Combustion of Purified Biogas after Carbon Dioxide Absorption Using Sodium Hydroxide

A Pertiwiningrum¹, I La’aliya¹, B U Windiaka¹, L M Yusiati¹, AW Harto²

¹Faculty of Animal Science, Universitas Gadjah Mada, Bulaksumur Street 1, Yogkarta, Indonesia
²Faculty of Engineering, Universitas Gadjah Mada, Bulaksumur Street 1, Yogyakarta, Indonesia

E-mail: artiwi@mail.ugm.ac.id

Abstract. Biogas is an alternative clean energy that can replace the utilization of LPG, fossil fuel for cooking. But many reports said that biogas is mixture composition which carbon dioxide composition must be removed. This study aims to investigate the combustion performance of purified biogas after sodium hydroxide absorption. Carbon dioxide removal has been conducted by absorption method. There are 4 type concentration of sodium hydroxide (NaOH) that used in this study 5, 15, 25 and 35. After carbon dioxide absorption using 5, 15, 25, 35% methane content of biogas increased. The increase in methane affected on the increase in calorific value. Purified biogas after absorption using 5, 15, 25 and 35% of sodium hydroxide increased 187.91, 225.42, 227.91, and 243.82 kJ respectively.

1. Introduction
The demand of energy has correlation with economic activity. In Indonesia, the increase in people’s income is very sensitive in increasing energy demand, for example in LPG (Liquid Petroleum Gas). In last ten years (2003-2013), final energy consumption in Indonesia increased from 79 million TOE to 134 TOE or grew on average at 5.5% per year [1]. Since the existence of the energy program conversion in Indonesia, energy consumption in household sector has shifted from kerosene to switch LPG for cooking needs. It was predicted that LPG consumption will increase 20.7% every year. In fact, the existence of LPG from energy based fossil fuel posed environment problem. Consumption energy has impact on global warming effect that caused by the increase in greenhouse gas emissions. Greenhouse gas emissions (GHGs) are dominated by human activities involving energy consumption especially fossil fuel energy [2].

To push the technological development needed to provide such clean energy for cooking, for example biogas technology. The development of biogas as clean energy for cooking has been known since nineteenth century but the great resurgence of interest biogas since global warming issue appeared. Biogas was generated from bacterial fermentation of organic wastes in the absence of free oxygen or anaerobic fermentation. It was formed from organic matter decomposing for example guts of large ruminant animals, agriculture and forestry residue, sewage, and municipal solid waste.
Well-established technology exists for generating biogas from animal manure [3]. Biogas consists of methane, flammable gases, that has role as fuel resource for cooking. In some cases, biogas has high concentration of carbon dioxide that affected on combustion performance. Good combustion of biogas can be improved by removing carbon dioxide [4]. Many technologies that been developed to improve combustion of biogas by methane enrichment through biogas purification. There many types of biogas purification: pressure adsorption, water and chemical absorption, membrane separation and cryogenic separation [5]. Through biogas purification it can absorb carbon dioxide and enhance methane fraction in biogas. Many chemical compounds can be used as absorbent in carbon dioxide removing in biogas purification like calcium hydroxide and sodium hydroxide. Caustic solvents like these are most abundant solvents and has researched more than 50 years [6]. Many researchers were reported that sodium hydroxide would be effective in carbon dioxide removing in biogas purification [6],[7]. In this study we tried to investigate effect of concentration of sodium hydroxide on biogas purification using and biogas combustion.

2. Material and Methods

2.1. Materials
Raw biogas that would be purified in this study was from dairy and cattle manure in Agrotechnology Innovation Center. Biogas purification was used absorption column from glass material with length of 48.36 cm and diameter of 8 cm. Sodium hydroxide was prepared is 99% concentration. High concentration of sodium hydroxide was diluted to 5, 15, 25 and 35% with aquadest.

2.2. Methods
Biogas purification was conducted with absorption column. Raw biogas was purified using sodium hydroxide 5, 15, 25, and 35% concentration. Biogas composition was analyzed by gas chromatography. Schematic of biogas purification was presented in Figure 2. Combustion performance of biogas can be investigated from water heating value that fuelled by purified biogas. Purified biogas was used as fuel for one litre of water. The calorific value of biogas was calculated using Eq. 1:

\[ Q = m \times c \times \Delta T \]

\( Q \) refers to the calorific value of biogas, \( m \) refers to mass of 1 litre of water, \( c \) refers to specific heat of water, and \( T \) refers to water temperature.
3. Results and Discussion

3.1. Methane Enrichment

Biogas purification using sodium hydroxide was proven can improve methane composition in biogas [8]-[9]. In this study, we investigated impact of variations of concentration on methane enrichment of biogas. Biogas purification uses 5, 15, 25 and 35% of sodium hydroxide. The increase in methane enrichment was presented in Table 1.

Table 1. Methane enrichment of biogas after biogas purification

| Concentration of sodium hydroxide (%) | % CH₄ before purification | % CH₄ after purification |
|--------------------------------------|---------------------------|--------------------------|
| 5                                    | 74.9                      | 70.6                     |
| 15                                   | 76.8                      | 81.4                     |
| 25                                   | 76.8                      | 82.6                     |
| 35                                   | 75.5                      | 88.3                     |

The success of carbon dioxide absorption was presented by methane enrichment. Concentration of 5% sodium hydroxide can't capable absorb carbon dioxide in biogas. Utilization of 5% sodium hydroxide actually decreases methane composition of biogas from 74.9 to 70.6%. But utilization of 15, 25 and 35% of sodium hydroxide increased methane composition of 5.99, 7.55, and 16.95 respectively. The best biogas purification was performed by 35% sodium hydroxide. In solution of sodium hydroxide reacted with carbon dioxide molecules when biogas purification running [10],[11]. The higher sodium hydroxide concentration results in greater the methane of biogas. The moist liquid of sodium hydroxide spontaneously absorbs carbon dioxide [12]. Tippayawong and Thanompongchart [13] also revealed that aqueous solution of sodium hydroxide is effective absorb carbon dioxide. They reported saturated point that reached by sodium hydroxide about 100 minute. Mechanism of carbon dioxide absorption in NaOH solution can be explained. In pure water, sodium hydroxide will completely ionize to be Na⁺ and OH⁻ and then when carbon dioxide is fed into the column carbon dioxide reacts with OH⁻ according to Arrhenius Acid Base Theory [14]. Actually sodium hydroxide cannot be readily generated because product from absorption as a precipitated powder, Na₂CO₃.
3.2. Combustion of Biogas

Biogas purification using sodium hydroxide was proven can improve methane that was represented by calorific value for heating water. Methane composition has correlation with calorific value of biogas. Methane enrichment is capable to increase calorific value of biogas. The linear relationship between CH₄ content and the biogas caloric value was also shown in this Table 2.

Table 2. Methane enrichment of biogas after biogas purification

| Concentration of sodium hydroxide (%) | Calorific value (kJ) |
|--------------------------------------|----------------------|
| 5                                    | 187.91               |
| 15                                   | 225.42               |
| 25                                   | 227.91               |
| 35                                   | 243.82               |

From this results showed that there was association between carbon dioxide removing and calorific value. The biogas caloric value was calculated from the energy it needed to boiled water. The empirical biogas caloric value was then compared with the theoretical biogas caloric value. The higher sodium hydroxide concentration results in greater the caloric value of biogas. This is due to biogas purification, methane in biogas as a flammable gas increased [5]. The increase in methane composition was caused by a reaction with sodium hydroxide solution and carbon dioxide carbon dioxide molecules through absorption process. The highest in the calorific value of biogas was performed by 35% of sodium hydroxide of 243.82 kJ. The ability of sodium hydroxide to absorb carbon dioxide based on Arrhenius Acid Base Theory as in Eq. 2. While carbon dioxide was reacted with water will produce H⁺ions (Eq. 3). So that ion-ions dissolved in H₂O will react as in Eq. 4 and 5.

\[ \text{NaOH} (s) \rightarrow \text{Na}^+ + \text{OH}^- \quad (2) \]

\[ \text{CO}_2 (g) + \text{H}_2\text{O} \rightarrow \text{H}^+ (aq) + \text{HCO}_3^- (aq) \quad (3) \]

\[ \text{HCO}_3^- (aq) + \text{OH}^- (aq) \rightleftharpoons \text{H}_2\text{O} (l) + \text{CO}_3^{2-} \quad (4) \]

\[ \text{H}^+ (aq) + \text{OH}^- (aq) \rightarrow \text{H}_2\text{O} (l) \quad (5) \]

The increase in calorific value after biogas purification through CO₂ removal using sodium hydroxide would encourage rural communities to use biogas energy for cooking. The higher calorific value of biogas has impact on the increasing types of cooking fuel that would be selected by rural communities. Although the use of biogas not fully replaces other fuels for cooking, it can be used as an environmentally friendly and clean alternative fuel for cooking.

4. Conclusion

From this results, it can be concluded that 35% of sodium hydroxide give the best performance in methane enrichment. The best methane enrichment has implication on the best calorific value of biogas. Biogas purification through absorption using 35% sodium hydroxide increased calorific value of biogas of 243.82 kJ for heating water. From this study, we can also concluded the highest concentration of sodium hydroxide give the best performance in methane enrichment.
References

[1] National Energy Council 2014 *Indonesia Energy Outlook* I Jonan (Jakarta: Ministry of Energy and Mineral Resources) p 41

[2] Intergovernmental Panel on Climate Change (IPCC) 2014 *Mitigation of Climate Change Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge: Cambridge University Press) p 100

[3] Tasnem A, S M Tauseef, and S A Abbasi 2012 *Biogas Energy* (New York: Springer) p 33

[4] Ambar P 2015 *Biogas Installation* (Yogyakarta: Center of Assessment of Development of National Livestock)

[5] Bianca Z B, Gheorge V, Nicoleta U, Mirela D, Gigel P, Mariana M, and Mariana F 2019 *Bulletin of Eng.* 12 65

[6] Fouad R H A, Maizirwan M, Mohammed S J, Sany I I, and Ahmad F I 2016 *Chinese J. of Chem. Eng.* 24 693

[7] Wojciech M B 2016 *Renew. and Sus. Energy Reviews* 54 1148

[8] Benidiktus L W, Denny W and Khairul A 2017 *J. Saintek* 27 128

[9] Fuad M and J Arif 2007 *Absorption of carbon dioxide gas in biogas using NaOH solution continuously* (Semarang: Diponegoro University)

[10] Aphicat S, Ratchaphon S and Khanita K 2017 *J. Energy Pro* 138 441

[11] Qie S, Hailong L, Jinying Y, Longcheng L, Zhixin Y and Xinhai Yu 2015 *Renew. and Sus. Energy Reviews* 51 521

[12] Dieter D and Angelika S 2008 *Biogas from Waste and Renewable Resource: An Introduction* (Frankfurt: FiBL Projekte)

[13] Nakorn T and Patipat T 2010 *Energy* 35 4531

[14] Miran Y, Sang-Jun H and Jung-Ho W 2013 *Journal of Enviro. Manag.* 114 512

Acknowledgments

This research was supported by Universitas Gadjah Mada through RTA Program, 2019. Authors wishing to say thank you for assistance or encouragement from colleagues, special work by students from Animal Science Faculty, Universitas Gadjah Mada.