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Effect of Absorbent Type on the Absorption Durability of Biogas Purification

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A B S T R A C T

Biogas purification is essential to increase methane concentration and reduce impurities such as carbon dioxide and hydrogen sulfide, which decrease calorific value and cause corrosion in energy systems. This study evaluates the effect of absorbent solution type on biogas purification efficiency and absorption durability using chemical absorption methods. Alkaline solutions, including sodium hydroxide (NaOH), potassium hydroxide (KOH), calcium hydroxide ($Ca(OH)_2$), and their binary mixtures, were employed at a concentration of 20% (w/v). Biogas derived from molasses fermentation was passed through bubble column absorbers and analysed using an Orsat apparatus over 2–10 days of absorption. Results show that all absorbents significantly increased methane concentration while reducing CO_2 and H_2S. The highest methane concentration of 86.75% was achieved using KOH on day four, exceeding the Indonesian biogas quality standard (SNI 8019:2014). Absorbent saturation occurred after approximately six days, indicated by declining purification performance. These findings confirm that chemical absorption using alkaline solutions is effective for biogas upgrading, with KOH demonstrating the best overall performance and durability.

Contribution to Sustainable Development Goals (SDGs):
SDG 7: Affordable and Clean Energy
SDG 15: Life on Land

1. INTRODUCTION

1.1. Research Background

Biogas is a renewable energy source produced through anaerobic digestion of organic materials such as agricultural waste, livestock manure, and industrial by-products [1]. It mainly consists of methane (CH_4) and carbon dioxide (CO_2), along with minor components such as hydrogen sulfide (H_2S), oxygen (O_2), nitrogen (N_2), and water vapor. The methane content determines the calorific value of biogas, while impurities reduce energy efficiency and may damage equipment [2].

Carbon dioxide lowers the heating value of biogas, whereas hydrogen sulfide is corrosive and hazardous [3]. Consequently, raw biogas often fails to meet utilization standards for industrial fuel, power generation, or vehicle fuel. To enhance its applicability, biogas must undergo purification or upgrading processes.

Among various purification techniques, chemical absorption is widely used due to its simplicity, high efficiency, and economic feasibility. Alkaline absorbents such as NaOH, KOH, and $Ca(OH)_2$ chemically react with acidic gas components, forming stable carbonate or sulfide products. This study evaluates the influence of absorbent type on purification efficiency and determines the operational durability of each absorbent before saturation.

1.2. Literature Review

Biogas is a renewable biofuel produced through the anaerobic digestion of biodegradable organic materials by microorganisms [4]. Typical feedstocks include livestock manure, agricultural residues, municipal solid waste, and industrial by-products such as glycerol [5]. The main components of biogas are methane (CH_4) and carbon dioxide (CO_2), accompanied by minor impurities such as hydrogen sulfide (H_2S), nitrogen (N_2), oxygen (O_2), moisture, ammonia, siloxanes, and particulate matter [6].

Impurities such as CO_2 and H_2S significantly limit the direct utilization of biogas. High CO_2 content lowers the heating value, while H_2S is highly corrosive and can poison catalysts and engines. Moisture promotes corrosion and condensation-related failures, whereas nitrogen dilutes methane concentration. Therefore, impurity removal is essential to enhance methane content and ensure safe, efficient biogas utilisation [7].

Various biogas purification techniques have been reported, including adsorption, membrane separation, biological desulfurization, refrigeration, and chemical absorption. Among these methods, chemical absorption is widely applied due to its operational simplicity, high removal efficiency for acidic gases, and low methane loss.

In a previous study [8], the use of alkaline solutions, namely NaOH, KOH, and $Ca(OH)_2$, for biogas impurity removal at a constant concentration of 1 M over a 14-day absorption period was investigated. The results indicated that all three solutions were effective in reducing impurities, leading to an increase in methane concentration from an initial value of 58.09% to 63.85%, 62.85%, and 60.77% for NaOH, KOH, and $Ca(OH)_2$, respectively.

Another study [9] evaluated NaOH and KOH solutions at concentrations of 0.05 M, 0.10 M, and 0.15 M for CO_2 removal. Optimal performance was observed at a concentration of 0.10 M, where the CO_2 content decreased from 2.14% to 1.56% with NaOH and to 0.30% with KOH.

In this study, biogas purification was performed using an absorption method to reduce carbon dioxide (CO_2) and hydrogen sulfide (H_2S) concentrations while increasing methane (CH_4) content. Absorption is a separation process in which a gas mixture is contacted with a liquid absorbent to remove specific components selectively. The absorption process applied in this work was chemical absorption, in which reactive chemical solutions are employed to enhance absorption rates and removal efficiency.

The absorbents used in this study included sodium hydroxide (NaOH), potassium hydroxide (KOH), and calcium hydroxide ($Ca(OH)_2$). The absorption of CO_2 and H_2S using NaOH, KOH, and $Ca(OH)_2$ follows these reactions [10]:

$$2KOH_{(aq)} + CO_{2\,(g)} \rightarrow K_2CO_{3\,(s)} + H_2O_{(l)}$$
$$2KOH_{(aq)} + H_2S_{(g)} \rightarrow K_2S_{(s)} + 2H_2O_{(l)}$$
$$CO_{2\,(g)} + 2NaOH_{(aq)} \rightarrow Na_2CO_{3\,(s)} + H_2O_{(l)}$$
$$2NaOH_{(aq)} + H_2S_{(g)} \rightarrow Na_2S_{(s)} + 2H_2O_{(l)}$$
$$Ca(OH)_{2\,(aq)} + CO_{2\,(g)} \leftrightarrow CaCO_{3\,(s)} + H_2O_{(l)}$$
$$CaO_{(s)} + H_2S_{(g)} \rightarrow CaS_{(s)} + H_2O_{(l)}$$

Initially, dissolved CO_2 in water forms weak carbonic acid (H_2CO_3), which subsequently reacts with NaOH or KOH to produce bicarbonate salts. Under excess alkaline conditions, the bicarbonates further react to form carbonate salts. In the case of $Ca(OH)_2$, CO_2 reacts directly with the absorbent, forming a white calcium carbonate ($CaCO_3$) precipitate. For NaOH and KOH solutions, hydrogen sulfide (H_2S), a strong acidic gas, initially forms hydrosulfide salts, which are subsequently converted into normal sulfide salts (sodium sulfide and potassium sulfide) in the presence of excess base. In contrast, H_2S reacts directly with $Ca(OH)_2$ to form calcium sulfide (CaS) and water [11].

1.3. Research Objective

The objective of this study is to investigate the effect of absorbent type on the absorption capacity and saturation time during biogas purification. This research also aims to evaluate the comparative effectiveness of different absorbent solutions for removing impurities and increasing biogas methane concentration.

2. MATERIALS AND METHODS

2.1. Materials

Biogas used in this study was obtained from the anaerobic fermentation of molasses wastewater produced at PT Energi Agro Nusantara (ENERO), Indonesia. Calcium hydroxide ($Ca(OH)_2$), sodium hydroxide (NaOH), and potassium hydroxide (KOH) of technical grade were used as absorbents. All solutions were prepared at 20% (w/v) in distilled water.

The experimental apparatus consisted of a biodigester, a rotameter, a water manometer, a bubble column absorption unit, and a gas holder. The bubble column absorber consisted of 12 glass columns, each filled with 500 mL of absorbent solution. Biogas from the biodigester was passed through the absorber at a controlled flow rate, allowing intimate gas–liquid contact.

2.2. Experimental Design and Treatments

The experimental apparatus consisted of a biodigester, a rotameter, a water manometer, a bubble column absorption unit, and a gas holder. The bubble column absorber consisted of 12 glass columns, each filled with 500 mL of absorbent solution. Biogas from the biodigester was passed through the absorber at a controlled flow rate, allowing intimate gas–liquid contact. The treatments consisted of NaOH solution, KOH solution, $Ca(OH)_2$ solution, NaOH and KOH solution, NaOH and $Ca(OH)_2$ solution, and KOH and $Ca(OH)_2$ solution. The solution concentration were 20% (w/v) in 500 mL. The absorbent solutions evaluated included single solutions (NaOH, KOH, $Ca(OH)_2$) and binary mixtures with a 1:1 ratio (NaOH–KOH, KOH–$Ca(OH)_2$, and NaOH–$Ca(OH)_2$). Absorption performance was evaluated over periods of 2, 4, 6, 8, and 10 days.

2.3. Orsat Analysis

Biogas compositions were analysed using an Orsat apparatus available at PT. ENERO, specifically in Waste Water Treatment and Biogas Plant Laboratory. The analysis was performed every 2 days. Orsat analysis was used to determine the compositions of CO_2, H_2S, and O_2 in biogas. The result of biogas will be compared with the result of biogas that hasn't been treated to determine whether the solution has been saturated or not.

3. RESULT AND DISCUSSION

The performance of alkaline absorbents (NaOH, KOH, $Ca(OH)_2$) and their combinations for biogas purification was evaluated at a concentration of 20% (w/v) over a 10-day absorption period. Variations in methane (CH_4), carbon dioxide (CO_2), oxygen (O_2), and hydrogen sulfide (H_2S) contents were monitored to assess purification efficiency and absorbent saturation behavior.

Table 1. Biogas Condition Before and After Purification.

Hari ke-	Konsentrasi (w/v)	Bahan	Kadar CH4 (%)	Kadar CO2 (%)	Kadar O2 (%)	Kadar H2S (%)
0	20%	NaOH	60.570	36	3	0.43
		KOH				
		Ca(OH)2	49.783	44.367	3.43	2.417
		NaOH + KOH				
		NaOH +Ca(OH)2	51.897	42.467	2.73	2.903
		KOH + Ca(OH)2				
2	20%	NaOH	84.133	12	2.85	0.017
		KOH	79.316	16.8	2.85	0.034
		Tanpa Larutan	**47.670**	**46.33**	**3.53**	**2.460**
		Ca(OH)2	71.066	24.8	2.446	0.688
		NaOH + KOH	74.892	21.7	2.356	0.052
		Tanpa Larutan	**57.070**	**37.87**	**2.87**	**2.193**
		NaOH + Ca(OH)2	68.128	26.8	2.73	1.342
		KOH + Ca(OH)2	66.746	28.4	2.77	1.084
		Tanpa Larutan	**49.940**	**43.2**	**2.967**	**3.630**
4	20%	NaOH	84.133	12	2,85	0.017
		KOH	86.753	9.7	2.53	0.017
		Tanpa Larutan	**44.290**	**48.83**	**4.26**	**2.610**
		Ca(OH)2	66.712	29	2.6	0.688
		NaOH + KOH	68.113	28	2.44	0.447
		Tanpa Larutan	**50.550**	**44.1**	**2.7**	**2.650**
		NaOH + Ca(OH)2	69.949	26.35	1.54	1.161
		KOH + Ca(OH)2	64.846	31.25	1.7	1.204
		Tanpa Larutan	**53.690**	**41.463**	**1.767**	**2.910**
6	20%	NaOH	83.948	12.1	2.9	0.052
		KOH	65.304	31	2.61	0.086
		Tanpa Larutan	**53.630**	**41.83**	**2**	**2.267**
		Ca(OH)2	60.297	33.92	3.2	1.583
		NaOH + KOH	65,853	29,7	2,81	0,637
		Tanpa Larutan	**50.110**	**44.2**	**3.267**	**2.420**
		NaOH + Ca(OH)2	69.349	25.9	2.77	0.981
		KOH + Ca(OH)2	60.065	34.1	3.51	1.325
		Tanpa Larutan	**55.467**	**38.13**	**3.767**	**2.630**
8	20%	NaOH	63.780	31.7	1.8	1.720
		KOH	82.548	14.4	2	0.052
		Tanpa Larutan	**42.170**	**50.67**	**3.67**	**3.490**
		Ca(OH)2	64.992	29.66	3.17	1.178
		NaOH + KOH	64.000	31.05	2.6	1.350
		Tanpa Larutan	**51.897**	**42.467**	**2.73**	**2.903**
		NaOH + Ca(OH)2	71.187	24.9	2.87	0.043
		KOH + Ca(OH)2	70.464	25.5	2.91	0.126
		Tanpa Larutan	**57.157**	**37.1**	**3.23**	**2.510**
10	20%	NaOH	56.626	38	3.17	1.204
		KOH	71.452	24.5	2.91	0.138
		Tanpa Larutan	**49.783**	**44.367**	**3.43**	**2.417**
		Ca(OH)2	70.426	25.4	2.4	0.774
		NaOH + KOH	62.096	32.4	2.44	2.064
		Tanpa Larutan	**51.897**	**42.467**	**2.73**	**2.903**
		NaOH + Ca(OH)2	62.774	32.3	2.55	1.376
		KOH + Ca(OH)2	59.976	35.2	2.62	1.204
		Tanpa Larutan	**53.793**	**40.73**	**2.87**	**2.607**

The biogas composition before and after purification is presented in Table 1, showing significant changes in all components following chemical absorption. Methane (CH_4) concentration varied with absorbent type and absorption time, reaching a maximum of 86.75% with KOH on day four and a minimum of 56.63% with NaOH on day ten. An opposite trend was observed for carbon dioxide (CO_2), with the lowest concentration of 9.7% obtained using KOH on day four and the highest value of 38% recorded for NaOH on day ten, indicating absorbent saturation. Oxygen (O_2) content showed relatively minor variation, ranging from 1.54% for the NaOH–$Ca(OH)_2$ mixture on day four to 3.51% for the KOH–$Ca(OH)_2$ mixture on day six. Hydrogen sulfide (H_2S) concentrations were consistently low, with a minimum of 0.017% achieved with KOH on day four and a maximum of 2.06% observed with the NaOH–KOH mixture on day ten, confirming the effectiveness of alkaline absorption in reducing sulfur impurities.

3.1. Effect of Absorbent Type on Methane Enrichment

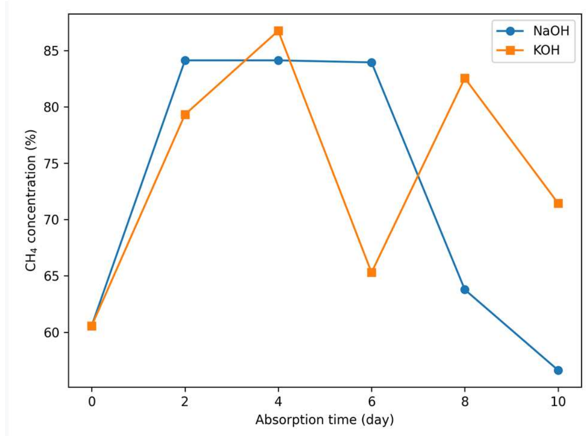

Fig. 2. Methane concentration as a function of absorption time for NaOH and KOH absorbents.

As shown in Figure 2, chemical absorption significantly improved biogas quality by increasing methane content and reducing acidic impurities [8]. Among the single absorbents tested, KOH exhibited the highest methane enrichment, achieving a maximum CH_4 concentration of 86.75% on day 4, followed by NaOH (84.13%) and $Ca(OH)_2$ (71.07%). The superior performance of KOH is attributed to its higher alkalinity and solubility, which enhance gas–liquid mass transfer and reaction kinetics with CO_2 and H_2S.

3.2. Absorption Time and Saturation Behavior

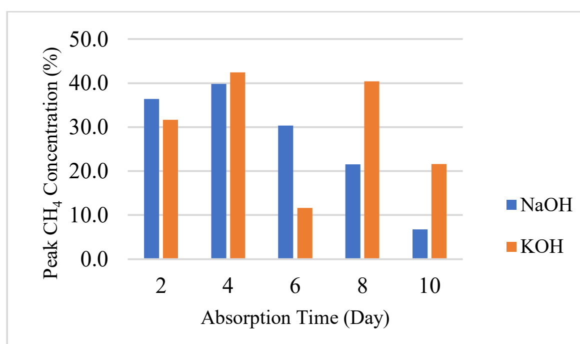

Fig. 3. Comparison of peak methane concentration obtained using different absorbents.

Based on the results from Figure 3, methane concentration increased rapidly during the initial absorption stage, reaching peak values around day 4, followed by a gradual decline. This trend indicates absorbent saturation [12], which limits long-term purification performance. KOH maintained higher methane levels than NaOH over most of the absorption period, suggesting greater resistance to saturation. However, both absorbents

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showed performance deterioration after prolonged operation, indicating an effective absorption duration of approximately 4–6 days under the studied conditions.

3.3. Implications for Biogas Purification

The results demonstrate that absorbent selection plays a critical role in both methane enrichment and operational durability. While mixed absorbents provided moderate improvements, single strong bases, particularly KOH, delivered superior and more stable performance. These findings highlight the importance of evaluating absorbent lifetime alongside removal efficiency when designing chemical absorption systems for biogas upgrading.

4. CONCLUSION

This study investigated the effect of alkaline absorbent type on biogas purification efficiency and absorption durability via chemical absorption. Based on the experimental results, the following conclusions can be drawn:1) All alkaline absorbents (NaOH, KOH, $Ca(OH)_2$, and their binary mixtures) effectively enhanced methane concentration while reducing CO_2 and H_2S contents, confirming the suitability of chemical absorption for biogas upgrading; KOH at 20% (w/v) exhibited the highest purification performance, achieving a maximum methane concentration of 86.75% on day four, exceeding the Indonesian biogas quality standard (SNI 8019:2014); Absorbent saturation was observed after approximately six days of operation, as indicated by a decline in methane enrichment, highlighting the importance of considering absorption durability in biogas purification system design.

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