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Feasibility study toward biogas purification of H2S impurities using wet and dry banana leaves

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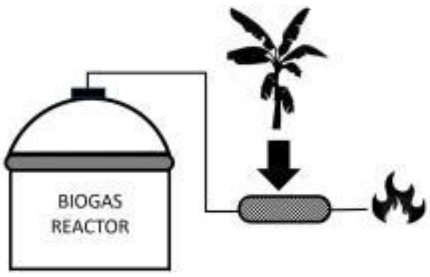
Graphical abstract



Abstract

Biogas, an alternative technology that produces environmentally friendly fuels, usually contains impurities which may infer the performance of combustion. Hydrogen sulfide (H_2S) gas is one of the impurities in the biogas. This study's objective is to assess the removal of hydrogen sulfide using banana leaves. Dry and wet banana leaves were selected to remove pure H_2S gas using simple arranged equipment. Scanning Electron Microscopy (SEM) and Energy-Dispersive X-ray Spectroscopy (EDX) analysis was also performed to establish the effect of H_2S adsorption on the surface of banana leaves. The adsorption capacity was determined using the adsorption isotherm equation. Wet banana leaves have a higher H_2S gas adsorption efficiency then dry banana leaves. Based on the SEM image, the morphology of the banana leaves after adsorption shows that there is damage of the surface leaves morphology than before adsorption. The adsorption capacity of wet leaves is 1.25–1.29 times greater than those of dry leaves, based on the Freundlich and Langmuir isotherms. Based on this study, banana leaves have the potential to be used as an impurity remover for H_2S in biogas. Further research with real biogas stocks is needed to obtain their true efficiency.

Keywords: biogas, impurity, material, nature, removal

1. Introduction

Fossil fuels represent approximately 80% of the global primary energy consumption in 2023 (IEA, 2024). In 2020, oil, coal, and natural gas supplied 30%, 26%, and 23% of the total energy supply respectively worldwide (Fernandez *et al.* 2024). For this reason, massive development of renewable energy is indispensable. Renewable energy development actually has the advantage of reducing political dependence on energy imports (Adebayo *et al.* 2021) and reducing environmental impacts, because renewable energy does not emit carbon emissions into the environment. The use of renewable energy in the last three decades has, driven by political support, continued to grow, developing increasingly advanced technology, and decreasing the cost of producing renewable energy (Renné, 2022). Biomass energy consisting of agricultural waste, forest waste, human waste, and animal waste can be used to meet various energy needs (Malik *et al.* 2021). Biomass energy has advantages over other forms of renewable energy, due to its accessibility and large storage capacity (Ozturk *et al.* 2017). In relation to climate change mitigation, biomass energy has the advantage of being carbon neutral (Ni *et al.* 2006).

Biogas is an alternative technology that produces environmentally friendly fuels because it comes from biomass (Q. Wang *et al.* 2023), organic waste (Tumusiime *et al.* 2022), organic liquid waste (Nurjuwita *et al.* 2020), food waste (C. Zhang *et al.* 2022), leaves (Vargas-Soplín *et al.* 2022), and animal waste (Abdeshahian *et al.* 2016; Khalil *et al.* 2019). From anaerobic activity by methane bacteria, biogas is able to produce gases such as CH_4, CO_2, H_2S, and other gases. Typically biogas comprises of 50–75% methane (CH_4), 25–50% carbon dioxide (CO_2), 0–10% nitrogen (N_2), 0–3% hydrogen sulfide (H_2S), 0–1% hydrogen (H_2), and trace gases (Aghel *et al.* 2022). While biogas in animal manure consists of 53% CH_4, 46% CO_2, 1% O_2, and 200 ppm sulfur (Eggemann *et al.* 2023). Other study investigates the production of biogas through the utilization of domestic waste or food waste in a biogas plant consisting of 42% methane, 45% carbon dioxide, 2.4% oxygen, and 156-193 ppm hydrogen sulfide (Catherine & Twizerimana, 2022).

From the gas content, there are several gas impurities such as CO_2 and H_2S which can interfere with the performance of biogas (Dupnock & Deshusses, 2020), especially related to combustion performance and SO_2 pollutant emission levels. In addition, the relatively high H_2S content in biogas can cause the corrosion of process equipment and have a negative impact on the environment, so these impurities must be removed by purification (Cristiano *et al.* 2020). Various methods of biogas purification have been carried out in several studies. These include water scrubbing (Noorain *et al.* 2019), physicochemical absorption (Liu *et al.* 2014; Maile *et al.* 2017), membrane separation (Zito *et al.* 2022), biotrickling filtration (Vikromvarasiri *et al.* 2017). Other methods that can also be used to separate H_2S from biogas are absorbent as a gas purifier (Surra *et al.* 2019). Because each of these purification techniques is unique, the best technology should be chosen by taking into account factors including investment, maintenance costs, operating circumstances, and purifying efficiency. As for discussion of which application of biogas will be used in local communities, it would be more appropriate to use the biosorption method, the ingredients required being easy to find in the local environment.

The concentration of hydrogen sulfide gas in biogas is relatively small (±0.1–2%) (Zhuo *et al.* 2022). High concentrations of this gas in biogas can cause corrosion in the combustion chamber (Latosov *et al.* 2017). In addition, this gas has an unpleasant odor (Omri *et al.* 2013), is toxic (Vovusha *et al.* 2019), and its combustion produces sulfur dioxide gas (Pompanon *et al.* 2022). It is a poisonous gas that, at high enough quantities (over 100 parts per million), can kill humans by poisoning their respiratory, endocrine, and central neurological systems (B. Zhang *et al.* 2022). Thus, there is an immediate need for sophisticated and effective H2S removal technologies. Numerous efficient physical and chemical techniques, such as adsorption, catalytic combustion, catalytic oxidation, and neutralization, have been documented up to this point for the desulfurization of odorous waste gases.

Actually, the process of H_2S gas removal has been carried out through several types of processes such as adsorption process (Fan *et al.* 2013; Feng *et al.* 2017; Sun *et al.* 2016; Balsamo *et al.* 2016; Cui *et al.* 2022; H. Zhang *et al.* 2021), absorption process (Y. Wang *et al.* 2019; Y. Wang *et al.* 2020; Liu *et al.* 2021), membrane process (Atash Jameh *et al.* 2025; Jusoh *et al.* 2025) and biological process (Brito *et al.* 2025; Do Vale Borges *et al.* 2025). The use of cheap adsorbent materials is preferred with special considerations for the use of biogas purification. Additionally, this research develops inexpensive absorbent materials using agricultural by-products.

A review of banana plants' possible applications has been completed recently. Several conventional absorbents used to absorb pollutant gases and impurities have been investigated by many researchers. However, the use of banana plants as a commercial absorbent in overcoming air pollution is not yet available (Sumiyati *et al.* 2019). Experiments carried out by Huboyo *et al.* (2022) showed that the H_2S gas adsorption efficiency values of three banana components—leaves, stems, and peel—were 76.52%, 51.83%, and 6.44%, respectively (Huboyo *et al.* 2022). According to this study, banana leaves have a promising future as H_2S gas absorbers. The adsorption process is linked to some of the physicochemical properties of banana leaves as a biosorbent for gaseous contaminants. According to the findings of the SEM characterization, the banana leaf's morphology possesses a porous surface that, in certain investigations, may trap pollutants inside its stomata or pores. Lignin, cellulose, and cuticular wax are among the chemical properties of banana leaves that can be utilized to make gas adsorbents (Wahyudi *et al.* 2022).

Considering the study's findings, banana leaves potentially become absorbent through their characteristics and efficiency parameter as absorbent. Therefore, this study will continue the previous research, in which banana leaves were used as biosorbents from the H_2S gas adsorption process, and will differentiate between leaf conditions when wet and dry. Furthermore, it will examine feasibility of banana leaves to become a biogas purifier

2. Materials and methods

2.1. Tools and materials

For sample weighing, an analytic balance (Mettler Toledo, Type ME204) was used; it was calibrated in September 2021. Pure H_2S gas (mixed with N_2) was introduced into a 50 L Tedlar bag with a special H_2S regulator. H_2S was introduced at a constant flow rate of 50 mL/min with a mass flow controller (Aalborg, GFCS-015466) for ten different contact times (5, 10, 15, 20, 25, 30, 35, 40, 45, and 50 minutes). Details of the equipment (**Figure 1**) used can be seen in the previous experiment (Wahyudi *et al.* 2023). We use a UV-Vis spectrophotometer (Thermoscientific Genesys 10S) to analyze the H_2S concentration using methylene blue in accordance with the Indonesian National Standard (SNI) 19-7117.7-2005.

2.2. Preparation of Banana Leaves as Biosorbent

Banana leaves are prepared from local banana plants. Leaves that are mature enough are selected. In this study there are two types of absorbents, namely wet banana leaves and dry banana leaves. Some of the initial steps that were applied to both types of absorbents were washing them with distilled water and wiping them before cutting them to a size of around 1 mm × 1 mm. To prepare wet banana leaves as an absorbent, drying is carried out by leaving them at room temperature for 24 hours. With dry banana leaves, after cutting, oven drying is carried out at 110°C for two hours.

2.3. Experimental system and procedures

Methylene blue spectrophotometry is the test method used in this study. As stated in the Indonesian National Standard 19-7117.7-2005, several steps are required, including the determination of the calibration curve, testing of test samples after the adsorption running process has been carried out, and concentration calculations.

Determination of the calibration curve is done by finding the factor (f) of sodium thiosulfate solution, determining the volume of the H_2S mother liquor, and making a calibration curve. The value of factor (f) is found by titrating the solution (25 mL KIO3 + 100 mL distilled water + 2 gr KI + 10 mL HCl 1:10 in an Erlenmeyer flask) with the TiO solution until light yellow and adding 5 mL of starch indicator until the blue color has just disappeared; the volume of the penitar solution is then recorded and the TiO factor value was obtained. Then the volume of the H_2S main liquor was determined by the titration method, where sodium thiosulfate was used as the titrant, while the H_2S main liquor and the blank (distilled water) were used as the titrant. In making the calibration curve, using a spectrophotometer at a wavelength of 670 nm, the four absorbance values obtained were then analyzed for the curve and the curve equation was also obtained.

Twenty milliliters of the sample solution were put into each measurement tube. 1 mL of $FeCl_3$, and 2 mL of p-aminodimethylaniline were added, then the sample was homogenized. After being homogenized once more, each tube was left for half an hour, after which it was diluted with distilled water to a 25 mL limit. At wavelength 670 nm, the absorbance of the measurement sample solution was measured, and a calibration curve was used to calculate the amount of H_2S gas present. Next, the concentration of the absorbent solution that had gone through the adsorption process was calculated according to the Indonesian National Standard 19-7117.7-2005.

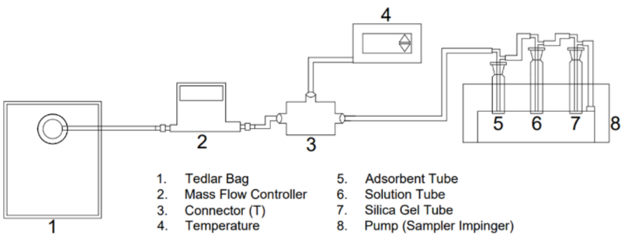


Figure 1. Simple Arranged Equipment

2.4. Data analysis

Analysis of the data obtained to obtain the value of the adsorption capacity of H_2S on wet and dry banana leaves using the Freundlich and Langmuir adsorption isotherm theory. Freundlich's concept derives the following equation:

$$\frac{X_m}{m} = k \cdot C^{1/n}$$

$$\mathrm{Log}\left(\frac{X_m}{m}\right) = \mathrm{Log}k + \frac{1}{n} \cdot \mathrm{Log}C$$

where

X_m = adsorbed weight

m = adsorbent weight

C = substance concentration

Then k and n are adsorption constants whose value depends on the type of adsorbent and the adsorption temperature. When a curve of log (X_m / m) against log C is made, a linear equation will be obtained with an intercept of log k and a slope of 1/n, so that the values of k and n can be calculated, while Langmuir's concept derives the following equation:

$$\frac{X_m}{m} = \frac{a \cdot C}{1 + b \cdot c}$$

$$m \cdot \frac{c}{X_m} = \frac{1}{a} + \left(\frac{b}{a}\right) \cdot C$$

By making a curve of m.c / X_m to C, a linear equation will be obtained with an intercept of 1/a and a slope (b/a), so that the values of a and b can be calculated, from the size of the values of a and b indicating the adsorption capacity.

2.5. SEM-EDX analysis

The size, shape, and surface characteristics of the tested absorbent particles were examined using SEM both before and after adsorption for each sample type. SEM EDX analysis was performed using Phenom ProX (The Netherlands). The components in the adsorbents, particularly S (sulfur), were quantified using the EDX.

3. Results and discussion

3.1. H_2S Removal performance

Table 1 contains data regarding the concentration of sulfuric acid pollutant gas (H_2S) on various types of adsorbents (wet leaves and dry leaves) and variations in contact time carried out by triplication.

Table 1. H_2S Concentration after Adsorption Process (ppm)

Adsorbent Type	Contact Time (minutes)									
	5	10	15	20	25	30	35	40	45	50
Wet Leaves	134.10	208.41	217.99	217.99	220.02	226.11	229.89	232.50	237.43	257.17
	44.99	178.51	184.90	188.96	207.83	210.15	211.31	218.28	222.05	224.66
	58.34	162.84	197.67	217.12	220.89	238.89	243.24	267.33	280.68	280.68
Average	**79.14**	**183.25**	**200.18**	**208.02**	**216.25**	**225.05**	**228.15**	**239.37**	**246.72**	**254.17**
Stdev	**48.06**	**23.15**	**16.69**	**16.51**	**7.30**	**14.40**	**16.04**	**25.24**	**30.40**	**28.13**
Dry Leaves	185.77	237.72	245.85	249.34	253.98	255.43	274.30	277.49	285.62	310.29
	116.40	171.84	172.42	190.70	195.35	207.25	208.70	215.95	229.02	252.53
	193.31	205.80	227.86	231.05	239.18	239.76	242.37	248.75	254.85	258.62
Average	**165.16**	**205.12**	**215.37**	**223.70**	**229.50**	**234.14**	**241.79**	**247.40**	**256.49**	**273.81**
Stdev	**42.40**	**32.95**	**38.28**	**30.00**	**30.49**	**24.58**	**32.80**	**30.79**	**28.34**	**31.74**

In **Figure 1**, the variation in contact time is linear with the resulting concentration value. In the adsorption process with banana leaf adsorbent, the concentration of H_2S gas increased with contact time when the lowest concentration was 44.99 mg/L and the highest was 310.29 mg/L. The difference in concentration of the 10 variations looks relatively stable with a contact time interval of five minutes. For the first 5 minutes of the experiment, there was a fairly intense adsorption process at the beginning so that there was high fluctuation between samples, both in wet and dry leaves. Further experiments are suggested to be able to provide more detailed time at the beginning of the adsorption process.

Contact time between the adsorbent and the adsorbate that is too long can cause the adsorbent conditions to become saturated and release of the adsorbate (Petrović *et al.* 2023). As can be seen in **Figure 2**, from the test results, the concentration of H_2S gas continued to rise with increasing contact time, so it can be concluded that the banana leaf adsorbent reached saturation level in a short time.

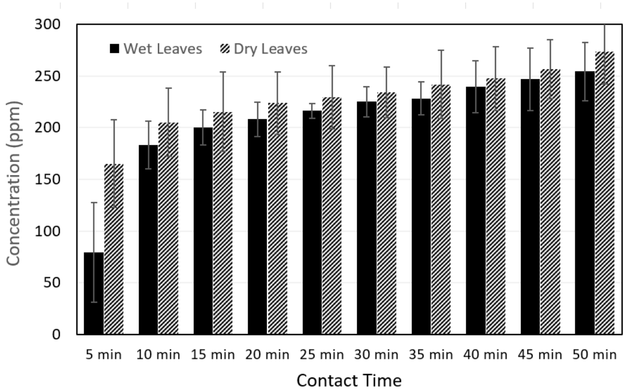


Figure 2. Graph of H_2S Concentration (Average)

The adsorption efficiency of H_2S gas of two adsorbents is significantly different. Average wet banana leaves have the highest adsorption efficiency of H_2S gas of 73.62% while dry banana leaves have an adsorption efficiency of 44.95%. Wet banana leaves have a higher H_2S gas adsorption efficiency compare to dry banan leaves because wet banana leaves have natural fiber structure and higher water content than dry leaves so that the adsorption process can occur more intensely due to the high solubility of H_2S gas in water which is facilitated by its natural fiber structure. Fibers owned by banana leaves include cellulose, hemicellulose, and lignin (Wahyudi *et al.* 2022).

Adsorption efficiency is affected by contact time. According to the results of the study, five minutes is the best adsorption efficiency at 0 – 10 minutes experiments because H_2S gas adsorption occurs to a maximum level. However, the optimum adsorption conditions need to be studied further to see the optimal conditions by taking into account the factors of the amount of material used, adsorption time and acceptable removal rate. After the five-minute contact time, the adsorption efficiency value decreased due to the contact time between the adsorbent and the adsorbate, which was too long and caused the adsorbent to become saturated and the adsorbate to be released. Past the optimum conditions, the adsorbent no longer works.

Figure 3 and Figure 4 demonstrate the efficiency of H_2S gas removal on wet and dry banana leaves. The gas removal efficiency of each adsorbent after 5 minutes is not significant from each treatment due to the lack of difference between two types of adsorbents in percentage of removal.

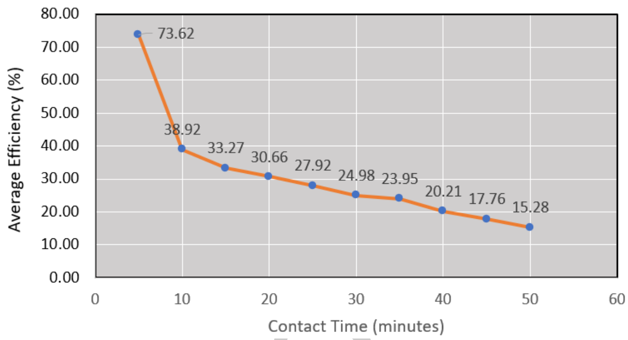


Figure 3. Graph of the Efficiency of H_2S Gas Removal on Wet Banana Leaves

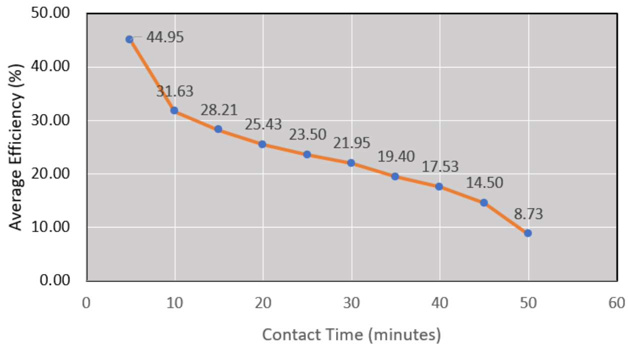


Figure 4. Graph of the Efficiency of H_2S Gas Removal on Dry Banana Leaves

3.2. SEM-EDX Characterization of Banana Leaves

SEM results of wet and dry banana leaves before and after adsorption are shown in **Figure 5 and Figure 6**. **Figure 5** is a SEM image of a wet banana leaf before and after adsorption

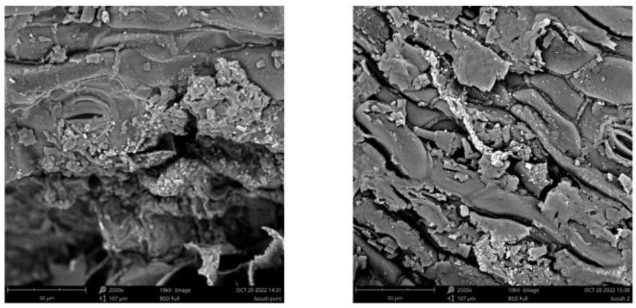


Figure 5. SEM Result of Wet Leaves. (A) Before Adsorption (B) After Adsorption

As seen in the figure, before adsorption the stomata were visible and there were few materials attached around the stomata. However, after adsorption the stomata are covered with materials sticking around them. This increasing amount of material arises due to damage of the morphology of the leaf surface. The same is seen in **Figure 6**, which is a SEM image of dried banana leaves before and after adsorption in which the morphology of the banana leaves after adsorption demonstrates damage to the morphology of the leaf surface compare to that before adsorption. This morphology damage may be due to the H_2S adsorption process that occurs in the two leaves as demonstrated in research conducted by Gao (2021) explaining that stomata can trap air pollution (Gao *et al.* 2021). In addition, a study from Zheng (2022) explains that the wax structure on leaves can block pollution (Zheng *et al.* 2022).

Based on EDX analysis (**Table 2** and **Table 3**), there was an increase in sulfur levels in leaves after the adsorption process, particularly from sulfur elements. The use of wet banana leaves increased the sulfur content in the leaves by about 1.6 times as compared to dry banana leaves that increased by only 1.04 times. The increase in the S element in this study was lower than previous study (Huboyo *et al.* 2022) which reached 20 times, but it was comparable to latest study (Wahyudi *et al.* 2023) which was around 1-1.6 times using various types of wet banana leaves. This demonstrates that banana leaves have potential as H_2S gas adsorbers.

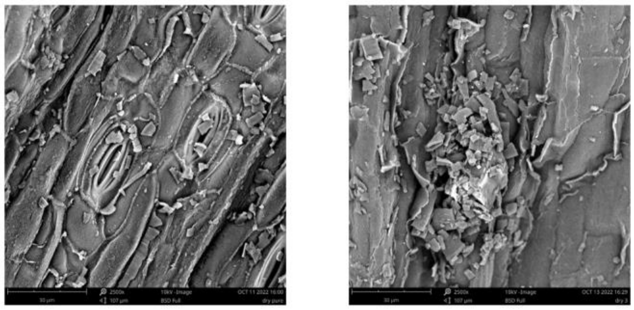


Figure 6. SEM Result of Dry Leaves (A) Before Adsorption (B) After Adsorption

Table 2. EDX Results on Wet Banana Leaves

Element Symbol	Wet Banana Leaves							
	Before Adsorption		After Exp 1		After Exp 2		After Exp 3	
	Atomic Conc.	Weight Conc.	Atomic Conc.	Weight Conc.	Atomic Conc.	Weight Conc.	Atomic Conc.	Weight Conc.
C	69.50	62.93	74.19	66.88	76.02	67.78	66.67	58.94
O	14.16	17.08	23.25	25.31	17.36	20.19	21.94	25.49
S	0.04	0.11	0.09	0.18	0.23	0.54	0.07	0.17
Si	0.09	0.19	3.24	5.89	0.30	0.62	1.68	3.45
P	0.04	0.09	0.08	0.19	0.17	0.39	0.10	0.23
N	15.33	16.24	20.21	18.40	9.52	9.13	8.34	8.48
K	0.56	1.63	0.90	2.37	1.49	4.06	0.98	2.81

Table 3. EDX Results on Dry Banana Leaves

Element Symbol	Dry Banana Leaves							
	Before Adsorption		After Exp 1		After Exp 2		After Exp 3	
	Atomic Conc.	Weight Conc.	Atomic Conc.	Weight Conc.	Atomic Conc.	Weight Conc.	Atomic Conc.	Weight Conc.
C	58.99	53.09	77.39	69.51	81.60	75.58	62.24	55.36
O	30.78	31.88	10.07	12.10	22.89	26.20	16.82	19.86
S	0.04	0.08	0.06	0.13	0.11	0.25	0.05	0.11
Si	0.02	0.05	1.44	2.91	0.22	0.47	0.02	0.05
P	0.09	0.19	0.05	0.12	0.15	0.32	0.11	0.25
N	15.23	13.77	10.19	10.79	23.14	21.09	19.04	19.78
K	2.31	5.70	0.25	0.73	0.81	2.31	1.24	3.56

Table 4. Adsorption capacity

Adsorbent Type (Banana Leaves)	Freundlich Isotherm		Langmuir Isotherm	
	R	Capacity (mg/g)	R	Capacity (mg/g)
Wet Leaves	0.843	5.818	0.509	5.335
Dry Leaves	0.871	4.656	0.578	4.148

3.3. Adsorption isotherm

The adsorption capacity (the amount of H_2S gas adsorbed in each unit weight of the adsorbent) is expressed in mg/g adsorbent. The adsorption capacity is determined using the adsorption isotherm equation. The adsorption isotherm models used are the Freundlich adsorption isotherm and the Langmuir adsorption isotherm. **Figures 7, 8, 9 and 10** show the Freundlich and Langmuir isotherm equations for wet and dry leaves.

Based on the calculation of the adsorption model for each isotherm, depending upon the type of wet banana leaf adsorbent, the regression coefficient on the Freundlich isotherm is 0.8426 with an adsorption capacity of 5.8182 mg/g adsorbent. The best regression coefficient for dry banana leaf adsorbent comes from the calculation of the Freundlich isotherm with a value of 0.8713 and an adsorption capacity of 4.6562 mg/g adsorbent. **Table 4** is a summary of the adsorption capacity.

The results of this adsorption capacity are slightly lower than previous studies (Wahyudi *et al.* 2023) for the same type of banana leaf, around 7.6 mg/g. These two studies indicate that the adsorption capacity of banana leaves is influenced by their water content and type.

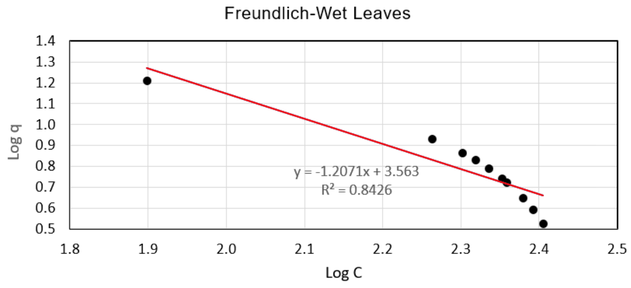


Figure 7. Graph of Wet Banana Leaves Freundlich Adsorption Isotherm

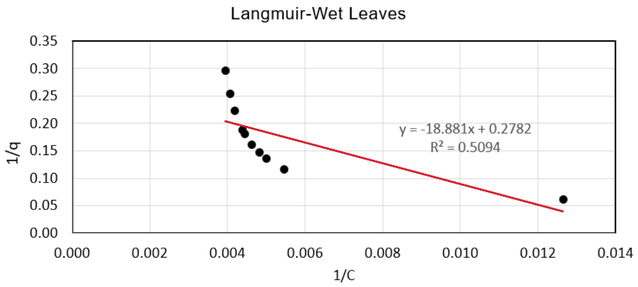


Figure 8. Graph of Wet Banana Leaves Langmuir Adsorption Isotherm

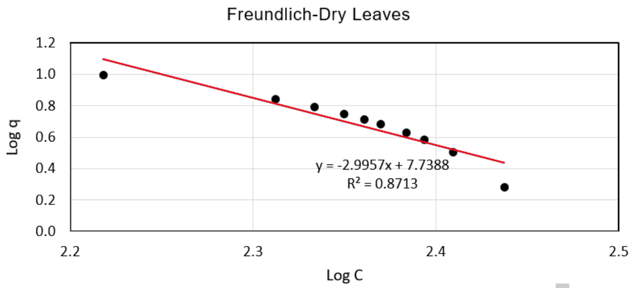


Figure 9. Graph of Dry Banana Leaves Freundlich Adsorption Isotherm

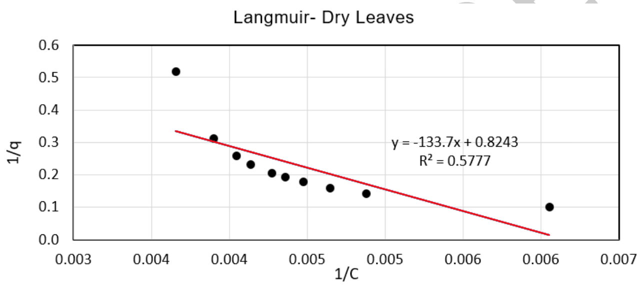


Figure 10. Graph of Dry Banana Leaves Langmuir Adsorption Isotherm

3.4. Implication of H_2S reduction in biogas purification

Biogas purification reduces the corrosive impact on the machinery by eliminating impurities like hydrogen sulfide. Additionally, the procedure removes pollutants' detrimental impacts on the environment and human health. Moreover the elimination of impurities raises the fraction of methane that is useable energy, improving the fuel's energy density. (Das *et al.* 2022).

Adsorption is one method of removing hydrogen sulfide both during and after digestion. In this study, it was found that both wet and dry banana leaves can be used as adsorbents in the H_2S gas adsorption process. Based on literature, livestock waste has a H_2S gas content reaching a concentration of 200 ppm (Eggemann *et al.* 2023). If carried out using the banana leaf adsorption process, the lowest output concentration of H_2S is expected to be 52.76 ppm. If tried with lower efficiency i.e. 44.95%, the H_2S output concentration reaches 110.1 ppm.

The use of wet banana leaves can reduce banana leaf waste, especially after the banana harvest. Not all banana leaves have economic value, i.e., are marketable. The use of wet banana leaves (not through drying treatment) will facilitate the practicality of making adsorbents. Fortunately, banana plants are usually found in rural areas where the potential for biogas is higher, especially from livestock waste, so there is an effortless supply chain in terms of providing adsorbents. On the other hand, it is still necessary to study the use of this used adsorbent. For example, if it is becoming fertilizer after going through the composting process, it should consider that the S content in it increases.

This study used pure H_2S gas as its adsorbate, hence ideal adsorption conditions for H_2S gas may occur. It's still unknown regarding the adsorption competition with other hydrophillic gases such as CO_2 and NH_3. These two impurity gases are present in sufficient amount in biogas From this study, further research can be conducted regarding the effect of banana leaves adsorbent on real biogas purification, especially on adsoprtion competition for impurity gases.

4. Conclusion

Wet and dry banana leaves can be used as adsorbents for H_2S gas adsorbate. The adsorption efficiency of H_{2S} gas of two adsorbents is significantly different in that average wet banana leaves have the highest adsorption efficiency of H_2S gas of 73.62% and dry banana leaves have 44.95%. Based on SEM images, there are proven changes to the morphology of the banana leaf surface due to the adsorption process. Adsorption capacity was higher for wet leaves than that of dry leaves based on Freundlich and Langmuir isotherms. Based on this study, banana leaves have the potential to be used as an impurity remover for H_2S in biogas. From this research it appears to be feasible to use the banana leaf adsorbent as a biogas purifier particularly for H_2S gas. Further research with real biogas experimentation is necessary.

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Author contributions

Haryono S Huboyo: Conceptualization, Methodology, Writing Review Editing, Funding Acquisition. **Badrus Zaman**: Data curation, Writing review, Supervision. **Bimastyaji Surya Ramadan**: Investigation, Lab Analysis, Writing- Original draft preparation. **Rahmatia Sarah**: Investigation, Lab Analysis. **Agung Budi Prasetijo**: Assisting set up device and visualization.

Data availability

All data supporting the findings of this study are available upon request

Consent for publication

Consent to publish was obtained from all authors.

Declaration of competing interest

The authors declare that they have no competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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