

Modification of a Double Adsorber Series Type with Multiple Stages Installed on Biodigester for Biogas Purification

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Abstract—Biogas produced from conventional biodigesters typically still contains impurities such as H₂S and CO, which can damage equipment and reduce combustion efficiency. This study aims to modify the adsorber into a series-type double adsorber integrated directly into the biodigester and evaluate its performance in purifying biogas. The study used a 200 L biodigester with 40 kg of cow rumen and 120 L of water. The fermentation process lasted 14 days with feed circulation. Purification was carried out using activated carbon as an adsorbent with a contact time of 60 minutes. Tested parameters included CH₄, H₂S, CO, O₂ levels, flame test, and FTIR characterization. The results showed that the double adsorber increased methane content from 69% to 91% and reduced H₂S to 0.7 ppm and CO to 0 ppm. The tool efficiency averaged above 90% for H₂S and CO absorption. The flame test showed an increased burning duration from 55 seconds to 1 minute 54 seconds. FTIR characterization confirmed the presence of O-H and C=O groups involved in the adsorption process. In conclusion, the series-type double adsorber modification is effective in improving biogas quality according to SNI 8019:2014.

Keywords—activated carbon, adsorption, biodigester, biogas, double adsorber

I. INTRODUCTION

Biogas is a flammable gas produced from the fermentation of organic materials by anaerobic bacteria. The main components of biogas are methane (CH₄) and carbon dioxide (CO₂), but biogas produced directly from conventional biodigesters still contains impurities such as hydrogen sulfide (H₂S), carbon monoxide (CO), and oxygen (O₂) [1]. The presence of these impurity gases is very detrimental because they can cause corrosion in engine equipment, reduce combustion efficiency, and produce harmful emissions to the environment. Wardana et al. [2] explained that the process of biogas formation occurs through three main stages: hydrolysis, acidogenesis, and methanogenesis, but the quality of the gas produced depends heavily on operating conditions such as temperature and pH. If the H₂S content in biogas increases, the CH₄ concentration can decrease drastically, resulting in non-optimal engine performance [3]. Therefore, biogas purification is a crucial step to improve gas quality so that it is suitable for use as a clean and efficient energy source.

Various purification methods have been developed, including adsorption, absorption, condensation, and wet scrubbers. Among these methods, adsorption using activated

carbon is considered the most effective. Activated carbon has a large pore surface area, ranging from 300 to 2000 m²/g, so it can significantly absorb impurities such as H₂S and CO₂ [4]. Another advantage of activated carbon is its relatively low cost and wide availability. Research by Suprianti et al. [5] showed that a mixture of activated carbon and zeolite can separate carbon dioxide from biogas using the adsorption method. Furthermore, Suprianti et al. [6] reported that variations in the shape of activated carbon and column scale affect the CO₂ adsorption performance in biogas, with an increase in methane content up to 89.3%. However, conventional biodigesters are generally not equipped with an integrated purification device, so the biogas produced still contains high levels of impurities.

Previous research by Dzaky Warsito et al. [7] successfully integrated one adsorber into a biodigester and increased methane content to 78%, but this figure has not met the SNI 8019:2014 quality standard which requires a minimum methane content of 80%. Meanwhile, Handayani, Ridwan and Febriana [8] carried out purification using two horizontal series-type adsorbers with silica gel and activated carbon adsorbents, which were able to increase methane content to 76.02% and reduce H₂S to 0.93 ppm. Kabeyi and Olanrewaju [9] confirmed that factors such as temperature, pH, C/N ratio, and toxic gas content such as H₂S greatly influence biogas production. Based on these studies, the proposed hypothesis is that by using two adsorbers arranged in series with multiple stages (double adsorber), the adsorption process will occur twice in sequence so that more impurity gases can be absorbed and the resulting methane content can exceed the SNI 8019:2014 standard. Characterization of the functional groups of the adsorbent before and after the process is also important using FTIR to determine the adsorption mechanism that occurs [10].

Based on the background and hypothesis, this study aims to: (1) modify the adsorber into a series-type double adsorber with multiple stages integrated directly into the biodigester, and (2) evaluate the performance of the modified equipment in purifying biogas, including increasing methane content, reducing H₂S and CO levels, analyzing equipment efficiency, and characterizing the adsorbent using FTIR. This research is expected to make a real contribution to the development of practical, cost-effective, and environmentally friendly renewable energy technology in line with the Sustainable Development Goals (SDGs) for clean and affordable energy.

II. METHODS

A. Equipment and Materials

The main equipment used in this study was a 200-liter High-Density Polyethylene (HDPE) biodigester with a diameter of 59 cm and a height of 93 cm. This biodigester was modified by installing a series-type double adsorber on its lid. Two acrylic adsorbers measuring 5.5 cm x 5.5 cm x 11 cm were arranged in series using ½ inch PVC pipe. The height of the series from the bottom of the biodigester to the top of the adsorber was 0.87 meters. Each adsorber was filled with activated carbon to a height of 9.4 cm (volume 285 cm³ per adsorber) based on a 15% safety factor calculation [11]. Three gas nozzles were installed on the series for sampling: before purification, after adsorber 1, and after adsorber 2. The biodigester was also equipped with a pressure gauge (2.5 bar/35 psi), thermometer, inlet pipe (2 inches), outlet pipe, and overflow tank. All connections were glued with pipe glue and coated with seal tape to prevent leakage, then a leakage test was carried out with air pressure for 24 hours before use.

The main materials used were 40 kg of cow rumen as substrate, 120 liters of water as solvent, and activated carbon as adsorbent. Supporting materials included pipe glue, dextone glue, inner tubes, and PVC pipe.

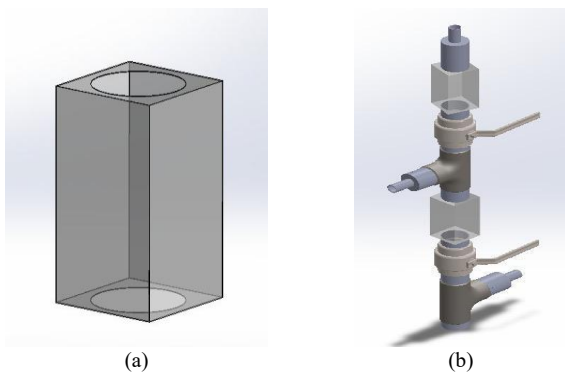


Fig. 1. Adsorber Design (a), Double Adsorber Series Multilevel Circuit (b)

B. Fermentation and Adsorption Process

40 kg of cow rumen was mixed with 120 liters of water until homogeneous using a mixing bucket. The mixture was then put into the biodigester through the inlet pipe. The anaerobic fermentation process took place for 14 days at room temperature (28–34°C) with pH maintained in the range of 6.5–7.2 using NaHCO₃ if necessary. During fermentation, feed circulation was carried out 20 rotations per day using a 5-liter bucket to increase contact between the substrate and microorganisms. Temperature and pH measurements were carried out three times a day (08.00, 12.00, and 18.00 WIB) using a thermometer and digital pH meter. The biogas produced was temporarily stored in used inner tubes that functioned as a gas holder before being flowed to the adsorber.

The purification process was carried out by flowing biogas from the biodigester by gravity (without a blower) to the double adsorber series. Biogas first entered adsorber 1, then automatically flowed to adsorber 2 through a series connecting pipe. The contact time between biogas and adsorbent was set for 60 minutes [1]. During the process, all stop valves on the purification line were opened, while the

sampling nozzles were tightly closed. After 60 minutes, biogas samples were taken from each nozzle (before purification, after adsorber 1, after adsorber 2) for composition analysis.

C. Measurements and Characterization

Methane (CH₄) levels were measured using a calibrated Mestek CGD02A detector. Hydrogen sulfide (H₂S), carbon monoxide (CO), and oxygen (O₂) levels were measured using an NP Portable Multi Gas Detector. The flame test was carried out by flowing biogas to the end of a hose and lighting it with a lighter. The duration of the flame was measured using a stopwatch from when the fire lit until it went out [12].

Activated carbon before and after the adsorption process (from adsorber 1 and adsorber 2) was characterized for its functional groups using Fourier Transform Infrared Spectroscopy (FTIR). The sample was ground with a mortar, dried in an oven at 80°C for 2 hours, mixed with KBr (ratio 1:100), and pressed into pellets. The pellets were measured at a wave number of 4000–400 cm⁻¹ with a resolution of 4 cm⁻¹ and 16 scans [13].

The efficiency of the double adsorber in reducing impurity gases (H₂S and CO) was calculated using the following formula [3]:

$$\text{Efficiency(\%)} = \frac{C_{\text{initial}} - C_{\text{final}}}{C_{\text{initial}}} \times 100\% \quad (1)$$

Where:

- C_{initial} = impurity gas level before purification (ppm for H₂S/CO, or %v/v for CH₄)
- C_{final} = impurity gas level after passing through adsorber 2 (ppm or %v/v)

III. RESULTS AND DISCUSSION

This study aims to purify biogas produced from a biodigester using a modified double adsorber type of multilevel series. The fermentation process was carried out in two experiments (duplo) with the same operating conditions but different implementation times (Experiment 1: May 10-23, 2025, Experiment 2: June 11-24, 2025). The results obtained include data on increasing methane (CH₄) levels, decreasing impurity gas levels (H₂S and CO), flame tests, and adsorbent characterization using Fourier Transform Infrared Spectroscopy (FTIR). The discussion is carried out separately for each experiment, then compared with the theory and findings of other researchers. The following are the results of the adsorber modification with a double adsorber type of multilevel series installed on the biodigester in Figure 3.



(a) (b)

Fig. 2. Double Adsorber installed on Biodigester (a), Double Adsorber series tiered type (b)

A. Fermentation and Purification Results of Experiment 1

In experiment 1, fermentation lasted for 14 days (May 10–23, 2025). During fermentation, the operating temperature was in the range of 26–45°C with an average of 30–32°C during the day. The initial pH of the substrate tended to be acidic (5.3–5.8) and gradually increased to 6.8–6.9 on days 13 and 14. This increase in pH was caused by the accumulation of ammonia from protein degradation and the consumption of volatile acids by methanogenic bacteria, in accordance with the statement of Kabeyi and Olanrewaju (2022) that methanogenic bacteria thrive at a pH of 6.5–8.0.

Table 1. Biogas Composition of Experiment 1 at Various Purification Stages

Date	Parameter	Before Purification	After Adsorber 1	After Adsorber 2
May 24, 2025	CH ₄ (%v/v)	69	81	91
	H ₂ S (ppm)	29.0	9.4	0.7
	CO (ppm)	10	0	0
May 25, 2025	CH ₄ (%v/v)	57	69	78
	H ₂ S (ppm)	48.2	11.5	1.6
	CO (ppm)	102	41	7
May 26, 2025	CH ₄ (%v/v)	55	64	74
	H ₂ S (ppm)	30.7	12.4	2.0
	CO (ppm)	176	19	0
May 27, 2025	CH ₄ (%v/v)	60	71	85
	H ₂ S (ppm)	32.5	10.6	1.5
	CO (ppm)	20	33	0
May 28, 2025	CH ₄ (%v/v)	30	0	0
	H ₂ S (ppm)	0	0	0
	CO (ppm)	0	0	0

Based on Table 1, on May 24-27, 2025, there was a significant increase in methane levels after purification. The highest methane levels were achieved on May 24, 2025, from 69% (before) to 81% (after adsorber 1) and 91% (after adsorber 2). H₂S levels were successfully reduced from 29.0 ppm to 0.7 ppm, while CO levels were successfully reduced from 10 ppm to 0 ppm. These figures have met and even exceeded the SNI 8019:2014 standard.

On May 28, 2025, a drastic decrease in all parameters occurred. This was caused by a subtle leak in the biodigester cover, which resulted in biogas. The resulting volume was very small and undetectable by the detector. This leak occurred because the seal on the biodigester lid was not fully sealed after being opened several times for pH and temperature measurements. Therefore, the data from May 28, 2025, was not used in further analysis.

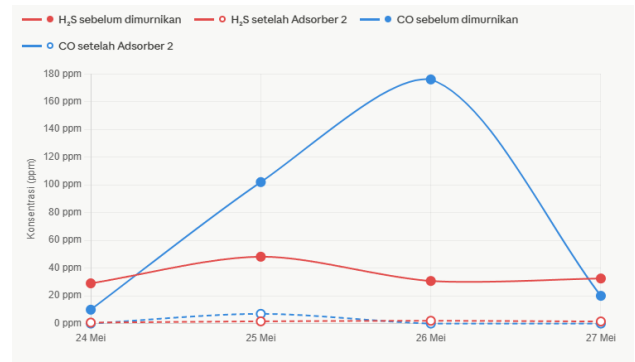


Fig. 3. Graph of the Decrease in H₂S and CO Levels in Experiment 1

Based on Figure 3, there was a very sharp decrease in H₂S levels after purification. On May 25, 2025, the H₂S level before purification reached 48.2 ppm, but after passing through adsorber 2 it dropped to only 1.6 ppm (96.68% efficiency). Similarly, with CO gas, on May 26, 2025, the CO level before purification reached 176 ppm, but after purification it became 0 ppm (100% efficiency). Fluctuations in the levels of impurity gases before purification were influenced by daily fermentation conditions, especially fluctuating temperature and pH.

B. Fermentation and Purification Results of Experiment 2

In experiment 2, fermentation lasted for 14 days (June 11–24, 2025). Based on experience from experiment 1, repairs were made to the biodigester lid seal using used inner tubes locked with a tank lid lock, so that there were no leaks during the experiment. The operating temperature was in the range of 27–45°C with an average of 30–33°C during the day. The initial pH ranged from 6.7–7.1 (more neutral than experiment 1) and stabilized in the range of 6.8–6.9 after the 7th day

Table 2. Biogas Composition of Experiment 2 at Various Purification Stages

Date	Parameter	Before Purification	After Adsorber 1	After Adsorber 2
June 25, 2025	CH ₄ (%v/v)	60	73	81
	H ₂ S (ppm)	34.3	13.6	2.5
	CO (ppm)	26	21	13
June 26, 2025	CH ₄ (%v/v)	69	79	90
	H ₂ S (ppm)	17.8	10.3	0.9
	CO (ppm)	44	14	0
June 27, 2025	CH ₄ (%v/v)	62	75	82
	H ₂ S (ppm)	21.4	13.3	2.1
	CO (ppm)	59	21	7
June 28, 2025	CH ₄ (%v/v)	65	75	86
	H ₂ S (ppm)	36.9	12.6	0
	CO (ppm)	50	37	0
June 29, 2025	CH ₄ (%v/v)	63	72	80
	H ₂ S (ppm)	41.3	14.4	1.2
	CO (ppm)	59	41	0

Based on Table 2, in experiment 2, all data show a consistent trend of increasing methane levels after purification. The highest methane levels were achieved on June 26, 2025, from 69% (before) to 79% (after adsorber 1) and 90% (after adsorber 2). H₂S levels were successfully

reduced from 17.8 ppm to 0.9 ppm, while CO levels were successfully reduced from 44 ppm to 0 ppm.

On June 28, 2025, the H₂S level after adsorber 2 reached 0 ppm (complete reduction) from the initial level of 36.9 ppm. This indicates that the activated carbon in adsorber 2 still has excellent adsorption capacity. However, on June 25, 2025, the CO level after adsorber 2 was still recorded at 13 ppm, slightly above the SNI standard (7-12 ppm). This was caused by the presence of a small amount of used adsorbent from the previous experiment that had not been completely replaced, resulting in a slight reduction in the CO₂ absorption capacity. Research by Ritonga et al. (2021) in Suprianti et al. (2023) also reported that repeated use of adsorbents without regeneration causes a decrease in efficiency.

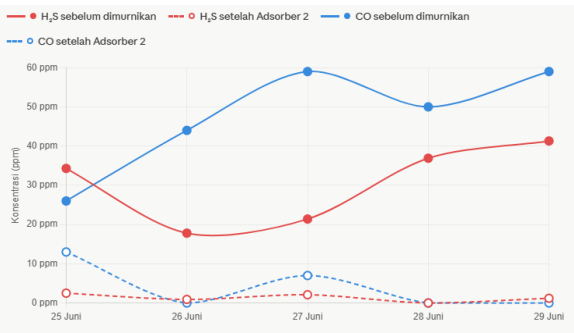


Fig. 4. Graph of the Decrease in H₂S and CO Levels in Experiment 2

Based on Figure 4, the reduction in H₂S levels after purification was very consistent with an average efficiency of 93.98%. The reduction in CO levels also showed a positive trend despite slight fluctuations, especially on June 25, 2025 (13 ppm CO remaining) and June 27, 2025 (7 ppm CO remaining). Overall, experiment 2 produced more stable biogas quality than experiment 1 due to the absence of leaks in the system.

C. Comparison of Tool Efficiency in Experiments 1 and 2

The efficiency of the double adsorber device in reducing pollutant gases is calculated based on the Ambarita formula (2020).

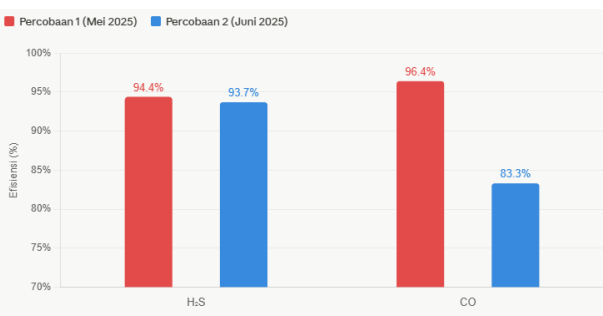


Fig. 5. Comparison of Tool Efficiency in Experiments 1 and 2

Based on Figure 5, the average efficiency of the device in experiment 1 for H₂S absorption reached 95.64% (based on data from May 24-27, 2025), while in experiment 2 it reached 93.98% (based on data from June 25-29, 2025). The CO absorption efficiency in experiment 1 reached an average of 98.28%, while in experiment 2 it reached 87.63%. The slightly lower efficiency in experiment 2 for CO absorption was due to the saturation factor of the adsorbent that had been used

previously, even though partial replacement had been carried out.

Ambarita's (2020) study reported a 95% H₂S absorption efficiency using activated carbon from palm oil waste in a single adsorption column. The results of this study showed equivalent or even better efficiencies (95.64% and 93.98%) even when using a two-column series configuration. The advantage of the double adsorber configuration is its ability to purify biogas twice sequentially, allowing impurities that escape from the first adsorber to be absorbed in the second adsorber. This is in line with the findings of Suprianti et al. (2023) who used two horizontal series adsorbents and successfully increased methane levels to 89.3% with 0 ppm H₂S.

D. Flame Test

Flame tests were conducted to visually verify the quality of the biogas produced. Tests were conducted on the biogas before purification, after adsorber 1, and after adsorber 2 using samples from experiment 2 (June 26, 2025), which produced the highest methane content.

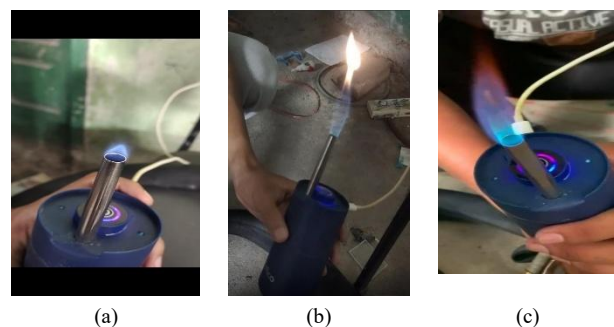


Fig. 6. Flame test before adsorption (a), after adsorption with adsorber 1 (b) and after adsorption with adsorber 2 (c)

Table 3. Flame Test Results at Various Refining Stages

Purification Stage	Flame Color	On Duration (seconds)	Information
Before refining	Little Blue	55	Low heat, low pressure
After Adsorber 1	Reddish blue	83 (1 minute 23 seconds)	The fire is bigger, there are still impurities
After Adsorber 2	Blue with a dash of red	114 (1 minute 54 seconds)	Large and steady fire

Based on Table 3, the biogas before purification produced a small blue flame with a duration of only 55 seconds. The blue color indicates relatively complete combustion, but the small flame indicates low gas pressure and flow rate due to the presence of impurities such as CO₂ and H₂S, which are not easily combustible (Hasil et al., 2021). After passing through adsorber 1, the flame became larger with a reddish-blue color and a duration of 83 seconds. The reddish color appears because a small amount of H₂S gas still burns with a characteristic red flame. After passing through adsorber 2, the flame grew even larger with a clear blue color with a slight red streak at the tip of the flame, with a duration of up to 114 seconds. The dominant clear blue color indicates very complete combustion with an ideal air-fuel ratio, while a slight red streak is still tolerable because the H₂S level is already below 1 ppm.

The increase in flame duration from 55 seconds to 114 seconds (an increase of 107%) was positively correlated with the increase in methane levels from 69% to 90% in experiment 2 on June 26, 2025. This result is in line with the research of Sains et al. (2024) which stated that the duration of biogas flame is directly proportional to the methane concentration.

E. Adsorbent Characterization with FTIR

To prove the adsorption mechanism that occurs in activated carbon, functional group characterization was carried out using FTIR on three samples: (A) activated carbon before contact with biogas (control), (B) activated carbon after use in adsorber 1, and (C) activated carbon after use in adsorber 2.

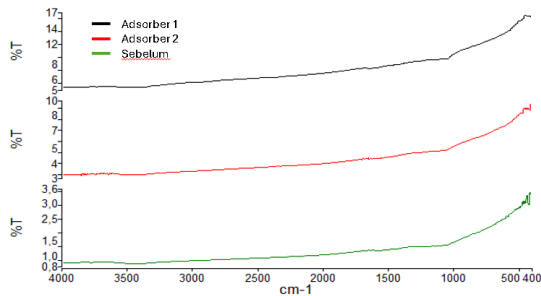
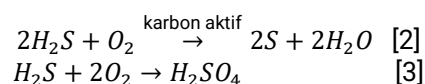


Fig. 7. FTIR Spectrum of Activated Carbon Before and After Adsorption

Based on Figure 4, in activated carbon before adsorption (spectrum A), only an absorption band is visible at wave numbers 434–402 cm^{-1} , which indicates the Fe-O group (metal-oxygen bond) originating from natural impurities in activated carbon (Campanale et al., 2023).

After being used in adsorber 1 (spectrum B), a new absorption band appeared at wavenumbers 3851–3468 cm^{-1} , indicating OH (hydroxyl) groups. According to Eso et al. (2021), hydroxyl groups on the surface of activated carbon can interact with H_2S molecules through hydrogen bonds and can catalyze the oxidation reaction of H_2S to elemental sulfur or sulfuric acid. The reaction that occurs is as follows:



On activated carbon after being used in adsorber 2 (spectrum C), an additional stronger absorption band appeared at the same wave number (3855–3468 cm^{-1}), indicating that the adsorption process took place more intensively on adsorber 2. In addition, an absorption band appeared at 2345 cm^{-1} indicating the absorption of trapped CO_2 gas, as well as a band at 1681–1650 cm^{-1} indicating the C=O group (Campanale et al., 2023). The absorption band at 407 cm^{-1} was still visible but with a changed intensity.

These FTIR results scientifically prove that the biogas purification mechanism by double adsorber occurs through physical and chemical adsorption processes involving OH and C=O functional groups as active sites for H_2S and CO_2 gas absorption. The longer activated carbon is used (in adsorber 2), the more functional groups are formed, thus increasing its adsorption capacity. This explains why the methane levels after adsorber 2 are always higher than after adsorber 1.

F. Research Limitations

Although the results obtained were very satisfactory, this study had several limitations. First, in experiment 1, a leak occurred in the biodigester, making the data on day 14 unusable. Second, the pressure gauge used (2.5 bar/35 psi scale) was unable to read the very low gas pressure at the beginning of fermentation, so the pressure data could not be presented accurately. Third, activated carbon regeneration was not performed in this study, so the efficiency reduction with repeated use cannot be predicted. Further research is recommended to overcome these limitations and test various types of adsorbents (zeolite, silica gel) and variations in gas flow rates

IV. CONCLUSION

Based on the results, it can be concluded that the modification of the adsorber equipment into a series-type double adsorber with multiple stages integrated into a 200-liter biodigester was successfully realized. This modification consists of two acrylic adsorbents measuring 5.5 cm x 5.5 cm x 11 cm arranged in series using ½ inch PVC pipe with a series height of 0.87 meters, and equipped with three gas nozzles for sampling. This tool has been proven to produce biogas that meets the Indonesian National Standard (SNI) 8019:2014. The performance of the series-type double adsorber in purifying biogas showed very good results, with an average H_2S absorption efficiency in Experiment 1 reaching 95.64% and in Experiment 2 reaching 93.98%, and CO absorption efficiency in Experiment 1 reaching 98.28% and in Experiment 2 reaching 87.63%. The increase in biogas quality was also confirmed by the flame test, where the flame duration increased from 55 seconds to 114 seconds with a clear blue flame color indicating complete combustion. FTIR characterization proved that the adsorption mechanism occurs through the formation of O-H and C=O functional groups on the activated carbon surface which play a role in absorbing H_2S and CO_2 gases.

Based on the limitations found during the study, it is recommended to use a tube or cylinder-shaped adsorber design to eliminate sharp corners that are prone to cracking and gas leakage. The use of a pressure gauge with a smaller scale (0-1 bar) or a digital pressure sensor is also recommended for more accurate pressure readings. Further research also needs to be conducted to study the regeneration method of saturated activated carbon, test other types of adsorbents (zeolite, silica gel, or mixtures), and test the effect of variations in biogas flow rate on purification efficiency.

ACKNOWLEDGMENT

This research was funded by Politeknik ATI Padang through the Applied Project scheme for the 2024/2025 Academic Year. Thanks are also conveyed to the Chemical Engineering Laboratory of Politeknik ATI Padang, the Padang Slaughterhouse (RPH), PT. Bratachem, and the Integrated Laboratory of Andalas University for their support and facilities.

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