

DEVELOPMENT OF HETEROGENEOUS ALKALI METHOXIDE CATALYST FROM FLY ASH AND LIMESTONE

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Abstract. This study is aimed to use fly ash and limestone as raw materials for preparing alkali methoxide heterogeneous catalysts for transesterification of palm oil into biodiesel. The heterogeneous catalyst was synthesized from fly ash and limestone through wet and dry methods and calcined within 1073–1273 K. X-ray diffraction and scanning electron microscopy analyses indicated the well-dispersed presence of the $\text{Ca}(\text{OCH}_3)_2$ crystal over the fly ash and limestone framework, which was mixed using wet method and calcined at 1073 K (W-800). Results showed that W-800 exhibited larger surface area and more uniform active sites than the other catalysts. About 88.6% of biodiesel was produced from commercial palm oil with W-800 as the catalyst. The product possesses physicochemical characteristics, such as density, kinematic viscosity and free fatty acid content, which satisfy the international biodiesel standard. The catalyst was used for biodiesel production for four cycles, and the biodiesel yield was maintained up to 91.87% from the initial value.

Keywords: biodiesel, fly ash, limestone, transesterification, palm oil.

1. Introduction

Biodiesel is an alternative energy source used to replace commercial diesel fuel which derived from fossil fuel. The advantages of biodiesel include its renewability, biodegradability, nontoxicity and low emission of CO and

CO_2 [1]. In research of biodiesel, scholars have focused on developing suitable catalysts, such as heterogeneous catalysts, which exhibit advantages over homogeneous catalysts. Compared with homogeneous catalysts, heterogeneous catalysts can be used for several times in biodiesel production, they do not require separation between the biodiesel product and the catalyst, and they can be easily obtained synthetically and in nature [2-4]. Commonly used heterogeneous catalysts in the manufacture of biodiesel include CaO [5, 6], MgO [7], SrO [8], $\text{Ca}(\text{OCH}_3)_2$ [9], H-zeolite [4], and sulphate glucose solid acid [10].

Calcium oxide (CaO) can be manufactured by thermal decomposition of CaCO_3 from limestone, fly ash and other raw materials. Fly ash exhibits potential to be used as a catalyst in the manufacture of biodiesel because it contains various compounds, such as CaO, SiO_2 , K_2O , Fe_2O_3 , and MgO [11]. Fly ash contains 5.3% CaO, 51.5% SiO_2 , 1.2% K_2O , 10.8% Fe_2O_3 and 2.0% MgO [12] and can be used as support for preparation of heterogeneous catalysts. It is produced during coal combustion. Fly ash, which is obtained from combustion residues in industries that use coal as an energy source (coal contributes around 60% of the total fuel for electricity generation in Indonesia [13, 14]), is very rarely utilized, even though fly ash has a relatively high economic value when processed properly [15]. Meanwhile, limestone can be easily obtained from nature and contains a maximum of 56 wt% of CaO. There are many limestone mountains in Indonesia. Most of this limestone is widely used as raw material for making cement. Because the need for renewable energy is increasingly high, the diversification of limestone as a raw material for making biodiesel catalysts is very promising.

Various studies have been conducted to identify the trans-esterification reaction parameters that could affect the yield of biodiesel; such parameters include the type of raw material, type and amount of catalyst, type and amount of alcohol, alcohol-to-oil molar ratio, temperature and free fatty acid (FFA) content [16]. A previous study conducted transesterification with 7:3 weight ratio mixture

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of CaO and SnO₂ solid catalysts, the temperature of 333 K, 6:1 methanol-to-oil molar ratio, the reaction time of 120 min and 3 wt % of catalyst loading; 87.46 % of biodiesel was obtained [16]. Theamet *et al.* [9] researched transesterification with Ca(OCH₃)₂ solid catalyst. Alkali methoxide was synthesized through the reaction of calcium and methanol in a slurry reactor. Transesterification was conducted at 353 K for 180 min by using 6:1 methanol-to-oil molar ratio and catalyst concentration of 1.5 wt % oil and yielded 94.70 % of biodiesel. These works confirm that Ca(OCH₃)₂ functions better than CaO/SnO₂. Ca(OCH₃)₂ contains more active catalytic sites for a reaction, higher surface area, total pore volume and average diameter than CaO [17]. These physical properties affect the rate of reaction.

The wet mixing method is a new method that has never been tried previously in biodiesel catalysts fabrication. The idea arises when raw materials are only mechanically mixed without any addition of the solution to make it more homogeneous. For that reason, limestone initially mixed with a solution such as water before being fed into other raw materials such as fly ash to get a more homogeneous and better catalyst.

In this study, alkali methoxide catalyst was synthesized through the reaction of calcination limestone-fly ash mixture and methanol by using dry and wet mixing methods. There are two purposes of this experiment: (i) increasing the value of fly ash, which is abundant in Indonesia, into a biodiesel catalyst that has a much higher economic value, and (ii) applying wet method as a new way of making biodiesel catalysts. The morphology and crystallography of the catalysts were characterized by scanning electron microscopy (SEM) and X-ray diffraction (XRD) analyses. The biodiesel produced using the developed catalyst was analyzed in terms of yield and physicochemical characteristics, such as density, kinematic viscosity and % FFA.

2. Experimental

2.1. Materials

Fly ash was provided by PT. APAC INTI, Central Java, Indonesia, and limestone was obtained from a local market in Semarang. Methanol (99%) and *n*-hexane were purchased from Merck (Darmstadt, Germany). Palm oil with initial FFA content of less than 2 % was commercially acquired from a local market in Semarang, Indonesia.

2.2. Catalyst Synthesis

The alkali methoxide catalyst synthesis process was based on modifications from several references where

the process stages consist of raw materials mixing process, heating process at low temperatures for removal of moisture content, and calcination process at high temperatures for catalyst formation. Initially, limestone was crushed, ground to fine powder and sieved (0.15 mm) before use. Fly ash was added with deionized (DI) water and incubated overnight to remove impurities [18, 19]. The sediment of fly ash was collected and dried at room temperature for 1 day to reduce the moisture content. Limestone powder and fly ash were mixed with a weight ratio of 1:1 through wet and dry methods [20]. The dry method was conducted by directly mixing the powdered limestone and fly ash. The wet method was performed by dissolving the powdered limestone in DI water and mixing with fly ash. The wet mixture was dried by heating in an oven at 383 K for 2 h to reduce the water content. The water content is assumed to decrease significantly considering the temperature used is 383 K, *i.e.* higher than the boiling point of water. The mixtures from wet and dry methods were calcined at high temperatures of 1073–1273 K for 7 h to generate CaO and Ca(OCH₃)₂ crystal from CaCO₃. According to the previous research, Ho *et al.* [21] have using calcination temperature of 1123–1273 K, while Volli and Purkait [22] used the temperature of around 1073–1273 K for the calcination process. Finally, alkali methoxide catalysts were synthesized by mixing 1 g of the catalyst in 25 ml of methanol followed by stirring at 150 rpm for 1 h at room temperature [9]. Methanol was doped into the catalyst by increasing the temperature from room temperature to 333 K [9, 17]. The design of the experiment is shown in Table 1.

Table 1

Design of experiment of catalyst synthesized from fly ash and limestone

Sample name	Mixing method	Calcination temperature, K
D-800	Dry	1073
D-900	Dry	1173
D-1000	Dry	1273
W-800	Wet	1073
W-900	Wet	1173
W-1000	Wet	1273

2.3. Characterization of Raw Materials and Catalyst

The morphology of the raw materials (fly ash and limestone) and catalysts was examined by scanning electron microscopy using JEOL-6510 (Seoul, Korea) under an acceleration voltage of 20 kV and a probe current of 1 nA.

Structural properties of the catalysts were analyzed by powder X-ray diffraction method using a Shimadzu

MAXima X XRD-7000 diffractometer (Kyoto, Japan) with Cu K α radiation ($k = 0.154$ nm) at 30 kV and 30 mA. The sampling pitch was set at 0.02° , and the pre-set time was 0.3 s. The scanning range was conducted from 20° to 90° with a scanning speed of $4^\circ/\text{min}$ in a continuous mode.

2.4. Transesterification and Purification of Biodiesel

Transesterification was carried out in a three-neck round-bottom flask (batch mode reactor) following modification method from several references [23, 24]. Initially, 250 ml of palm oil was heated at 333 K [25]. The warmed palm oil was fed to the reactor with the final molar ratio between palm oil and methanol set to 1:6 [26, 27]. The mixture was stirred at 700 rpm and 333–338 K for 3 h [28, 29]. The mixture was centrifuged after the methanolysis reaction. The solid catalyst was recovered by filtration, and residual methanol was removed using DLab RE100-Pro rotary evaporator (Beijing, China). The mixture was then placed in a decanter and allowed to stand overnight to ensure the complete separation between methyl esters and the glycerol phase. The glycerol phase was then collected from the mixture to obtain a methyl ester phase (biodiesel). Centrifugation was conducted on DLab DM0412 (Beijing, China) at 1600 rpm for 15 min to support the separation between the rest of glycerol and methyl ester after decantation [30].

2.5. Biodiesel Characterization

Fatty acid methyl ester (FAME) was analyzed using gas chromatography spectrometry (GCMS) (Brand Shimadzu GCMS-TQ8030 type). Helium gas was used as carrier gas at a flow rate of 1.20 ml/min. The yield obtained from the reaction was calculated using Eq. (1) [31]:

$$\text{Yield}(\%) = \frac{\text{Weight of biodiesel}}{\text{Weight of oil}} \cdot 100 \quad (1)$$

The following physical properties of biodiesel were analyzed: kinematic viscosity, density, and acid number. Kinematic viscosity has an effect on the engine CI speed, while density would affect in fuel atomizer and emission [32]. On the other side, % FFA could affect kinematic viscosity. These biodiesel properties were characterized using the following international standards: (i) kinematic viscosity was determined using glass capillary viscometers according to ISO 3104:1994 [33]; (ii) density was measured using hydrometer method according to ISO 3675:1998 [34]; and acid number was determined using titrimetric method under ISO 7537:1997 [35]. Based on the international standard of biodiesel, the viscosity of biodiesel is in range of 2.3–6.0 mm²/s.

2.6. Catalyst Reusability

The catalyst was separated from the mixture by filtration after each reaction cycle to evaluate its reusability. *n*-Hexane was used as a washing agent to clean the catalyst surface. The catalyst was then dried at 378 K and reused for the next reaction cycle through recalcination for 2 h. For the next reaction cycle, a new batch of palm oil and methanol was added to the batch reactor containing the used catalyst following the procedures as mentioned above in subsection 2.4. Four transesterification cycles were carried out to evaluate catalyst reusability.

3. Results and Discussion

3.1. Characteristics of Raw Materials

3.1.1. SEM and EDX analyses

The SEM images (Fig. 1) indicate the morphological characteristics of the raw materials, namely, fly ash and limestone, before calcination. Burned and unburned carbon (or char) was observed in the raw fly ash. Furthermore, the SEM images showed the small particle size of the raw fly ash due to the release of CO₂ during combustion; the particles tended to agglomerate on large ones (Fig. 1a). The fly ash particles have an irregular spherical shape and smooth surface. Fly ash is a suspended solid from gas produced by burning coal at very high temperatures (reaching 723 K). In this process, carbon will be formed from hydrocarbon materials and small metal particles and can be carried by gas [36]. Limestone is a solid rock obtained from limestone mountain. Limestone has larger particles than fly ash (Fig. 1b) and cubic shape with rough surface due to the preparation processes (crushing and grinding). The size of limestone particles varies between 0.5 and 3 μm .

The elemental composition of fly ash and limestone was examined by EDX analysis (Table 2). Fly ash is dominated by carbon (77.29 wt %), consistent with the previous result that fly-ash obtained from burning coal processing yielded carbon and small metal particles. These elements can form oxide compounds, such as Na₂O, MgO, Al₂O₃, K₂O, CaO, and FeO, which are very useful and needed in the production of biodiesel [37]. Limestone is dominated by oxygen (55.89 wt %), followed by calcium (38.72 wt %) and carbon (5.32 wt %). Mg, Al, S and Fe particles were also found but in small amounts. The three most prominent elements in limestone form CaCO₃, with content reaching more than 99 wt %.

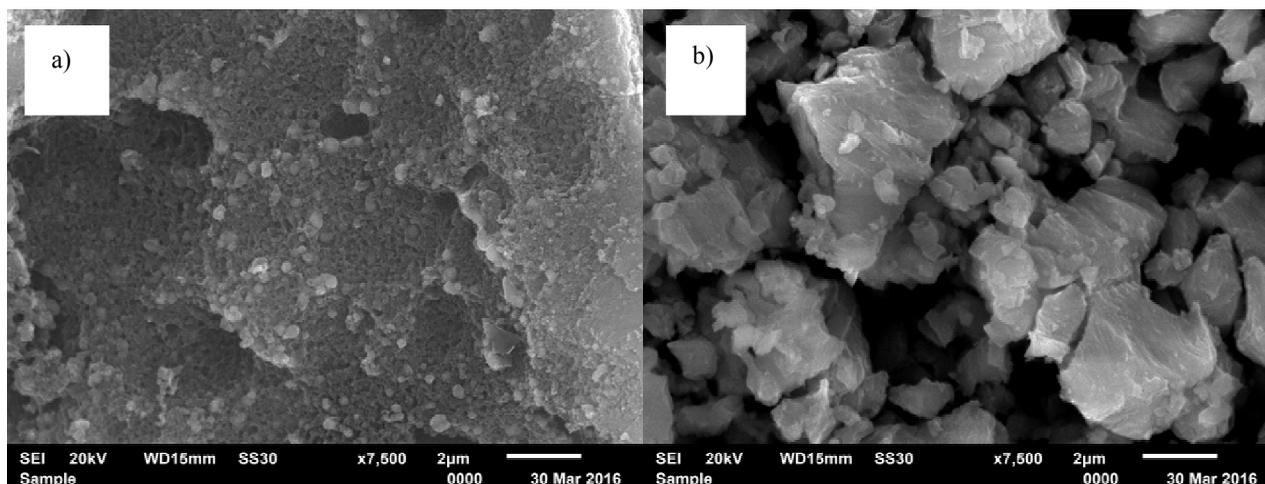


Fig. 1. SEM images of fly ash (a) and limestone (b)

Table 2

Elemental composition of fly ash and limestone

Sample	Elements (wt. %)									
	C	O	Na	Mg	Al	S	K	Ca	Fe	Si
Fly ash	77.29	15.56	0.40	0.47	0.25	0.81	0.12	0.93	4.16	n.d.
Limestone	5.32	55.89	n.d.	0.01	0.02	0.01	n.d.	38.70	0.03	0.02

Note: n.d. is not detected

3.1.2. XRD analysis

The XRD patterns of the raw materials before calcination, namely, fly ash and limestone are shown in Fig. 2. Based on the XRD spectra (upper line), limestone is dominated by calcite in 18.25°, 28.94°, 34.35°, 47.35°, 54.59°, 62.84°, 64.48°, 72.03°, and 84.94°; a weak peak of aluminate exists in 59.94°. Calcite is a carbonate mineral and the most stable polymorph of calcium carbonate.

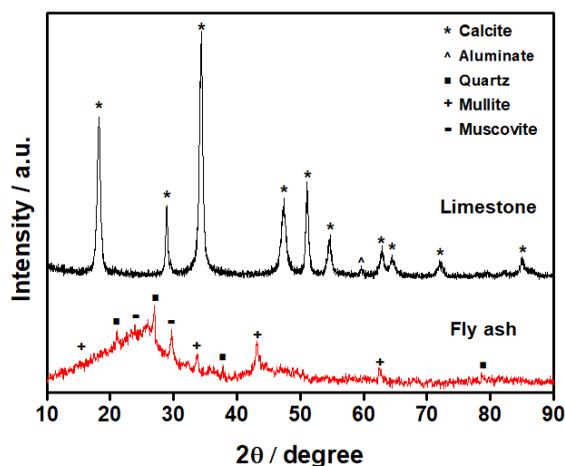


Fig. 2. XRD patterns of fly ash and limestone as raw materials of the catalyst

The presence of calcite in the XRD spectra is consistent with the EDX result that the dominant elements in limestone are C, O and Ca. Based on the XRD spectra (bottom line), fly ash is composed mainly of quartz in 21.21°, 26.93°, 37.75°, and 78.66 and mullite (M) in 14.71°, 33.70° and 43.15° [38, 39]. A small amount of muscovite is also found at 25.95° and 29.71°. Fly ash is primarily composed of amorphous material and some crystalline phases, which are represented by the 'hump' with 2θ of 18°–35° [22].

3.2. Characteristics of the Catalyst

3.2.1. SEM analysis

Fig. 3 shows the morphology of the catalysts fabricated at various calcination temperatures (1073–1273 K) and mixing methods (wet or dry). Overall, the synthesized catalysts have irregular shapes, an agglomerated structure, and various sizes. The agglomerated structure indicates the formation of metal oxides upon calcination of the catalyst [21]. The rough surface of the catalysts indicates the formation of CaO and $\text{Ca}(\text{OCH}_3)_2$ crystals on the catalyst surface during thermal treatment. The increase in the calcination temperature from 1073 to 1273 K increases the catalyst particle size. According to previous reports [40–42], the increase in the calcination temperature increases the particle size, and

leads to the decreased surface area [43]. The increase in the surface area could increase the number of active sites, resulting in more effective catalytic activity.

The catalyst prepared through wet method has more spongy and porous structures than the one prepared through dry method. The spongy and porous structures indicate a highly absorbent surface [44], where the absorption ability indicates the capability of the catalysts. The catalyst produced by the wet method also possesses a more solid form than that prepared by the dry method. Mixing raw materials using wet method leads to even distribution of limestone because its form is slurry when

mixed with fly ash. Hence, the catalyst is solid and smaller [10]. Table 3 shows the particle sizes of the catalysts based on the SEM images.

Table 3

The range of catalyst particle size

Sample name	Range of particle size, μm
D-800	0.385–0.700
D-900	0.475–0.815
D-1000	0.906–1.204
W-800	0.243–0.665
W-900	0.500–0.665
W-1000	0.800–1.160

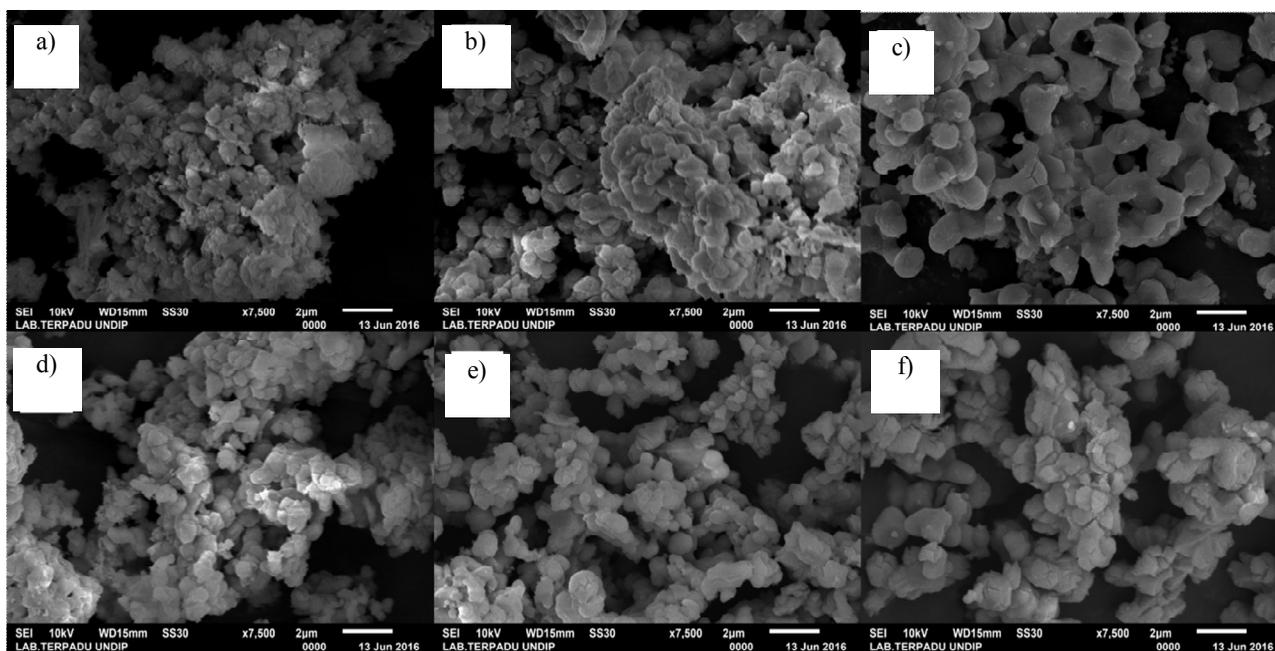


Fig. 3. SEM images of developed catalysts: D-800 (a), D-900 (b), D-1000 (c), W-800 (d), W-900 (e) and W-1000 (f)

3.2.2. XRD analysis

The XRD patterns of the catalyst prepared from fly ash and limestone through wet and dry methods are shown in Fig. 4. The figure shows three noticeable peaks. First, the main component in all catalysts is CaO crystal, which was formed from CaCO_3 of limestone during calcination. Calcium methoxide ($\text{Ca}(\text{OCH}_3)_2$), mullite (Al_2O_3), quartz and dicalcium silicate were also found. The presence of these elements could be due to the strong impregnation of limestone within fly ash. According to Ho *et al.* [21], dicalcium silicate is an impurity in catalysts, and its formation should be avoided. However, the presence of dicalcium silicate in the developed catalyst could lead to appreciable catalyst basicity due to the presence of Si–O–Ca bond [45]. Second, as the calcination temperature increases, the intensity of CaO and $\text{Ca}(\text{OCH}_3)_2$

peaks also increase. Hence, CaO and $\text{Ca}(\text{OCH}_3)_2$ crystals were successfully formed during calcination and continuously grew when the temperature was raised. Under the same condition, the intensities of the peaks of mullite, quartz and dicalcium silicate decrease with increasing calcination temperature. High temperatures become an alternative solution to reduce the dicalcium silicate content in the catalyst so that it can work well. Moreover, quartz and mullite from fly ash were converted relatively well and became the developed catalyst. Third, the catalyst produced using wet or dry method exhibits peak intensities that are more or less similar to those of all elements. Hence, the mixing method did not significantly affect the elemental composition of the catalyst and the calcination process.

Crystallinity degree is related to catalytic activity and indicates the regularity of atoms in the cell unit and crystal lattice. This parameter can be determined using the

magnitude of the amount of the crystal content in a material by comparing the area of the crystal curve to the total area, which consists of amorphous and crystal area. In general, the higher the crystallinity degree, the better the performance of the catalyst [46]. However, crystallinity is not an absolute parameter of catalyst performance. For example, if dicalcium silicate crystal, which is an impurity, is formed on the catalyst, then the catalyst performance will decrease. The crystallinity degree of the catalyst is shown in Fig. 5a. When the calcination temperature is high, the rate of crystal formation increases due to an increase in CO₂ release. Increasing the calcination temperature will increase the mobility of atoms in particles, thereby facilitating the assembly of atoms to form crystals. Using two mixing methods at the same calcination temperature produced a catalyst with insignificant degree of crystallinity, but the

degree of the catalyst prepared by dry mixing method is slightly higher. Although the distribution is evenly distributed, limestone and fly ash are not dissolved in water. Thus, no chemical reaction exists between limestone and water, hindering the formation of new types of the desired element.

In addition to crystallinity degree, the size of Ca(OCH₃)₂ crystal in the developed catalyst is important because it is associated with catalyst activity or performance. The size of Ca(OCH₃)₂ crystal was determined using Scherrer's formula [47]:

$$D = \frac{K\lambda}{\beta \cos 2\theta} \quad (2)$$

where K is the Scherrer's constant (0.94), λ is the wavelength (1.54056 Å), β is the peak width at half the highest intensity (FMHW) and θ is the Bragg angle.

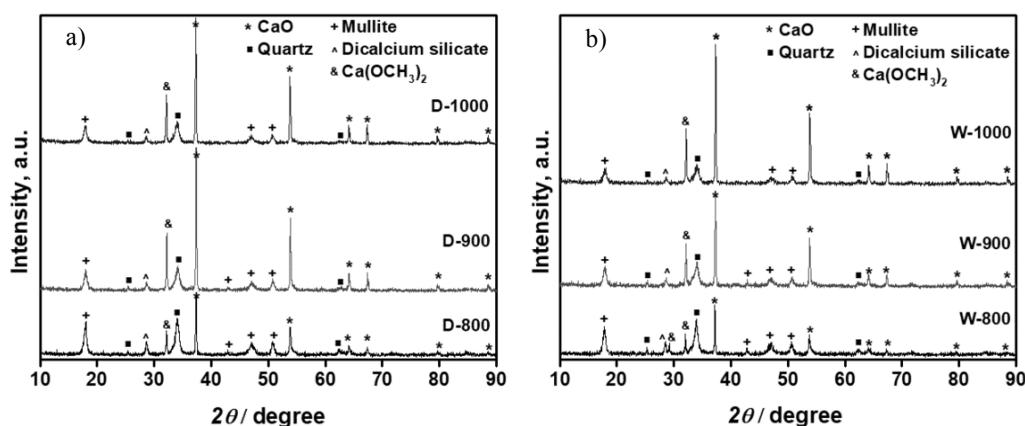


Fig. 4. XRD patterns of the developed catalyst fabricated using dry (a) and mixing (b) methods

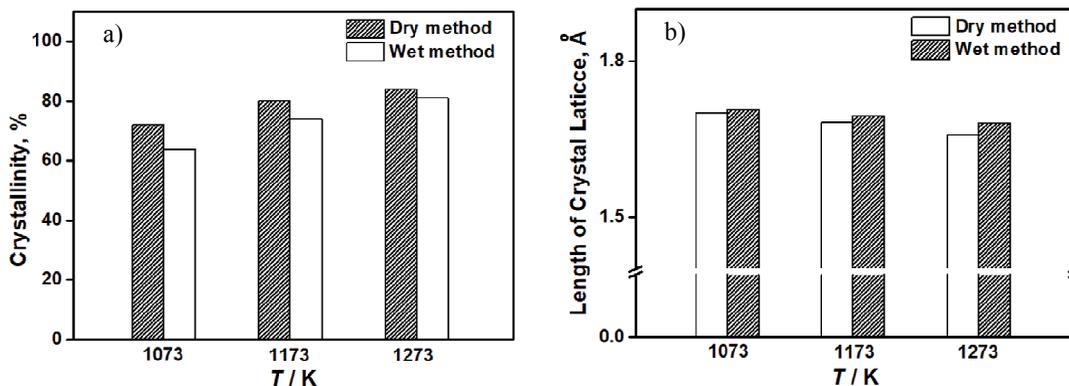


Fig. 5. Percent crystallinity (a) and length of Ca(OCH₃)₂ lattice (b) in the developed catalyst

The length of the Ca(OCH₃)₂ lattice in the developed catalyst was calculated using analytical software (Fig. 5b). The higher the calcination temperature, the lower the size of the Ca(OCH₃)₂ crystals. This phenomenon is due to the reduced growth of the crystalline nucleus, although the crystal growth rate increases with increasing calcination

temperature. This result is consistent with the report of Valverde *et al.* [48], who stated that increasing the calcination temperature will increase the rate of crystal formation, but the size of crystals formed is small. Claudia *et al.* [49] explained that high calcination temperatures could produce the catalyst under the supersaturated

condition. In contrast to the growth rate of the crystal nucleus, the increase in the nucleation rate results in the small size of the $\text{Ca}(\text{OCH}_3)_2$ crystals formed. According to Ngamcharussrivichai *et al.* [50], high calcination temperatures also damage the hydroxyl crystal bond, leading to the crystal lattice defects and smaller size of the $\text{Ca}(\text{OCH}_3)_2$ crystal. Increasing the calcination temperature increases the kinetic energy and promotes the collision of particles; as such, collision causes the breakage of the crystal nucleus and small particle size.

3.3. Performance of Catalyst on Biodiesel Production

3.3.1. Effect of the catalyst on the yield and physicochemical characteristics of biodiesel

The results of the transesterification of commercial palm oil with the catalyst prepared from fly ash and limestone are shown in Fig. 6. As the calcination temperature of the catalyst increases, the yield of biodiesel decreases. The yields of biodiesel produced using D-800, D-900 and D-1000 are 83.6, 82, and 81.3 %, respectively, and those using W-800, W-900 and W-1000 are 88.6, 85.6 and 82.2 %, respectively. The decrease in biodiesel yield is related to the active site and active area of the catalyst. As explained in the previous section, the particle size of the catalyst increases when the calcination temperature is high. Large particle sizes lead to a smaller surface area of the catalyst and lower biodiesel yield. Also, the wet mixing method causes even distribution of limestone, resulting in more solid catalyst morphology and increased catalyst performance [10].

The comparison of alkaline methoxide catalyst on biodiesel production between this research and others is shown in Table 4. From that data, the yield of produced biodiesel is comparable with other researches. Pure chemicals were mainly used as catalyst raw materials in previous experiments [9, 17, 51]. Moreover, a previous study used pure $\text{Ca}(\text{OCH}_3)_2$ as biodiesel catalyst directly, without any catalyst synthesis [52]. The utilization of fly ash and limestone as biodiesel catalyst resulted in the yield of 88.6 %, and it is high enough since the raw materials are not from pure chemical.

The density of biodiesel samples obtained is within 0.864–0.882 g/ml (Fig. 6b). The biodiesel density satisfies the ISO standard of 0.85–0.89 g/ml [33]. Fig. 6c shows that the kinematic viscosity of biodiesel increased when the catalyst was fabricated at high calcination temperatures. Moreover, the FFA percentage increased when the catalyst was prepared at high calcination temperatures. The kinematic viscosity exhibits a linear correlation with %FFA. According to the ISO standard, the standard value of kinematic viscosity and %FFA are 2.3–6 mm^2/s and the maximum of 0.8 %, respectively [34, 35]. Hence, the kinematic viscosity and %FFA of all samples meet the standard.

3.3.2. Catalyst reusability test in terms of methyl ester yield

The stability of the catalyst prepared from fly ash and limestone and used to produce biodiesel was investigated. The catalysts lead to high yield and good physicochemical characteristics of biodiesel. The catalyst used from the initial transesterification was recovered after each batch reaction and washed with *n*-hexane. As shown in Fig. 7, the catalyst was successfully utilized for four cycles. The decreases in the yield of biodiesel generated using D-800, D-900, D-1000, W-800, W-900, and W-1000 are 25.62, 30.84, 36.86, 8.13, 18.78, and 27.80 %, respectively, from the first to the fourth cycle. The catalyst started losing activity slowly after being used for four cycles due to catalyst deactivation as a result of catalyst hydration from its reaction with water in transesterification. Moreover, the transesterification of triglycerides and alcohol will produce glycerol as a side product, which can poison the catalyst [53] and can form calcium glyceroloxide compounds [54]. Mootabadi *et al.* [55] explained that reduced catalyst activity could be due to the decomposition of Ca from CaO or $\text{Ca}(\text{OCH}_3)_2$. Ca was dissolved in alcohol and decreased the number of active catalytic sites. Fig. 7 also indicates the superior reusability of the catalyst produced from the wet mixing method over the sample prepared by the dry method. Even distribution of fly ash and limestone in the catalyst resulted in a good active site and high surface area.

Table 4

The comparison of alkaline methoxide catalyst on biodiesel production

Catalyst Raw Materials	Source	Yield, %	Reference
Pure calcium granules - Methanol	Palm stearin	94.7	[9]
Pure calcium - Methanol	Refined Soybean Oil	98	[17]
Pure CaO - Methanol	Crude Jatropha Oil	87	[51]
Pure $\text{Ca}(\text{OCH}_3)_2$	Soybean Oil	> 90	[52]
Fly ash – Limestone - Methanol	Palm Oil	88.6	<i>This work</i>

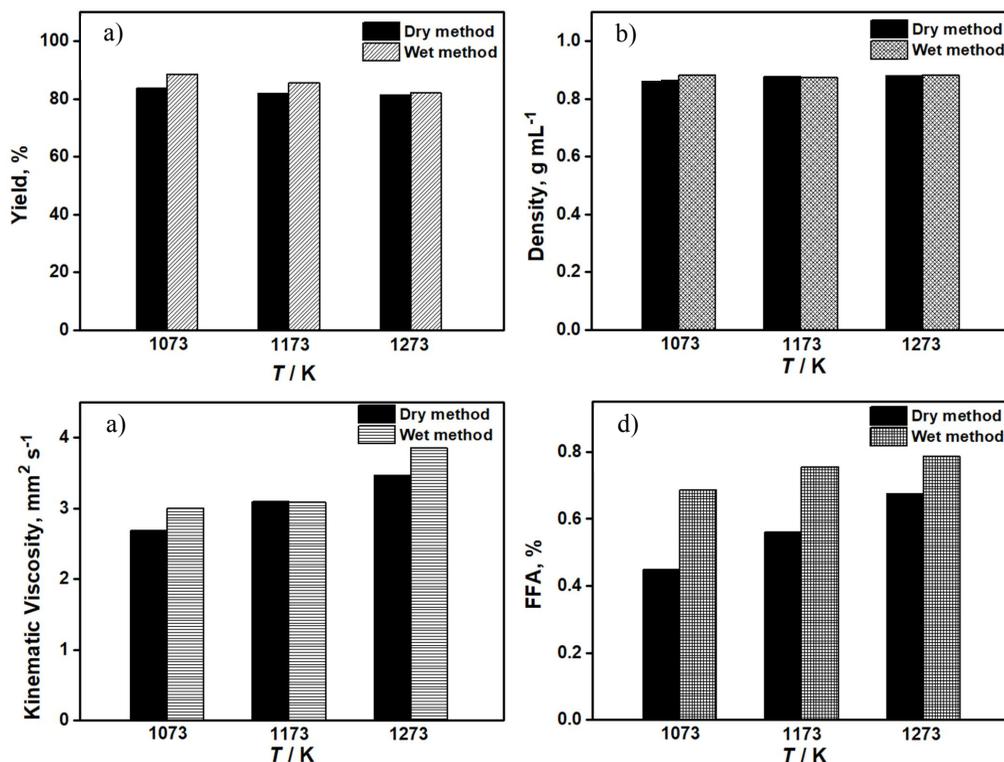


Fig.6. Yield (a), density (b), kinematic viscosity (c) and %FFA (d) of biodiesel generated using the developed catalyst

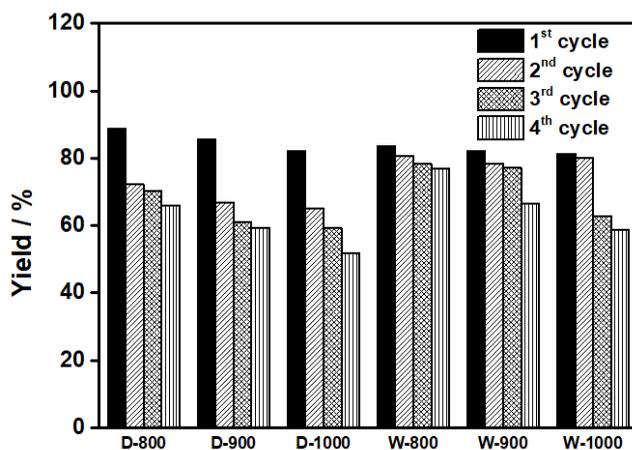


Fig. 7. Reusability test results for the developed catalyst prepared from fly ash and limestone

4. Conclusions

In this study, a catalyst was fabricated from fly ash and limestone through two mixing methods (wet and dry), characterized and used for biodiesel production. The calcination temperature was investigated from 1073 to 1273 K. The results showed that the yield of biodiesel from transesterification was 88.6% when using the catalyst fabricated by wet mixing method and calcined at

1073 K (W-800), comparable with the yield from other researches. The resulting catalyst was solid and uniform and had high surface area despite the low percent crystallinity. The active sites of the catalyst were more distributed, leading to better catalytic performance. The produced W-800 catalyst exhibited good stability during the recycling experiment, with only 8.13% decrease detected after four cycles. Hence, industrial wastes, such as fly ash, and the abundant limestone in Indonesia, can be

effectively utilized to develop a low-cost and highly efficient catalyst for producing biodiesel – a useful and alternative source of green energy.

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ОДЕРЖАННЯ ГЕТЕРОГЕННОГО ЛУЖНОГО МЕТОКСИДНОГО КАТАЛІЗАТОРА ІЗ ЗОЛЬНОГО ПИЛУ ТА ВАПНЯКУ

Анотація. Зольний пил та вапняк використано як сировину для приготування гетерогенних лужних метоксидних каталізаторів для переестерифікації пальмової олії в біодизельне паливо. Каталізатори синтезовано за допомогою мокрого і сухого методу з наступним прожарюванням за 1073–1273 К. Присутність диспергованих кристалів $\text{Ca}(\text{OCH}_3)_2$ над каркасом золи і вапняку підтверджено даними рентгенівської дифракції та скануючої електронної мікроскопії. Найкращі результати отримані в присутності каталізатора, одержаного мокрим способом і прожареного за 1073 К (W-800). Показано, що такий каталізатор має більшу площу поверхні і більш однорідні активні ділянки, у порівнянні з іншими каталізаторами. Близько 88,6 % біодизелю одержано з промислової пальмової олії з використанням W-800 як каталізатора. Фізико-хімічні характеристики, такі як густина, кінематична в'язкість і вміст вільних жирних кислот, відповідають міжнародним стандартам для біодизеля. Каталізатор використовувався для виробництва біодизеля протягом чотирьох циклів, а вихід біодизеля підтримувався до 91,87 % від початкового значення.

Ключові слова: біодизель, зольний пил, вапняк, переестерифікація, пальмова олія.