

Waste Cooking Oil to Biodiesel: An Efficient Synthesis Using Calcium Oxide (CaO) Nano-Catalyst

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Abstract

Waste cooking oil (WCO) is used to produce biodiesel, a liquid fuel from biomass that may be used for a diversity of purposes. The manufacture of biodiesel from recycled WCO and methanol in the existence of calcium oxide (CaO) nano-catalyst (NC) offers an amount of profit, including waste management, the environment, and the economy. The thermal collapse was used to produce an NC of CaO, which was then calcined at 500°C before being characterized with the use of x-ray diffraction (XRD) and scanning electron microscopy (SEM) methods. The XRD measurements showed high-purity NC scale crystal sizes, with a denoted particle size of about 30 nm. The porous structure and morphology of the produced NC were visible in the SEM images. The greatest WCO to biodiesel conversion, which is among the uppermost conversions thus far recorded, was calculated to be 96% under optimal testing circumstances, which were 50°C, a 1:9 WCO oil to “methanol” ratio, 1% by weight of catalyst load rate, and a 60-minute response period. American fuel regulations (ASTM D6571) were used to investigate the characteristics of biodiesel. At 1500 rpm, all reactions are carried out at distinctive demands.

Keywords: Waste cooking oil (WCO), Biodiesel, nano-catalyst (NC), methanol, calcium oxide (CaO)

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1. Introduction

Global use of fossil fuels contributes significantly to environmental issues and emissions of conservatory gases. Other conservatory gases into the impression. Environmental change is a result of the climate's developing ozone-harming substance focus, which is raising the World's normal temperature. As a result, heat waves, hurricanes, droughts, floods, and heat waves become more frequent and more severe [1]. One of the many outcomes of decreasing fossil fuel reserves and concurrently rising prices for oil and oil derivatives may be an increase in combustion-related environmental pollution. The exhaustion of fossil fuel assets and price volatility may raise concerns about energy security for nations that primarily import fossil fuels. To decrease dependence on petroleum derivatives, this might prompt a quest for substitute energy sources, for example, renewable [2]. For various ventures, including fabricating, transportation, farming, medical care, and training, admittance to reasonable and reliable energy is fundamental.

However, it is also true that fossil fuels and other non-renewable resources still provide the world's energy requirements. Because of their high energy density, ease of extraction, and well-established distribution networks, fossil fuels like coal, oil, and ordinary gas have conquered the energy market since the beginning of time [3]. Due to concerns about their non-renewability, price fluctuations in the supply, and the depletion of fossil fuels, meeting the world's need for energy for transportation, industry, home use, and the production of heat is extremely challenging. Coal, oil, and flammable gas are instances of restricted assets whose stores are being depleted as they are taken and utilized. When high-quality deposits become scarce, extraction and production costs rise as well as difficulties increase. Concerns are raised concerning the security and openness of energy later on [4]. The extensive use of fossil fuels for a variety of purposes has depleted the natural resources that are already available. Natural gas, oil, and coal are examples of finite fossil fuels that were produced over millions of years. The energy demand, particularly those derived from fossil fuels, has significantly increased as a result of transportation, urbanization, industrialization, and population growth. The rapid rate of consumption is

depleting the current reserves [5]. The extraction and use of fossil fuels have negative effects on the environment, including habitat loss, deforestation, air pollution, and pollution of the water supply. Environments might endure, biodiversity might endure, and the accessibility of regular assets might be impacted by these activities. Change in Land Use Often, the extraction of fossil fuels requires a lot of land use, like cutting down trees, changing habitats, and affecting the environment. In addition to contributing to resource scarcity, this causes ecological imbalances, a loss of biodiversity, and a lack of resources [6]. In transportation and modern areas, petroleum derivatives have for some time been the principal energy sources. For several businesses and transportation networks, fossil fuels similar to oil, coal, and ordinary gas have provided a dependable and energy-dense fuel supply for many years. Due to their high energy density, they are efficient for driving extensive industrial operations and long-distance transportation these industries now have a reliable energy supply [7]. The demand for fossil fuels has significantly increased as a result of worries about environmental degradation, rapid urbanization, and high population growth. The number of people who require energy for everyday purposes like transportation, heating, and power has increased, and so has the demand for fossil fuels. As a result, more efforts and money have been spent on renewable energy technology, energy efficiency programs, and sustainable behavior. People, businesses, and governments are realizing how important it is to reduce emissions of greenhouse gases and switch to cleaner energy sources to slow climate change and improve air quality [8]. The high population density in numerous emerging nation metropolises exacerbates air pollution issues. Poor air quality and higher concentrations of harmful chemicals may result from the concentration of emissions from automobiles, industrial sources, and domestic activities in areas with a high population density. The use of fossil fuels for energy production may worsen air pollution in developing nations. Major air pollutants, particularly those produced by coal-fired power plants, include sulfur dioxide and nitrogen oxides [9]. Conservatory gases are released into the atmosphere when fossil fuels are used, causing weather changes and harm to the environment. Renewable energy sources, which are alternatives to fossil fuels, produce little or no carbon emissions, reducing their negative property on the atmosphere and contributing to the fight against universal warming. The viability and cost-effectiveness of alternative energy sources have increased as a result of technological advancements. Solar, wind, hydropower, biomass, and geothermal energy systems are becoming more efficient, scalable, and affordable. The amount of money invested in and utilized in these technologies has increased as a result of this [10].

Solar, wind, hydropower, geothermal, and biomass are among the emerging and increasingly utilized forms of renewable energy. The transportation sector is a significant contributor to air pollution and petroleum consumption. Utilizing electric vehicles, which are propelled by energy generated from renewable sources, may offer a potential means of reducing our reliance on fossil fuels. The multiplication of EVs is being filled by headways in battery innovation and charging foundations [11]. Population growth, urbanization, and pollution in the environment, in attendance, is a critical need to decrease reliance on fossil

fuels and switch to force systems that are more environmentally friendly. As a result, renewable energy technology, energy efficiency measures, and sustainable practices are now receiving more attention and funding. People, businesses, and governments are realizing how important it is to cut greenhouse gas emissions and switch to cleaner energy sources to improve air quality and prevent climate change [12]. The review [13] discusses the response exterior technique used to optimize the response constraint that influences transesterification development for producing biodiesel. The GO@MgO NC was examined using SEM. Under ideal conditions, the highest "biodiesel" virtue for MgO was (93.84%). Portraying the physical and substance characteristics of the manufactured driving forces allowed experts to more promptly appreciate how different exploratory variables influenced the "biodiesel" yield. The study [14] examined a "CaO"-TiO₂ NC-impetus that was found to have bifunctional properties, include fundamental and corrosive stages, and influence the transesterification cycle reactant action. To simultaneously transesterify the dairy scum oil feedstock, these bifunctional properties are required. The response data indicated that the catalyst had poor catalytic activity if it did not contain TNPs or had a low TNP-to-catalyst ratio. The paper [15] investigated the greatest "biodiesel" invention, the base-catalyzed procedure was examined under a variety of reacted ratios, such as the group ratio of catalyst to oil and the molar ratio of alcohol to oil. A base-catalyzed transesterification of utilized cooking oil, the perfect proportion, and measure of zinc-doped calcium oxide were viewed as 13:4 and 6 weight percent, separately. The high energy value, spark position, and thickness of the produced "biodiesel" were evaluated and compared to regular diesel. The research [16] determined that the catalyst was produced through a straightforward solid-state response, mixing, and thorough grind at 800 °C for 240 minutes outdoors using a water scale from a sanitization unit. The impetus was examined via X-beam diffraction, Fourier-change infrared spectroscopy, and checking electron microscopy. The majority of XRD peaks are characterized by "CaO", as shown by the experiments. The study [17] provided the effect of rising the calcium load (10, 15, and 25 weight %) was looked at. The carbon-based calcium oxides that were produced were characterized with the assistance of the acid and basic sites, elemental analysis, FTIR, XRD, SEM, and BET. Supported systems, in contrast to calcium oxide, were simple to recover and reuse for three cycles without losing activity, facilitating oil transesterification with methanol. A pseudo-2 organize model with an activation energy of 49.8 kJ mol⁻¹ better matched the kinetic data.

2. Experimental

2.1 Processing of a waste cooking oil collection

Cafes, restaurants, and street vendors in Addis Ababa provided the waste cooking palm oil that was used to fry food. After settling for four to six days at room temp and heaviness, the used cooking oil was drinkable through the sieve with holes of 100 nm to take away any non-living residue and poised food particles, and it was heated to 110 °C to eliminate the water.

2.2 Development of NC

The “CaO” NC was made using the thermal decay method that was described by “Zhen-Xing Tang and David Claveau”. To create a nitrate solution, 11.81 grams of calcium nitrate tetrahydrate ($\text{Ca}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$) were dissolved in 25 milliliters of ethylene glycol resolution and 2.10 grams of (sodium hydroxide) NaOH were added while the mixture was vigorously stirred. To produce nanoparticles of consistent size, the gel resolution was static for approximately 300 minutes after being agitated for 10 minutes. After being cleaned with distilled water, it was vacuum dried. “CaO” nanoparticles of various sizes were produced following calcination at 500 °C.

2.3 Formation of the PP/sago starch Composites

The size of the crystallites and the primary components of the produced catalyst were denoted by X-ray diffraction (XRD). A minute Flex 600 XRD classification with Ni-filtered CuK energy at $\lambda = 0.155$ nm and an SEM JSM-IT300 LV was used to examine the catalyst's shape.

2.4 Method of Transesterification

Triglycerides, which are often present in vegetable oils or animal fats, are used to make biodiesel, a form of sustainable fuel. Transesterification, a chemical process that produces it, involves “biodiesel” is formed commencing triglycerides during a transesterification procedure via alcohol and a catalyst. “biodiesel” was produced in a laboratory by combining waste cooking oil, methanol, and a nano-sized calcium oxide NC. To carry out the transesterification procedure, a flask with a capacity of 300 milliliters, a prohibited magnetic stirrer, and a temp sensor was placed on a heated plate. Used cooking oil was heated to the required response temp before the addition of “methanol” and the catalyst to the response thermos. The response mixture was stirred for ten minutes following the addition of the “CaO” catalyst, whose weight varied between 0.5 and 5% of the WCO's mass. 100ml of utilized cooking oil was added, and the blend's temp was acclimated to go from 30 to 70 °C with 5-degree stretches. The response blend was persistently mixed throughout the important period while transesterification advanced. At 1500 rpm stirring speed and atmospheric pressure, all transesterification processes occurred. To follow the temp of the response, a thermometer was put inside the jar.

2.5 Identification of biodiesel

To eliminate extra unreacted methanol, the divided “biodiesel” was boiled over the high-temperature point of “methanol”(64.8 °C). Moreover, not very many suspended strong impetuses are disposed of by settling it for a few days, after which the biodiesel's consistency, explicit gravity, water content, complete corrosiveness, debris contented, sulfur content, streak point, and cloud point were estimated as per ASTM D6751, the American Culture for difficult and resources.

3. Results and Discussions

3.1 WCO classification

The boiling method alters the compound and objective properties of the oil as a result of several chemical events similar to polymerization, hydrolysis, corrosion, and objects transmit among oil and food. The WCO example compound and objective characteristics are listed in Table 1.

3.2 Description of the catalyst

The XRD diffraction strength of “CaO” nanoparticles is depicted in Figure 1. The 2 value of the produced “CaO” catalyst ranges from 15 to 70 degrees. The crisp spectra, as depicted in Figure 2 demonstrated the powder's extreme crystallinity. At 2-theta, there were pronounced peaks of 33.26°, 38.42°, 44.04°, 54.93°, and 65.3°. The crystallite size width (D) of the “CaO” nanoparticle in nanometers was estimated using the Debye-Scherrer equation ($D = K/\cos$). Table 2 depicts the outcomes. According to SEM descriptions, the generated “CaO” NC usually consists of irregularly shaped, absorbent particles with active sites. To put it another way, the catalyst's larger surface area for response is demonstrated by the particles' various sizes and shapes.

3.3 Improvement of the response parameter

A baseline response lacking catalyst was conducted using response conditions of response temp at 50 °C, response. This response yields no biodiesel. By maintaining the response temp at 50 °C, the response time at 90 minutes, and the oil-to-“methanol” ratio at 1:9 while varying the catalyst's percentage mass from 0.5% to 5% w/w with the mass of WCO, as depicted in Figure. 3, the impact of the impetus utilized the “biodiesel” yield rises when the catalyst attention rises from 0.4 to 1% w/w, while the “biodiesel” yield decreases as the catalyst loading attention rises further.

Consequently, the most favorable catalyst quantity was identified as 1% w/w catalyst load with a 96% “biodiesel” output. It is also inexpensive, safe for the environment, simple to use, and has a high basicity that makes it suitable for reuse in organic solvents.

3.4 “Methanol” to WCO molar ratio

In the transesterification methodology to make biodiesel, the molar proportion of utilized cooking oil to “methanol” is ordinarily roughly 1:3. This indicates that the process requires approximately 3 moles of “methanol” for every mole of used frying oil. The waste cooking oil's fatty substances are responded with “methanol” and an impetus during the transesterification interaction to make “biodiesel”(unsaturated fat methyl esters) and glycerol. The abundance “of methanol” advances the union of “biodiesel” by speeding up the cycle. The methanol-triglyceride stoichiometric molar ratio during the transesterification process is 1:3. As a result, The rate change in yield has been seen with the response temp at 50°C, response span at an hour and a half, and keeping up with the 1% ideal worth of the impetus amount with the mass of the WCO.

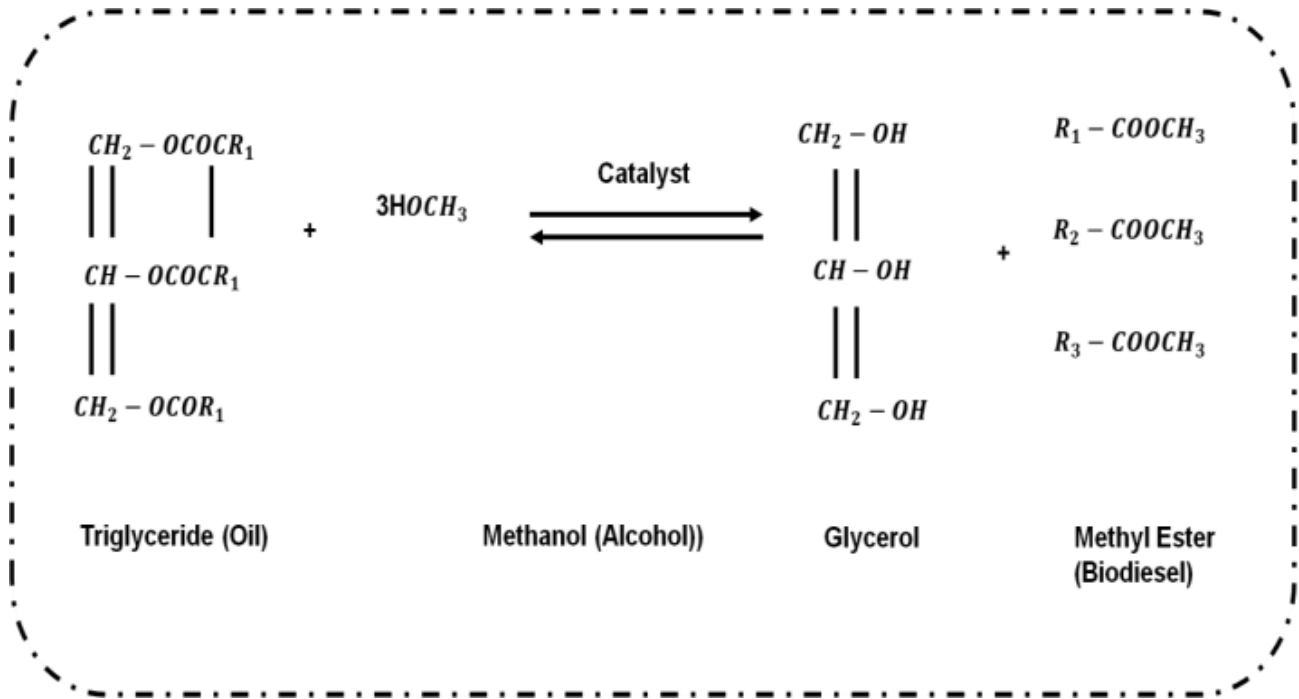


Figure 1: Methyl Ester (Biodiesel)

Table 1: Physicochemical parameters of the collected waste frying oil

Physicochemical property	Values
objective status at 40°C	fluid
FFA content (Wt % of oil)	1.55
Rate of Iodine (g I ₂ /100 g)	85
Thickness at 40 °C in mpa.seconds (Dynamic)	58.32
Thickness at 40 °C in mm ² /s (Kinematic)	63.39
shade	Oily
Solidity at 40°C (in Kg/m ³)	921
Ash substance	0.022
acidic rate (mg KOH/gm)	3.09

Table 2: XRD structure results at peak levels

Two values in Degree	λ - X-ray wavelength in nm	Intensity	K-constant	D-(size) In nm	β-beta FWHM
32.26	0.1540	384.4	0.95	27.1	0.33°
37.42	0.1540	1001	0.95	27.38	0.33°
53.93	0.1540	496.9	0.95	29.15	0.33°
64.21	0.1540	123.8	0.95	30.63	0.33°

67.40	0.1540	95.7	0.95	31.22	0.33°
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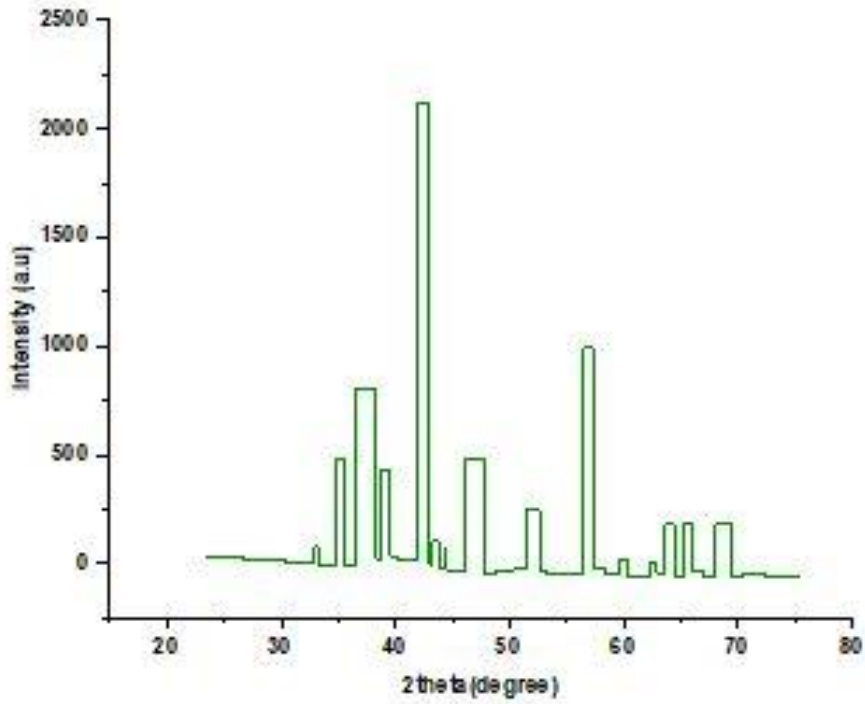


Figure 2: XRD of produced “CaO” with NC

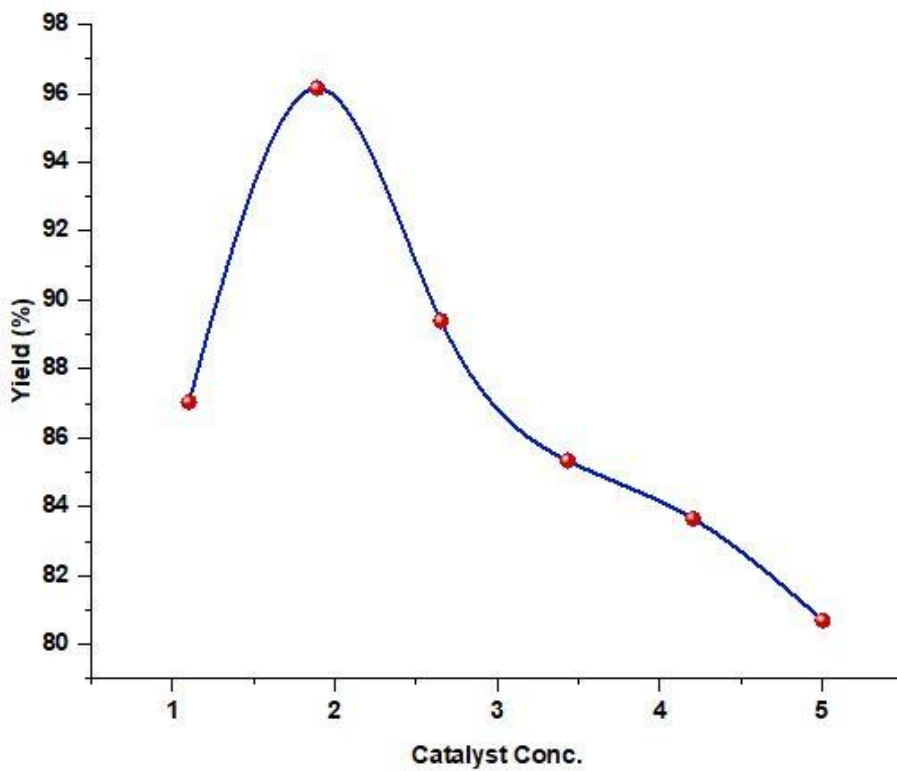


Figure 3: Manipulation of the “CaO” Catalyst concentration (%) on “biodiesel” yield (%)

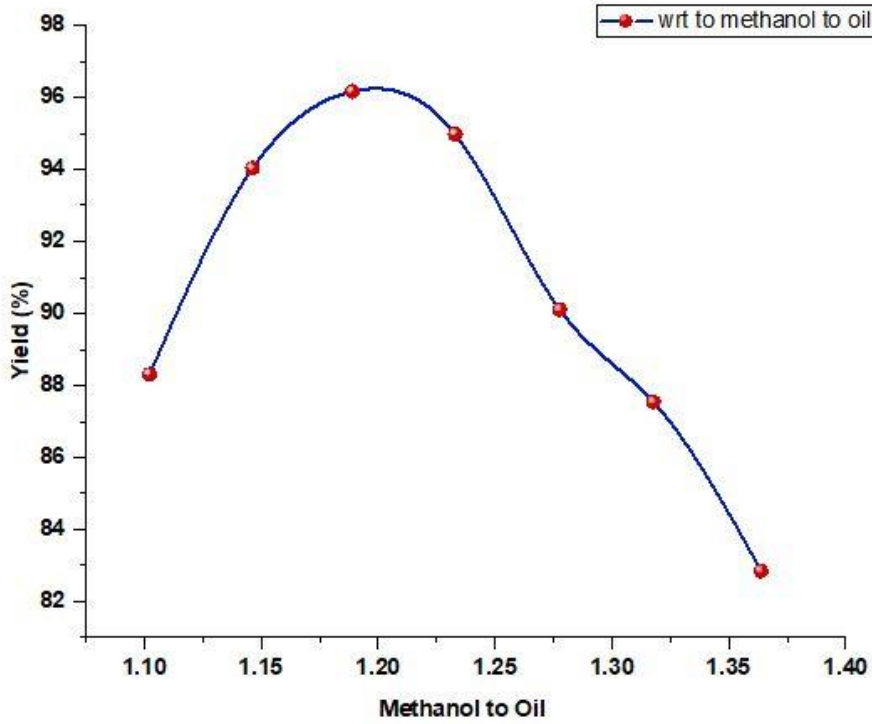


Figure 4: WCO “methanol” ratios from 1:4 to 1:10 affect “biodiesel” yield (%)

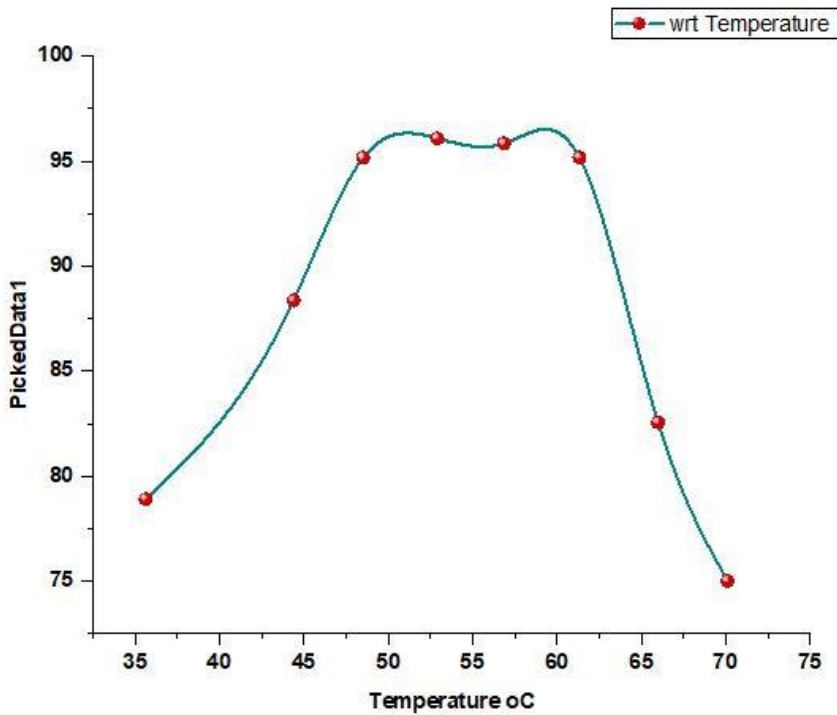


Figure 5: Response temperature on “biodiesel” yield (%)

Table 3: Compared to standards and biodiesel's properties

Property	Test Result	EPSE Diesel Limits	ASTM D6751, limit for B100
Thickness at 15 °C, g/ml	0.8799	Statement	—
Thickness at 20 °C, g/ml	0.8764	Statement	—
Flash Point (PMCC-FPT), oC	97	Mini 61	Mini 94
Cloud point, oC	10	Maxi + 6	Report
Kinematic stickiness at 40 C mm ² /sec	5.3	1.9–6.1	1.8–6.0
Water and sediment, % v/v	0.03	Maxi 0.06	Max. 0.06
Total Acidity, mg KOH/g	0.498	—	Maxi 0.501 (D874)
Ash content, mass %	Trace	Maxi 0.02	Maxi 0.02 (D874)
Sulfur content, mass%	0.0144	Max. 3	Maxi. 0.06

The amount of “biodiesel” produced is significantly partial by the oil to “methanol” molar ratio shown in Figure 4. While the molar ratio is increased commencing 1:5 to 1:9, the yield of “biodiesel” also rises. The ideal ratio of oil to “methanol” was originated to be 1:9, which resulted in 96% biodiesel. “methanol” should be available in abundance to support the improvement of methoxy species on the impetus' outside, which resolve build the speed of methanolysis. A byproduct of the transesterification process is glycerol. Glycerol is very soluble in excess methanol, so it prevents “methanol” from reacting with the reactants and catalysts. As a result, it is more challenging to separate the product's glycerol from the glycerol, resulting in an opposite shift in equilibrium and a decrease in “biodiesel” yield.

3.5 Response temperature

Keeping up with the impetus stacking and molar proportion of “methanol” to oil at their ideal levels while shifting the response temp commencing 30 °C to 70 °C has created the consequence displayed in Figure. 5. A variety of response temp range from 30 to 70 °C, Tat demonstrates the invention of “biodiesel” from used cookery oil. The perfect temperature, 50 °C, results in a “biodiesel” output of 96%. As the temp climbs, the “biodiesel” yield increments. Over this point, the creation quickly dropped down, topping a 74% yield at 70 °C.

Thermal energy is required to overcome the diffusion resistance that has built up over the three stages of the response mixture. When methanol's boiling point is reached, it will quickly evaporate and form an important number of foam, which slows down the procedure and lowers the production of biodiesel.

3.6 General effects of the response parameter

As displayed in Table 3, the created biodiesel's thickness, explicit gravity, water, and dregs content, all-out sharpness, debris content, and sulfur content were undeniably taken a look at as per ASTM D6571. Squander cooking oil may be changed over into biodiesel, a greener option in contrast to diesel fuel, to be utilized in homes for cookery.

4. Conclusion

A “CaO” NC with an indicated particle size of 30 nm was produced through thermal decay, and it was then used as a catalyst in the transesterification of WCO to produce biodiesel. The ideal response boundaries, which incorporated a WCO to “methanol” molar proportion of 1:9, 1 weight percent of “CaO” NC, 50 °C response temp, and a response time of an hour and a half, prompted an ideal “biodiesel” yield of 96%. The generated biodiesel's thickness, explicit importance, stream and deposit content, entire acidity, ash content, and sulfur content were all examined following ‘American fuel standards (ASTM D 6571). The outcomes demonstrated that the “biodiesel” met the standard to a high degree. “biodiesel” from WCO is not only a cleaner alternative to diesel fuel for home cooking, but it is also an environmentally friendly method for recycling fried vegetable oil.

References

- [1] N. A. F. A. Zik, S. Sulaiman, P. Jamal, (2020). Biodiesel production from waste cooking oil using calcium oxide/nanocrystal cellulose/polyvinyl alcohol catalyst in a packed bed reactor. *Renewable Energy*, 155, 267-277.

- [2] R. Foroutan, R. Mohammadi, H. Esmaeili, F. M. Bektashi, S. Tamjidi, (2020). Transesterification of waste edible oils to biodiesel using calcium oxide@ magnesium oxide nanocatalyst. *Waste Management*, 105, 373-383.
- [3] Y. S. Erchamo, T. T. Mamo, G. A. Workneh, Y. S. Mekonnen, (2021). Improved biodiesel production from waste cooking oil with mixed methanol-ethanol using enhanced eggshell-derived CaO nano-catalyst. *Scientific Reports*, 11(1), 6708.
- [4] C. Komintarachat, S. Chuepeng, (2020). Catalytic enhancement of calcium oxide from green mussel shell by potassium chloride impregnation for waste cooking oil-based biodiesel production. *Bioresource Technology Reports*, 12, 100589.
- [5] M. Ahmad, S. Asif, J. J. Klemeš, M. Mubashir, A. Bokhari, S. Sultana, P. L. Show, (2022). Conversion of the toxic and hazardous Zanthoxylum armatum seed oil into methyl ester using green and recyclable silver oxide nanoparticles. *Fuel*, 310, 122296.
- [6] A. Rafati, K. Tahvildari, M. Nozari, (2019). Production of biodiesel by electrolysis method from waste cooking oil using heterogeneous MgO-NaOH nano catalyst. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 41(9), 1062-1074.
- [7] M. Ahmad, A. Y. Elnaggar, L. K. Teong, S. Sultana, M. Zafar, M. Munir, S. Z. U. Abidin, (2022). Sustainable and eco-friendly synthesis of biodiesel from novel and non-edible seed oil of *Monotheca buxifolia* using green nano-catalyst of calcium oxide. *Energy Conversion and Management: X*, 13, 100142.
- [8] K. Cholapandian, B. Gurunathan, N. Rajendran, (2022). Investigation of CaO nanocatalyst synthesized from *Acalypha indica* leaves and its application in biodiesel production using waste cooking oil. *Fuel*, 312, 122958.
- [9] M. Zhang, G. Ramya, K. Brindhadevi, M. Alsehli, A. Elfakhany, C. Xia, A. Pugazhendhi, (2022). Microwave assisted biodiesel production from chicken feather meal oil using Bio-Nano Calcium oxide derived from chicken egg shell. *Environmental Research*, 205, 112509.
- [10] S. S. Bargole, P. K. Singh, S. George, V. K. Saharan, (2021). Valorisation of low fatty acid content waste cooking oil into biodiesel through transesterification using a basic heterogeneous calcium-based catalyst. *Biomass and Bioenergy*, 146, 105984.
- [11] N. F. Sulaiman, N. I. Ramly, M. H. Abd Mubin, S. L. Lee, (2021). Transition metal oxide (NiO, CuO, ZnO)-doped calcium oxide catalysts derived from eggshells for the transesterification of refined waste cooking oil. *RSC advances*, 11(35), 21781-21795.
- [12] S. Rasheed, R. Begum, Amirullah, A. Rasheed, A. A. Khan, A. Zubair, (2022). Optimised biodiesel production from waste vegetable cooking oil catalysed by green synthesised calcium oxide nanoparticles. *International Journal of Renewable Energy Technology*, 13(4), 377-395.
- [13] B. Aghel, A. Gouran, E. Parandi, B. H. Jumei, H. R. Nodeh, (2022). Production of biodiesel from high acidity waste cooking oil using nano GO@MgO catalyst in a microreactor. *Renewable Energy*, 200, 294-302.
- [14] W. Nabgan, B. Nabgan, M. Ikram, A. H. Jadhav, M. W. Ali, A. Ul-Hamid, N. F. Khusnun, (2022). Synthesis and catalytic properties of calcium oxide obtained from organic ash over a titanium nanocatalyst for biodiesel production from dairy scum. *Chemosphere*, 290, 133296.
- [15] J. Kataria, S. K. Mohapatra, K. J. J. O. T. E. I. Kundu, (2019). Biodiesel production from waste cooking oil using heterogeneous catalysts and its operational characteristics on variable compression ratio CI engine. *Journal of the Energy Institute*, 92(2), 275-287.
- [16] A. Gouran, B. Aghel, F. Nasirmanesh, (2021). Biodiesel production from waste cooking oil using wheat bran ash as a sustainable biomass. *Fuel*, 295, 120542.
- [17] L. di Bitonto, H. E. Reynel-Ávila, D. I. Mendoza-Castillo, A. Bonilla-Petriciolet, C. J. Durán-Valle, C. Pastore, (2020). Synthesis and characterization of nanostructured calcium oxides supported onto biochar and their application as catalysts for biodiesel production. *Renewable Energy*, 160, 52-66.
- [18] A. Attari, A. Abbaszadeh-Mayvan, A. Taghizadeh-Alisarai, (2022). Process optimization of ultrasonic-assisted biodiesel production from waste cooking oil using waste chicken eggshell-derived CaO as a green heterogeneous catalyst. *Biomass and Bioenergy*, 158, 106357.