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THE EFFECT OF CALCINATION TEMPERATURE ON THE QUALITY OF QUICKLIME FROM DIFFERENT LIMESTONE MINES IN WEST SUMATERA, INDONESIA

Reni Desmiarti*[,1], Ellyta Sari[1], Firdaus[1], Erda Rahmilaila Desfitri[1], Amelia Amir[1], Inva Salsabil[1], Maulana Yusup Rosadi[2], Nofri Naldi[3]

[1]Department of Chemical Engineering, Bung Hatta University, Padang, Indonesia
[2]Graduate School of Engineering, Gifu University, Gifu, Japan
[3]Department of Chemistry, Andalas University, Padang, Indonesia

*Corresponding author
Email: renitk@bunghatta.ac.id

Abstract. *Quicklime is a widely used industrial chemical and its characteristics may be affected by the limestone characteristics and calcination temperature. The present study investigated the quicklime characteristics obtained from limestone after calcination at different temperatures (800, 900, and 1000 °C) from six geological-different mines in West Sumatera, Indonesia. X-ray fluorescence (XRF) analysis was performed to characterize the elemental compositions in limestone and quicklime. The stoichiometric evaluation was examined to compare the obtained carbon dioxide (CO_2) from experimental and theoretical results during calcination. Based on elemental composition from XRF analysis, all the investigated limestones are very pure limestones, with impurities of less than 1%. The level of calcium oxide (CaO) after calcination at 1000°C increased to more than 90% for all investigated limestone. The obtained CaO and CO_2 mass after calcination at 1000°C for 5 h were more than 70 and 60 grams, respectively. However, the experimental results on CaO and CO_2 mass were 5–12% less than theoretical mass, reflecting the partial decomposition of calcium carbonate during the calcination process.*

Keywords: *calcination; carbon dioxide; limestone; quicklime*

1. Introduction

West Sumatra, Indonesia deposits about 23.3 million tons of limestone over million years, and several mines are determined as limestone mines for several industries in West Sumatra (Energy and Mineral Resources of West Sumatra, 2021). Limestone composes of dolomite magnesium carbonate ($CaMg[CO_3]_2$) and other constituents, such as iron, potassium, pyrite, silica, and quartz (Romero *et* al., 2021; Lewicka *et al*., 2020). During thermal processing, carbonate decomposes and form calcium oxide (CaO) and gaseous carbon dioxide (CO_2) (Sandström *et al*., 2021; Fedunik-Hofman *et al*., 2019; Giammaria and Lefferts, 2019). Quicklime is an essential raw material for industrial applications, such as food processing, water, and wastewater treatment, plastics, glass, and agriculture (Yadav *et al*., 2021; Ontiveros-Ortega *et al*., 2018). It is essential to understand the basic characteristics of limestone (e.g., geological characteristics) for achieving the good quality of quicklime and satisfying the demand of the industry. The continuous growth of global industries has led the industry itself and academy to focus on developing alternative cement, material constructions, additives, and other demanding materials, involving reduced energy demand and greenhouse gas emission (Cabera-Luna et al., 2021). Therefore, escalating the

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knowledge of limestone and quicklime characteristics is challenging to reach sustainable development for industries.

Limestone characteristics along with calcination temperature may affect the quality of quicklime. Calcination of limestone between 800 and 1000°C may produce quicklime with small impurities through the calcination reaction (Section 2.2.3). The investigations of the influence of calcination temperature on quicklime characteristics are piled in an enormous study and have shown that the formation of quicklime involved the destruction of the crystal structure of calcite at 600–850°C (Ontiveros-Ortega et al., 2018; Nordin et al., 2015; Kudlacz and Rodríguez-Navarro, 2014). CaO started to form under the temperature of 800°C, involving the decomposition of chemical materials without CO_2 pressure control in the kiln. However, the temperature can limit the calcination process, which controls the heat transfer through the particle to the reaction interface (Zhou et al., 2021), resulting in low purity of quicklime. The characteristics of limestones also affect the calcination process, increasing the temperature to 1000°C generates greater volumes of micropores, which can affect the quality of quicklime (Ontiveros-Ortega et al., 2018).

Different geological locations may influence the characteristics of limestone, and the information of quicklime quality from different limestone mines in West Sumatra is still limited. Therefore, this study aims to investigate the quicklime characteristics after calcination in different temperatures (800, 900, and 1000°C). For this purpose, different limestones obtained from six different locations in West Sumatra are examined to evaluate limestone characteristics.

2. Methods

2.1. Limestone

Limestones used in this study were obtained from six different regions in West Sumatra, Indonesia, namely 50 Kota (L1), Agam, (L2), Tanah Datar (L3), Padang Panjang (L4), Sijinjung (L5) and Dharmasraya (L6). These locations were selected to evaluate the characteristics of West Sumatran quicklime, which is commonly used for the cement industry in West Sumatra. The limestone was crushed in the range size of 3–5 cm and calcined at three different temperatures (800, 900, and 1000°C) for 5 h to produce quicklime. The produced quicklime was pulverized and analyzed for mineral composition.

2.2. Analytical methods

2.2.1. X-ray fluorescence (XRF) analysis

The mineral composition was observed by XRF analysis using an XRF spectrometer (Rigaku Supermini200, Latvia). XRF spectrometer irradiate the X-rays and measured the fluorescent emission wavelength of samples (Izhar et al., 2018). The identified elemental composition of minerals, such as CaO, MgO, Fe_2O_3, SiO_2, Al_2O_3 was selected to evaluate the characteristics of limestone and quicklime.

2.2.2. Loss of ignition (LOI)

LOI was measured based on the procedures described in APHA standard methods. Briefly, the weight of limestone (before calcination) and quicklime (after calcination) was recorded. And the dry weight ratio of quicklime and limestone was recorded as LOI.

2.2.3. Stoichiometric equations

The stoichiometric equation for CaO and CO_2 was calculated on the %weight basis of quicklime Theoretically, 1 mol of $CaCO_3$ will produce 1 mol CaO and I mol CO_2. The available level of CaO in quicklime based on XRF analysis was >60%, which is equal to 1.3 mol for CaO (>70 gram) and CO_2 (>55 gram). Thus, the availability of $CaCO_3$ that converted into CaO and CO2 was >1.3 mol, which is equal to 130 gram (99%) (multiplied by $CaCO_3$ molecular mass: 100 gram/mol) based on the calcination reaction (1).

$$CaCO_{3(s)} \rightarrow CaO_{(s)} + CO_{2(g)} \quad \Delta H_r^\circ = 175{,}5\ kJ/mol \tag{1}$$

3. Results and Discussion

3.1. Quicklime characteristics

Quicklime characteristics evaluated by the mineral composition before and after calcination are shown in Table 1. The level of CaO from L1 increased from 55.9% to 59.6, 83.1 and 93.1% after calcination under temperatures of 800, 900, and 1000°C, respectively. A similar trend of the increasing of CaO level from different limestones suggested that the increasing temperature to 1000°C are the optimum temperature for calcination. The level of CaO after calcined under 1000 °C for L1, L2, L3 L4, L5, and L6 are 93.1, 91.2, 91.7, 85.9, 92.5, and 90.7%, respectively. Temperature is an essential factor for the calcination process in increasing the CaO level (Jiang *et al*., 2019; Fuchs *et al*., 2019). The level of CaO increased and other impurities levels decreased with the increase of temperature indicating that the purity of quicklime from all investigated limestone increased due to thermal decomposition of all minerals at high temperature (Table 1). The results also reflect that the limestones used in this study affect the quicklime characteristics after calcination, in which the calcination rates increased, thus the complete calcination reaction can be achieved (data not shown). A similar result showed that the calcination temperature affects the reactivity of quicklime (950–1250°C) for 2 hours, involving the microstructural characteristics of limestone (Houngaloune *et al*., 2010).

The brightness indicator based on Fe_2O_3 composition in the limestone indicates that all limestone samples from different locations had a percentage of Fe_2O_3 less than 0.3 % before and after calcination, except for L4. Fe_2O_3 gives the brightness indicator in limestone and its percentage indicates the purity of limestone (Hwidi *et al.*, 2018). Figure 1 shows the different visualization of quicklime produced after calcination from different temperatures. L4 had the highest Fe_2O_3 composition (0.55%), and its percentage is 45% higher than the maximum standard composition of Fe_2O_3 in a produced quicklime (Hwidi *et al.*, 2018). The investigation of the available concentration of Fe_2O_3 in limestone has been assisted several industries to select the appropriate limestone for their specific commercial production (Panjaitan *et al.*, 2021). In West Sumatra, limestone from L5 and L6 has been selected as the raw material to produce precipitated calcium carbonate.

Table 1. The mineral composition observed in limestone and quicklime after calcination at different temperatures (800, 900, 1000°C)

Calcination temperature (°C)	Limestone	CaO (%)	MgO (%)	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)
Before calcination	L1	56.4	0.43	0.01	0.01	0.03
	L2	56.4	0.45	0.01	0.09	0.03
	L3	58.4	0.53	0.47	0.02	0.05
	L4	53.1	0.50	2.95	0.55	0.52
	L5	57.7	0.39	0.20	0.05	0.06
	L6	55.7	0.77	0.05	0.01	0.05
800	L1	59.6	0.25	0.64	0.26	0.06
	L2	56.8	0.46	0.11	0.22	0.03
	L3	58.1	0.48	0.28	0.27	0.10
	L4	57.6	0.41	1.55	0.05	0.32
	L5	60.3	0.38	0.70	0.27	0.10
	L6	59.5	0.27	0.60	0.24	0.03
900	L1	83.1	0.78	0.48	0.21	0.08
	L2	85.2	1.13	1.61	0.18	0.01
	L3	85.7	0.53	1.42	0.51	0.15
	L4	85.3	0.63	1.86	0.07	0.52
	L5	86.2	0.31	0.78	0.32	0.10
	L6	87.8	0.57	0.57	0.28	0.07
1000	L1	93.1	0.70	0.65	0.33	0.12
	L2	91.2	0.49	1.74	0.09	-
	L3	91.7	0.93	0.70	0.33	0.13
	L4	85.9	0.73	7.33	0.27	0.55
	L5	92.5	0.59	0.04	0.19	0.04
	L6	90.6	0.47	0.69	0.30	0.09

3.2. LOI and CO_2 mass content

Increasing temperature from 800 to 1000°C decreased the LOI of quicklime due to the complete reaction of limestone to form CaO and CO_2. Limestone from L1 contained 43.1% of LOI and its level decreased to 39.1, 15.2, and 4.91% after calcined at 800, 900, and 1000°C, respectively (Figure 2). A similar trend was observed for all investigated limestone, where the level of LOI decreased with the increase of calcination temperature. The temperature of 1000°C in this study is the optimum temperature to converse limestone into CaO and CO_2, indicated by the low level of LOI. The result showed that some property in all investigated limestone from different mines is easy to decompose against the calcination temperature, indicated by similarity in the chemical composition of limestone. The decreasing trends of LOI in this study also can reflect that the calcination rates were increased (data not shown), thus a high purity of quicklime can be obtained. However, a study by Carran *et al*., (2012) showed that LOI in the observed quicklime after calcination was 30–42%. This might be due to the limestone characteristics (e.g., the presence of crystalline calcite veins) which can affect the LOI level and calcination rate.

Figure 1. Different visualization of quicklime produced after calcination from different temperatures

CO_2 gas was generated during the calcination process as the limestone was decomposed during calcination to produce quicklime (Vola *et al*., 2018). The traditional method of calcination emits CO_2 into the atmosphere. This study tried to calculate the CO_2 mass content produced from the calcination process, and Figure 3(a–b) shows the CO_2 mass from the stoichiometric experimental and theoretical results. The results showed that all the investigated limestone produced more than 50 grams of CO_2 from 150 grams of limestone. However, the value is 5% lower compared to the theoretical CO_2 mass content. The findings suggested that the calcination reaction only occurs on the particle surface, not in the whole particles (Ontiveros-Ortega *et al*., 2018; Maina, 2013) resulting in low CO_2 mass content. The CO_2 mass content in this study was observed similar from different limestone mines, indicating a similar release rate of CO_2 for each calcination temperature. Another possibility also can be explained by the similar composition of limestone from different mines that can result in a similar calcination rate, thus resulting in a similar content of CO_2. This finding coincides with Guo *et al*. (2015) where the release of CO_2 is affected by limestone characteristics, particularly in water content.

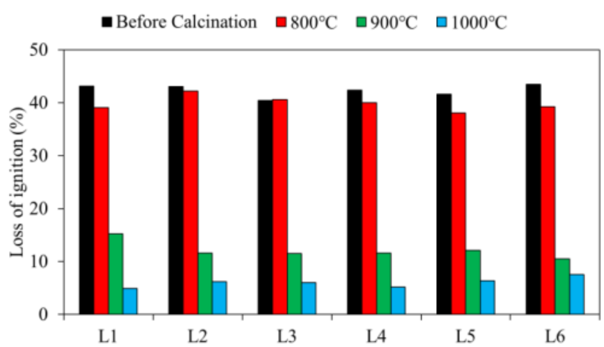

Figure 2. LOI level of limestone from different limestone mines and LOI level of quicklime after calcination at different temperatures (800, 900, and 1000°C).

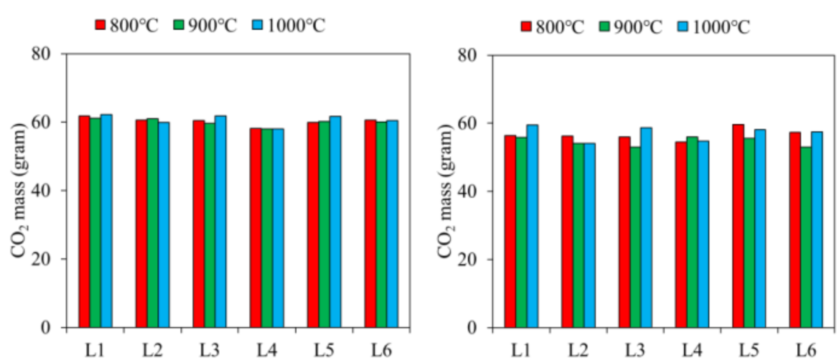

Figure 3. CO_2 mass content was produced from (a) experimental and (b) theoretical results of the calcination process of limestone from different limestone mines under different temperatures (800, 900, 1000°C).

4. Conclusions

This study conclude that the West Sumatran limestones produced quicklime with the impurities less than 1% after calcined at 1000°C. Increasing temperature from 800 to 1000 could increase the purity of produced quicklime. Further investigation on the particle characteristics of quicklime after calculations will be examined to evaluate the optimum temperature condition and limestone characteristics from different limestone mines.

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