6TH International Conference and Workshop on Engineering and Technology Research (ICWETR) LAUFET 2025: 40-49

Production of Biodiesel Fuel From Waste Cooking Oil

[1*]Ugochukwu R. C., [2]Ogwueleka T. C. and [3]Balogun S.

[1,2,3]Department of Civil Engineering, Faculty of Engineering, University of Abuja, Nigeria.

[1]romanus.ugochukwu@uniabuja.edu.ng, [2]toochukwu.ogwueleka@uniabuja.edu.ng
[3]samson.balogun@uniabuja.edu.ng

https://www.laujet.com/

Keywords:

Waste cooking oil, Pilot plant, Trans-esterification, Biodiesel, Characterization

Corresponding Author:
romanus.ugochukwu@uniabuja.edu.ng
+2348033292027

ABSTRACT

Human activities generate waste from food processing during production. This waste causes environmental pollution, especially the pollution from waste cooking oil generated in our homes. Investigation on ways to reduce the effect of this waste oil pollution on the environment and waters, mitigates the study to achieve an appropriate method to dispose of the waste oil without causing problems to our environment. The renewed engineering process converts the waste cooking oil to biodiesel, which is beneficial in powering diesel engines and has greenhouse gas properties that reduce carbon emissions after combustion. A mini pilot plant suitable for home use was fabricated and used for the production of biodiesel through the trans-esterification process. The waste cooking oil was pretreated and trans-esterified in the pilot plant fabricated to produce biodiesel, glycerin, and water. The biodiesel produced was characterized in the laboratory and compared with the ASTMD 6751 biodiesel standard. Variables affecting the yield of biodiesel production were studied. The results showed that a maximum yield of 93% biodiesel occurs at 6:1 methanol to oil, a catalyst concentration of 1.06%, and a temperature of 85°C are best for the complete trans-esterification process. The reaction time of 2 hours and 30 minutes is most appropriate for complete reaction to produce biodiesel.

INTRODUCTION

Environmental pollution forms one of the major problems facing Nigeria and other sub-Saharan African countries in terms of its effects on health and the environment. Waste cooking oil Pollution comes from frying activities at homes and workplaces. A typical problem is the pollution caused by the use and disposal of vegetable oil waste resulting from the production process and also the waste oil from cooking, fries and other human activities generated from frying oil. Waste cooking oil disposal results in the pollution of the environment, pollution of the ground, and sub-surface water and destruction of aquatic life. In Nigeria, waste oils from production and waste oil generated at individual homes, restaurants, hotels and other places are on the increase. This will pose potential danger and negative effects on our environment, water course and aquatic life soon.

The majority of this waste oil generated is disposed openly to the environment and others are washed away in the kitchen sink into the drain to the septic tank from there it percolates into the soil to the underground water thereby reducing the biological oxygen demand of microbial activities in the septic tank and also destroy plants and aquatic life. Environmental degradation, ozone depletion and the increase in the cost of crude oil in the local and international oil market call for an in-depth discussion for an alternative fuel and energy source that will be environmentally friendly will preventing environmental, water and air pollution. Biodiesel refers to diesel fuel produced by reacting vegetable oil or animal fats with alcohol in the presence of a catalyst. Such oil is sourced from groundnut, palm fruit, soybean, castor seed etc. and animal fats. The alcohols are ethanol or propanol. Rapid advancements of the past centuries, global energy need have skyrocketed. This demand continues to grow yearly, but the overreliance on oil and its excessive consumption, 105 times faster than its formation in nature, has led to increased prices in the global market (Lopresto, 2024). Also, the non-availability of crude to refine in some states affects the supply of fuel. These reasons request an alternative source of fuel for the states. The transportation sector around the world has considerably increased fuel consumption, reaching 61.5% of the total, especially in the last few decades (Sabah, 2024). In Nigeria, the demand for fuel for the transportation sector and household Generators in the last 16 years has increased in as a breakdown or disruption in the crude, refining, and distribution chain will cause a chaotic situation. The manufacturing sector is worst hit by this problem and this has caused companies to close and fold up, while others have relocated to other countries that are favourable. An alternative source of fuel, biodiesel, serves as a substitute to meet the demand and replace petroleum-based fuel. With the rapid advancements of the past centuries, global energy needs have skyrocketed. This demand continues to grow yearly, but the overreliance on oil and its excessive consumption is 105 times faster than its formation in nature and this has led to increased prices in the global market. The urgency to overcome dependence on fossil fuels is further underscored by their significant contribution to the current environmental crises, particularly the alarming increase in greenhouse gas (GHG) emissions (Jayaraman et al. 2024; Lopresto 2024). Palm biodiesel is free of sulphates and is simple to work with existing equipment. Palm biodiesel has a higher flash point compared to petroleum diesel, it is a non-toxic material that is renewable and biodegradable. It has some environmental advantages, as it reduces the emissions of sulphur dioxide, hydrocarbons, carbon monoxide and carbon dioxide, as well as particulate matter emissions. It has a higher cetane number than petroleum diesel, Biodiesel improves engine performance while also emitting less harmful emissions.

The maximum boiler efficiency of 64.98% with B100 fuel was achieved, which is lower than that of pure diesel as fuel, 65.30% (Krunal et al., 2021). Biodiesel production from waste cooking oil is a viable alternative both to satisfy renewable energy demand and utilize a low-cost feedstock (WCO) to produce an alternative fuel to petroleum diesel. The conversion of waste cooking oil to biodiesel achieved 91.4 ± 0.2% after 5 min of reaction time (Juliati et al., 2023). The depletion of fossil fuels has been the primary global issue facing the world in recent times. Some recent studies have been focused on finding energy or fuel derived from renewable sources, e.g., biodiesel production, which has potential advantages over fossil fuels and its flexibility of feedstock. Biodiesel generated from used and non-used vegetable oils typically provides positive impacts on some aspects, including the environment, waste conversion, energy fulfillment, and the global and national economy. Studies revealed that around 70 % of the costs in bio-fuel production are derived from feedstock. The utilization of electro-catalysts for the transesterification of waste cooking oil and palm oil lowers the ash content of the produced biodiesel (0.0015– 0.002 %), which was lower than that of the standard of biodiesel established by ASTM (0.01 %). (Darwin 2023). The Indonesian government implemented a series of biodiesel mandates to encourage the use of palm oil-based biodiesel. The program was extended in January 2020 to increase the biodiesel blend to 30 %. In August 2023, the blend was further expanded to consist of 35 % biodiesel. This mandate aims to reduce dependence on fossil fuels, improve energy and help to create local jobs and reduce greenhouse gas emissions (Anggara et al., 2024). This study is projected to present an economic method of reducing the pollution of waste cooking oil by evacuating it and turning it into biodiesel for diesel engines and glycerol for soap making.

MATERIALS AND METHODS

Materials

Waste cooking oil is the feedstock, and it was sourced from food processing company restaurants (Season 7 fast food), and hotels (Modoc Hotels, Gwagwalada Abuja). The alcohol used for the trans-esterification process was Solveco ethanol 96% Analytical Grade, while the potassium hydroxide used as the catalyst was obtained from Tecno Pharmchem, which was 90% purity. The ethanol used was Solveco ethanol 96% Analytical Grade. An analytical weighing balance (Ohaus), a heat-resistant settling funnel, and a thermometer were the materials used in the research work.

Description of the pilot plant

The mini pilot plant was fabricated, which is domestically friendly and cost-effective. The plant was arranged in a manner that the operations from the feeding of the feedstock (WCO) to filtration, to the reaction/transesterification process and separation are by gravity. The feeder is made of a cylindrical container of 200mm diameter and 300mm depth with a lid. The feeder has a heating mechanism that heats the waste cooking oil. At the bottom of the feeder is an outlet with a half-inch valve that is locked during heating. There is a filtering unit connected to the bottom of the feeder. It contains a wire mesh of 212 micrometers that filters the heated WCO. The filtration unit is connected to the cylindrical container 200mm in diameter by 400mm deep. In this chamber, there is a rotating stirrer that mixes the WCO and the ethanol. This chamber is the transesterification unit. This is where the WCO is mixed with ethanol thoroughly. The trans-esterification chamber has an opening with a valve at the bottom. this opening is opened after complete mixing over a set period and the mixed oil is allowed to flow into a settling container where the mixtures are allowed to settle in layers with biodiesel at the top, followed by glycerol and water at the bottom.

Pre-treatment unit

The waste cooking oil was weighed and fed into the upper tank where the WCO was heated to a temperature of between 60oC to evaporate the water it contains, this was to allow the complete trans-esterification reaction, because the presence of water in the oil will produce more of glycerol (i.e. soap) than biodiesel (John et al., 2015). After heating, the oil at its hot temperature has a low viscosity. the valve at the bottom of the tank was opened to allow the heated oil to flow via a pipe into a filtering unit. This unit contains filters that remove particles of food items present in the heated oil.

Trans-esterification unit

The trans-esterification unit contains a stirrer, heater, thermometer, alcohol recycling hose, and condenser. The heater supplies heat to the chamber, rotary stirrer helps to mix the content in the trans-esterification unit. A thermometer was attached to the cover of the unit to indicate the temperature inside the unit. On the cover of the trans-esterification unit was also an alcohol recycling tube attached to a condenser. The condenser has a water recycling that condenses evaporated alcohol from the chamber and recovers it for reuse.

Ethanol and potassium hydroxide were weighed and put in the tank, and were heated to a temperature of 60oc and stirred continuously for 40 minutes to dissolve the catalyst (potassium hydroxide). The heated and filtered oil was allowed to flow into the trans-esterification unit to mix with the mixture of ethanol and potassium hydroxide (ethoxide). The contents of the trans-esterification unit were heated to a temperature of 85 °C and stirred continuously at a rate of 120- 200 rpm for 2 hours, 30 minutes for a complete trans-esterification reaction.

Separation Unit

The separating unit consists of an inverted conical tube attached to a locking valve. The valve to the trans-esterification unit was opened after a complete trans-esterification reaction to allow the reactant to flow into the separating unit. The content in the separating unit was allowed to stand for 24 hours to allow the content to separate by gravity. After 24 hours, the content in the separating unit settles in layers, with biodiesel settling at the top, little water and glycerol at the bottom. The valve at the bottom of the separating unit was opened to decant water, glycerol and biodiesel.

Washing

The biodiesel produced from waste fried oil exhibited a brownish discoloration. The biodiesel was made to flow through warm water where the discoloration was removed from the biodiesel leaving the biodiesel that is golden color.

Calculations of materials (Batching by weight)

Measurement for quantities of materials used was calculated using weight/volume, and it was derived as follows

Waste Cooking Oil (WC)

Volume of cooking oil = 300ml

Density of waste cooking oil = (g/l) = 9.78g/cm3

Weight of waste cooking oil = 9.78 x 0.3 = 293 g.

Potassium Hydroxide (Catalyst)

Weight of 0.5 Percent of catalyst wco = 0.5% of 293g = 0.5/100 ×wt of wco = 0.5x293

Weight of KOH = 1.465g**Ethanol (Alcohol)**

C_2H_5OH- 3moles of 100% per mole of oil = (0.3×148) g = 44g

Quantities of material used

a. Quantity of waste cooking oil used = 293g

b. Density of waste cooking oil – mass/L = 9.78g/cm3

c. Quantity of Catalyst use (KOH) = 3.05 g

d. Quantity of ethanol used = 44g

e. pH level of mixture = 7.3

RESULTS AND DISCUSSION

The results of the tests carried out on the waste cooking oil are presented in Table 1. It shows the properties of the feedstock (WCO) used for biodiesel production properties as the color of the WCO appears to be brownish. The temperature of the feedstock was 34 °C before the trans-esterification process of the biodiesel production, density was 9.78 g/cm3. PH was determined to be 7.34. The flash and fire points of the waste oil were 81 °C and 120 °C, respectively. Moisture content in the waste oil was determined to be 0.175%, while the kinetic and kinematic viscosities carried out with a viscometer were 0.808 Mpas and 7.905 Mpas, acid value and the saponification value were 0.56% and 195.87%. Fatty acid, the lipid composition, and the calorific value were 8.4, 55% and 4478 j/g, while the specific gravity was determined to be 9.8 g/cm

Table 1. Characteristics of Waste Cooking Oil.

Stream Name.	**Biodiesel production from waste cooking oil by Ugochukwu Romanus.**	**Unit**	**Result**
1	Colour	Brown	
2	Temperature	^{0}C	34^{o}c
3	Density	g/cm^3	9.78
4	P.H		7.34
5	Flash Point	^{0}C	81
6	Fire Point	^{0}C	120
7	Moisture Content	%	0.175
8	Kinematic viscosity	Mpas	0.808
9	Dynamic viscosity	Mpas	7.905
10	Acid value	%	0.56
11	Saponification value		195.87
12	Free Fatty Acid		8.4
13	Lipid Composition Of Waste Cooking Oil	%	55
14	Calorific Value	j/g	4478
15	Specific Gravity	g/cm	9.78

The trans-esterification process of biodiesel production from waste cooking oil depends on varying degrees of parameters and the interactions of the feedstock (WCO) and alcohol (Tadesse et al., 2019). The main operational variables that affect the quantity and quality of biodiesel produced include methanol-to-oil molar ratio, reaction temperature, residence time, catalyst concentration, and mixing intensity. The lower and upper limits of the experimental parameters are summarized in Table 2.

Table 2: Produced biodiesel and standard ASTMD6751 Biodiesel

Characteristics	**Petroleum Diesel**	**Produced biodiesel**	**ASTMD6751 Biodiesel**
Colour	Golden brown	Golden yellow	Golden yellow
Temperature	NA	28	NA
Density	0.84	1.51	0.878
Flash Point	60-80	60	100-170
Fire Point	78	79	170
Dynamic Viscosity	1.3-4.1	1.89	NA
Kinematic Viscosity	1.3-4.1	1,25	1.9-6.0
P.H	5.5-8.0	7.55	NA
Pour Point	18	13	15-16
Caloric Value	38.3	21.60	37.27
Specific Gravity	0.82-0.95	1.51	0.850-0.890
Boiling Point	360	130	315-350

Trans esterification of waste cooking oil is essentially reversible; the removal of products after formation can help reduce the amount of excess alcohol required for the reaction equilibrium to remain shifted towards the product formation (Dimitrios et al., 2023). The experiments were conducted 5 times for each set of conditions and it was observed a biodiesel production increased from 1:1, 3:1, 6:1 and from the molar ratios 9:1, and 12:1 the production dropped, leaving the peak value of 6:1 as the point of maximum biodiesel production. The ethanol to oil ratio was investigated for five different levels (1:1, 3:1, 6:1, 9:1 and 12:1 ethanol: oil). The optimum biodiesel yield was obtained at a methanol: oil mix concentration of 6:1, which is different from the ratio 10:1 in Dimitrios et al.

(2023). The reason for this difference may be a result of different feedstock, non-edible oil used, or fresh oil used as feedstock. The effect of catalyst concentration was investigated at five concentration levels varying from 11% to 43%. Catalyst loading and the amount of catalyst required to perform the maximum conversion that will ensure a complete reaction to yield maximum biodiesel were investigated. The dosage of the catalyst concentration fed into the system was regulated by adding the catalyst by increasing from 1, 2, 3, 4, 5 and 6wt% to the mass of waste cooking oil while keeping other reaction parameters constant at a reaction temperature of 85 °C and molar ratio of methanol to oil at 6:1. It was observed that at the catalyst concentration of 1%, there was maximum 79% biodiesel yield, this is the same to the result of 1% obtained by some literature (Tadesse et al., 2019; Maryam et al., 2022).

The reaction time for the maximum biodiesel yield was conducted. Reaction times were changed from 60 to 240 min to explore the effect of time on esterification reactions. However, other parameters were fixed at 2 wt% catalyst loading, a 6:1 WCO: methanol molar ratio, and 85 °C temperature. The highest yield of biodiesel, 93% ± 21/2 hr, was found at a reaction time. There was hardly any refinement in biodiesel yield after increasing the reaction time from 120 to 180 min. There is a reduction in biodiesel yield after 180 min and this phenomenon is best described by the reversible esterification reaction and can be checked by not allowing the reaction duration to exceed its optimum value. Therefore, the optimum reaction condition was at 2 hr 30 minutes at 2 wt% catalyst loading, a 6:1 methanol molar ratio, and 85°C temperature. It was found out that the reaction time of 2 ½ hours yielded 99% biodiesel and this differs from the result of 2 hours obtained in Maryam et al (2022).

CONCLUSION AND RECOMMENDATIONS

Conclusion

Reacting waste cooking oil, ethanol and potassium hydroxide catalyst at the mixing speed of 200rpm at a moderate temperature, and mixing ratio of waste cooking oil to alcohol and time produce 93% biodiesel, this is a little bit higher than 91.4% Juliati et al. (2023), the yield of 90% obtained (Darwin et al. 2023) and 82% biodiesel yield Anggara et al. (2024). Considering the close similarities in the properties of the biodiesel produced and the ASTMD6751 standard biodiesel, this research presents this produced biodiesel as a fuel suitable to power diesel engines as an alternative source of diesel in situations of scarcity and taking care of pollution caused by waste cooking oil to the environment. Maximum biodiesel yield in this production process was carried out and found that maximum biodiesel yield occurs at conditions: 6:1 waste cooking oil, 1.06% catalyst, 2 hours 30 minutes and temperature of 85oc. A mini pilot plant suitable for domestic biodiesel production was fabricated. The pilot plant has 3 sections as the pre-treating stage, the filtering, trans- esterification section and the separating unit. The pilot plant was used to produce biodiesel.

Recommendations

Due to the waste cooking oil generation in homes and other food processing companies is on the increase and as such causes pollution to the environment, surface and ground water when disposed of. It is recommended that the waste cooking oil should not be disposed or discharged into drainage or on the vegetative surface to cause pollution, rather, it should be collected and converted into biodiesel which will be useful to power diesel engines, making use of the simple and cost effective pilot plant fabricated, and thereby turning waste to wealth.

REFERENCES

Ajinkya D. D., Hina K. and Pratiksinh D. C. (2016). Production of Biodiesel fuel from Waste Soya bean Cooking Oil by Alkali Transesterification Process. College of Renewal Energy and Environmental Engineering, Agricultural University of India. 11: .260-266.

Alemayehu G. and Abile T. (2014). Production of Biodiesel from Waste Cooking Oil and Factors Affecting Its Formation: A Review. International Journal of Renewable and Sustainable Energy, 3. 92-98.

Amirthavalli V. I. and Anita R. W. (2022). Production of Biodiesel from Waste Cooking Oil using Meso Porous MgO-SnO2 Nano Composite. Journal of Engineering and Applied Science, 69:92.

Andre R. A. Ribeiro F. C., Joana C. and Jorge A. C. V. (2013). Alternative Feedstock for Biodiesel Production. , 730-732. 623-629.

Anggara D. B. Iriany E. N. Dwina R. H, Rondang T. and Yacine B. (2024). Biodiesel Production Using Waste Cooking Oil and Amberlite 62i As Heterogeneous Catalyst. Sustainability Energy Solution. Case Studies in Chemical and Environmental Engineering 10 101011

Acevedo J.C., Acenedo, A. Z., Arenas. E. and BecenuL.C. (2018). Analysis of the Biodiesel Production Yield from Waste Frying Oil. International Meeting of Applied Science and Engineering, Journal of Physics Conference, 1128

Carolina, T., Daniel, L., Pinto, F., Roberta, N., Sanda, M.F.O., Azevero, and Simone M. C. (2015). Micro Lipid and Biodiesel. ACS. Publications 24(9) 5235-5243.

Chria, Y. C., John, K. M., Lin, C. W., Jhong-L. W., Wen, J. and Sheng, L. (2017). Reduction of Resistant Organic Emission during Incineration Start-up By using crude waste cooking oil as an alternative fuel. Taiwan Association for Aerosol Research, 11. 899-912.

Darwin, M. Thifal, M. A, Zhairi M., Atmadian P. and Muhammad, R. I. (2023). The Synthesis of Biodiesel from Palm Oil and Waste Cooking Oil via Electrolysis by Various Electrodes. Case Studies in Chemical and Environmental Engineering, 8. 100512

Deepak, V., Amit, P., Janmit, R. M. and Jai, R. T. (2017). Production of Biodiesel from Transesterification. International Conference on Innovation Trends in Science, Engineering and Management, 203-22.

Diego R., Dionisio M. R. and Jose R. (2017). Production of Biodiesel from Waste Cooking Oil and Castor Oil Blends. The Italian Association of Chemical Engineering Transactions, 57, 679-684

Elkady M. F., Ahmed, Z. and Ola, B. (2015). Production of Biodiesel from Waste Vegetable Oil via K.M Micro Mixer Hindawi, Journal of Chemistry, 10. 1-10.

Gopalakrishnan S, Gopalakrishnan S., Ubaidulla J., Shanmugasundaram P., Tamilarasu, T. and Yuvaraj. K. (2017). Production of Biodiesel from Used Cooking Oil. IJIRST//National Conference on Recent Advancement in Mechanical Engineering, 17. .90-95.

Ghanei R., Ghanei R., Falahati V., Heydarisnasab, A. and Moradi, G. R. (2014). Process of Optimization for Biodiesel Production from Waste Frying Oil with Constructional Lime. International Journal of Bioscience, 4. 36-45.

Hassan I. E. Shimi, H. I. Shimi, E. I. Ahmad, S. F., Guzine I. E. D., Naheed, K. A. and Shakinaz T. S. (2016). Evaluation of Biodiesel Production from Spent Cooking Oils. A. Techno Study of Egypt. Asian Research Publishing Network (ARPN), Journal of Engineering and Applied Sciences, 11. 10280-10290

Heshan I. G., Abubaker A., Ahmed A. and Alshureef, M. (2015). Recycling of Waste Cooking Oil to Biodiesel Production. Journal of a Multi-disciplinary Engineering Science and Technology, 2 721-725.

Hillary, R. and Christopher, E. (2016). Optimization of Production Variables of Biodiesel using Calcium Oxide as a Heterogeneous Catalyst; an Optimized Process, Material Process for Energy. Communicating Current Research and Technological Development, 7. 320-326.

Iloamaeke .I, Onuigbo C.C, Umedum L.N. and Umeobika, C. U. (2016). Production and Characterization of Biodiesel from the Seed of Dacryodes edulis (African pear). International Journal of Current Research, 8, 25230- 25234.

Jayaraman K., R, Vijayakumar J. S. and Mohammed E H. (2024). Characterization of Properties of Used Cooking Oil-Derived Biodiesel and Liquid Insulation Towards Sustainable and Environmentally Friendly Reclaimed Products. Iran Journal Chemical Engineering, 43, 9.

John A. D. and Mathew, F X. (2015). Biodiesel Production from Broiler Chicken Waste. World Academy of Science, Engineering and Technology International Journal of Agricultural Biosystem. Engineering Volume 9

Joshua Kagan. (2015). Third and Fourth Generation Biofuel: Technologies, Market and Economics

Juan M.S. and Patrick A. (2015). Highly Effective Enzymatic Biodiesel Production Promoted by Induced Emulsification. Journal of Biotechnology for Biofuels, 8 (1) 58,

Juliati B. T., Binawati G, S. Perangin-angin, R. N. S, Parlin F. S and Eko K. S (2023). Homogenizer-intensified Amidation of Free Fatty Acids in Waste Cooking oil for biodiesel production". South African Journal of Chemical Engineering 46. 271–27.

Krunal K. and Ramana P. V. (2021). Diesel-fired Boiler Performance and Emissions Measurements using a Combination of Diesel and Palm Biodiesel. Case Studies in Thermal Engineering 27. 101324.

Laura, J. A., Erick, S., Pamela H., Robinson B. and Rodrigo, N. (2006). Biodiesel Production from Rapeseed Oil with Waste Frying Oils. PhD Thesis Program in Science and Natural Resources, Chemical Engineering. Universidae Dela Frontera.,

Liu Y., Chen W. H, Ma L, Wang B and Xu Z. L. Synthesis and Pharmacological Activities of Xanthone Derivatives as Alpha-Glucose inhibitors. www.yeastgenome.org

Lopresto. C.G. (2024). Sustainable Biodiesel Production from Waste Cooking Oils for Energetically Independent Small Communities: An Overview. International Journal of Environmental Science and Technology 22:1953–1974

Madhumeeta, C., Ashwini, T., Kshitija, M., Priyanka D. and Sulabha, B. D. (2015). Production of Biodiesel using Waste Temple Oil from Shani Shingnapur Temple, Maharashtra, India using Chemical and Biotechnology" International Journal of Agriculture and Biotechnology, 2,443-450.

Mathiyazhagan, M. and Ganapathi, (2025). A Production of Biodiesel from Waste Cooking Oil and Factors affecting its Production. Research in Plant Biology, 2, 1-5.

Maryam, H. Ijaz A. B. Muhammad Z. and Muhammad, S. (2022). Production of Biodiesel from Non-edible Feedstock using Environment-Friendly Nano-magnetic Fe/SnO Catalyst. Scientific Reports, 12:16705

Maximino M., Maria L. Molina. M. and Jesus Gonalez L. (2008). Biodiesel and Alternative Fuel. Bentham Science, 2(1), 25-34

Miranda A. I., Andriotis C, Hohkemieier T. Yashim A. LalBanwari, M. Aidyn, M P, Rami K. N, Rochfort Simone W. D. Rodrick F. (2017), "Spangenberg German, Subuduhi Sanjukta. Biotechnology biofuel".

Mohammed F., Anita R. and Abdul N. (2015). Biodiesel Production from Low FFA Waste Cooking Oil using Heterogeneous Catalyst Derived from Bones. 76. 362-368.

Nur S T. and Sarina, S. (2016). Overview of Catalyst in Biodiesel Production. Journal of Engineering and Applied Science, 1. 439-448.

Nidhi Y., G. Y. and Ahmaruzzaman. M.D. (2023). Microwave-assisted Biodiesel Production using SO3H Functionalized Heterogeneous Catalyst Derived from a Lignin-rich Biomass. Scientific Reports. 13:9074

Ogala, H. Adegoke, A I, Elinge, C. M. and Ige, A. R. (2017). Production and Characterization of Biodiesel from Nigerian Neem Seed Oil Using Two-Step Trans Esterification International. Journal of Applied Research and Technology. 6 (11) 29-33.

Radia S. and Abdelsallem, R. O. (2015). The Synthesis of Biodiesel from Vegetable Oil. Procedia Social and Behavioral Science, 195, 1633-1633

Sabah, M. F. Aghareed M.T., Randa M. O. Shereen M. and Abdel Hamid. S, (2024). Sustainable Production of Biodiesel from Waste Cooking Oil using Magnesium Oxide Nano catalyst: An optimization study". Nature Scientific Report 2024.

Said N.H., Ani F.N. and Said M.F.M. (2015). Review of Production of Biodiesel from Waste Cooking Oil using Solid Catalyst. Journal of Mechanical Engineering and Science, (8), 1302 – 1311.

Subhrajit R. L., Alen V., S. and Mahesh K. G. (2016). Trans-Esterification of Waste Cooking Oil using Heterogeneous Catalyst. Journal of Engineering and Science, (7). 1-7.

Tadesse A. D. Tadios T. M. and Yedilfana S. M. (2019). Optimized Biodiesel production from Waste Cooking Oil (WCO) using Calcium oxide (CaO) Nano catalyst. Scientific Reports, 9:18982

Ugochukwu G C, Adindu C.S., Aloh C.H., Eneh F U, Orjiakor O.A. and Enemoh C.G. (2017). Characterization of Biodiesel Produced from Waste Cooking Oil from a Food Vendor within Awka, Nigeria. Frontier Science 7 42-45.

Zaibunnisa H. S., Ahmed N. and Mehwish J. (2015). Production of Biodiesel from Waste Canola Cooking Oil in Pakistan. *International Journal of Chemical Engineering and Applications*, (6) 436-439.