ORIGINAL RESEARCH

Open Access

Calcium oxide from *Pomacea* sp. shell as a catalyst for biodiesel production

Yosephine Yulia Margaretha, Henry Sanaga Prastyo, Aning Ayucitra[*] and Suryadi Ismadji[*]

Abstract

Heterogeneous catalysts are promising catalyst for the transesterification reaction of vegetable oils to produce biodiesel. In this study, the *Pomacea* sp. shell was used as the raw material for CaO catalyst. The calcination of *Pomacea* sp. shell was conducted at 900°C for 2 h. The raw material and the resulting CaO catalyst were characterized using X-ray diffraction, X-ray fluorescense spectrometry, and Fourier transform infrared spectroscopy analysis. From the experimental results, it was found that the maximum yield of fatty acid methyl esters was 95.61% at the following reaction conditions: reaction temperature of 60°C, a reaction period of 4 h, a ratio of methanol-oil at 7:1, and amount of catalyst at 4% *w/w*. The physical and chemical properties of biodiesel were determined based on ASTM standard, and the values obtained were confirmed with the Indonesian National Standard (SNI-04-7182-2006) and (B100)-ASTM D6751-07b.

Keywords: Biodiesel, Transesterification, Solid catalyst, CaO, Palm oil

Background

The extensive use of fossil fuel in human activities during the last several decades causes the depletion of fossil fuel source; therefore, the search of other alternative energies is crucially important [1,2]. One of the alternative fuels which have been developed over a century ago is biodiesel. Biodiesel has been chosen as an alternative fuel because it is renewable, produces lower emission, and possesses high flash point, better lubrication, and high cetane number [3].

Studies about the transesterification of vegetable oils or animal fats into biodiesel have been conducted by various researchers. At the time of reaction, the triglycerides will gradually be converted into diglycerides, monoglycerides, and glycerol. At each change of conversion, one mole of ester formed [4]. Different kinds of catalysts have been in use to produce biodiesel from a different kind of oil. The catalysts commonly used for biodiesel production are categorized into several types: homogeneous catalysts (sodium hydroxide, potassium hydroxide, sulfuric acid, etc.) [5], heterogeneous catalysts (cation-exchange resin, hydrotalcites, etc.), and enzymes (*Chromobacterium viscosum*, *Candida rugosa*, and *Porcine pancreas*) [6].

Homogeneous catalyst has been used extensively for biodiesel production, but the use of this kind of catalyst began to decrease because it has several drawbacks: it cannot be recovered [7] or regenerated after the reaction and also it produced toxic wastewater. To replace the homogenous catalyst, enzyme and heterogeneous catalysts have been developed and studied. The use of enzyme as a catalyst is less desirable because it is much more expensive than the homogeneous catalyst. Heterogeneous catalysts such as KOH/Al_2O_3 [8] and alumina/silica [9] have a high level of alkalinity and reliable performance for biodiesel production. Nevertheless, these catalysts have some drawbacks since they are easily dissolved in methanol, relatively difficult to synthesize, and susceptible to humidity. For acid catalyst, higher molar ratio of methanol/oil should be used, and it requires longer reaction time [8,10,11]. Therefore, a new heterogeneous catalyst should be developed, which is reactive at low temperature and pressure, has short time reaction for various raw materials, easy to get, has a high conversion, and low biodiesel production cost [12].

Golden snails (*Pomacea* sp.) are mostly found in muddy areas such as in a rice field. It is considered as pests; therefore, its presence in the rice field is not desired. However, the meat of *Pomacea* sp. has high protein content and can be utilized as animal feed or as

* Correspondence: aayucitra@yahoo.com; suryadiismadji@yahoo.com
Department of Chemical Engineering Widya Mandala Surabaya Catholic University, Kalijudan 37, Surabaya 60114, Indonesia

an alternative food for human consumption. In Indonesia, this mollusk has been cultivated in small industrial scale. Its meat has been utilized as raw materials for various kinds of food, while the shell is discarded as waste. The utilization of *Pomacea* sp. shell as an alternative raw material in the production of solid catalyst for biodiesel is expected to raise its economic value and helps to overcome the waste problems of *Pomacea* sp.

Pomacea sp. shell can be utilized as a solid catalyst for biodiesel production because it contains $CaCO_3$ which can be converted into CaO during calcination. CaO is a heterogeneous catalyst which is most widely studied because of its high alkalinity, low solubility, cheaper price than KOH/NaOH, and also the ease of handling [13,14].

This research was focused on developing a new type of catalyst for biodiesel production from *Pomacea* sp. shell. The capability of the catalyst derived from the snail shell was tested on the transesterification of palm oil into biodiesel. The process parameters for biodiesel production were also studied.

Methods

Materials and catalyst preparation

The *Pomacea* sp. shell was obtained from a small town called Pati, located in Central Java, Indonesia. Prior to use, the shell was repeatedly washed using tap water to remove dirt and other impurity material and then dried overnight at 100°C. The shell was then crushed and calcined at 900°C for 2 h in a tubular furnace to convert $CaCO_3$ into CaO. After the reaction is complete, nitrogen with a flow rate of 3 l/min was introduced to furnace to cool down the system and to prevent the air entering the system. Subsequently, the catalyst was removed from the furnace and kept in a desiccator to prevent contact with air.

Methanol used in this study was purchased as analytical grade from MERCK, Germany. Palm oil was purchased from the local supermarket, and the composition of fatty acid in the oil was analyzed using gas chromatography. The results are shown in Table 1. The gas chromatography analysis of fatty acid was performed using a Shimadzu GC-2014 equipped with FID and a DB-wax capillary column. The operating condition for fatty acid determination as follows: helium was used as a gas carrier with a flow rate of 40 m/s. The injector temperature was set at 200°C, while the detector was operated at 300°C. The initial oven temperature was 100°C and maintained in this isothermal condition for 2 min. Then, the oven temperature was increased to 220°C at a heating rate of 10°C/min and held for 33 min.

Other important parameters such as water content and acid value content in the oil are also given in Table 1. The acid value was determined according to ASTM

Table 1 Composition of fatty acid in palm oil and other characteristics

	Composition
Fatty acid (%)	
Lauric acid (C12:0)	0.81
Myristic acid (C14:0)	1.22
Palmitic acid (C16:0)	42.42
Palmitoleic acid (C16:1)	0.21
Stearic acid (C18:0)	4.68
Oleic acid (C18:1)	40.78
Linoleic acid (C18:2)	9.45
Linolenic acid (C18:3)	0.11
Arachidonic acid (C20:0)	0.32
Water content (%)	0.05
Acid number (mg KOH/g oil)	0.85

D664, and the water content was determined according to ASTM D6304-07.

Transesterification reaction procedure

The transesterification of palm oil into biodiesel using CaO derived from *Pomacea* sp. shell was carried out in a 500-ml three-neck round-bottom flask equipped with a reflux condenser, thermometer, and magnetic heating mantle. The transesterification experiments were carried out at a temperature of 60°C and stirring speed at 700 rpm. The initial mass of the palm oil used in this study was 200 g. The amount of catalyst varied from 1% to 5% *w*/*w*, and oil to methanol ratios were 1:5 to 1:11. Reaction time used in this study was 4 h. After the reaction completed, the catalyst was removed from the mixture using vacuum filtration. The excess methanol was then recovered from the biodiesel mixture using a rotary vacuum evaporator. After the separation of methanol, the glycerol was removed from the biodiesel in a funnel separator. The biodiesel was obtained in the upper layer, while the glycerol as the byproduct was in the lower layer. For the comparison, biodiesel preparation using NaOH as a catalyst was also conducted under the same operating condition with those using CaO as catalyst.

Catalyst characterization

The raw material (*Pomacea* sp. shell) and the catalyst were characterized using several methods such as X-ray diffraction, X-ray fluorescense (XRF) spectrometry, Fourier transform infrared spectroscopy (FTIR) analysis, and nitrogen sorption analysis. XRD analysis was employed to investigate the crystalline structure of the raw material and catalyst. The diffraction spectra of both materials

were obtained on a Philips X'Pert diffractometer (Almelo, The Netherlands) using CuKα as the radiation source. The measurement was conducted in 2θ angle between 8° to 72°. XRF spectrometry was used to identify and determine the bulk composition of a catalyst, and for this purpose, Rigaku ZSX100e X-ray fluorescence (Tokyo, Japan) was employed. FTIR measurement was carried out under FTIR spectrophotometer (Shimadzu 8400S, Nakagyo-ku, Kyoto, Japan) using the KBr technique with a wavenumber range of 4,000 to 700 cm^{-1}. Surface analysis of the catalyst was conducted by nitrogen sorption experiment at its boiling point (−196°C) using a Quadrasorb SI (Quantachrome Instruments, FL, USA). Degassing of catalyst before the nitrogen sorption measurement was conducted under vacuum condition for 24 h at a temperature of 150°C. The standard BET equation was employed to calculate the BET surface area of the catalyst. The BET calculation was performed in the relative pressure (p/p_0) range of 0.06 to 0.3.

Biodiesel characterization

Selected physical and chemical properties of biodiesel including viscosity, cetane index, fatty acid composition, flash point, water and sediment content, and heat of combustion were determined. The values were then compared with the Indonesian National Standard (SNI-04-7182-2006) and Biodiesel (B100)-ASTM D6751-07b. The cetane number was evaluated by ASTM D613 which is a standard method for cetane number of diesel fuel oil. The density was determined by ASTM D1298, while the kinematic viscosity using ASTM D445-10. Standard test method for water and sediment in middle distillate fuels using centrifuge (ASTM D2709) was employed to determine the water and sediment content in biodiesel. For flash point determination, ASTM D93 (standard test method for flash point by Pensky-Martens closed cup tester) was employed. The average values of physical and chemical characteristics of biodiesel obtained in this study are summarized in Table 2.

The fatty acid methyl ester (FAME) content in the biodiesel was determined using gas chromatography (GC) method. For this purpose, the GC (Shimadzu GC-2014) was equipped with a capillary column DB-wax (length 30 m × diameter 0.25 mm × film thickness 0.1 μm) and a flame ionization detector operated at 300°C. Helium was used as the carrier gas with a linear velocity of 40 cm/s. The injector temperature was 250°C at splitless condition. The initial oven temperature was 50°C with an equilibration time of 3 min. After isothermal period, the oven temperature was increased to 250°C at a heating rate of 10°C/min and held for 8 min. Peaks of methyl esters were identified by comparison with the reference standard. The biodiesel yield was calculated by the following expression: Yield = (weight of biodiesel × % FAME)/(weight of oil) × 100%. %FAME is the concentration of FAME obtained by GC analysis.

Results and discussion

Characterization of catalyst

The X-ray diffraction patterns of the raw material (Figure 1) and CaO catalyst (Figure 2) show the presence of $CaCO_3$ and CaO. The presence of $CaCO_3$ is indicated by 2θ at 26.2°, 33.1°, 37.8°, 45.8°, and 52.4°, while for CaO at 2θ, it is around 32.2°, 37.3°, and 53.8°. The presence of $Ca(OH)_2$ is also observed in Figure 2 as indicated by diffraction peaks at 18.0°, 28.6°, 34.1°, 47.0°, and 50.8°. Calcium oxide has strong basic property due to the presence of oxygen anion generated on its surface [15,16], and the exposure of this compound to ambient air results to the formation of $Ca(OH)_2$ due to the reaction of H_2O which is present in the air with its strong basic surface.

The bulk composition of a catalyst was determined by XRF, and the result is depicted in Figure 3. The composition of the catalyst produced by calcination of *Pomacea* sp. shell mainly consists of CaO (96.83%) with small amount of other metal as impurities as indicated in Figure 3. The FTIR spectra of both *Pomacea* sp. shell and catalyst are given in Figure 4. For both *Pomacea* sp. shell spectra, the characteristic peaks of C-O stretching and bending modes of $CaCO_3$ are observed at 2,513, 1,420, 867, and 3,117 cm^{-1}. During the calcination process, $CaCO_3$ decomposed into CaO and CO_2. This is in line with the FTIR spectra of the catalyst which indicate that the intensity of characteristic peaks belonging

Table 2 Comparison of the properties of biodiesel produced from palm oil

Property	Biodiesel produced in this study	SNI	(B100)-ASTM D6751-07b
Density at 15°C (g/mL)	0.87 ± 0.09	0.85 to 0.89	-
Kinematic viscosity at 40°C (cSt)	3.7 ± 0.2	2.3 to 6.0	1.9 to 6.0
Flash point (°C)	163 ± 2.2	100 min	93 min
Cetane number	57 ± 2.2	51 min	47 min
Acid number (mg KOH/g)	0.40 ± 0.07	0.8 max	0.5 max
Water and sediment (vol.%)	0.03 ± 0.006	0.05 max	0.05 max

With catalyst from *Pomacea* sp. shell with the Indonesian National Standard (SNI-04-7182-2006) and (B100)-ASTM D6751-07b.
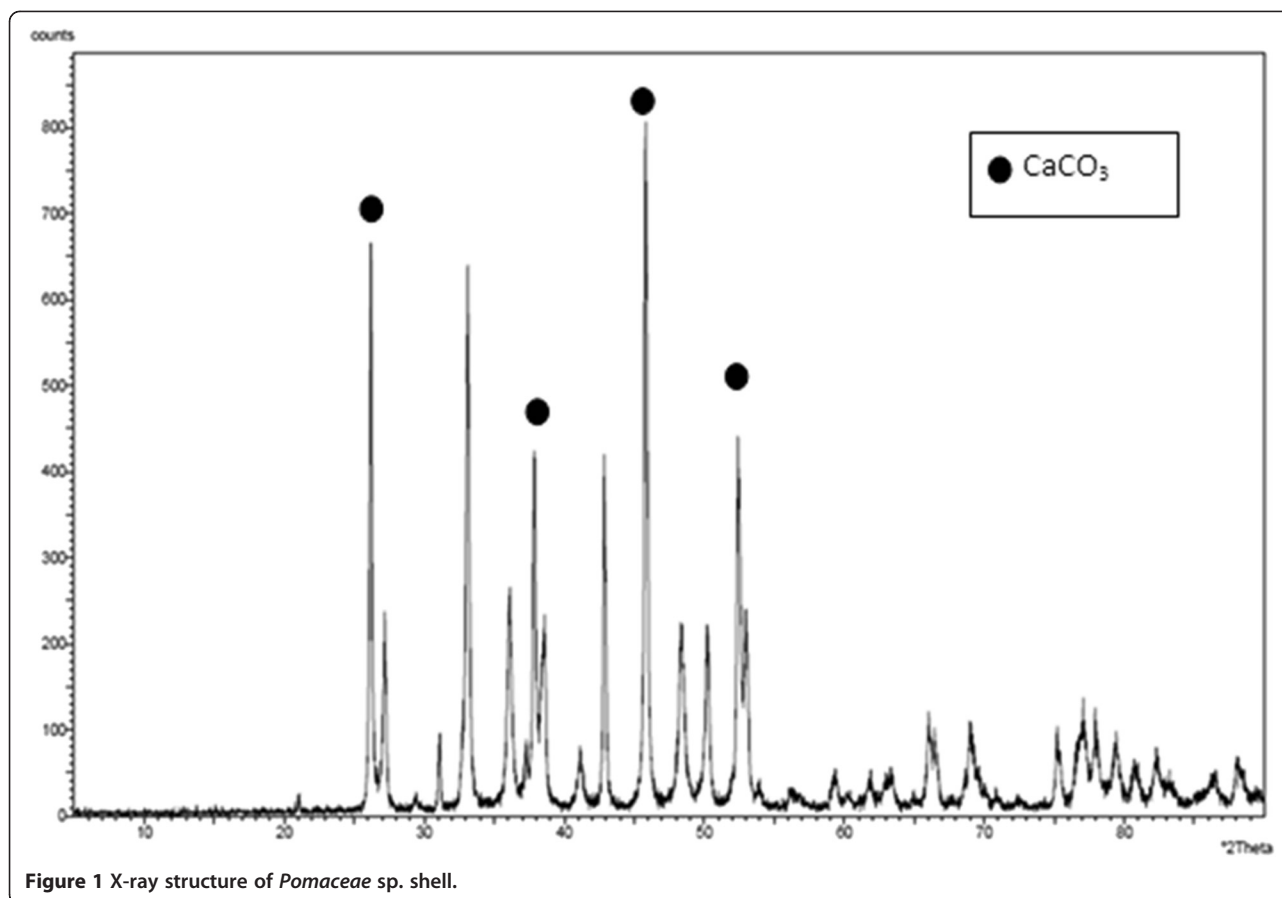
**Figure 1 X-ray structure of *Pomaceae* sp. shell.**

to $CaCO_3$ decreases. After the calcination process, a new peak appears at 3,620 cm^{-1}; this evidence indicates the formation of basic OH groups which attached to the calcium atoms [17]. The physical and chemical characteristics of CaO catalyst are summarized in Table 3.

Transesterification of palm oil
The transesterification of palm oil into biodiesel was conducted at different process parameters. Table 4 summarizes the yield of biodiesel obtained at different operating conditions (amount of catalyst 1% to 5% *w/w*, reaction time 4 h, and methanol to oil ratio 5:1 to 11:1). The maximum yield of biodiesel obtained in this study was 95.61 ± 2.43 at operation condition: catalyst amount of 4% *w/w* (catalyst to oil ratio) and methanol to oil ratio of 7:1. This result is comparable to that obtained by Chen et al. [18] in other heterogeneous catalyzed transesterification process and higher than the result obtained by Buasri et al. [19]. The maximum yield obtained from the process with heterogeneous catalyst was slightly lower than the process using NaOH as catalyst (97.24%). Even the heterogeneous catalyst produces lower yields of biodiesel, however, this process offers more advantages compared with homogeneous one, such as environmentally friendly, the catalyst is re-useable, etc.

By increasing the amount of catalyst, the yield of biodiesel also increased, as indicated in Table 4. In transesterification process, the CaO basic sites catalytically transform the methanol into nucleophile molecule which is much more reactive, and subsequently, this nucleophile attacks the carbonyl carbon structure of glyceride molecules [16,20]. As the amount of catalyst increases, the available catalytically basic sites also increase leading to the increase of biodiesel yield.

Stoichiometry of a transesterification reaction shows that in order to produce biodiesel, 3 mol of methanol/1 mol of triglyceride was needed [21]. Since the transesterification reaction is a reversible reaction, the adding of excess methanol drives the reaction towards the formation of biodiesel. In general, the conversion of triglyceride into fatty acid methyl esters (biodiesel) increased when the methanol to oil ratio was increased from 5:1 to 7:1. However, further increased of methanol to oil ratio caused the yield of biodiesel decreased, as indicated in Table 4. With the excessive amount of methanol, the formation of fatty acid methyl esters and glycerol becomes faster, and after the appreciable amount of glycerol was produced, the reaction between catalytically active sites of CaO with glycerol occurred and produced calcium glyceroxide [16,22]. This calcium glyceroxide is less active

Figure 2 X-ray structure of the catalyst.
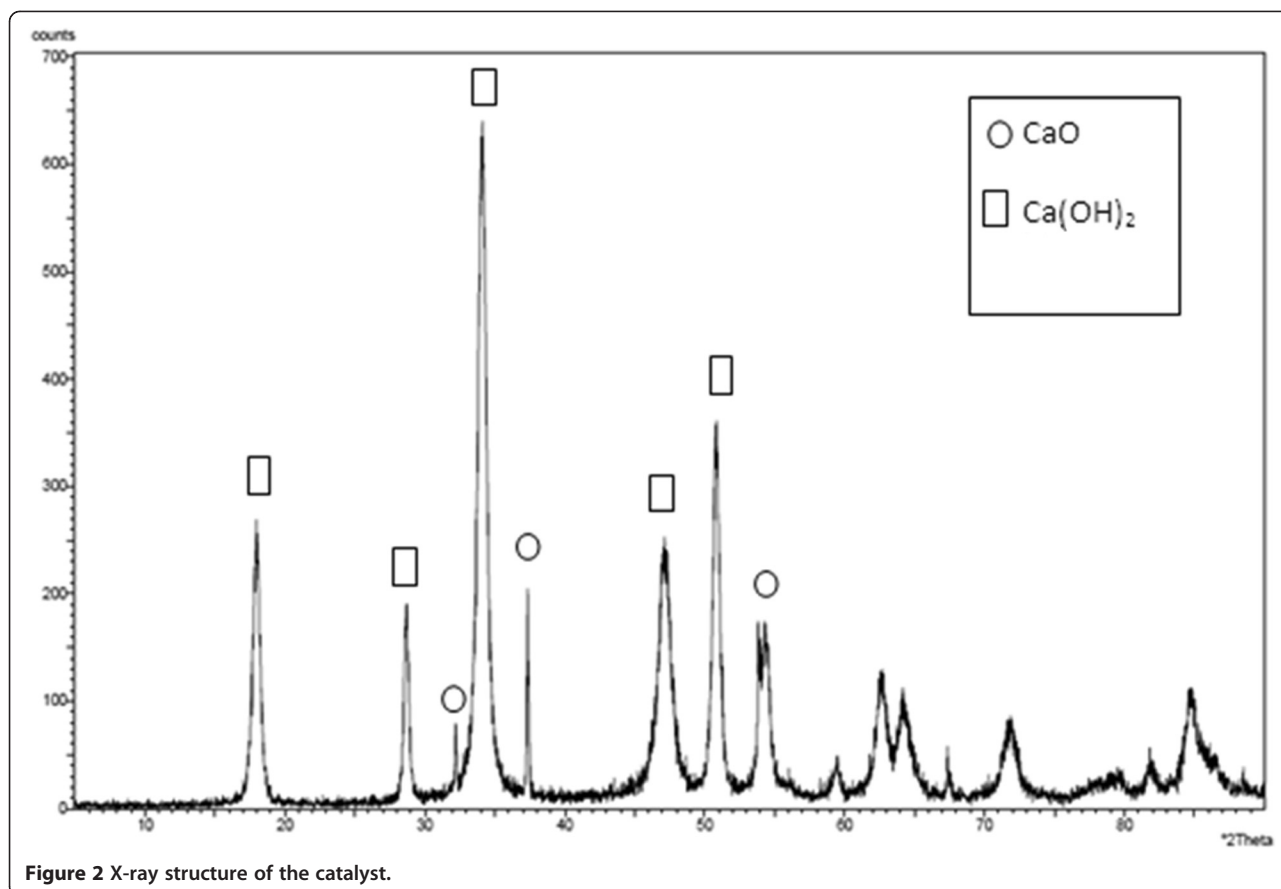
than CaO for transesterification of palm oil; therefore, less biodiesel was obtained. More detailed information about the reaction mechanism of the formation of calcium glyceroxide and its effect on the transesterification reaction may be found in the paper of Kouzu and Hidaka [16].

One of the important considerations in selecting a heterogeneous catalyst for transesterification of vegetable oils in the industrial scale production is its stability. The catalyst should be stable in a period time of operation without losing its catalytic capability or activity. In order to test the stability of CaO catalyst derived from *Pomacea* sp. shell, three reaction cycles were carried out using the following reaction condition: the amount of catalyst was 4% *w/w*, methanol to oil ratio was 7:1, and reaction time was 4 h. Furthermore,

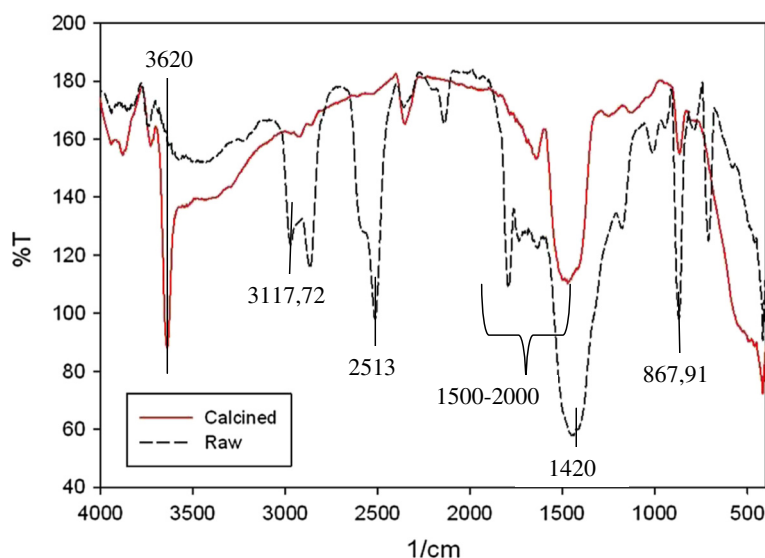**Figure 3 XRF spectra of the catalyst.**
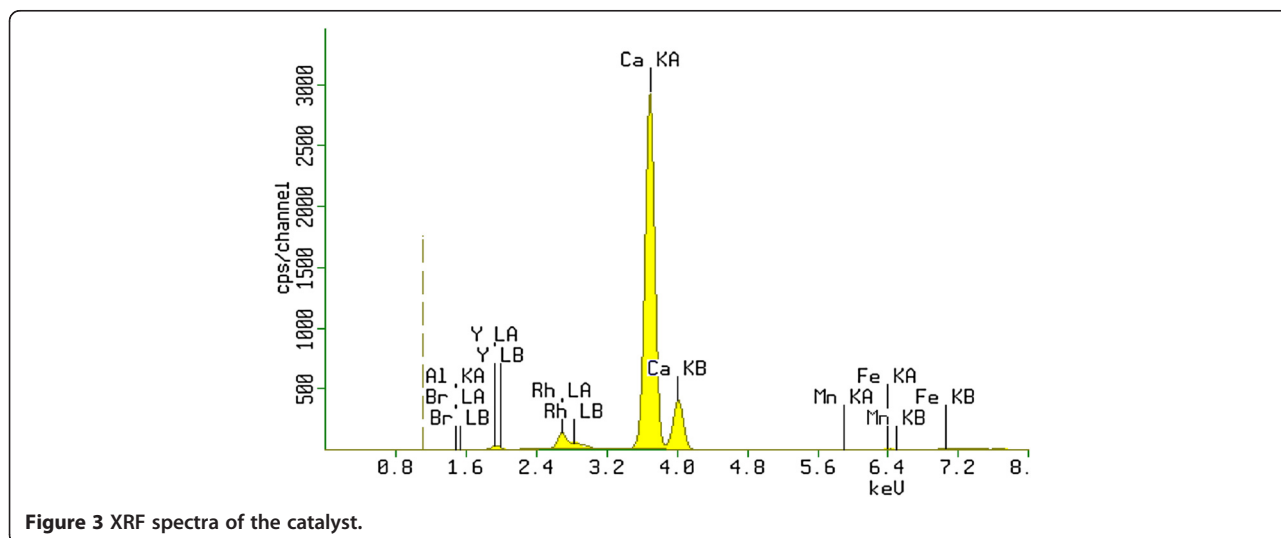
Figure 4 FTIR spectra of the raw material and CaO catalyst.

three different procedures for spent catalyst treatment were employed. The first procedure is the cheapest and easiest procedure; the spent or used catalyst was directly used without any further treatment for subsequent transesterification process. The second procedure involved the washing of spent catalyst with methanol to remove biodiesel and unconverted palm oil from the surface of the catalyst. As the last procedure, re-calcination of spent catalyst was conducted to determine the stability of the catalyst.

Figure 5 depicts the yield of biodiesel at different spent catalyst treatments under cycle reaction conditions. Figure 5 clearly shows that the treatment of spent catalyst has great influence on the yield of biodiesel. For untreated spent catalyst, the deactivation of the CaO catalyst already occurred in the second cycle, thus the yield of biodiesel significantly decreased from around 95% to 38% (Figure 5a). Further use of this spent catalyst made the conversion of palm oil into fatty acid methyl esters (biodiesel) did not occur. During the separation

of spent catalyst from the liquid mixture, the adsorption of H_2O from the ambient atmosphere by the basic sites of CaO catalyst could not be avoided which caused the de-activation of catalyst. The reaction between the basic sites of CaO and the ambient H_2O was fast, and

Table 4 Effect of different process variables on the yield of biodiesel

Amount of catalyst (%)	Reaction time (h)	Methanol to oil ratio	Yield of biodiesel (%)
1	4	5:1	70.86 ± 3.46
		7:1	86.63 ± 4.72
		9:1	78.98 ± 3.14
		11:1	83.50 ± 2.87
2	4	5:1	81.91 ± 2.44
		7:1	86.33 ± 3.48
		9:1	83.51 ± 4.22
		11:1	84.07 ± 2.73
3	4	5:1	86.93 ± 3.03
		7:1	87.60 ± 1.98
		9:1	91.26 ± 2.51
		11:1	89.22 ± 4.02
4	4	5:1	91.91 ± 3.91
		7:1	95.61 ± 2.43
		9:1	90.16 ± 2.78
		11:1	92.55 ± 3.82
5	4	5:1	93.48 ± 3.07
		7:1	85.81 ± 4.32
		9:1	85.28 ± 2.17
		11:1	91.16 ± 3.44

Table 3 Physical and chemical characteristics of the CaO catalyst

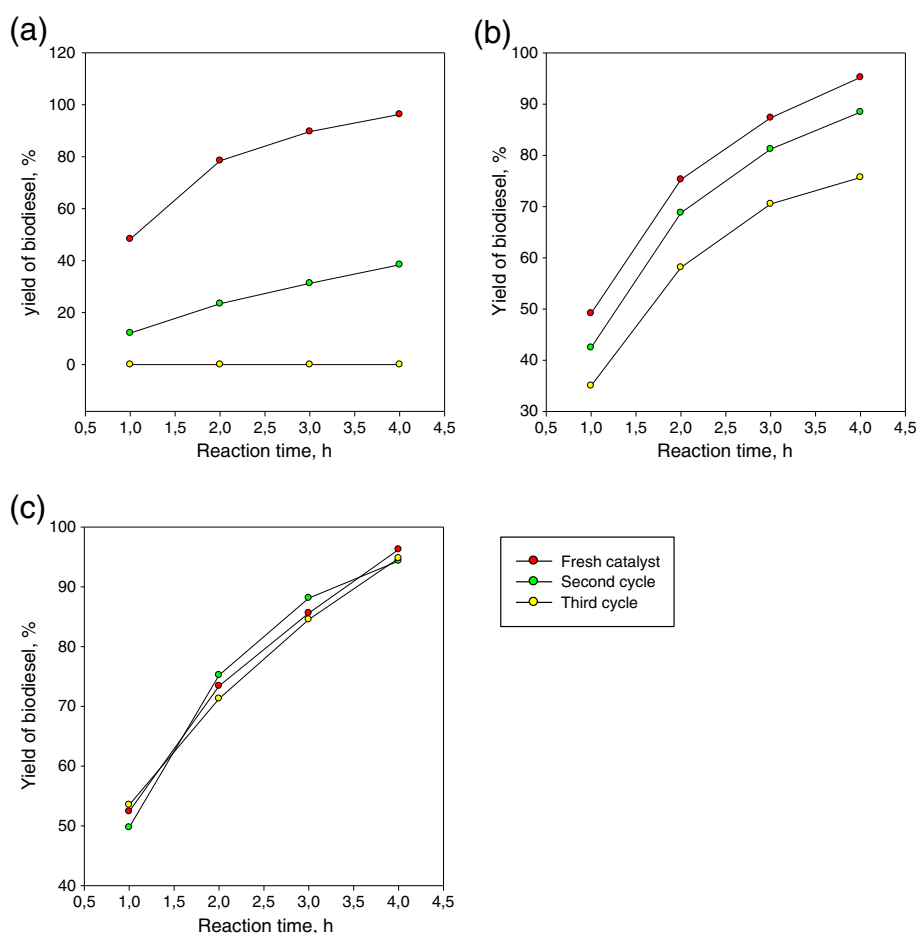| Property	Value
BET surface area (m^2/g)	17
Pore volume (cm^3/g)	0.04
Mean pore size (nm)	3.2
Particle size (mesh)	80/100
CaO content (%)	96.83
SiO_2 (%)	0.60
FeO (%)	0.42
Others	2.15

Figure 5 The yield of biodiesel at different spent catalyst treatments under cycle reaction conditions. (**a**) Untreated spent catalyst, (**b**) washing of spent catalyst with organic solvent, and (**c**) re-calcination of spent catalyst.

according to Kouzu et al. [22], it took only 3 min to appreciably reduce the catalyst activity.

The treatment of spent catalyst with methanol gave better yields of biodiesel than non-treated spent catalyst. Here, the conversion of palm oil into FAME for the second and third cycles was higher than the transesterification process using non-treated spent catalyst, as indicated in Figure 5b. As mentioned in the previous paragraph, the contact between the basic site and ambient H_2O may cause the deactivation of catalyst due to the formation of hydroxide groups on the surface of the catalyst, and during washing of this spent catalyst with methanol, the hydroxide groups on the surface of catalyst were isolated; these isolated OH groups with the help of the basic site of CaO still could act as an active site for transesterification reaction [16,23].

Figure 5c shows the yield of biodiesel synthesized using re-calcined spent catalyst. After transesterification process, the surface of spent catalyst was covered by hydrate, carbonate, and other compounds such as unreacted oil, biodiesel, glycerol, etc.; therefore, the catalytic activity

of this spent catalyst drastically reduced. In the re-calcination process, all of those impurities were perfectly removed from the surface of the catalyst. By removing those impurities, the available basic sites in CaO surface also significantly increase, and the catalytic activity is similar to fresh catalyst. However, one of the drawbacks of using re-calcination method is the high energy requirement.

Biodiesel characterization

Density is one of the most important characteristics of biodiesel. In a combustion system, pumps and injectors require a precise amount of fuel to provide proper combustion [24], and fuel density is the main characteristic that determines the amount or mass of fuel injected into the combustion chamber. The density of the biodiesel produced in this study is given in Table 2, and the value is in accordance with the Indonesian National Standard (SNI-04-7182-2006).

Viscosity of biodiesel is another important characteristic of biodiesel; it affects the atomization of fuel upon injection into the combustion chamber. Fuel with

high viscosity has the tendency to form deposit in the engine, but fuel with low viscosity may not provide sufficient lubrication in the combustion system. The Indonesian National Standard has set the standard viscosity for biodiesel which is in the range of 2.3 to 6.0 cSt, while the ASTM viscosity standard for biodiesel is 1.9 to 6.0 cSt. The average viscosity values of biodiesel produced from palm oil using CaO catalyst derived from Pomacea sp. shell is 3.7 ± 0.2 cSt. This average viscosity is in the range of the standard value of viscosity of biodiesel from SNI and ASTM.

Flash point of biodiesel relates to the ignition of the fuel. In order to handle the fuel safely, moderate value of flash point is required. The biodiesel produced in this study possesses higher flash point value than SNI and ASTM standards (Table 2); therefore, this fuel is safe for handling and storage for a period of time. The combustion quality of diesel fuel during compression ignition is indicated by an index called as cetane number. This index has great influence on the performance of the engine especially during combustion and exhaust emission. The low value of cetane index creates the problem to the engine during start up and produces noise. Also, during the combustion, smoke exhaust gas will be produced [25]. The average cetane number of the biodiesel obtained in this study is higher than the standard value of SNI and ASTM (Table 2). The cetane number of biodiesel depends on the distribution of fatty acids in the raw material (oil); the longer fatty acid carbon chains, the higher the cetane number. In this study, palm oil was employed as raw material for biodiesel production, where methyl palmitate and methyl oleate are the major compounds in palm oil. These fatty acids have cetane indexes of 59.3 and 85.9, respectively [25]. Therefore, the minimum standard of cetane index will be easily fulfilled if palm oil is used as the raw material for biodiesel production. Furthermore, the other physical characteristic of biodiesel is also affected by the composition and length of fatty acid as mentioned by Ramos et al. [26].

The control of acid number on biodiesel production is also important since this parameter indicates the quantity of free fatty acids and mineral acids present in the biodiesel. Biodiesel with high value of acidity will cause corrosion and engine deposits, especially in the fuel injectors. The increase of acid number during storage is a strong indication that the degradation of biodiesel takes place. Water contamination is also another important parameter in biodiesel quality. Several problems associated with the presence of excess water in biodiesel are low calorific value, corrosion, growth of microorganisms, oxidation, and degradation of biodiesel during long-term storage. The standard values of these parameters were fulfilled by the biodiesel produced in this study as indicated in Table 2.

Conclusion

A catalyst for biodiesel production was prepared from the Pomacea sp. shell. The transesterification reaction of palm oil into biodiesel using this heterogeneous catalyst was studied under various operating conditions, and the maximum yield of biodiesel (95.61 ± 2.43) was obtained on the condition as follows: catalyst 4% and methanol to oil ratio 7:1. The reusability and stability are very important criteria for large-scale production of biodiesel using CaO catalyst prepared from Pomacea sp. shell. The activity of spent catalyst could be restored by re-calcination process. The physical and chemical properties of biodiesel produced conform to the available standards.

Authors' contributions
YYM and HSP collected the experimental data, AA drafted the manuscript, and SI developed the idea and corrected the manuscript. All authors read and approved the final manuscript.

References
1. Eddine, BT, Salah, MM: Solid waste as renewable source of energy: current and future possibility in Algeria. Int. J. Energy Env. Eng. **3**, 17 (2012)
2. Marasabessy, A, Kootstra, AMJ, Sanders, JPM, Weusthuis, RA: Dilute H_2SO_4-catalyzed hydrothermal pretreatment to enhance enzymatic digestibility of jatropha curcas fruit hull for ethanol fermentation. J. Energy Env. Eng. **3**, 15 (2012)
3. Kouzu, M, Kasuno, T, Tajika, M, Sugimoto, Y, Yamanaka, S, Hidaka, J: Calcium oxide as a solid base catalyst for transesterification of soybean oil and its application to biodiesel production. Fuel **87**, 2798–2806 (2007)
4. Dias, JM, Ferraz, M, Almeida, MF: Comparison of the performance of different homogeneous alkali catalysts during transesterification of waste and virgin oils and evaluation of biodiesel quality. Fuel **87**, 3572–3578 (2008)
5. Pugnet, V, Maury, S, Coupard, V, Dandeu, A, Quoineaud, AA, Bonneau, JL, Tichit, D: Stability, activity and selectivity study of a zinc aluminate heterogeneous catalyst for the transesterification of vegetable oil in batch reactor. Appl. Catal. A. **374**, 71–78 (2010)
6. Demirbas, A: Progress and recent trends in biodiesel fuels. Energy Conv. Manag. **50**, 14–34 (2009)
7. Liu, X, He, H, Wang, Y, Zhu, S: Transesterification of soybean oil to biodiesel using SrO as a solid base catalyst. Catal. Comm. **8**, 1107–1111 (2007)
8. Noiroj, K, Intarapong, P, Luengnaruemitchai, A, Jai-In, S: A comparative study of KOH/Al_2O_3 and KOH/NaY catalysts for biodiesel production via transesterification from palm oil. Renewable Energy **34**, 1145–1150 (2009)
9. Lukić, I, Krstić, J, Jovanović, D, Skala, D: Alumina/silica supported K2CO3 as a catalyst for biodiesel synthesis from sunflower oil. Biores. Technol. **100**, 4690–4696 (2009)
10. Gao, L, Teng, G, Lv, J, Xiao, G: Biodiesel synthesis catalyzed by the KF/Ca-Mg-Al hydrotalcite base catalyst. Energy Fuel **24**, 646–651 (2010)
11. Ngamcharussrivichai, C, Totarat, P, Bunyakiat, K: Ca and Zn mixed oxide as a heterogeneous base catalyst for transesterification of palm kernel oil. Appl. Catal. A. **341**, 77–85 (2008)
12. Serio, MD, Cozzolino, M, Tesser, R, Patrono, P, Pinzari, F, Bonelli, B, Santacesaria, E: Vanadyl phosphate catalysts in biodiesel production. Appl. Catal. A. **320**, 1–7 (2007)

13. Yoosuk, B, Udomsap, P, Puttasawat, B, Krasae, P: Improving transesterification activity of CaO with hydration technique. Biores. Technol. **101**, 3784–3786 (2010)
14. Viriya-Empikul, N, Krasae, P, Puttasawat, B, Yoosuk, B, Chollacoop, N, Faungnawakij, K: Waste shells of mollusk and egg as biodiesel production cata. Biores. Technol. **101**, 3765–3767 (2010)
15. Iizuka, T, Hattori, H, Ohno, Y, Sohma, J, Tanabe, K: Basic sites and reducing sites of calcium oxide and their catalytic activities. J. Catal. **22**, 130–139 (1971)
16. Kouzu, M, Hidaka, J: Transesterification of vegetable oil into biodiesel catalyzed by CaO: a review. Fuel **93**, 1–12 (2012)
17. Garcia, JLT, Alvarez, M, Aguilar, DH, Quintana, PJ: Spectroscopic, structural and textural properties of CaO and CaO-SiO2 materials synthesized by sol–gel with different acid catalysts. Non-Crystal Solids **354**, 729 (2008)
18. Chen, YH, Huang, YH, Lin, RH, Shang, NC, Chang, CY, Chang, CC, Chiang, PC, Hu, CY: Biodiesel production in a rotating packed bed using $K/\gamma\text{-}Al_2O_3$ solid catalyst. J. Taiwan Inst. Chem. Eng. **42**, 937–944 (2011)
19. Buasri, A, Chaiyut, N, Loryuenyong, V, Rodklum, C, Chaikwan, T, Kumphan, N: Continuous process for biodiesel production in packed bed reactor from waste frying oil using potassium hydroxide supported on *Jatropha curcas* fruit shell as solid catalyst. Appl. Sci. **2**, 641–653 (2012)
20. Hattori, H, Shima, M, Kabashima, H: Alcoholysis of ester and epoxide catalyzed by solid base. Stud. Surf. Sci. Catal. **130**, 3507–3510 (2000)
21. Singh, SP, Singh, D: Biodiesel production through the use of different sources and characterization of oils and their esters as the substitute of diesel: a review. Renew Sustain Energy Rev. **14**, 200–216 (2009)
22. Kouzu, M, Kasuno, T, Tajika, M, Yamanaka, S, Hidaka, J: Active phase of calcium oxide used as solid base catalyst for transesterification of soybean oil with refluxing methanol. Appl. Catal. A. Gen. **334**, 357–365 (2008)
23. Liu, X, He, H, Wang, Y, Zhu, S, Piao, X: Transesterification of soybean oil to biodiesel using CaO as a solid base catalyst. Fuel **87**, 216–221 (2008)
24. Dzida, M, Prusakiewicz, P: The effect of temperature and pressure on the physicochemical properties of petroleum diesel oil and biodiesel fuel. Fuel **87**, 1941–1947 (2008)
25. Rashid, U, Anwar, F, Knothe, G: Biodiesel from Milo (*Thespesia populnea L.*) seed oil. Biomass Bioenergy **35**, 4034–4039 (2011)
26. Ramos, MJ, Fernandez, CM, Casas, A, Rodriguez, L, Perez, A: Influece of fatty acid composition of raw materials on the biodiesel properties. Biores. Technol. **100**, 261–268 (2009)