The performance of biogas combustion after carbon dioxide absorption using sodium hydroxide (NaOH)

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Abstract. The improvement of biogas calorific value is required before distributed to users. The improvement of the calorific value can be done by carbon dioxide removal. This study was aimed to investigate the efficiency of biogas combustion after carbon dioxide removal by the absorption using sodium hydroxide (NaOH). In this study, we used 4 types of sodium hydroxide based on its concentration: 5, 15, 25 and 35% i.e N1, N2, N3, and N4 respectively. The absorption using N1, N2, N3, and N4 decreased carbon dioxide content with the increasing concentration of NaOH. The decrease in carbon dioxide content also led to the increase in biogas combustion that represented by calorific value. of biogas. The calorific value after the absorption using N1, N2, N3, and N4 were 10711.73 ± 33.98; 1999.53 ± 9.93; 1253.43 ± 28.43; and 1328.13 ± 8.98 kJ respectively. The results also showed that the absorption can increase the water heating value boiled with biogas. The water heating value after absorption using N1, N2, N3, N4 were 187.91 ± 10; 225.42 ± 1.77; 227.91 ± 8.47; and 243.82 ± 1.92 respectively. The best performance in combustion is biogas after carbon dioxide absorption using 35% NaOH.

1. Introduction
Biogas is one of livestock waste treatment that is used as resource of renewable energy. It is produced by anaerobic digestion of organic materials from livestock waste or other organic materials. Biogas provides alternative energy that is renewable, environmentally friendly, and makes the livestock environment clean [1]. Livestock waste is all residue from livestock activities, either liquid waste, solid waste, or gas waste that can be used as resource of energy. The biogas production from many types of livestock waste is shown in Table 1.

Table 1. Biogas production from livestock waste

| Livestock      | Biogas (m³/ kg of manure) |
|----------------|---------------------------|
| Cattle and buffalos | 0.023 to 0.040          |
| Pig            | 0.040 to 0.059           |
| Poultry        | 0.065 to 0.011           |
| Horse          | 0.020 to 0.035           |
| Sheep and goat | 0.010 to 0.031           |

Source: Suyitno et al [2]
Biogas consists of mixture gases from methane (CH$_4$) as flammable gas, carbon dioxide (CO$_2$) and other gases. The composition of gases in biogas depends on decomposed substances of raw materials of biogas [3, 4]. Table 2 shows biogas composition according to Peter [3] and Muhammad et al [5].

### Table 2. Composition of biogas

| Gas                   | Composition (%) |
|-----------------------|-----------------|
| Methane (CH$_4$)      | 55 to 70        |
| Carbon dioxide (CO$_2$) | 30 to 45       |
| Hydrogen sulphide (H$_2$S) | Small amount |
| Hydrogen (H$_2$)      | 1 to 2          |
| Nitrogen (N$_2$)      | 1 to 2          |
| Oxygen (O$_2$)        | Small amount    |
| Water vapour (H$_2$O) | 0.3             |

Source: Peter [3] and Muhammad et al [5]

In some cases, biogas has high composition of carbon dioxide that results in low efficiency of biogas combustion. A good efficiency of combustion depends on the concentration of methane. The higher methane gas content, the greater calorific value of biogas. The quality of biogas performed by its calorific value can be improved by removing hydrogen sulfur, water, and carbon dioxide content in biogas; this is called a purification process [6]. The presence of non-methane gases, especially carbon dioxide, can reduce the calorific value and lower the efficiency of combustion. Through purification, methane can be separated from carbon dioxide [7]. The separation of methane from carbon dioxide can be conducted with sodium hydroxide or NaOH [8]. Compared to calcium hydroxide (Ca(OH)$_2$), NaOH solution has better performance in carbon dioxide absorption [9]. According to [10], sodium hydroxide has a good capability to absorb carbon dioxide up to 58.11%. In this study, we tried to use higher concentration of NaOH solution compared to [10] to investigate the effect of using high concentration of NaOH solution on the efficiency of biogas combustion. Higher concentration of NaOH solution would be effective to absorb carbon dioxide in biogas until it reached the saturation point.

### 2. Material and methods

#### 2.1. Material

The biogas purification used the absorption unit system consisted of an absorption column with length of 48.36 cm and diameter of 8 cm, PVC pipes, and gas compressor with pressure ranged from 0 to 7 bar. The biogas being purified was processed from cattle manure of the Friesian Holstein and Ongole cattle farm in Agro-technology Innovation Center. The sodium hydroxide prepared was 99% concentration.

#### 2.2. Methods

##### 2.2.1. Preparation of NaOH solution

50; 150, 250; and 350 g of NaOH was diluted in 1000 mL distilled water to make 5; 15, 25; and 35% concentration of NaOH. First, 1000 ml distilled water was put in a flask and added with NaOH solution that had been diluted with water in a measuring glass. The solution was shaken until it became homogeneous, then the homogeneous solution of NaOH was inserted into a bottle that had been labeled.

##### 2.2.2. Biogas purification

Biogas purification was conducted using absorption column. The installation of the absorption column is shown in Figure 1. The raw biogas from bio-digester was flowed towards to absorption column by
gas compressor with a pressure ranged from 3 to 5 bar for 15 minutes. Then the purified biogas was collected in a venoject and analyzed for its composition by gas chromatography.

![Diagram of biogas purification installation](image1)

**Figure 1.** Biogas purification installation (1: bio-digester, 2: biogas holder, 3: compressor, 4: absorption column, 5: venoject, and 6: gas faucet)

### 2.2.3. Calorific value test

The calorific value of biogas was calculated from water heating value fueled by purified biogas. One liter of distilled water was boiled with the purified biogas packaged in biogas bottle. The initial temperature and heating temperature were recorded regularly. The schematic of calorific value test is presented in Figure 2.

![Diagram of calorific value test](image2)

**Figure 2.** The schematic of calorific value test

The water heating value that presented the calorific value of biogas was calculated using Eq. 1:

$$ Q = m \times c \times \Delta T $$

(1)

Q refers to the water heating value, m refers to mass of 1 liter of distilled water, c refers to specific heat of water, and T refers to water temperature. Then water heating value was compared to theoretic calorific value of biogas calculated from methane content using Eq. 2:
\[ Q = LHV \times \text{mol biogas} \] (2)

LHV refers to lower heating value of methane in biogas, calculated from the heating value of 1 mole of methane multiplied by the methane mole fraction. The efficiency of biogas combustion was calculated by comparing water heating value with theoretical calorific value of biogas. The calculation of theoretical calorific value, water heating value, and efficiency of biogas combustion were tested with Duncan’s Multiple Range Test (DMRT).

3. Results and discussion

3.1. Carbon dioxide absorption

The biogas purification was conducted through the absorption using NaOH solution for 10 minutes. Purified biogas was analyzed for its carbon dioxide content. It was assumed that biogas only consisted of methane and carbon dioxide gases so that the value of methane content was obtained from 100% minus carbon dioxide concentration. After the absorption using NaOH solution there was a decrease in carbon dioxide concentration, presented in Table 3. The increasing in NaOH concentration resulted in better carbon dioxide reduction.

| NaOH | 5%  | 15%  | 25%  | 35%  |
|------|-----|------|------|------|
| CO₂ reduction | +17.09 | -19.68 | -25.09 | -52.11 |

Only absorption using 5% NaOH could perform the increase in carbon dioxide content. When biogas was added with 15, 25, and 35% NaOH solution, they decreased the carbon dioxide content in biogas (19.68, 25.09, and 52.115 respectively). The ability of NaOH solution to absorb carbon dioxide was because in water solution, NaOH formed Na ions (Na⁺) and hydroxide ions (OH⁻) while CO₂ molecules in biogas reacted with water molecules (H₂O) and formed carbonate acid. The best carbon dioxide reduction was performed by 35% NaOH solution. It means that NaOH concentration affects the carbon dioxide absorption [11]. Sodium hydroxide is moist liquid and spontaneously absorbs carbon dioxide [8]. Moreover [12] reported that methane is not enough attractive than carbon dioxide to react with NaOH solution. Therefore, the two types of gases can be separated.

3.2. Efficiency of biogas combustion

From carbon dioxide analysis, the theoretical calorific value of biogas can be calculated according to Eq. (2) and the water heating value. Based on the results, there were increases in the theoretical calorific value of biogas and water heating value when biogas was absorbed using NaOH solution. From this calculation, the efficiency of biogas combustion can be determined (see Table 4).

| NaOH solution | 5% | 15% | 25% | 35% |
|---------------|----|-----|-----|-----|
| Calorific value of biogas (kJ) | \(1071.73 \pm 33.98^a\) | \(1199.53 \pm 9.93^b\) | \(1253.43 \pm 28.43^b\) | \(1328.13 \pm 8.98^b\) |
| Water heating value (kJ) | \(187.91 \pm 10.00^a\) | \(225.42 \pm 1.77^b\) | \(227.91 \pm 8.47^b\) | \(243.82 \pm 1.92^c\) |
| Efficiency of combustion (%) | \(17.43 \pm 0.18^a\) | \(18.78 \pm 0.62^ab\) | \(19.01 \pm 0.64^bc\) | \(19.92 \pm 1.21^c\) |

\(^a,b,c^\) superscript showed significant difference (P<0.05)

The absorption using 5% NaOH with the calorific value of 1071.73 ± 33.98 kJ showed a significant difference compared to 15% NaOH with the calorific value of 1199.53 ± 9.92 kJ. However, 15% NaOH had no significant difference compared to 25% NaOH. The highest calorific value performed
by 35% NaOH showed a significant difference. The same trend was also performed on the data of water heating value.

The efficiency of combustion showed the efficient level of biogas yield to produce heat or energy. Based on the results in Table 4, the highest efficiency of combustion was also performed by 35% NaOH solution. The higher calorific value resulted in the higher efficiency of combustion as evidenced by the results in Table 4. The efficiency of biogas in this study was ranged from 17 to 19.92%. It means the combustion of biogas was not efficient enough to be used for cooking. However, although the result of the absorption using NaOH solution was not significantly efficient, the increased NaOH concentration was proven to increase the heat combustion to heat water.

4. Conclusion
From this study we conclude that the utilization of NaOH solution resulted in carbon dioxide reduction. The highest carbon dioxide reduction was performed by 35% NaOH solution. It also affected the highest theoretical calorific value of biogas and the water heating value (1328.13 and 243.82 kJ respectively). However, biogas purification using NaOH absorption did not significantly increase the efficiency of biogas combustion because it was still below 60%. The efficiency of biogas combustion from biogas purification by absorption using 35% NaOH was 19.92%.

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.

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