-order model may not adequately describe the adsorption process. Hence it is not the best fit for the adsorption of waste palm olein vegetable oil using RHA at 30 °C.

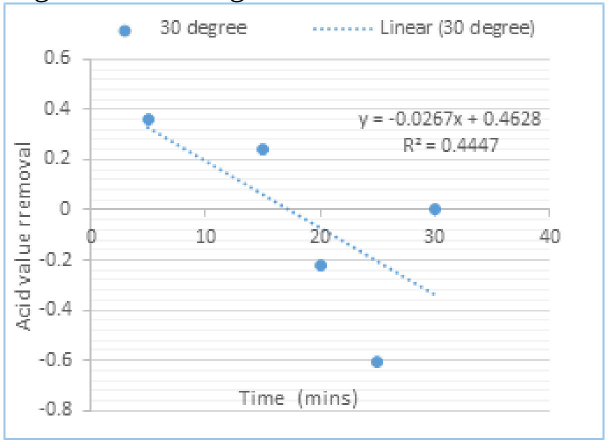

**Figure 9. Pseudo first order model at 30°C**

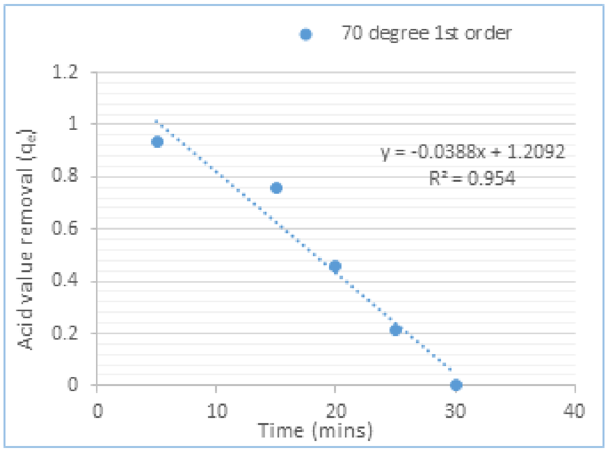

**Figure 10. Pseudo first order model at 70 °C**

### 3.4.2 Pseudo second order kinetic model

The adsorption kinetics of waste palm Olein vegetable oil regeneration using rice husk ash (RHA) for acid value reduction was analyzed through the pseudo-second order kinetic model at two temperatures: 30°C and 70°C.

**Table 4. Pseudo second order kinetic model**

| Kinetic parameters | 30 °C | 70 °C |
|---|---|---|
| $q_e$ Calculated | 27.173913 | 26.246719 |

| | | |
|---|---|---|
| $q_e$ actual | 26.54363 | 22.857143 |
| % difference | 2.3194416 | 12.914286 |
| $k_2$ | 0.0395977 | 0.0066344 |
| $R^2$ | 0.9989 | 0.9755 |

At 30 °C, the calculated acid value reduction ($q_e$) was 27.17 mg KOH/g, with an actual reduction of 26.54 mg KOH/g, showing a 2.32 % difference and a rate constant ($k_2$) of 0.0396, yielding an $R^2$ of 0.9989. At 70 °C, the calculated $q_e$ was 26.25 mg KOH/g, while the actual was 22.86 mg KOH/g, resulting in a 12.91 % difference, $k_2$ of 0.0663, and $R^2$ of 0.9755. The high $R^2$ indicates a strong correlation between the model and experimental results.

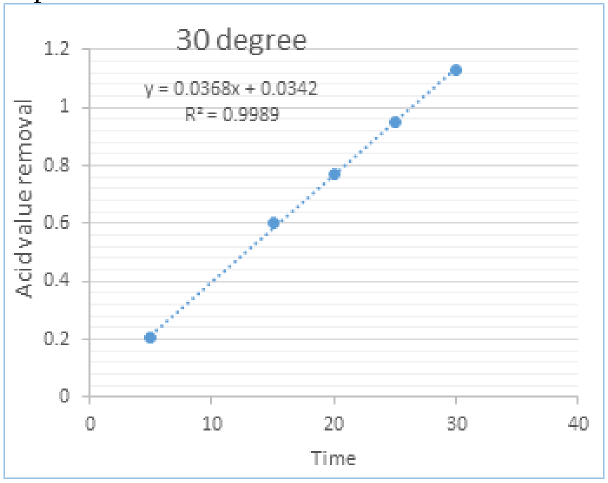

**Figure 11. Pseudo second order model at 30°C**

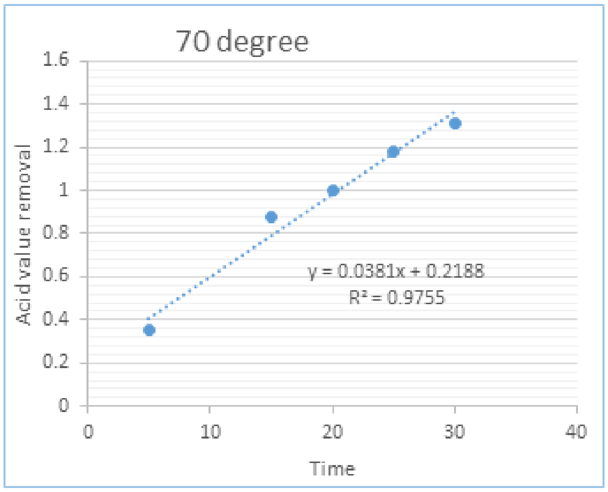

**Figure 12. Pseudo second order model at 70°C**

These results indicate that the pseudo-second order model effectively describes the adsorption process under varying temperatures. This model assumes that the rate of adsorption is proportional to the square of the number of unoccupied sites, which aligns well with the observed data, suggesting a chemisorption mechanism (Ho, 2006).

## 4.0 Market Analysis

The study on biodiesel production from waste palm olein using rice husk ash highlights key implications. Market demand for biodiesel could surge, especially in niche sectors, potentially reaching 100 million gallons annually, affecting agricultural prices. Sustainability policies will encourage the use of waste materials, prompting incentives for eco-friendly practices. Additionally, economic viability through lower production costs may boost market acceptance. Finally, global trade dynamics can shift as developed nations' biofuel policies impact competition for developing countries (Cremonez *et al*., 2023; Yang *et al*., 2023; Rachapudi *et al*., 2023).

To enhance biodiesel's competitiveness against petroleum diesel, several strategies can be implemented. Cost reduction can be achieved through advanced technologies and waste feedstocks, lowering production costs. Government incentives like tax credits can help offset initial expenses. Additionally, infrastructure development is crucial for distribution and blending facilities. Regulatory support can promote biodiesel use in fleets by mandating blends. Lastly, market education about biodiesel's environmental benefits can boost consumer demand (Cremonez *et al*., 2023; Bravo-Fritz *et al*., 2023; Rachapudi *et al*., 2023).

## 5.0 Environment Impact Assessment for Biodiesel production

The research project "Transforming Waste to Wealth: Biodiesel production from waste palm olein using rice husk ash as adsorbent" in Emene, Enugu State, focuses on sustainable biodiesel production. It capitalizes on local palm oil processing and utilizes waste sources for biodiesel production (Embong *et al*., 2021). The Environmental Management Plan (EMP) monitors air and water quality, soil health, and biodiversity, ensuring compliance with environmental standards (Advisera, 2023). Community engagement is emphasized to promote transparency (WRI, 2023).

Quality assurance protocols maintain data integrity, while the International Organization for Standardization (ISO) 14001 framework guides environmental compliance (Rahman *et al*., 2023). The project assesses air quality and evaluates noise levels to minimize disturbances. It also examines water and soil for contaminants, ensuring environmental safety (WRI, 2023).

Socially, the project offers job opportunities and economic benefits but may risk exacerbating inequalities if benefits are unevenly distributed (Cremonez *et al*., 2022). Health impacts from potential pollution must be considered to avoid respiratory issues (MDPI, 2023).

Compliance with local and national regulations is essential for sustainability (Oklahoma State University, 2023; U.S. EPA, 2023). Overall, while the project aims to transform waste into wealth, careful management of social equity and health implications is crucial for sustainable outcomes (Stachetti *et al*., 2009; Buyx, 2023).

## 6. Conclusion

The research on regenerating waste palm olein vegetable oil using rice husk ash (RHA) as an adsorbent highlights important advancements in renewable energy and waste management. The study identified optimal regeneration conditions of 19.4 minutes, 1.97 grams of RHA, and a temperature of 30.1°C, demonstrating the efficiency of RHA in removing free fatty acids through a pseudo second-order kinetic model. The biodiesel produced from this process met ASTM standards, confirming its suitability for commercial applications.

These findings are significant as they address two critical issues: the management of agricultural waste and the production of sustainable energy. By utilizing RHA, an abundant by-product of rice milling, the research promotes a circular economy where waste materials are transformed into valuable resources. This not only reduces environmental pollution but also contributes to the development of renewable energy sources that can mitigate reliance on fossil fuels. Ultimately, this innovative approach underscores the potential for integrating waste management strategies with renewable energy production, paving the way for more sustainable practices in both sectors and enhancing overall environmental sustainability.

### 6.1 Contributions

The study innovatively repurposing two waste materials-waste palm Olein and rice husk ash-to create biodiesel which addresses the challenges of waste management and resource scarcity and enhances the sustainability of biodiesel production by using an environmentally friendly adsorbent.

The study also provides insights into the efficiency, cost-effectiveness, and feasibility of utilizing agricultural waste in energy production, promoting a circular economy and reduced environmental footprint.

### 6.2 Recommendations

The use of enzymes and microorganisms capable of metabolizing waste vegetable oil is an alternative for more research to make treatment and recycling easier and cleaner.

This research is focused on the regeneration of waste vegetable oil using rice husk ash for biodiesel production hence, more research should proceed in using regenerated waste vegetable oil to chemically produce biodegradable polyurethane sheets, greases, bio lubricants, soaps and alkyd resins etc.

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