Murex Turnispina Shell as Catalyst for Bio-diesel Production

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Authors' contributions

This work was carried out in collaboration between all authors. Author MOE performed the laboratory analysis, managed the literature searches and wrote the first draft of the manuscript. Authors PACO, VIEA and BHH designed the study. Author BHH did the laboratory supervision and obtained the grant for the purchase of chemicals, all characterizations and analysis. All authors read and approved the final manuscript.

Original Research Article

ABSTRACT

Excellent heterogeneous catalyst was developed from waste murex turnispina shell and used in the transesterification of waste cooking oil (WCO) with methanol to obtain fatty acid methyl ester (FAME), otherwise known as bio-diesel. Finely ground murex turnispina shell was subjected to controlled calcination temperatures ranging from 500 to 900ºC for 4h at a ramping rate of 4ºC/min. The characterization results indicate that this process substantially improved both BET specific surface area and the amount of basic sites. Transesterification of waste cooking oil was used to determine the activity of developed catalyst. The effects of different reaction parameters such as the calcination temperature, molar ratio of methanol to WCO, catalyst loading and reaction time on the

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transesterification reaction were investigated. The data obtained showed that at 830ºC calcination temperature, catalyst amount of 3 wt. %, methanol/oil mole ratio of 6:1, 2 h reaction time and at methanol reflux reaction temperature of 65ºC, 99% FAME yield was obtained. The catalyst showed good stability during the recycling experiments and it was sustained for four consecutive runs. Murex turnispina shell-derived catalyst is cost effective catalyst for FAME production via transesterification of WCO with methanol and it offers a novel opportunity to utilize both waste cooking oil and waste murex turnispina shells.

1. INTRODUCTION

One major setback against bio-diesel production at industrial scale today is its high pump price due mainly to high cost of material input. Chief among the production materials are the feedstock and catalysts. It is the need to reduce the pump price of bio-diesel that informed the present research on the use of both feedstock and catalyst from waste sources. Bio-diesel is fuel composed of mono-alkyl esters of long chain fatty acids derived from renewable sources such as vegetable oils and animal fats. Bio-diesel has received much attention as an alternative green fuel due to its non-toxic, sulfur- and aromatic-free, biodegradable and renewable features [1-6]. The need for green fuel cannot be over emphasized considering the current reality of global warming, environmental degradability and pollution; as well as the perennial price rise of fossil fuel and the fear of its sustainability. Understandably, the last decade has witnessed an unprecedented search for superior reaction pathways for bio-diesel production, with the main aim of reducing the cost of bio-diesel production, in order to make it more competitive with fossil fuel. As a result, studded effort has been made at searching out the best production options for bio-diesel from cheap sources, in order to compete or possibly, beat fossil fuels in engine performance, reduced cost of production, environmental friendliness and production sustainability.

So far, homogeneous, heterogeneous and enzymatic catalysts have been extensively investigated and most of them have been found effective though not without some concerns [7-12]. For instance, the most frequently used alkaline catalysts, sodium hydroxide and potassium hydroxide and their acid counterparts, tetraoxosulphate (VI) acid and hydrochloric acid have had to contend with rigorous separation and purification techniques which are time consuming and environmentally benign, adding to the increased cost of production [10,13]. For this reason attention was shifted to heterogeneous catalysis. Most heterogeneous catalysts, such as the metal oxides and oxides of alkaline earth metals like magnesium, calcium, strontium, among others, proved very successful but the high cost of these metal oxides made competition with fossil fuel, unattractive [14,15]. Hence, attention was diverted to sourcing heterogeneous catalysts from abundant waste materials in our environment [16,17]. This innovation, if successful, would serve the dual purpose of being a cheap source of heterogeneous catalyst for bio-diesel production as well as clearing our environment of wastes, which disposals, had been sources of great worry and financial waste to various Governments while land space, previously occupied by these wastes, would be made available for farm activities.

This present work uses waste murex turnispina shell, as a source of heterogeneous catalyst for the transesterification of waste cooking oil. Both feedstock (waste cooking oil) and catalyst source (Murex turnispina shell), are obtained from waste sources. Murex turnispina is a species of snail shell generated in tons daily from numerous sea food restaurants scattered in the environment. The disposal of Murex shell and indeed other biological calcareous deposits have been a source of great concern to government because shell is not biodegradable and as result its presence defaces the environment, emits foul odour and occupies valuable land space that would otherwise have been used for farm purposes.

Catalyst formulated from murex turnispina shell was characterized to determine the physico-chemical properties, obtain the chemical facts and the physical proofs of its catalytic activity while the effects of reaction conditions such as methanol/oil mole ratio, catalyst amount, calcination temperatures and reaction time were investigated to determine the best performing conditions.

2. MATERIALS AND METHODS

2.1 Materials

Waste cooking oil (WCO) was obtained from students' cafeteria in Engineering Campus, University of Science Malaysia, Nibong Tebal, Malaysia. Waste murex turnispina shells were picked from the waste dumping site of one of the several Chinese seafood restaurants in Bukit Tambul, Pulau Penang, Malaysia. HPLC grade methanol (99.9%) and n-hexane (96.0%) were purchased from Sigma-Aldrich, Malaysia. Analytical grade methyl heptadecanoate (99.5%) was obtained from Merck, Malaysia. All chemicals were of analytical grade and were used as such.

2.2 Methods

2.2.1 Preparation of catalyst

The shells of murex turnispina were thoroughly washed with clean water followed by drying in an oven at 105ºC for 24 h. The dried shells were mashed to powder in a mortar and sieved with 125-150 µm range mesh size. The sieved powder was calcined at various temperatures ranging from 500–900ºC at a heating rate of 4ºC per min in a Carbolite furnace for 4 h similar to the procedure described in literature [18]. The calcined shell catalysts were stored in a desiccator for further use.

2.2.2 Catalyst characterization

The textural characteristics of calcined catalysts were determined by N_2-adsorption-desorption at $-195^{o}C$ using ASAP 2020 Micromeritics surface area and porosity analyzer using the Braeuner-Emmett-Teller (BET) method. Active surface functional groups of catalysts were identified by Fourier transform infrared (FTIR) analysis using KBr disc method with the spectra recorded in the range of 4000–400 cm^{-1}. The crystalline phase of calcined catalyst was defined by X-ray diffraction (XRD) spectroscopy over Philips PW1710 X-ray diffractometer coupled with Cu k_{α} radiation source. The morphology of catalyst was investigated by scanning electron microscopy (SEM) using Philips XL30S microscopy. The mean metallic content of the synthesized catalyst was determined by an electron dispersive X-ray (EDX) analyzer attached to the SEM instrument. The base strength of the catalyst was determined using the Hammett indicator method ($H_.$)

2.2.3 Transesterification reaction procedure

Waste cooking oil transesterification with methanol was carried out in a 250 mL two neck round-bottomed glass reactor. In a typical study, the reaction was initiated by introducing waste cooking oil (76 mL), methanol (15 mL) and catalyst (3 wt. % based on the amount of waste cooking oil used). Reflux coil-type condenser was attached to the glass reactor and placed on a heat source equipped with heating mantle, a motor and a thermocouple; while a sizeable magnetic stirrer was placed inside the 250 mL round-bottomed flask for proper mixing. The reaction was set at the reflux temperature of methanol (65ºC). The reaction was kept under the above conditions of for the duration of 30 – 150 min. At the end of the reaction, the reaction mixture was allowed to cool down to room temperature. The reaction mixture was then decanted from the reactor and finally separated from the catalyst by centrifugation to prepare for analysis.

Methyl heptadecanoate was used as internal standard while applying the European Regulation Procedure, EN 14103 for the determination of the quantitative FAME content. The fatty acid methyl ester content was centrifuged for 10 min at 3000 rpm in Thermo Scientific, HERAEUS PICO 17 centrifuge. 12.5 mg of sample was mixed with 0.25 mL of the pre-prepared internal standard solution. The FAME content was then determined using Gas Chromatography (GC-*2010 Plus*, Gas Chromatograph SHIMADZU, Japan) equipped with a fused silica capillary column (Supelco Nukol^{TM}, 15 m x 0.53 mm x 0.5 µm film thickness); a split/splitless injection unit with FID detector. The injection was performed in split mode with a split ratio of 100:1. Thereafter, one micro liter (1 µL) of the final solution was injected into the column. Helium ($He_{(g)}$) at 2 mL/min was used as a carrier gas. The percentage of FAME content was calculated using European Regulation Procedure, EN 14103. The percentage of FAME content was expressed according to eq. 1

$$\% \text{ AME content} = \frac{\sum A - Ais}{Ais} \times \frac{Cis \times Vis}{ms} \qquad \text{(eq.1)}$$

Where

$\sum A = Total$ peak area of FAME
Ais = Peak area of internal standard
Cis = Concentration of internal standard
Vis = Volume of internal standard (mL)
m_s = Mass of sample (mg)

2.2.4 Re-usability test

The developed catalyst was subjected to stability test. The catalyst was filtered after the initial reaction with WATMAN filter paper in a buchner funnel. The solid was thoroughly washed with hot water and dried in an oven at 105ºC for 24 h. The recovered catalyst was used for further transesterification of waste cooking oil under the established optimum reaction conditions.

The re-usability of the formulated catalyst, which represents its capability to perform the same catalyst activity in subsequent reactions, was evaluated by conducting several other experimental runs using the same catalyst after the first run at the optimum conditions obtained for WCO conversion. The catalyst after the first, and subsequent reactions was recovered, washed with hot water to remove any residue adhered to the surface of the catalyst, filtered and dried in the oven at 105ºC for 12 hr. After drying, further calcination was done at 500ºC for 2 h. The calcined catalyst was subjected to further reaction cycles of transesterification until the catalyst was saturated or insufficient to be used for further experiments.

3. RESULTS AND DISCUSSION

3.1 Catalyst Characterization

3.1.1 XRD analysis

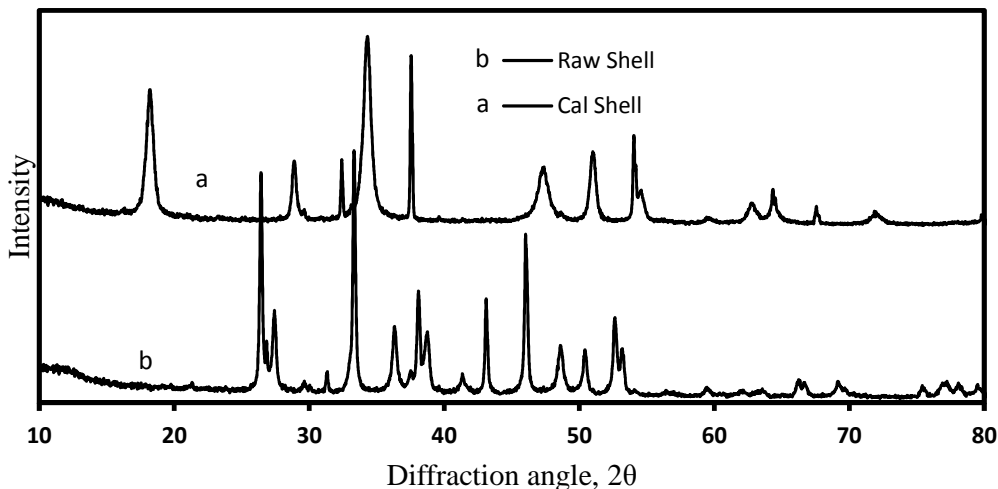The powdered XRD patterns of calcined murex shell (a) and raw murex shell (b) catalysts are presented on Fig.1. As illustrated from the figure, the main crystalline phase present in the calcined catalyst is cubic lime, CaO at $2\theta = 32.5º$, $37.5º$ and $54º$. Meanwhile, the main crystalline phase in the raw shell catalyst is orthorhombic Aragonite crystal, $CaCO_3$. The absence of $CaCO_3$ peaks in the calcined catalyst is an indication that adsorbed CO_3 was completely evolved by calcination at 830ºC. These results are in agreement with those already published in literature [18].

3.1.2 FTIR analysis

The FTIR spectra for raw and calcined shell catalysts are shown on Fig. 2. The broad band between 3200 and 3000 cm^{-1} of raw catalyst is assigned to stretching mode of hydroxyl groups of Ca-OH and adsorbed water molecules on the surface of the raw shell catalyst. This band was absent in the calcined catalyst showing complete elimination of moisture by calcination. The intense spectral band at 420 cm^{-1} in the calcined shell catalyst is assigned to Ca–O bonding vibration or Ca–OH transition. The spectral bands in the raw catalyst at 1415, 879 and 700 cm^{-1} are attributed to asymmetric stretching vibrations, out-of-plane bending and in-plane bending vibration modes, respectively for CO_3^{-2} molecules. Upon calcination, murex shell starts to lose carbonate thereby forcing absorption bands of CO_3^{-2} molecules to shift to higher energies observed at 1404, 956 and 864 cm^{-1}. These results are in agreement with those already published in literature [19,20,21].

Fig. 1. X-ray diffraction (XRD) patterns of calcined murex shell catalyst (a) and raw shell (b)

3.1.3 Textural properties and basicity

The textural properties of raw and calcined shell catalysts are shown on Table 1. It was observed that the calcined catalyst has strong base strength (18< *H.* < 23.4) which was found excellent for the transesterification of waste cooking oil and methanol. The strong basicity of the calcined murex turnispina catalyst was attributed to the presence of high concentration of cubic lime, CaO, observed by XRD and confirmed by the EDX result after calcination. Also, it was observed that the controlled calcination of the shell at 830ºC increased the BET surface area (S_{BET}) from 0.3906 to 33.43 m^2g^{-1} and the total pore volume from 0.0077 to 0.077 cm^3g^{-1}. It has been reported that the basicity of a catalyst and its large specific surface area results in high catalytic activity [22]. Figs. 3a and 3b show the nitrogen adsorption-desorption isotherms of raw and calcined shell catalysts respectively. Both catalysts showed Type IV isotherms. IUPAC classified Type IV isotherms as mesoporous solids [23]. For the calcined catalyst, a fairly linear increase of adsorbed volume at initial low pressures was observed; followed by a steep increase in nitrogen uptake at relative pressure of P/Po = 0.44 to 0.84 and from P/Po = 0.95 to 0.99, which is due to capillary condensation inside the mesopores. The increase in the mesoporosity after calcination of shell catalyst confirmed the expulsion of adsorbed moisture, carbon dioxide

and the structural phase change of metal oxide to a more active phase as confirmed by XRD analysis.

Table 1. Textural properties of raw and calcined shell catalysts calcined at 830ºC for 4h

	Raw murex	Calcined @ 830ºC
BET surface area (m^2g^{-1})	0.3906	33.4315
Total pore volume (cm^3g^{-1})	0.007743	0.0766
Average pore width (Å) (4V/A by BET)	792.9539 Å	91.6607 Å

3.1.4 EDX and SEM analysis

The change on the elemental composition between the raw and the calcined shell catalyst was examined by EDX and the results are illustrated on Table 2 and Fig. 5. The calcium content of the calcined catalyst increased compared to the raw catalyst from 34.8 to 53.13 wt. %. The oxygen and carbon contents of the raw catalyst, on the other hand, decreased compared to the calcined catalyst from 48.94 to 43.39 wt. % and from 16.25 to 3.25 respectively. This result is confirmed by the EDX
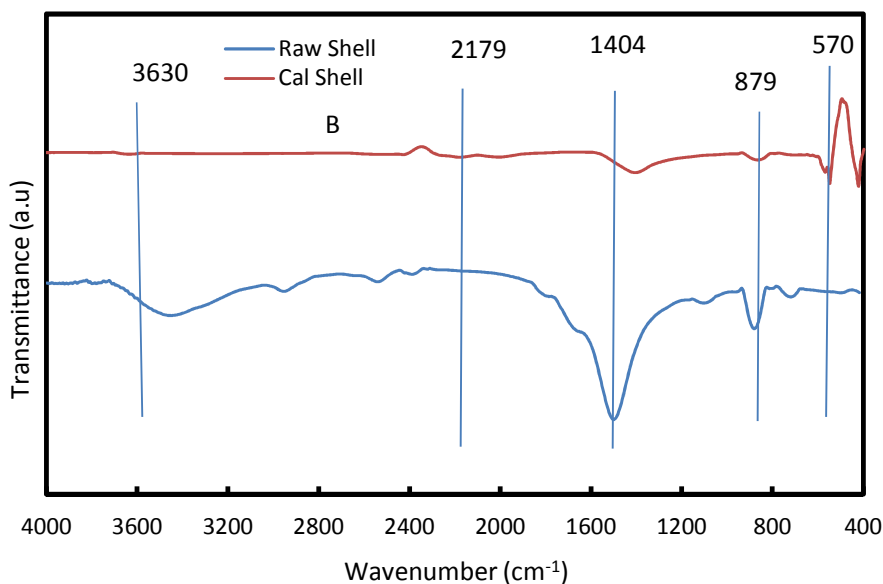

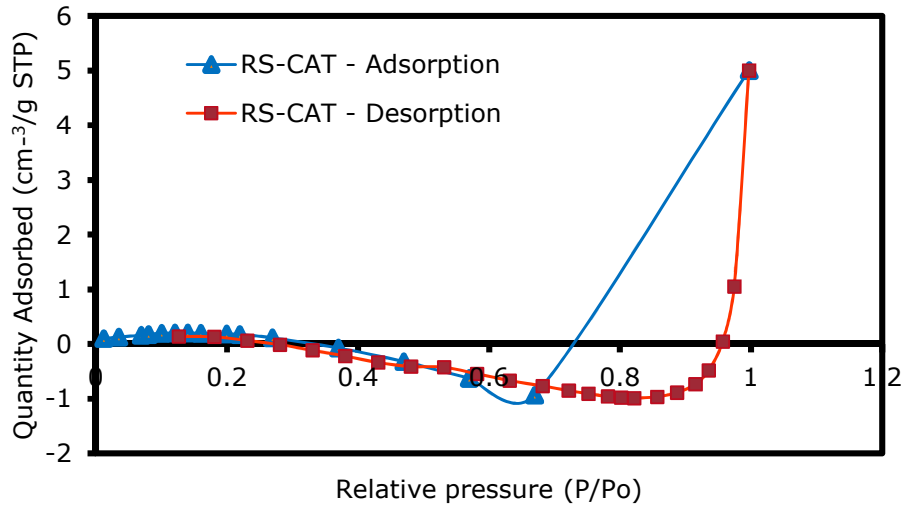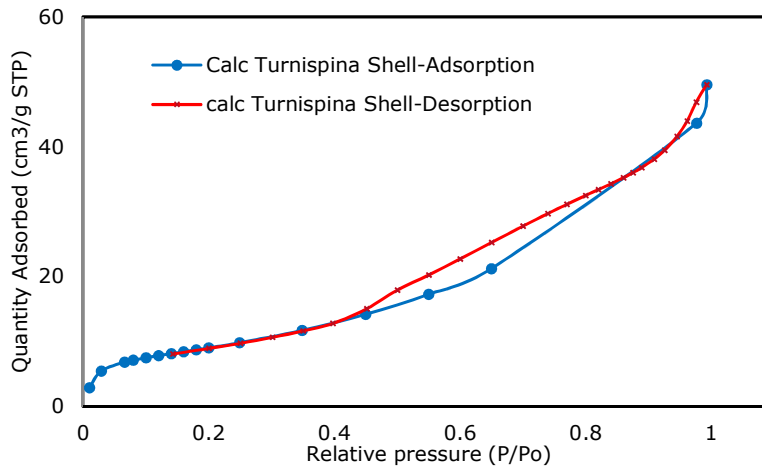**Fig. 2. FTIR spectra of raw catalyst (A) and calcined catalyst (B)**

Fig. 3a

Fig. 3b

Fig. 3. Nitrogen adsorption-desorption isotherm of murex turnispina shell calcined at 830⁰C for 4h

spectra for raw and calcined catalysts (Fig. 4) respectively. The Ca:O ratio increased from 2:6 in the raw catalyst to 3:5 in the calcined catalyst. Thus, the thermal treatment of raw shell at 830⁰C resulted in the removal of over 90% adsorbed carbon and 11.34% by weight oxygen in the form of CO_3^{-2}. The removal of CO_3^{-2} from the calcined catalyst by thermal treatment was responsible for the increased surface area observed in BET analysis and the increased Ca:O ratio and phase change to more active form, giving the CaO enough base strength needed for the transesterification of waste cooking oil. The

morphology of raw catalyst (RS) and calcined catalysts (S83) are shown on Fig. 4. The SEM images show that the raw shell particles have a spherical shape with smooth surface appearing as logs of wood. Irregular shape of unburned carbon is also demonstrated on the raw shell. Small particles of raw shell catalyst tend to agglomerate on the bigger one which was also confirmed in other studies. The calcined shell catalyst SEM image shows quadratic-like, glass-like crystals growing on each other. This result agrees with the report of studies in literature [20,21,23].
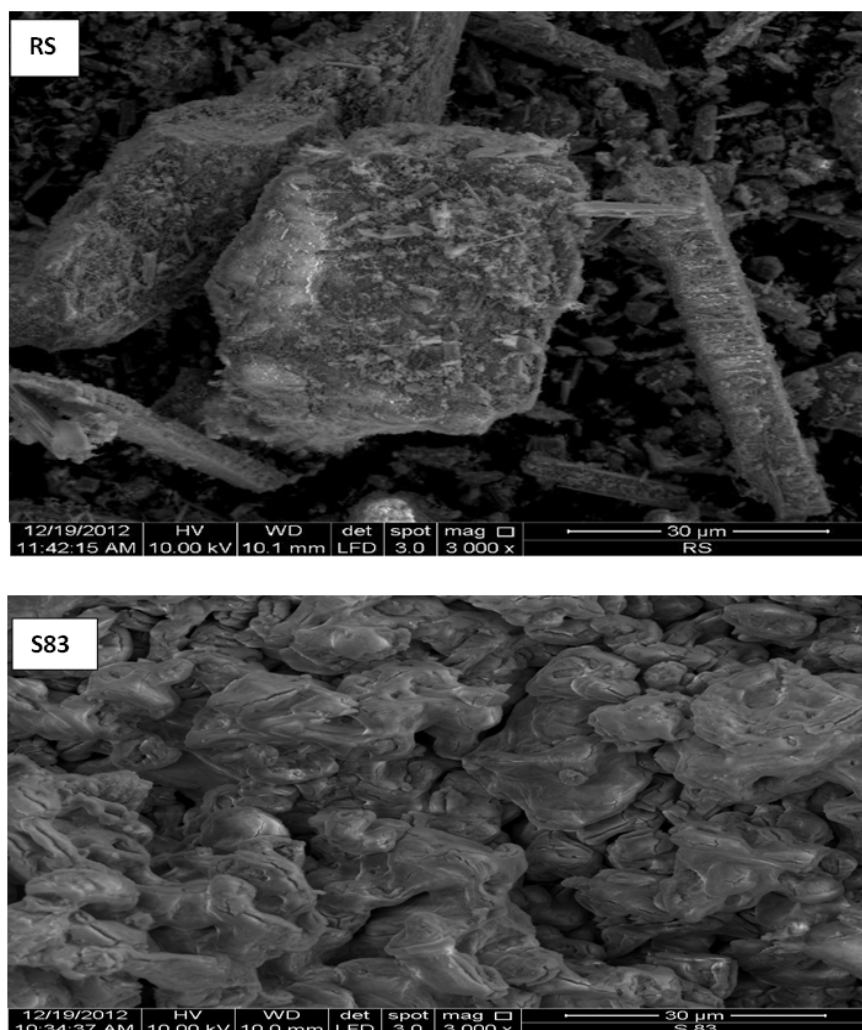
Fig. 4. SEM image of raw murex shell (RS) and murex shell catalyst calcined at 830°C for 4h (S83) at 3000x magnification

Table 2. EDX analyses results of raw and calcined murex shell

Element	Raw-Shell (wt%)	Calcined-Shell (wt%)
Carbon	16.25	3.25
Oxygen	48.94	43.39
Calcium	34.8	53.13

3.2 Transesterification Reaction of WCO with Methanol

3.2.1 Effect of calcination temperature

Preliminary experiments were performed to evaluate the effect of calcination temperatures of catalyst sample on the transesterification of waste cooking oil with methanol. The effect of calcination temperature on WCO conversion and FAME yield was studied by first of all using the raw catalyst in the transesterification reaction of WCO with methanol while fixing the other reaction conditions. The fixed reaction conditions for optimum performance include, reaction time: 120 min; Catalyst loading: 3wt.%; Methanol/oil mole ratio: 6:1; Reaction temperature: 65°C. This was followed by the use of the catalysts calcined at various temperatures ranging from 500 - 900°C. The results are presented in Fig. 6. It was observed that when the raw catalyst was used, only very low WCO conversion was observed and about 10% FAME yield was obtained. The FAME yield increased gradually
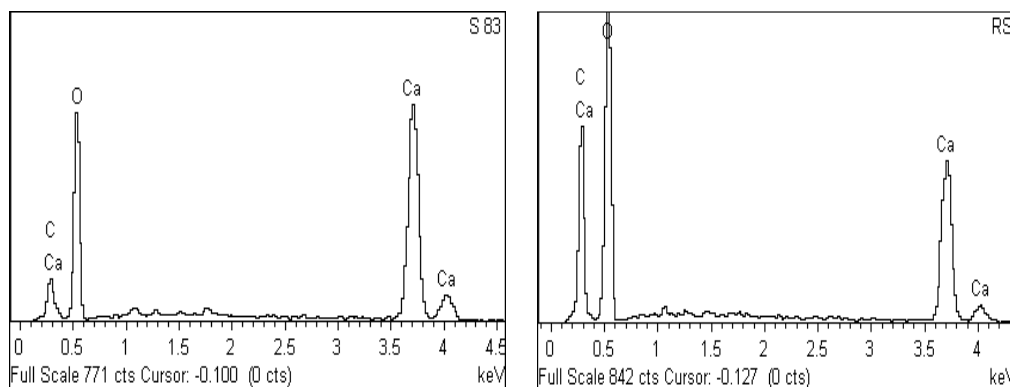
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Fig. 5. Energy dispersive X-ray spectra (EDX) for murex turnispina shell calcined at 830°C for 4h (S83) and raw murex shell (RS)
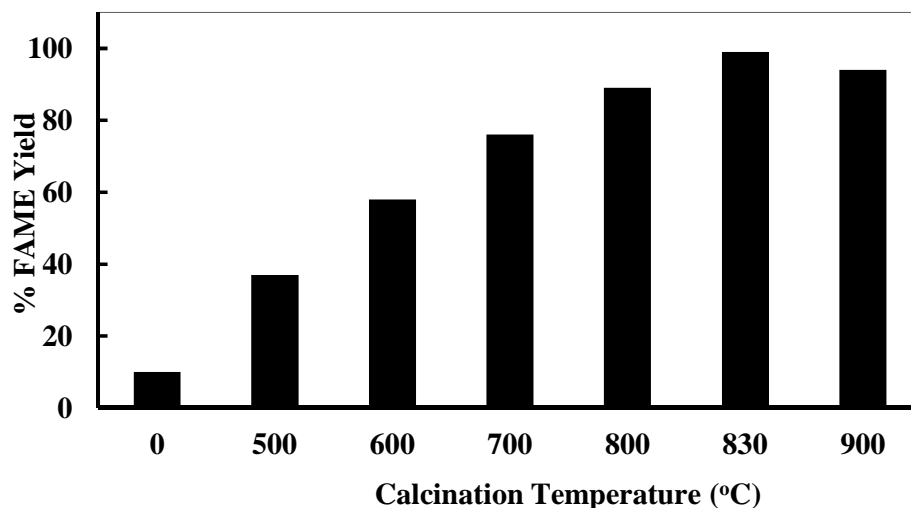

Fig. 6. Effect of calcination temperature of catalyst on the transesterification of WCO with methanol. Reaction conditions: Reaction time: 120 min; Catalyst loading: 3wt.%; Methanol/oil mole ratio: 6:1; Reaction temperature: 65⁰C

with increase in calcination temperature from 500 - 830°C when 100% WCO conversion and 99% FAME yield was obtained. The increase in the conversion of WCO and FAME yield with increase in calcination temperature was an indication that calcination temperature affected WCO conversion and FAME yield. This was attributed to the gradual decarbonation of murex turnispina shell catalyst as the temperature of calcination increased. Mollusk shells generally are known to contain $CaCO_3$ as their main Ca-based component.

From the result of DTA/TGA analysis (not shown), a major loss of mass was recorded from 700 - 830⁰C on the TGA curve corresponding to decomposition and desorption of sample, which showed up as an endotherm on the DTA curve, signifying melting and change in crystal structure of CaO. As a result, no reasonable conversion of WCO was obtained before de-carbonation of catalyst could take place. Also, on the TGA curve, the evolution of H_2O molecules, $Ca(OH)_2$ and organic compounds from the shell sample was sequentially observed at temperatures from 250 to 700°C; whereas the major decomposition with 50% weight loss occurred around 750 to 830°C and this was attributed to the decarbonation of sample and subsequent production of CaO. It was only after the liberation of active CaO at 800–830°C, that effective conversion (99%) was obtained. No corresponding increase in FAME yield was obtained with increased calcination temperature

above 830ºC as further increase in calcination temperature inversely suppressed the catalytic activity of the catalyst. Higher calcination temperature will bring about the sintering of the catalyst and therefore the lowering of the surface area. The shrinkage of the catalyst grains would eventually suppress the active sites and result in waste of valuable energy resource [24].

3.2.2 Effect of reaction time

In order to evaluate the effect of reaction time on WCO conversion and FAME yield, reactions were allowed to proceed for variant durations of 30 to 180 min and the results obtained are shown on Fig. 7. When the other reaction conditions were fixed at catalyst loading: 3wt.%; methanol/oil mole ratio: 6:1; reaction temperature: 65ºC; the reaction time was found to be a dominant parameter controlling the transesterification of waste cooking oil and FAME yield. At the first 30 min, the observed FAME yield was merely above 30%. After that, the FAME yield increased gradually until a maximum FAME yield of 99% was obtained after 120 min. When the reaction was elongated for more than 120 min, no further increase in FAME yield was observed as all the WCO had been converted. The presence of methanol as a solvent to the reaction medium was necessary to promote FAME yield by increasing the miscibility of reactants with catalyst, which effect increased with time until maximum conversion was obtained.

3.3 Effect of Catalyst Loading

The presence of catalyst is imperative for transesterification reaction to proceed. The effect of catalyst concentration on the conversion of WCO and FAME yield was investigated using variable weight percentage from 1.0 – 5.0 wt. %; based on the weight of oil as shown on Fig. 8; while other reaction conditions were fixed at reaction time: 120 min; methanol/oil mole ratio: 6:1; reaction temperature: 65ºC. The FAME yield increased slowly with increasing amount of catalyst from 1.0 to 3.0 wt. % where 100% WCO was completely converted and 99% FAME yield was obtained. This behaviour was expected due to increase in the concentration of active sites that are necessary to catalyze the transesterification reaction. The role of the basic sites is to initiate the transesterification reaction by abstracting a proton from methanol to form methoxide anion. Methoxide anion attacks carbonyl carbon (R_1) in a molecule of the triglyceride leading to the formation of alkoxycarbonyl intermediate. Alkoxycarbonyl intermediate further transforms into a more stable form as fatty acid methyl ester (FAME) and anion of diglyceride. Methoxide cation attracts the anion of diglyceride leading to the formation of diglyceride. The sequence is repeated twice for R_2 and R_3 of the triglyceride molecule (where R_1, R_2 and R_3 represent the carbon chains of fatty acid, triglyceride). Increasing the catalyst loading beyond 3 wt. % gave no corresponding increase in FAME yield. The reason for the reduced production of fatty acid methyl ester with excess catalyst was attributed to increase in viscosity of the reaction mixture as observed in literature [25,26]. Hence, 3 wt.% of murex Turnispina shell-derived catalyst relative to oil is considered the best catalyst amount for the transesterification of waste cooking oil.
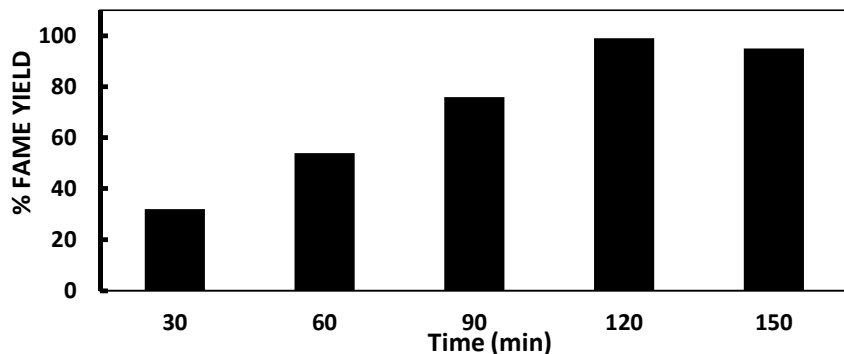

Fig. 7. Effect of reaction time on the transesterification of WCO with methanol. Reaction conditions: Catalyst loading: 3wt. %; Methanol/oil mole ratio: 6:1; Reaction temperature: 65ºC
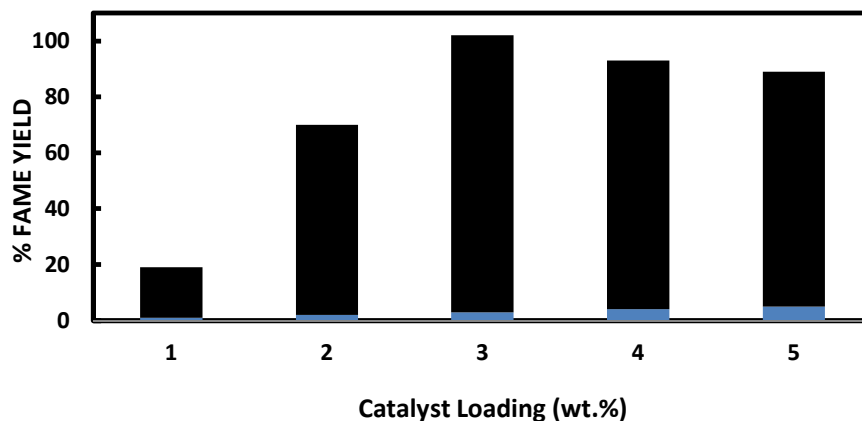
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Fig. 8. Effect of catalyst loading on the transesterification of WCO with methanol. Reaction conditions: Reaction time: 120 min; Methanol/oil mole ratio: 6:1; Reaction temperature: 65°C
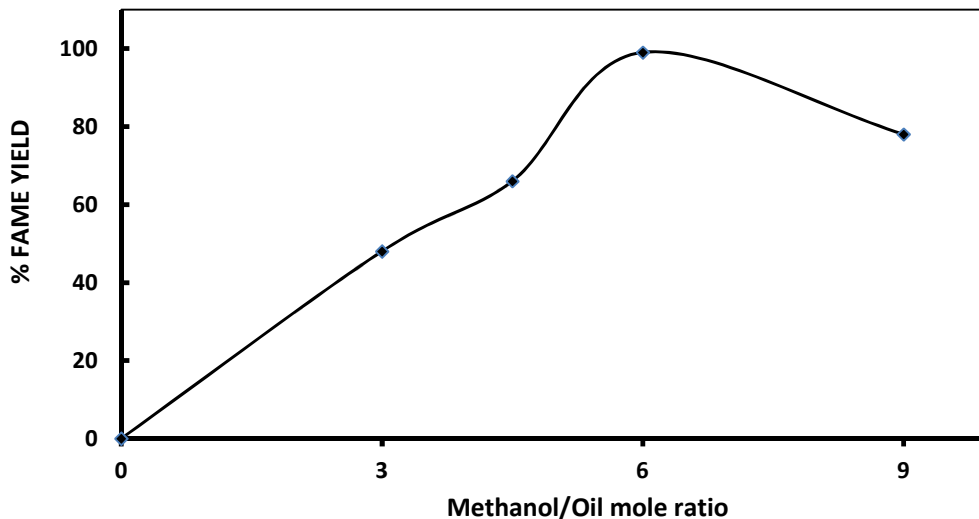

Fig. 9. Effect of methanol/oil mole ratio on the transesterification of WCO with methanol. Reaction conditions: Reaction time: 120 min; Catalyst loading: 3wt. %; Reaction temperature: 65°C

3.4 Effect of Methanol/Oil Ratio

Transesterification of WCO with methanol is a reversible reaction. Stoichiometrically, three moles of methanol reacts with one mole of triglyceride. As a result, one mole ratio higher than the stoichiometric ratio of WCO with methanol is required to shift the equilibrium of the reaction towards the fatty acid methyl ester (FAME) production. The behaviour of WCO transesterification with methanol at different mole ratios from 3:1 to 9:1; over murex turnispina shell-derived catalyst (calcined at 830°C for 4h) was investigated while the other reaction conditions were kept constant at reaction time:

120 min; catalyst loading: 3wt.%; reaction temperature: 65°C; and the result is shown on Fig. 9. The FAME content increased significantly by increasing the methanol/oil mole ratio from 3:1 to 6:1. This higher amount of methanol would promote the formation of methoxy species on CaO surface and should also shift the reaction equilibrium to the right. Further increase in methanol/oil ratio up to 9 did not promote significant increase in FAME yield. This was attributed to the dissolution of glycerol in excessive methanol which inhibited the reaction of methanol to the reactants and catalyst. This result is in agreement with the observation of Viriya and co-workers [24]. The optimum
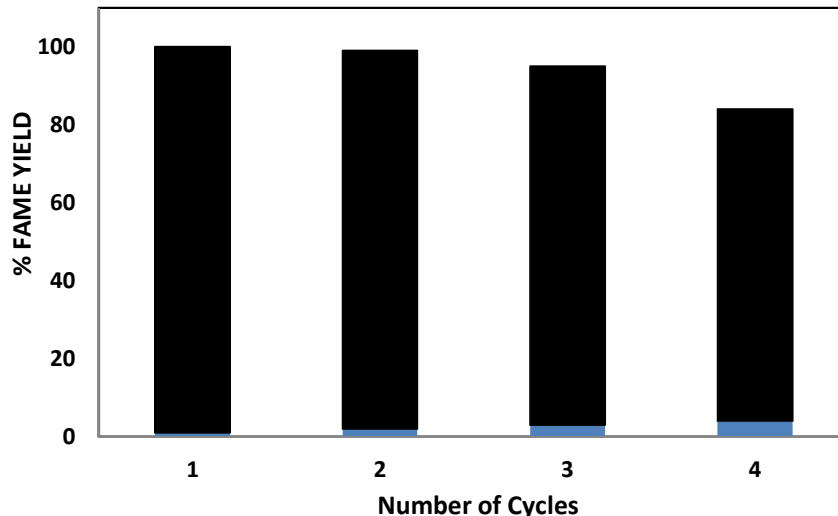
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Fig. 10. Re-usability test results of murex shell-derived catalyst. Reaction conditions: Reaction time: 120 min; Catalyst loading: 3wt. %; Methanol/oil mole ratio: 6:1; Reaction temperature: 65ºC

MeOH/oil mole ratio was 6:1 over the catalyst in this study which gave the optimum yield of 99% FAME.

3.5 Reusability Test

The murex turnispina shell-derived catalyst calcined at 830ºC for 4 h was subjected to further transesterification after the initial use to determine its after-use value under established best reaction conditions such as reaction time: 120 min; catalyst loading: 3wt.%; methanol/oil mole ratio: 6:1; and reaction temperature: 65ºC (Fig. 10). At completion of 2 h reaction time, the catalyst was filtered from the reaction mixture, washed with methanol to remove any adsorbents. The catalyst was later dried in an oven at 105ºC for 24 h before being used again in the transesterification of waste cooking under the reaction conditions of methanol/oil mole ratio (6:1), catalyst amount (3 wt%) and reaction time of 2 h. From the result, it was observed that the murex turnispina-derived catalyst showed gradual loss of activity until the fifth run when it dropped to about 80% FAME yield. This deactivation was due to structural changes leading to the failure to maintain the form of CaO or its transformation to other forms such as $Ca(OH)_2$ [25,26,27]. The observed reduction in activity is also ascribed to the decrease in catalyst quantity due to progressive filtering and washing that followed each step. CaO is slightly soluble in methanol.

4. CONCLUSIONS

The transesterification of waste cooking oil with methanol was conducted using murex turnispina shell-derived catalyst as basic heterogeneous catalyst. The formulated catalyst was found to be excellent in the transesterification reaction of WCO with methanol. The overall results indicated that a FAME yield of 99% was obtained. It was found that the controlled calcination of the raw shell at 830ºC for 4h at 4ºC/min ramping rate gave the most excellent heterogeneous catalyst activity in this study. The optimum catalyst loading was 3 wt.%. It was also established that increasing the methanol/oil mole ratio increased the FAME yield. A ratio of 6:1 gave the best FAME yield. At methanol reflux reaction temperature of 65ºC, the optimum reaction time was 120 min. The catalyst showed good stability during the recycling experiments and it was sustained for four consecutive runs. Murex turnispina shell-derived catalyst is cost effective catalyst for FAME production via transesterification of WCO with methanol and it offers a novel opportunity to utilize both waste cooking oil and waste murex turnispina shells.

ACKNOWLEDGEMENT

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RESEARCH HIGHLIGHTS

- Excellent heterogeneous catalyst for transesterification of waste cooking oil was formulated from waste murex turnispina shell
- Data obtained from characterization such as base strength, DTA/TGA, XRD, FTIR, BET, SEM, EDX analyses showed the formulated catalyst as effective heterogeneous catalyst for the transesterification of WCO.
- Catalyst efficiency was tested by application in the transesterification of WCO with methanol where 99% FAME yield was obtained.
- Stability test confirmed the heterogeneous catalyst could be re-used for upward of four runs without much loss in efficiency.
- Novel application of waste cooking oil and waste murex turnispina shell to valuable product, bio-diesel.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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