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HOMOGENEOUS CATALYSTS FOR THE PRODUCTION OF BIODIESEL FROM GROUNDNUT OIL

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ABSTRACT

Biodiesel production from renewable feedstocks has gained significant attention as a sustainable alternative to fossil diesel due to rising energy demand and environmental concerns. In this study, biodiesel was produced from groundnut oil via alkali catalyzed transesterification using potassium hydroxide (KOH) as a homogeneous catalyst. The effects of key reaction parameters reaction temperature (50–80 °C), catalyst concentration (0.2–0.8 mol dm^{-3}), reaction time (40–70 min), and methanol to oil molar ratio (5:1–11:1) on fatty acid methyl ester (FAME) yield were systematically investigated. The physicochemical properties of the groundnut oil, including acid value and moisture content, were also determined to assess its suitability for biodiesel production. The results showed that biodiesel yield increased with increasing reaction temperature and time up to optimal values, beyond which a decline in conversion was observed. Maximum FAME conversion of 94.7% was achieved at a reaction temperature of 70 °C, catalyst concentration of 0.6 mol dm^{-3}, reaction time of 70 min, and methanol to oil ratio of 7:1. The findings demonstrate that groundnut oil is a viable feedstock for biodiesel production using homogeneous catalysis and compare favorably with yields reported in related studies employing both homogeneous and heterogeneous catalysts.

Keywords: Biodiesel, Groundnut Oil, Catalyst, Petroleum, FAME

INTRODUCTION

The exigency of energy, limited reserve, the rapidly rising price of petroleum based fuel, and the deleterious effect of greenhouse gases have dictated to steer our attention toward alternative sources of energy. The quest for eco-friendly technology is driving the research initiatives to find potential energy sources that are renewable, biodegradable, non-toxic, and mostly carbon neutral (Arbab *et* al., 2015). Biodiesel is a renewable energy source that can replace fossil-based diesel and can reduce the drawbacks of diesel emission (Abedin *et* al., 2014). Diesel is obtained by fractional distillation from crude petroleum oil that typically contains a mixture of pure hydrocarbon molecules (no oxygen molecule) that range in size from 8 to 21 carbon atoms. Biodiesel, on the other hand, consists of long-chain hydrocarbons with an ester functional group (–COOR). Thus, it is defined as mono alkyl esters of long-chain fatty acids derived from various feedstock, namely, plant oils, animal fats, or other lipids. It is also known as triacyl glycerides (TAGs), or more simply, triglycerides (Hoekman *et* al., 2012). Biodiesel is produced using the transesterification or alcoholysis process, which is usually facilitated by acids, bases, enzymes, and other type and form of catalysts (Ong *et* al., 2019). The catalysts can either be in a homogeneous or in a heterogeneous phase as of the reactants. If the catalyst remains in the same phase (usually liquid) to the reactants during alcoholysis, then that is the homogeneous catalyst. If the catalyst is in a different phase (usually non-liquid) to the reactants, then that is the heterogeneous catalyst (Ruhul *et* al., 2015). The appropriate catalyst selection depends on several factors, namely, the amount of free fatty acids (FFAs) in the oil, the water content, etc.

Energy consumption is inevitable for human existence. There are various reasons for the search of an alternate fuel that is technically feasible, environmentally acceptable, economically competitive and readily available. (Pinto *et al.* 2005). The first reason is the increasing demand for fossil fuels in all sectors of human life, be it transportation, power generation, industrial processes and residential consumption. This increasing demand give rise to environmental concerns such as larger CO_2 and greenhouse gas emissions and also global warming. Biodiesel is an alternative fuel similar to conventional diesel. (Atabani *et al.,* 2012). It is usually produced from straight vegetable oil, animal fats, tallow, non-edible plant oil and waste cooking oil. Its biodegradability, non-toxicity and being free of sulfur and aromatics makes it advantageous over the conventional petrol diesel. (Hoekman *et al.,* 2012). It emits less air pollutants and greenhouse gases other than nitrogen oxides.In addition, it is safer to handle and has lubricity benefits than fossil diesel. (Ramanathan *et al.,* 2009).

This work will utilize potassium hydroxide (KOH), a homogeneous catalyst to produce biodiesel from groundnut oil. Homogeneous catalysts are generally more reactive and highly selective compared to heterogeneous catalyst.

MATERIALS AND METHODS

Materials

Three neck round bottom flask,magnetic bar, separating funnel, magnetic stirrer, foil paper, measuring cylinder, Beaker.

Reagent

Potassium hydroxide (KOH) Methanol (CH_3OH) Distilled water.

Groundnut Oil Sampling

Finished products of Groundnut oil sample were obtained from a commercial Centre in Dutse, Jigawa state. Finished Groundnut oil product is mainly used food purpose. It is extracted using traditional methods in a very small quantity of 2 to 4 gallon per preparation, but in the recent years some industries started manufacturing groundnut oil in very huge amount.

Method of Reaction

There are different methods used in production of biodiesel, these include transesterification, Esterification, pyrolysis and on, but in this study transesterification reaction process was adopted considering the type of feedstock and the catalyst used.

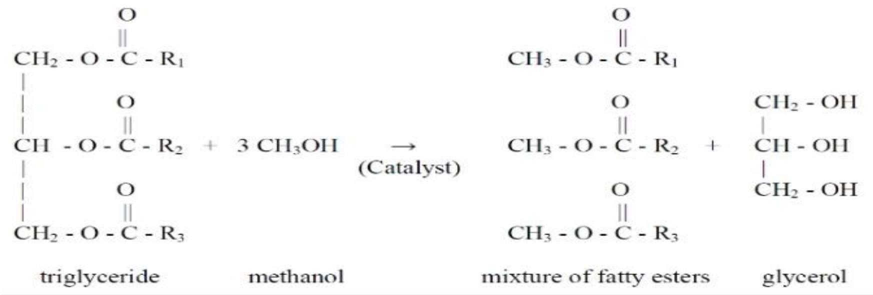

Figure 1: Transesterification Process (Mustapha et al., 2024)

Preparation of Catalyst

Potassium hydroxide (KOH) was used as catalyst for this study, which was prepared in different concentration; which are 0.20,0.40, 0.60,and 0.80 mol/dm^3. The required concentrations was obtained by dissolving 2.8g, 5.6g, 8.40, and 11.2 g of KOH Pellet in 250ml distilled water.

Transesterification Reaction

A procedure by Demirbas et al., (2009) was adopted with some modifications. A volume of 20ml of potassium hydroxide solution was measured and introduced into a 500ml three- neck round bottom flask, in the same flask 50ml of methanol was added together with the magnetic bar the flask was covered with aluminum foil paper. The round bottom flask was placed on a heating mantle (hot plate) and allowed to heat for 2 minutes. 10ml of groundnut oil was introduced into the round bottom flask, and the flask was attached to a condenser and heated to the required temperature and time on heating mantle. On completing the reaction, the mixture was allowed to cool before transferring it into the separating funnel to separate the glycerol. The excess methanol was removed by heating the mixture at 70^{o}C for 20 minutes. The catalyst was removed by washing the biodiesel with warm water and allowed to settle in the separating funnel for 24 hours. The same procedure was repeated for various reaction parameters throughout the optimization process. The biodiesel conversion was completed and recorded (Demirbas et al

Table 1: Parameters used for Transesterification Reactions

Reaction parameters	1	2	3	4
Temperature ^{o}C	50	60	70	80
Catalyst concentration (mol/dm^3)	0.20	0.40	0.60	0.80
Reaction time (mins)	40	50	60	70

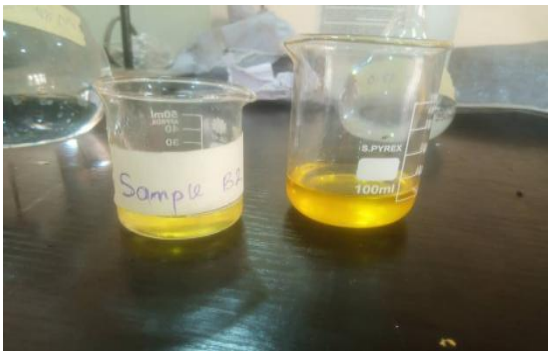

Figure 2: Biodiesel produced from the laboratory

Determination of Acid Value and Free Fatty Acid Value

A vololic potassium hydroxide solution was introduced in a burette and was titrated against 0.2g oil sample and 25 cm^3 of ethanol. Ten drops of phenolphthalein were added as an indicator. The Potassium hydroxide solution drops were added whilst stirring until a faint pink color remains. The titration was carried out three times to ensure accurate results. From the titration values acid value and free fatty acid content was calculated.

$$A.V = \frac{Mass\ of\ KOH \times M\ of\ KOH \times average\ titrate\ value}{Mass\ of\ oil\ sample\ taken} \quad (1)$$

$$A.V = \frac{56.1 \times 0.1 \times 0.1}{0.2}$$

$$A.V = 2.805$$

$$FFA = \frac{Acid\ value}{2}$$

$$FFA = \frac{2.805}{2}$$

$$FFA = 1.4025$$

Determination of Moisture Content

A volume of 100 cm^3 of groundnut oil sample was weighed and heated on a heating mantle at 100^{o}c for 7 minutes. The heated oil was allowed to cool down and then weighed.

Moisture content = Initial mass of oil sample – Final mass of oil sample

$= 81.15g - 80.05g$

$\mathbf{= 1.1g}$

The moisture content of oil sample was $1.1g$

RESULTS AND DISCUSSION

Results

The results of optimization reactions for biodiesel synthesis are presented in table 4.1 below.

Table 2: Results of Optimization Reactions for Biodiesel Production

No. of reactions	Temperature (°C)	Catalyst conc. (mol/dm^3)	Time (mins)	Methanol to oil ratio	FAME (%)
1	50	0.20	40	5:1	62.50
2	60	0.20	40	5:1	65.80
3	70	0.20	40	5:1	91.50
4	80	0.20	40	5:1	87.30
5	70	0.20	40	5:1	82.80
6	70	0.40	40	5:1	78.90
7	70	0.60	40	5:1	86.30
8	70	0.80	40	5:1	77.90
9	70	0.60	40	5:1	85.20
10	70	0.60	50	5:1	76.10
11	70	0.60	60	5:1	88.00
12	70	0.60	70	5:1	92.30
13	70	0.60	70	5:1	91.50
14	70	0.60	70	7:1	94.50
15	70	0.60	70	9:1	89.10
16	70	0.60	70	11:1	92.50

Biodiesel conversion yield was calculated using the formula below.

Biodiesel conversion (%) = $\frac{weight\ of\ biodiesel}{weight\ of\ oil\ sample} \times 100$ (2)

The graphical representation of biodiesel conversion against temperature, catalyst, reaction time, and methanol to oil ratio have been depicted in figures 1,2 ,3,and 4, respectively.

Biodiesel conversion (%) vs Temperature graph

Best temperature = 70°C

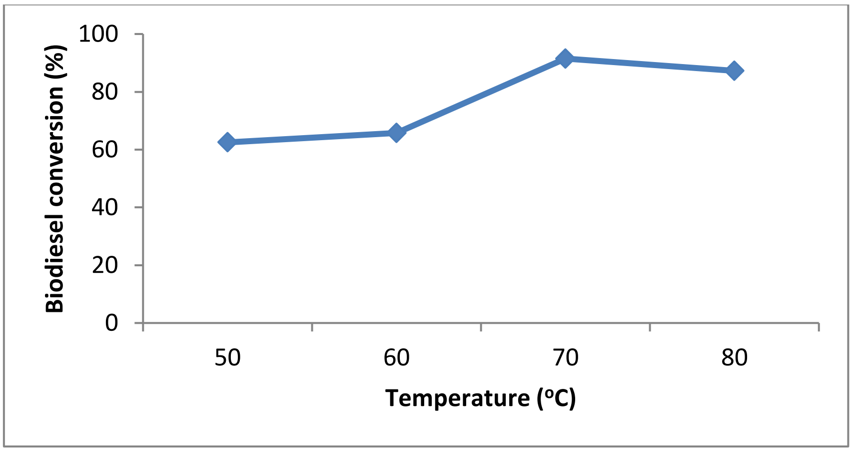

Figure 3: Effect of Temperature Reaction

Biodiesel conversion (%) vs Catalyst concentration graph

Best catalyst concentration = 0.6 mol/dm^3

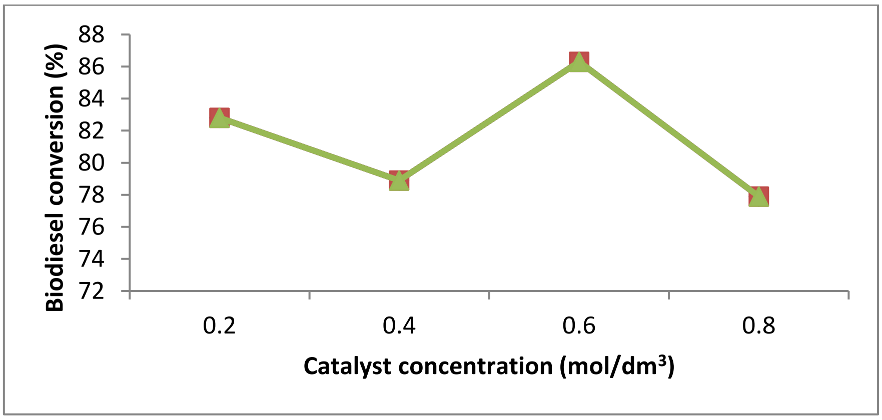

Figure 4: Effect of Catalyst Concentration

Biodiesel conversion (%) vs Reaction time graph

Best Reaction time = 70 mins

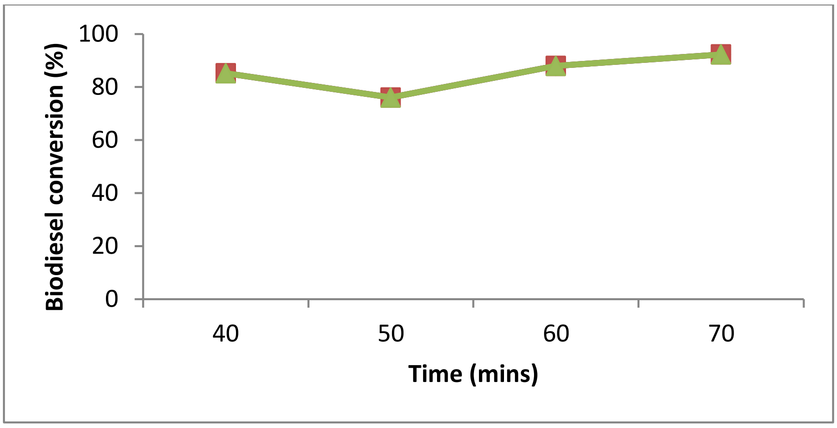

Figure 5: Effect of Reaction Time

Biodiesel conversion (%) vs Methanol to oil ratio graph
Best Methanol to oil ratio = 7:1

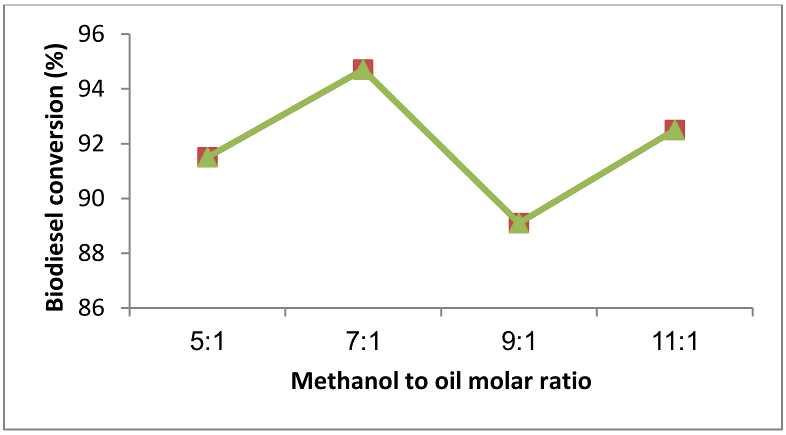

Figure 6: Effect of Methanol to Oil Ratio

Table 3 Summary of the Related Studies using Different Catalyst

Catalyst sample	Synthesis method	Feedstock	Reaction condition	FAME yield	Reference
CaO	Transesterification	Groundnut oil	3h,3wt%,1:25,160℃	98.7%	(Lee,*et.,al*,2015)
Fe_2O_3	Transesterification	Groundnut oil	5h, 3.6wt%,1:12, 60℃	89.2%	(Nunes, *et.,al,2020)*
Fe_2O_3/ CaO	Transesterification	Groundnut oil	3h,1wt%,1:15, 650℃	92%	(Ezzah *et., al2016)*
KOH	Transesterification	Groundnut oil	,0.6wt%,1:7, 70℃	94.7%	This study

Discussion

The reaction parameters have different effects on FAME (Fatty Acid Methyl Ester conversion, the Parameters used are temperature of reaction, reaction time, catalyst concentration and methanol to oil ratio. The study was carried out to derive the most needful parameter for transesterification reaction between methanol and groundnut oil using potassium hydroxide (KOH) as a catalyst.

RESULTS AND DISCUSSION

Effect of Reaction Temperature

Reaction temperature plays a crucial role in the transesterification process by influencing reaction kinetics and mass transfer between reactants. In this study, FAME conversion increased significantly as the reaction temperature rose from 50 °C to 70 °C, achieving a maximum yield of 91.5–94.7%. This enhancement can be attributed to increased molecular collisions and reduced viscosity of the reaction mixture, which facilitate better interaction between methanol and triglycerides (Usman et al., 2024).However, a decline in biodiesel yield was observed at 80 °C, likely due to methanol evaporation and possible catalyst deactivation at elevated temperatures (fereidooni et al., 2018). Similar trends have been reported by Demirbas et al., (2009) and Aghel et al., (2023), who observed optimal biodiesel yields near the boiling point of methanol.

Effect of Catalyst Concentration

Catalyst concentration strongly affects biodiesel yield by determining the availability of active sites for transesterification. The FAME conversion increased as KOH concentration was raised from 0.2 to 0.6 mol dm^{-3}, indicating enhanced catalytic activity. However, further increase to 0.8 mol dm^{-3} resulted in reduced yield, possibly due to soap formation caused by excess catalyst reacting with free fatty acids. This phenomenon hinders phase separation and lowers biodiesel recovery (suzihaque et al., 2022).Similar observations have been documented in studies by radar sadaf et al., (2018) emphasizing the importance of optimizing catalyst dosage.

Effect of Reaction Time

Reaction time influences the extent of triglyceride conversion to methyl esters. The results showed a steady increase in FAME yield with increasing reaction time, reaching an optimum at 70 min. Beyond this period, no significant improvement was observed, suggesting that equilibrium had been attained (Raqeeb et al., 2015). Prolonged reaction times may also promote reverse reactions or soap formation. This behavior aligns with findings reported by Ghosh et al., (2024) and mustapha et al., (2021), who noted that optimal reaction times typically range between 60 and 90 min for alkali-catalyzed biodiesel production.

Effect of Methanol to Oil Ratio

Methanol-to-oil molar ratio is a critical parameter in transesterification since the reaction is reversible. Increasing the ratio from 5:1 to 7:1 improved FAME conversion, with the highest yield recorded at 7:1. Further increase beyond this ratio led to a reduction in yield, which may be attributed to difficulties in glycerol separation and dilution of reactants. Similar optimal ratios have been reported in literature for groundnut oil and other vegetable oils (Usman et al., 2024; raqeeb et al., 2015).

CONCLUSION

In conclusion, biodiesel was successfully produced from groundnut oil via alkali catalyzed transesterification using methanol, in the presence of potassium hydroxide (KOH). The product (FAME) was analyzed and the results obtained are shown in figure 1, 2, 3, 4 and table 2. Biodiesel (FAME)can be synthesized at different reaction parameters which are: Reaction time , reaction temperature, catalyst concentration and methanol to oil ratio, but the most suitable ranges are 70 minutes, 70℃ , 0.6M, and 7:1 respectively. The FAME (biodiesel) produced at these reaction parameters gave the highest conversion yield which is shown in table 1.

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