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Effects of Transesterification Process Parameters on Production of Biodiesel from Oil Extracted From Cat Fish Using Raw, Acid, Alkaline and Thermally Modified Potassium Hydroxide as Catalyst

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ABSTRACT: This research work was aimed at studying the effects of transesterification process parameters on the production of biodiesel from oil extracted from catfish using raw, acid, alkaline, and thermally modified potassium hydroxide from clay as catalysts. The catfish oil was extracted using an oven at a temperature of 35 °C. The extracted catfish oil was converted into biodiesel using the transesterification method at a constant temperature of 60 °C for 60 min. The process parameters for the production of biodiesel from fish oil using raw, acidic, alkaline, and thermally modified potassium hydroxide from clay as catalysts were analyzed. The process parameters: methanol to oil molal ratio (mol/mol), catalyst concentration (weight%), reaction time (hours), reaction temperature (°C) and agitation speed (rpm) were the independent variables used in determining the biodiesel yield (vol/vol), which was the dependent variable. The experimental or actual maximum optimal biodiesel yield for biodiesel production from the process parameters had different yields using the fish oil with raw, acid, alkaline, and thermal KOH as catalysts. Results obtained showed the highest biodiesel yield was obtained at a reaction time of 3 hours, a reaction temperature of 70 °C, a methanol/sample molal ratio of 12:1, a catalyst concentration of 4 wt%, and an agitation speed of 400 rpm, respectively. It was also observed that the agitation speed and the thermally modified KOH catalyst had a significant effect on the biodiesel yield.

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The challenges plaguing the world in terms of global warming are enormous. Environmental contamination and a decline in fossil fuel supplies have prompted the hunt for an alternate source of energy. Due to global warming and the depletion of fossil fuels, more research has been conducted in order to promote higher usage of biofuels over fossil fuels. Biodiesel, a leading biofuel with a clean energy source, has served as a viable alternative to fossil fuels and petroleum-based fuels. All around the world, only about half of edible oils are recycled into animal feed or used as raw materials for paint or lubricants, with the remainder

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thrown into the environment. Finally, using this waste oil for biodiesel production is critical to reducing and recycling it into viable biodiesel for biofuels, removing the environmental and health concerns associated with it and lowering the cost of biodiesel manufacturing. Biodiesel has typically higher oxygen content, and more chemically active as solvent than the conventional petroleum diesel. (Rahman *et al*., 2021). With an expanding global population, the current reliance on natural resources is no longer sustainable, necessitating the development of alternative energy sources due to the environmental effects caused by natural resource depletion. The extraction of bioactive compounds from agro-industrial waste and food or bye products for production of high market value products thereby reducing the reliance on natural resources is welcoming development. (Carneiro *et al.,* 2018). Since the introduction of diesel-powered automobile engines, petroleum-based diesel (Petro-diesel) has been the primary source of combustive energy for these engines. Continuous use of fossil fuels has contributed significantly to environmental pollution, including ozone layer depletion, greenhouse gas emissions, energy insecurity, and other impacts linked to incomplete combustion and poisonous pollutants. Research aimed at exploiting non-edible plant and animal resources as an alternative to traditional fossil fuels, which would normally impact the environment as a result of these issues, is critical. This ensures cleaner energy that is less environmentally hazardous, as well as the use of bio-resources that might otherwise contribute to pollution. 86% of the world energy consumption and about 100% of the energy used in the transportation sector are generated from fossil fuels (Demirbas, 2009). Currently, the number of accessible oil reservoirs across the world is constantly decreasing. As a result, long-term policies must be developed that focus on the use of renewable fuels to progressively replace the decreasing production of fossil fuels. According to Dhar *et al*., (2012), the production and consumption of fossil fuels have increased the concentration of CO_2 in the atmosphere, therefore causing damage to the environment. Biodiesel has grown in popularity as an alternative to standard petroleum-based diesel fuels due to its ability to minimize greenhouse gas emissions and reliance on fossil resources. It is made from renewable sources like as plant oils, animal fats, and even algae, making it an eco-friendly choice. According to Aransiola *et al*., (2012), 95% of biodiesel is processed from edible oil which may create a lot of problem, such that in the long run, there will be a shortage of food supply leading to global imbalance and demand in the market. In converting these edible oils into biodiesel, food availability will decrease since the food resources will have been converted into automotive fuels. According to the study, the increase in oil crop plantations for biodiesel production will increase deforestation in several countries. Subsequently, the link between food and fuel income will be blurred because both fields will be competing for the same oil resources. This means that the biodiesel industry will be competing for space with the food industry for increased plantations of oil crops. Therefore, nonedible oils and feedstocks become essential and more sustainable oils for biodiesel production. However, this research considers a non-edible feedstock for biodiesel production by exploring the extracted oils of the non-edible waste gotten from smoked catch fish oil. Biodiesel can be considered an alternative to fuel since it reduces greenhouse gas emissions while delivering cleaner source energy by releasing CO_2 during emissions, balancing the CO_2 used during feedstock growth. Biodiesel is a fatty acid monoester derived from renewable feedstocks such as animal fats, vegetable oil, etc. There are numerous methods for dealing with triglyceride viscosity, including pyrolysis (heat cracking), dilution, transesterification, and microemulsion. The most commonly used method is transesterification which is an ester conversion process that splits up the triglycerides thereby replacing it with alkyl radical of the used alcohol. (Rama *et al.,* 2019).

MATERIAL AND METHODS

The methods adopted for this work are a sequential pattern of events that include sample collection and preparation, oil extraction and characterization, catalyst preparation and characterization, biodiesel production from extracted catfish oil, and a study on their effect on the process parameters of biodiesel production.

Materials utilized for this work: The materials utilized for this work include glassware and other consumables, analytical-grade reagents, and electronic equipment, which are listed below;

Glass wares and consumables: The glassware and consumables utilized for this work are the conical flask, beaker, Soxhlet extraction apparatus, measuring cylinder, pycnometer, three-neck round bottom flask, reflux condenser, separating funnel, viscometer, petri dish, filter paper, masking tape, spatula, forceps, and masking foil. All glassware used was manufactured by pyrex.

Analytical-grade reagents: The analytical-grade reagents used are ethanol, sodium hydroxide, calcium oxide, magnesium oxide, lithium carbonate, sodium thiosulfate, chloroform, acetic acid, potassium hydroxide, sulfuric acid, hydrochloric acid, phenolphthalein, and starch. All analytical-grade reagents listed are manufactured by May and Baker.

Electronic equipment: The electronic equipment utilized for this research work includes a weighing balance, laboratory hot plate, heating mantle, tabletop refractometer, muffle furnace, and hot air oven.

Sample Collection, Preparation, and Characterization: The catfish was obtained from a local fish farming and processing farm. The catfish was prepared and dried in an industrial oven. During the drying process, the catfish oil was collected and stored. The collected sample was subjected to physicochemical characterization in order to ascertain values for its moisture content, free fatty acid, acid value, refractive index, peroxide value, iodine value, saponification value, flash and fire point, kinematic viscosity, cloud and pour point, specific gravity, molecular weight, energy value, etc. The extracted sample yield was then calculated using equation 1.

$$Oil\ yield\ (\%) = \frac{Weight\ of\ oil}{Sample\ weight}(100)\ (1)$$

Equation 1: Equation used to calculate the sample yield extracted from the smoked cat fish.

Moisture content: The moisture content was determined by the dry oven method. With this procedure, it was possible to quantify the amount of moisture present in the sample. 5 g of the sample was weighed into a dry, clean petri dish of already known weight. The dish and the sample are then introduced into a hot-air laboratory oven set to 105 °C. After an hour, the petri dish containing the sample is removed from the oven and placed in a desiccator, where it is allowed to cool. After cooling, the final weight is taken. The moisture content was then calculated using equation 2.

$$\%\ moisture = \left(\frac{\text{Weight loss}}{\text{Sample weight}}\right) * 100 \quad (2)$$

Specific gravity: The specific gravity was determined according to the method described in Sivaramakrishnan and Ravikumar, (2012). A 50-ml pycnometer (specific gravity bottle) is initially weighed. It is then filled to the mark with the sample and reweighed. The specific gravity value was then calculated using equation 3.

$$Specific\ gravity = \frac{\text{Sample mass}}{\text{Sample volume}} \quad (3)$$

Refractive index: The refractive index was determined using a tabletop refractometer (HI96800), manufactured by Hanner Instruments.

Kinematic viscosity: The measurement of kinematic viscosity was done using a glass u-tube viscometer manufactured by PoultenSelfe and Lee Ltd. (PSL ASTM-IP 350). The sample flow time is calculated as the time in seconds it takes the sample to flow from the upper meniscus to the lower meniscus of the bulb. The kinematic viscosity value was then calculated using equation 4.

$$Kinematic\ viscosity = ct(mm^2s^{-1})\ (4)$$

Where c is a viscosity constant 0.4891 and t = time

Free fatty acids: The free fatty acid was determined according to the method specified in ASTM 2004. With this method, 0.5 g of the sample was weighed into a 250 ml volumetric flask, and 20 ml of ethanol and 3 drops of phenolphthalein were added. The whole solution was allowed to homogenize and then titrated with a 1 molar solution of sodium hydroxide. The FFA value was then calculated using equation 5.

$$FFA = \frac{(Titre\ value)(conc.\ of\ KOH)\ (56.1)}{\text{Sample weight}} \quad (5)$$

Peroxide value: The peroxide value was determined according to the method of Boerlage and Broeze, (1994). Adopting this method, 0.5 g of the sample was weighed into a conical flask. A mixture of 25 ml of glacial acetic acid and chloroform in a ratio of 2:1 was added to the sample. 1 ml of 10% potassium iodide was also added, and the mixture was agitated vigorously, covered, and kept in the dark for one minute. Afterwards, 35 ml of starch indicator was added. The whole solution was titrated with 0.02 molar sodium thiosulfate solution, and a change in color from pale black to white was observed. Titration was also made for blanks. The peroxide value was then calculated using equation 6.

$$Peroxide\ value = \frac{(100)(\text{V1} - \text{V2})(\text{Conc. of titrant})}{\text{Sample weight}} \quad (6)$$

Where V_1 is titre value of sample and V_2 is titre value of blank

Iodine value: The iodine value was determined according to the method of Boerlage and Broeze, (1990). Adopting this method, 0.5 g of the sample was weighed. 15 ml of chloroform and. 25 ml of Wiji's solution are added and agitated vigorously. The mixture was covered tightly and placed in the dark for thirty minutes. Afterwards, 20 ml of 10% KI and 150 ml of distilled water were added. The solution was observed as it turned red. 5 ml of 5% starch solution indicator was added, and the mixture was observed as the solution turned blue-black. The solution was titrated with a 0.1N sodium thiosulfate solution until a black precipitate appeared in the colorless solution. Titration was also made for blanks. The iodine value was then calculated using equation 7.

$$Iodine\ value = \frac{(12.69)(\mathrm{V2} - \mathrm{V1})(\mathrm{Conc.\ of\ titrant})}{\mathrm{Sample\ weight}} \quad (7)$$

Where V_1 is titre value of sample and V_2 is titre value of blank

Saponification value: The saponification value was determined according to the method of Boerlage and Broeze, (1994). In this method, 0.5 g of the catfish oil was weighed into a conical flask. 50 ml of 0.5 N ethanoic KOH was added to the sample. The mixture was refluxed to saponify the sample. The unreacted KOH was titrated back with 0.5N hydrochloric acid using three drops of phenolphthalein as an indicator. The saponification value of the sample was calculated using equation 8.

$$Saponification\ value = \frac{(\mathrm{V2} - \mathrm{V1})(\mathrm{Conc.\ of\ titrant})(56.1)}{\mathrm{Sample\ weight}} \quad (8)$$

Molecular weight: The molecular weight was determined using equation 9

$$Molecular\ weight\ (MW) = \frac{56.1 \mathrm{\ x\ } 1000 \mathrm{\ x\ } 3}{(\mathrm{SV} - \mathrm{AV})} \quad (9)$$

Where AV = (mKOH/moil, mg/g) and SV is the saponification value (mKOH/moil, mg/g)

Ester value: The ester value was measured using equation 10

$$Ester\ value = \frac{100 \mathrm{\ x\ } (\mathrm{IS} - 1\mathrm{A})}{\mathrm{IS}} \quad (10)$$

Where IS represent index of saponification and IA represents index of FFAs

Melting point: The melting point was determined using a melting point apparatus.

Energy value: The energy value was determined using a bomb calorimeter manufactured by Par.

Catalyst modification processes: The catalysts were modified with sulfuric acid (H_2SO_4), calcium oxide (CaO), and thermally in order to enhance their performance, stability, selectivity, optimize their processes, improve product quality, and reduce production costs.

Acid modification processes: To achieve acidic modification, the catalyst (KOH) was modified with sulfuric acid, H_2SO_4. The acidification or neutralization process was carried out by gradually adding H_2SO_4 to a previously prepared 10% w/w KOH solution while stirring the mixture at a temperature range of 25 to 30 °C. The pH of the combination was regularly checked until it reached 7.0 (the neutralization point). The mixture was then filtered to remove precipitates or impurities, rinsed with water and methanol to remove any remaining acid or impurities, and heated to produce a powdered modified catalyst.

Alkaline modification processes: In order to modify the catalyst with an alkaline solution, the catalyst (KOH) was treated with calcium oxide (CaO). This procedure involved adding 2% w/w calcium oxide (CaO) to a previously prepared 10% w/w KOH solution while stairing. The mixture was then heated to between 100 and 150 °C, allowed to cool, and then filtered to eliminate any remaining solids or impurities.

Thermal modification processes: To thermally modify the catalyst (KOH), it was heated in an oven to 150 °C for 2 hours in order to improve its surface area and catalytic activity.

Biodiesel Production (Transesterification) and Purification Process: The transesterification reaction was carried out in a 500 ml, three-necked glass spherical reactor equipped with a thermometer, sample outlet, and condensation system. The heating system consists of an electromagnetic hot plate that heats the reactor and rotates the metal knob in the reactor via an electromagnetic field. To eradicate moisture, the reactor was preheated to 65 °C. A reflux condenser with cold water running through the outer jacket was inserted in the reactor's mid-neck, and a mercury-filled glass thermometer was stored in a plastic bung installed in the reactor's right neck. The left neck of the reactor was also left open for reactant input (oil mixture, methanol, and catalyst) before being closed. To guarantee proper dissolution, the calculated amount of methanol and catalyst were added to each experiment's sample and pre-stirred for 3 minutes. Then, 50 ml of the sample mixture was added, and the stirring mechanism was activated at the determined agitation speed, establishing time zero of the reaction. Each reaction was allowed to continue at the designated time and temperature. After the metanalysis reaction was finished, the transesterification product was allowed to sit in a separating funnel for twelve hours to separate the glycerol and methyl ester (biodiesel). The glycerol was removed using the funnel tap, leaving behind the methyl ester (biodiesel), as shown in figure 1. A drop of 1 mol of sulfuric acid was applied to the separating funnel containing the biodiesel. Hot distilled water was also added, and the mixture was vigorously stirred. The mixture was then allowed to settle and separate into two phases: water and water-soluble pollutants on the bottom, and biodiesel on top. The two separated-phase mixtures will subsequently be separated using the separating funnel tap. The washed lower layer of water was decanted into a beaker and discarded, while the washed upper biodiesel layer was rinsed again to ensure adequate separation. As the washing procedure progressed, three drops of phenolphthalein indicator were added to the waste water, which became brilliant and continued to be pink when tested with phenolphthalein. To remove any remaining impurities and undesired components, such as excess methanol or existing water impurities, the washed biodiesel sample was dried on a laboratory hot plate at roughly 100 °C for 1 hour until it appeared crystal clear, allowing the residual water molecules to evaporate. The biodiesel was then cooled and placed in metric specimen bottles.

Fig 1: Biodiesel and glycerin separation process, glycerol filtration process and produced biodiesel sample.

Investigation of the effect of production process parameters on biodiesel yield: The catalyst concentration, reaction time, temperature, methanol/sample mole ratio, and agitation speed were varied sequentially in the following order:

Effects of catalyst concentration: In order to ascertain the effect of catalyst concentration on the biodiesel yield, all other parameters were kept constant (temperature at 50 °C, reaction time at 3 hours, methanol/oil sample mole ratio at 12:1, and an agitation speed of 300 rpm). The catalyst concentration was varied at 1%, 2%, 3%, 4%, and 5%.

*Effects of reaction time***:** In order to ascertain the effect of the reaction time on the biodiesel yield, the reaction time was varied at different intervals: 1 h, 2 h, 3 h, 4 h, and 5 h for each production. While other process conditions were kept constant (temperature at 50°C, methanol/oil sample mole ratio at 12:1, agitation speed at 400 rpm, and catalyst concentration of 3%).

Effect of reaction temperature: In order to ascertain the effect of reaction temperature on the biodiesel yield, the reaction temperature was varied at 40°C, 50°C, 60°C, 70°C, and 80°C. While catalyst concentration and reaction time were kept constant at 3% and 3 hours, respectively, the methanol/oil sample mole ratio was kept constant at 12:1, while the agitation speed was kept constant at 400 rpm for the reaction period.

Effects of agitation speed: In order to ascertain the effect of agitation speed on the biodiesel yield, the agitation speed was varied at 100 rpm, 200 rpm, 300 rpm, 400 rpm, and 500 rpm. While catalystconcentration was at 3%, reaction time was at 3 hours, temperature was at 50°C, and the methanol/sample mole ratio was kept constant at 12:1.

Effects of the methanol/oil mole ratio: In order to ascertain the effect of the methanol/sample mole ratio on the biodiesel yield, the methanol/sample mole ratio was varied at 4:1, 6:1, 8:1, 10:1, and 12:1. While other parameters were kept constant as follows: catalyst concentration and reaction time were kept constant at 3% and 3 hours, respectively; the methanol/oil sample mole ratio was kept constant at 12:1; the agitation speed was kept constant at 400 rpm; and the temperature kept constant at 50°C for the reaction period.

RESULTS AND DISCUSSION

Analysis of the physiochemical properties of the oil sample: As shown in Table 1, viscosity is a measure of the fluidity of a sample. That is the measure of resistance to flow; the greater the viscosity, the less readily the liquid flows. It is one of the most important parameters required in the design of a combustion system. A direct relationship exists between the oil viscosity and some chemical characteristics of the lipids, including the degree of unsaturation and chain length of the fatty acids that constitute the triacylglycerol. Viscosity slightly decreases with an increased degree of unsaturation and rapidly increases with polymerization (Stanciu, 2011). Gunstone, (2008) reported that the viscosity of oil is highly temperature-dependent and that each oil has a specific viscosity curve, which depends on its chemical composition and quantity of impurities. It is important to note that the viscosity of biodiesel is highly dependent on the type of feedstock oil used. The density of the sample was found to be 884.6 kg/m^3, therefore evaluating the specific gravity, which is the ratio of the density of the substance to that of water (1 g/cm^3) at 15.6 °C, implies that the specific gravity of the sample is 0.8846. This can be used to determine the purity of the sample to match the desired standards. The specific gravity of the sample was 0.8846; this value falls within the standard range required for biodiesel production, which is 0.87 to 0.90 (Ibeto, 2012). The higher the viscosity, the more the oil tends to cause problems such as incomplete combustion and particulate matter emissions when used directly in diesel engines (Ziejewski *et al.***,** 1993). Trans-esterification of oils and fats using short-chain alcohols such as methanol results in monoesters having viscosities closer to petroleum-based diesel fuel (Graboski and McCormick, 1998). The specific gravity of biodiesel will depend on the type of feed stock used, the fatty acid composition of the mixed esters, and their purity. It is essential to monitor the specific gravity of diesel fuel and correlate it against performance indicators, such as the cetane number and heating value. However, the specific gravities of hydrocarbons are strongly affected by temperature (Tat and Van Gerpen, 2000). The refractive index is used to measure the increase in the autoxidation of fats and oils. The refractive index of oils depends on their molecular weight, fatty acid chain length, degree of unsaturation, and degree of conjugation. The refractive index of an oil increases (nonlinearly) with chain length and the unsaturation of fatty acids. The refractive indices and peroxide values of the oils and fats can significantly increase while exposed to light and heat. Generally, an oil's refractive index values vary between 1.447 and 1.482. The refractive index value obtained for the sample was 1.4648. The degree of unsaturation of an oil greatly influences its oxidative stability and the stability of the biodiesel derived from it (Shahidi, 2005). The moisture content of the sample is 0.931% by weight. This obtained moisture content value is within the ASTM biodiesel standards. The moisture content in oil must not exceed 0.95% by weight according to the ASTM D4557 standards so as to prevent excessive soap formation during the chemical trans-esterification reaction. The produced soap also increases the viscosity of the reaction mixture, sometimes causing gel formation, which can trap the resulting ester and glycerin together, thereby making the separation of glycerol from ester difficult (Wright *et al.***,** 1994). Generally, it is recommended that feedstock oils do not contain too much water to ensure successful transesterification. If it does, a drying step has to be conducted prior to transesterification. Free water can be removed by centrifugation or by heating to an elevated temperature. Dissolved water, in contrast, has to be removed by steaming off (i.e., heating to near the boiling point of water) (Fan *et al.***,** 2010). A high-water content in biodiesel can cause corrosion of internal combustion engine components such as pumps, injectors, and fuel line tubes and affect the heat of combustion, which results in greater power consumption. The presence of higher amounts of water also allows microbes to grow during storage and may affect engine components such as filters and pumps. The formation of gelling and the nucleation of oil or biodiesel can take place as water may freeze at low temperatures.

When oil and fat react with alkali, their long-chain fatty acid salts result in the formation of soap, glycerol, and fatty acids. Soaps, which are the salts of longer-chain fatty acids, are produced by treating a fat with alkali. The saponification value, which is defined as the number of milligrams of potassium hydroxide required to saponify 1 gram of fat, is an indicator of the average molecular weight of the triacylglycerol in the fat sample. Dividing the mean molecular weight by 3 gives an approximate mean molecular weight for the fatty acids present in the fat sample. Fat that is composed of short-chain fatty acids will have a greater number of fatty acids compared to fats containing long-chain fatty acids. In the present study, the saponification value of the oil sample was 295.557 mg KOH/kg. This indicates the amount of potassium hydroxide (KOH) required to saponify a certain amount of oil or fat, which is an important property in determining the quality and suitability of the oil or fat for biodiesel production. This indicates a high proportion of fatty acids of low molecular weight. This shows a low tendency towards soap formation and fewer difficulties in the separation of products if utilized as feedstock for biodiesel production.

The peroxide value is the measurement of the primary oxidation product, hydroperoxide, and is a widely used chemical test for the determination of fat and oil quality (Aidos *et al*., 2001). The oxidative process of oils and fats is one of the main causes of the deterioration of the principal organoleptic and nutritional characteristics of foodstuffs. The number of peroxides present in the oil is an index of their primary oxidative level and their tendency to go rancid. The complex oxidation process can be summarized into two phases: in the first phase, fatty acids react with oxygen and determine odorless compounds as peroxides; during the second phase, the peroxides degrade into many substances as volatile aldehydes, responsible for the rancid odor and flavor; and in the non-volatile portion, The lower the peroxide value, the better the oil quality and its state of preservation (O'Brien, 2009). In this study, the peroxide value of the oil is 4.820 milliequivalents/kg. If the peroxide value is higher, the oils will not remain stable and will become rancid easily, so they should be utilized immediately after extraction.

Oil acidity is an important quality parameter determining the presence of free fatty acids (FFAs) and other non-lipid acid compounds (Rubio-Rodriguez *et al***.,** 2008).FFAs is mostly generated by a hydrolysis reaction of triglycerides. Oil acidity depends on several factors, such as oil composition, extraction procedures, and raw material freshness. The acid value quantifies the amount of acid present in the sample. It is the mass of potassium hydroxide in mg that is required to neutralize 1 gram of chemical substance (Ulberth *et al***.,** 2007). As oil goes rancid, triglyceride (TAG) converts to fatty acids (FA) and glycerol, which increases the acid number. Kai *et al***.,** (2012) reported that the acid value in feedstock oil should be less than 2.5 mg KOH/g oil for the base-catalyzed transesterification process.

Table 1: Proximate and ultimate analysis of the cat fish oil

Parameters	**Values**
Sample	Cat fish oil
Density (kg/m^3)	884.6
Kinematic viscosity @ 40^{0}C (mm^{2}s^{-1})	48.781
Refractive index @ 29^{O}C	1.4648
Acid value (mgKOH/kg)	47.486
Free acid value (mgKOH/kg)	3.593
Saponification value (mgKOH/kg)	295.557
Smoke point ^{O}C	108.00
Boiling point ^{O}C	138
Molecular weight (g/mol)	589.375
Peroxide value (meq/kg)	4.820
Moisture content (weight %)	0.931
Average oil yield (w/w %)	65.2
Specific gravity	0.8846

Effects of process parameters on biodiesel yield: The following parameters: catalyst concentration, reaction time, reaction temperature, methanol/oil ratio, and agitation speed were plotted against the biodiesel yield for the raw, alkaline, acid, and thermally modified catalysts, as shown from figures 2 to 6.

Effects of catalyst concentration on biodiesel yield: Fig. 2 below shows a graphical representation of the effect of catalyst concentration variation on biodiesel production using the different modified catalysts. The catalyst concentration variation for biodiesel production varied from 1 to 5% wt at regular intervals. The catalysts (raw, alkaline, acid, and thermal) had a maximum biodiesel yield of 69.37%, 74.09%, 80.85%, and 84.14% vol, respectively, at a concentration of 4 wt%. It was observed that the biodiesel yield increased progressively as the concentration was increased, and a decline was observed above the optimum values with all other parameters kept constant. From the plot below, it can be observed that the thermally modified catalyst had a higher biodiesel yield.

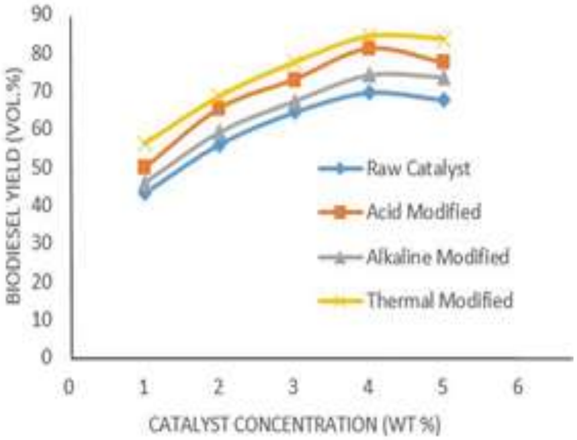

Fig 2: Effect of catalyst concentration variation on biodiesel yield

Effects of reaction time on biodiesel yield: Fig. 3 is a graphical representation of the effect of reaction time on biodiesel production using the catalysts. The time variation for the production was monitored for 1 to 5 hours at regular intervals. The catalysts (raw, alkaline, acid, and thermal) had their maximum biodiesel yield at 69.37%, 74.09%, 80.85%, and 84.16% vol, respectively, at 3 hours. For all the catalysts, biodiesel yield increased progressively with an increase in reaction time, and a decline was observed above the optimum values. From the plot below, it can be observed that the thermally modified catalyst had the optimum biodiesel yield.

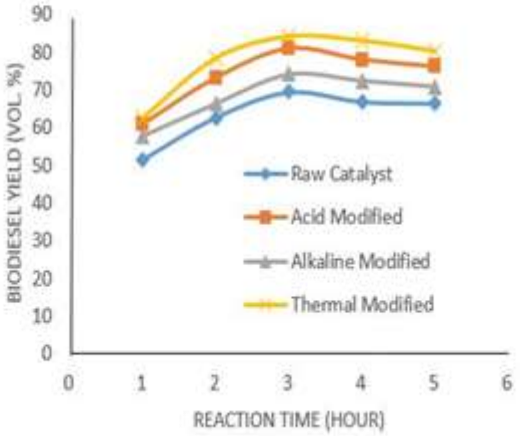

Fig 3: Effect of reaction time on biodiesel yield

Effects of reaction temperature on biodiesel yield: Fig. 4 is a graphical representation of the effect of temperature variation on biodiesel production using various catalysts. Temperature variation for the production of biodiesel was monitored from 40 °C to 80°C at regular intervals, and other parameters were kept constant. The catalysts (raw, alkaline, acid, and thermal) had their maximum biodiesel yield at 67.1%, 74.23%, 76.34%, and 91.65% vol, respectively, at a temperature of 70°C, and a decline was observed above the optimum values. From Fig. 4, it can be observed that the thermally modified catalyst had the optimum biodiesel yield.

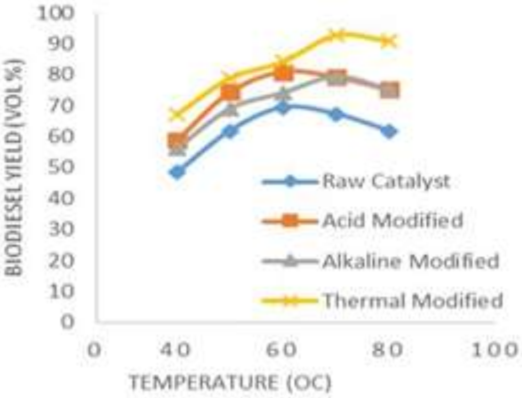

Fig 4: Effect of temperature on biodiesel yield

Effects of the methanol/oil ratio on biodiesel yield: Fig. 5 is a graphical representation of the effect of methanol/oil ratio variation on biodiesel yield using various catalysts. The methanol/oil ratio variation for the production was monitored for 4:1 to 14:1 at regular intervals. The methanol/oil ratio on the various catalysts (raw, alkaline, acid, and thermal) had their maximum biodiesel yield at 73.82%, 79.26%, 83.93%, and 91.7% vol, respectively, at a methanol/oil ratio of 12:1. However, a decline or decrease was observed above the optimal values. From Fig. 5, it can be observed that the thermally modified catalyst had the optimum biodiesel yield.

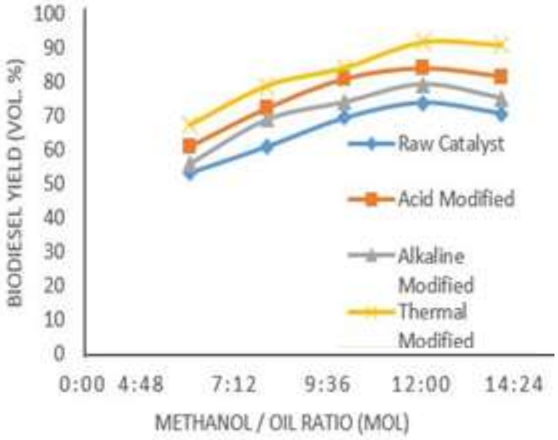

Fig 5: Effect of methanol/oil ratio on biodiesel yield

Effects of agitation speed on biodiesel yield: Fig. 6 is a graphical representation of the effect of agitation speed variation on biodiesel production using various catalysts. The agitation speed variation for the production process was monitored for 200 to 500 rpm at regular intervals. The catalysts (raw, acid, alkaline, and thermal) had their maximum biodiesel yield at 78.31%, 89.03%, 83.40%, and 96.50% vol, respectively, at an agitation speed of 400 rpm. However, a noticeable decrease was observed above the optimum values. From Fig. 6, it can be observed that the thermally modified catalyst had the optimum biodiesel yield.

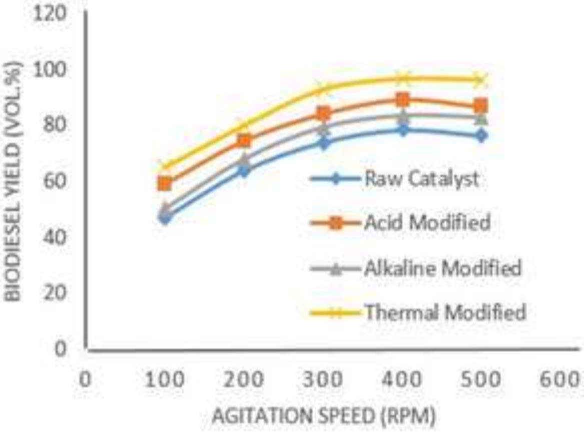

Fig 6: Effect of agitation on biodiesel yield

Conclusion: The use of potassium hydroxide catalysts has proven to be efficient in converting waste smoked catfish oils into a more useful bioenergy resource. Diesel engines can operate on smoked fish oils, but they cannot do so for an extended period. This necessitates the transesterification of the oil to obtain a lighter derivative (biodiesel), which is more combustible in diesel engines. The results obtained from this study indicated that all the process parameters, namely catalyst concentration, reaction time, reaction temperature, methanol/sample ratio, and agitation speed, all had significant effects on the biodiesel yield. Also, the triglyceride conversion to methyl ester was very satisfactory. In view of the above findings, other waste vegetable oils can be exploited using the same optimal process conditions established herein. In the alternative, other feasible methods to convert waste vegetable oils to biodiesel, which is conveniently combustible in present-day diesel engines without modification, could also be exploited.

Declaration of Conflict of Interest: The authors declare no conflict of interest in this work.

Data Availability Statement: Data are available upon request from the first author or corresponding author or any of the other authors.

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