

## Research Article

# Removal of Hydrogen Sulfide from Biogas Using a Red Rock

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The potential of red rock (RR) materials for the removal of  $H_2S$  from biogas was studied. The rock samples were collected, sieved, and organized in various particle size ranges such as  $0.32\text{-}250\ \mu\text{m}$ ,  $250\text{-}500\ \mu\text{m}$ ,  $500\text{-}750\ \mu\text{m}$ ,  $750\ \mu\text{m}\text{-}1\ \text{mm}$ , and  $1\text{-}1.5\ \text{mm}$ . These samples were calcinated at the various temperatures as  $500^\circ\text{C}$ ,  $750^\circ\text{C}$ , and  $1000^\circ\text{C}$  and then characterized for phase composition by energy-dispersive X-ray florescent technique, surface morphology by Zeiss Ultra Plus Field Emission Scanning Electron Microscopy (FE-SEM), and surface area by the Brunauer-Emmett-Teller (BET) method. The calcinated RR was filled in the bed reactor, and biogas was allowed to pass through the adsorbent while recording the inlet and exit concentration of  $H_2S$ . The results show that particle size, calcination temperature, adsorbent mass, and biogas flow rate were parameters that influenced the removal efficiency and adsorption capacity of RR. The sample sieved at  $0.32\text{-}250\ \mu\text{m}$  and calcinated at a temperature of  $1000^\circ\text{C}$  showed 95% high removal efficiency and adsorption capacity of  $0.37\ \text{g}/100\ \text{g}$  of the sorbent. Regeneration of spent materials when exposed to air, keep on by reuse in the column, appeared to have nearly similar removal efficiency as the original calcined sample. Thus, the overall performance of the material is promising, which is due to the presence of metals such as iron and magnesium, among others. Therefore, proving the successful elimination of contaminant, RR is an available material for biogas purification.

## 1. Introduction

Biogas is a mixture of various gasses that are obtained through the biological degradation of organic matter in the lack of oxygen [1]. It is a renewable energy that belongs to the category of biofuels. The biogas composition differs according to the material used in the whole process of production. The main components are carbon dioxide ( $CO_2$ ) and methane ( $CH_4$ ), although it likewise encompasses some amounts of contaminants like  $H_2S$ ,  $NH_3$ , volatile halogenated organics, and siloxanes [2].

Kitchen waste, bagasse, and garden waste can be used to produce biogas. These wastes from food remains, bagasse, and garden waste are naturally organic, hence easily degradable by a microorganism [3] which then release ammonia gas, carbon dioxide, methane, and hydrogen sulfide to the atmosphere. Compositions are carbon dioxide 30-45%, methane 50-70%, and some impurities like hydrogen sulfide [4]. Therefore, to make the environment clean, these wastes can be used to produce biogas. The recommended industrial

exposure limit for  $H_2S$  is from 8-10 ppm per day [5], and according to WHO, it is 0.05 mg/L [6].

The availability of hydrogen sulfide in ignition process leads to the formation of  $SO_2$  which is very detrimental to the ecosystem [7, 8] and harmful for animal health and human as it leads to headaches, nausea, dizziness, irritation of mucous membranes, and sudden death. Therefore, care has to be taken to remove hydrogen sulfide before biogas is used. The current researchers are mostly searching for materials that could cause the elimination of  $H_2S$  from biogas. Several materials can adsorb and take hydrogen sulfide from biogas [2, 9-11]. There are various methods used in removing  $H_2S$  from biogas and commonly can be classified into two major groups as physical-chemical approaches and biotechnological method, the former one being traditional but dominates the today's market [12]. The biological method used in the purification of biogas is biotrickling filters, biofilters, and bioscrubbers [13]. In physical adsorption, gas molecule attracts and adheres to the surface of adsorbent by using intermolecular forces and this process

is ordinarily exothermic, the heat that is released ranging from 2 to 20 kJ/g mol [14]. Chemical sorption is a process that involves the reaction between the surface of the material and the adsorbent where there is a creation of a new chemical bond at the surface of the adsorbent as surface chemistry and surface area plays an essential part for hydrogen sulfide elimination [15].

Red soil is a remaining product of an intensive chemical weathering process that affects rocks through leaching and oxidizing processes. Literature shows that red soils contain a massive amount of iron in the form of magnetite ( $\text{Fe}_3\text{O}_4$ ), goethite [ $\text{FeO}(\text{OH})$ ], and hematite ( $\text{Fe}_2\text{O}_3$ ) [16]. Biogas adsorption is a prominent method due to low-cost material as red mud soil and clay soil [17, 18] which are rich in iron oxide where  $\text{H}_2\text{S}$  will be oxidized by iron oxide into elemental sulfur.

By considering the benefits of biogas, there is a need of developing cost-effective materials for the purification process [19]. Therefore, this study is intended at investigating the elimination of hydrogen sulfide from biogas using RR materials collected from Nadosoito village in Monduli district in Tanzania. The red color of the materials makes them peculiar and unique, indicating possible iron presence which might facilitate the hydrogen sulfide removal and thus would be worth for investigation. The biogas purification process was done on-site at ambient conditions.

## 2. Materials and Methods

**2.1. Sample Collection and Adsorbent Preparation.** RR materials were collected from Nadosoito village in Monduli district, which is located in the Northern part of Tanzania -3.42703 South and 36.44103 East. This material contains Na, Mg, K, Ca, Zn, and Fe in high proportions. The material was crushed, sieved into diverse particle size as 0.32-250  $\mu\text{m}$ , 250-500  $\mu\text{m}$ , 500-750  $\mu\text{m}$ , 750  $\mu\text{m}$ -1 mm, and 1-1.5 mm, and then samples were calcinated at various temperatures as 500°C, 750°C, and 1000°C for about 2 hours in the furnace (Thermo Scientific 1200 Box Furnace) and then permissible to cool ready for adsorption purposes.

**2.2. Material Characterization.** The textural properties of the red rock samples were analyzed; the specific surface area was determined by the Brunauer-Emmett-Teller (BET) method while pore size distribution evaluated through the Barrett-Joyner-Halenda (BJH) method. Nitrogen adsorption-desorption isotherms were evaluated at 77 K by using the Quantachrome NOVA 4200 (Win©1994-2013, v11.03) at University of Dar es Salaam. The BET surface area, pore diameter, and pore volume were analyzed for the raw sample, calcined, and those that had undergone adsorption. Sample composition was determined by energy-dispersive X-ray fluorescence spectrometer (XRF), model MiniPal4 (Pw4030)-Rh manufactured by PAN Analytical, using the software provided with the instrument. The surface morphology of the samples (RR-B) and (RR-C) was investigated using Zeiss Ultra Plus Field Emission Scanning Electron Microscopy (FE-SEM) from Indian Institute of Science and Technology Bangalore.

**2.3. Evaluation of Adsorbent Performance.** The sorption and removal experiments were carried out at domestic household premises in Arusha, Tanzania, where the biogas was produced in two digesters from biomass, human wastes, and the kitchen remaining wastes. A plastic bed reactor of 5 cm length and 1 cm width was packed with cotton wool inside, and without the adsorbent, biogas was allowed to pass through the reactor at the ambient condition to verify whether cotton wool does absorb  $\text{H}_2\text{S}$  or not; it appeared that cotton wool does not react with  $\text{H}_2\text{S}$ . The adsorbent was filled in the bed reactor where both ends of the bed reactor were supported with cotton wool, and the biogas was then allowed to pass through. The concentration of  $\text{H}_2\text{S}$  was measured once before the filter and then monitored every 10 minutes after the filter.

Photo and schematic diagram for the experimental setup are shown in Figure 1. Flowmeter model JBD2.5-SA was used to monitor the flow rate, while for measuring the gases found in the biogas, the Geotech Biogas 5000 analyzer model was used.

The adsorbent performance was expressed as percentage removal efficiency (RE), and it was calculated by using the formula below:

$$\text{RE} = \frac{C_0 - C}{C_0} 100\%. \quad (1)$$

Sorption capacity (SC) of the RR samples, in a gram of sulfur per 100 grams of sorbent, was determined as defined in the literature [20]:

$$\text{SC} = \text{WHSV} * \left[ \frac{M}{V_{\text{mol}}} * \int_0^t (C_0 - C) dt \right], \quad (2)$$

where  $M$  is the atomic weight of sulfur, WHSV is the weight hourly space velocity in  $\text{mLh}^{-1}\text{g}^{-1}$ ,  $V_{\text{mol}}$  is the gas molar volume at standard conditions in  $\text{Lmol}^{-1}$ ,  $C_0$  and  $C$  are the concentrations of  $\text{H}_2\text{S}$  before and after adsorption, respectively, in ppm, and  $t$  is operating time [20].

**2.4. Sample Regeneration.** A separate experiment was done to examine the capability to regenerate an adsorbent by exposure to air. Experiment on the removal of  $\text{H}_2\text{S}$  was first performed on RR samples for about 150 min, following this test; the sample was removed from the bed reactor and spread in a sheet to exposure to air over one week. The sample was filled back into the bed reactor, and the experiment on the  $\text{H}_2\text{S}$  removal test was proceeded.

## 3. Results and Discussion

**3.1. Composition of Biogas.** On-site experiment for determining biogas composition was carried out using Biogas 5000 gas analyzer as per Table 1. The biogas composition in two digesters differs according to feedstock used and the size of the digester.

Hydrogen sulfide concentration was monitored for about one hour before the adsorption process. In digester one, the

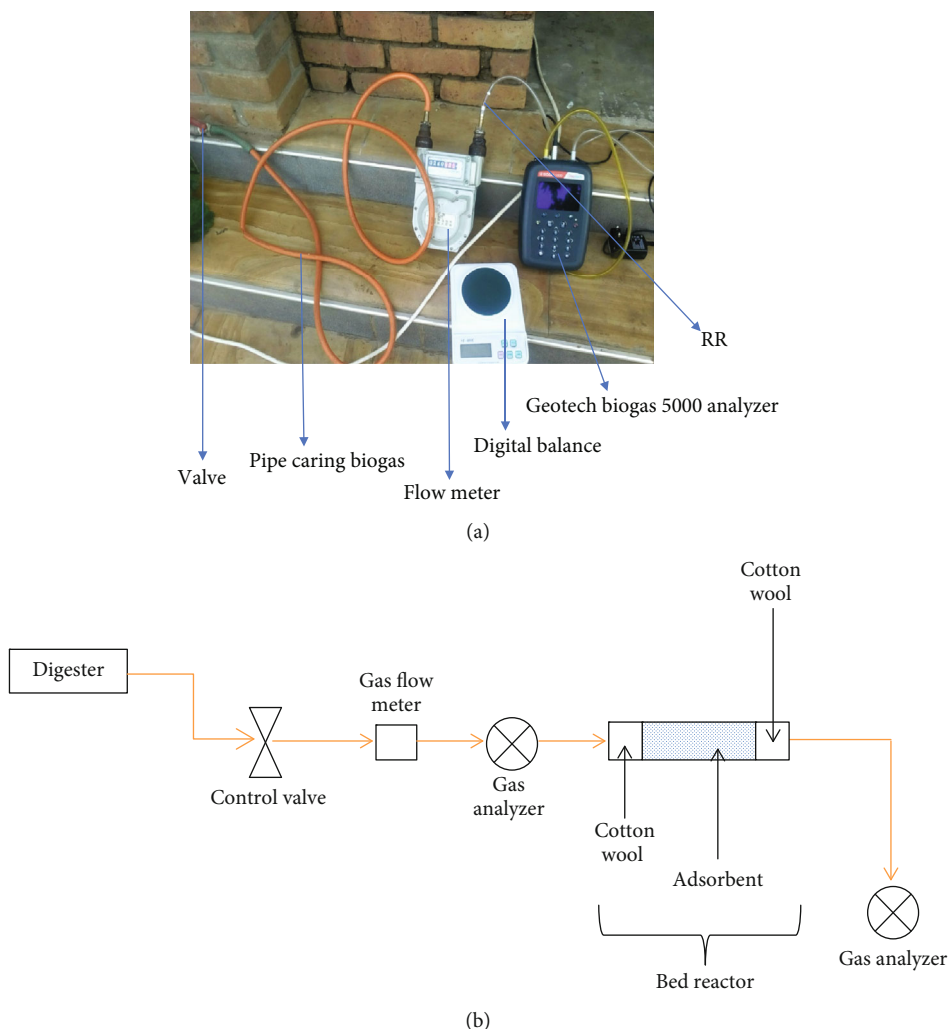


FIGURE 1: On-site experiment of biogas purification: photo (a) and schematic diagram (b).

TABLE 1: Composition of biogas within two digesters.

Component	Biogas in digester 1	Biogas in digester 2
CH <sub>4</sub>	65-69%	70-71%
CO <sub>2</sub>	34-37%	27-29%
H <sub>2</sub> S	526-539 ppm	801-1230 ppm
NH <sub>3</sub>	18-20 ppm	20-24 ppm

H<sub>2</sub>S concentration remains nearly constant while in digester two it varies because of the feedstock variation.

**3.2. Textural Characteristics of the Adsorbent.** The textural properties of the RR materials have been analysed for three samples, raw sample RR-A, calcined sample at  $T_c = 1000^\circ\text{C}$  RR-B, and the sample has undergone adsorption RR-C. Nitrogen adsorption/desorption isotherms are displayed in Figure 2(a), while Figure 2(b) displays pore size distribution, calculated through the BJH method.

Consider Figure 2(a); the calcined sample RR-B adsorbs more N<sub>2</sub> compared to the rest as it poses the highest BET surface area as per Table 2.

In Figure 2(b), is seen, the sample RR-B possesses large pore diameter; hence, it has more differential volume when compared to other samples, and it is following a large surface area.

The BET analysis summary is displayed in Table 2 for three samples: as it is seen, the BET surface area of the raw sample RR-A is smaller compared to the calcined sample RR-B while eventually decreases in the sample RR-C that undergoes adsorption because the micropores created had occupied by adsorbate. The pore size evaluation of all samples shows they are of more mesopores rather than macropores. Availability of micropores and mesopores should favor adsorption as reported in the literature [21].

**3.3. Morphological Studies.** The surface morphology of calcined (RR-B) and utilized sample (RR-C) is as shown in SEM image in (Figure 3). The morphology of calcined sample (Figure 3(a)) and (Figure 3(c)) showed there was small but irregular pore size with roughness on surface due to calcination effect as the result surface area increased which reflects Table 2 above. Worth to note that morphology of RR is very similar to that observed by [22] where red mud was used for

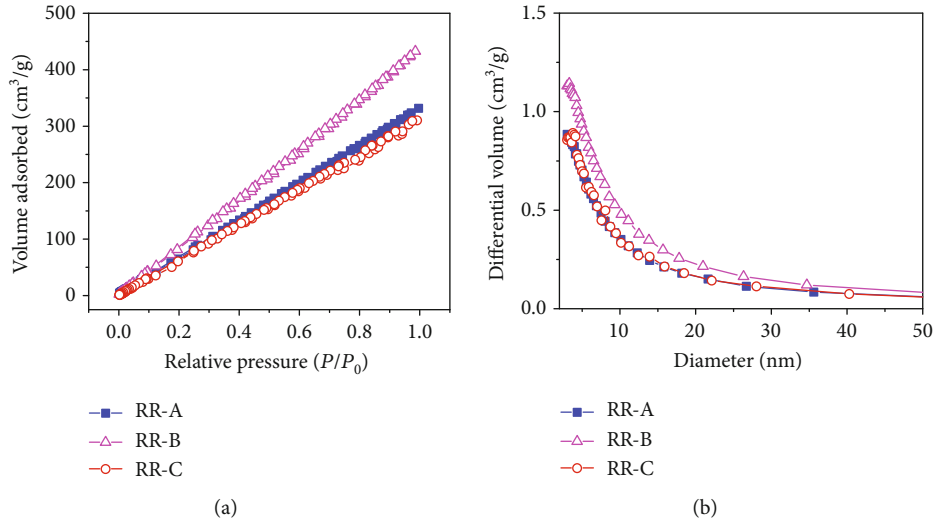


FIGURE 2: (a) Nitrogen adsorption/desorption isotherms. (b) Pore size distribution calculated from desorption isotherm using the BJH method.

TABLE 2: Multipoint BET summary for raw sample (RR-A), calcined (RR-B), and utilized sample (RR-C).

Sample	Particle size ( $\mu\text{m}$ )	$S_{(\text{BET})}$ ( $\text{m}^2/\text{g}$ )	Pore diameter ( $\text{\AA}$ )	$V_{(\text{total})}$ ( $\text{cc}/\text{g}$ )	Ref
RR-A	0.32-250	546	31	0.47	This study
RR-B	0.32-250	696	32	0.63	This study
RR-C	0.32-250	494	30	0.48	This study
Red mud	0.1-160	31.7	18.2	0.015	[22]

hydrogen sulfide adsorption. Nevertheless, spent sample (RR-C) pores collapse and formation of spots and channelled like structure was observed which might be due to the hydrogen sulfide attachment (Figure 3(b)) and (Figure 3(d)). Therefore, according to this surface morphology, it supports Table 2 that means the spent sample decreases in surface area due to the attachment of hydrogen sulfide.

**3.4. Mineral Composition and pH of RR Material.** Elemental composition of RR material calcined at  $1000^\circ\text{C}$  is displayed via bar diagram in Figure 4 whereby the results from XRF analysis show that Si, Ca, Fe, and Al are most abundant compounds present in the sample. Some transition elements also were found but in a minimal amount. The pH value for the red rock sample falls under basic, which is about 10. The alkalinity of the red rock favors the hydrogen sulfide removal. This phenomenon is similar to the observation reported in [23]. The oxides of some elements are available in the RR (Table 3, and the iron oxide is present in a higher amount compared to other elements that favour facilitating the whole process of purification. According to literature, two forms of iron oxide have excellent removal efficiency of hydrogen sulfide from biogas that is  $\gamma\text{-Fe}_2\text{O}_3$  and  $\alpha\text{-Fe}_2\text{O}_3$ . They react very rapidly with hydrogen sulfide, and the regeneration process is practically completed [24]. In addition to iron(III) oxide, the following metal oxides may be detected: aluminium, sodium, magnesium, titanium, calcium, and potassium; although the oxides of the mentioned metal exhibit very minimal hydrogen sulfide reaction at room temperature, instead they react

with carbon dioxide found in biogas and in air [24]. Bauxite  $\text{Al}(\text{OH})_3$  has been used for biogas purification with a removal efficiency of 94.7%, although it contains silica, some clay minerals, iron hydroxide, and different oxides of which only bauxite reacts with hydrogen sulfide from biogas [25]. Additionally, activated MgO has been used for purification of biogas, especially carbon dioxide removal [26] and not hydrogen sulfide. Activated carbon and iron sponge can be used to remove  $\text{H}_2\text{S}$  from biogas;  $\text{CO}_2$  is removed using amine solution, sodium hydroxide, and potassium hydroxide [19, 27] while water is removed through the use of silica gel [28, 29]. This supports the current study that iron oxide is mostly responsible for the removal of  $\text{H}_2\text{S}$  from biogas rather than oxides of the elements found in the sample RR.

**3.5. Adsorption Ability of RR Material.** In this section, adsorption performance of the RRs was explored in terms of the effect of particle size, calcination temperature, the mass of adsorbent, and biogas flow rate on the  $\text{H}_2\text{S}$  removal.

**3.5.1. Effect of Particle Size.** Selection of particle size of an adsorbent is significant to enhance the adsorption ability of the material [30, 31]. Particles with larger diameter have lower adsorption ability of hydrogen sulfide from biogas than the particle of smaller size [32, 33]. According to our study, outcomes on hydrogen sulfide adsorption using red rock samples of different particle size are obtained as shown in Figure 5. It is seen that the sample of the smallest particle size of about  $0.32\text{--}250\ \mu\text{m}$  calcined at  $1000^\circ\text{C}$  shows good



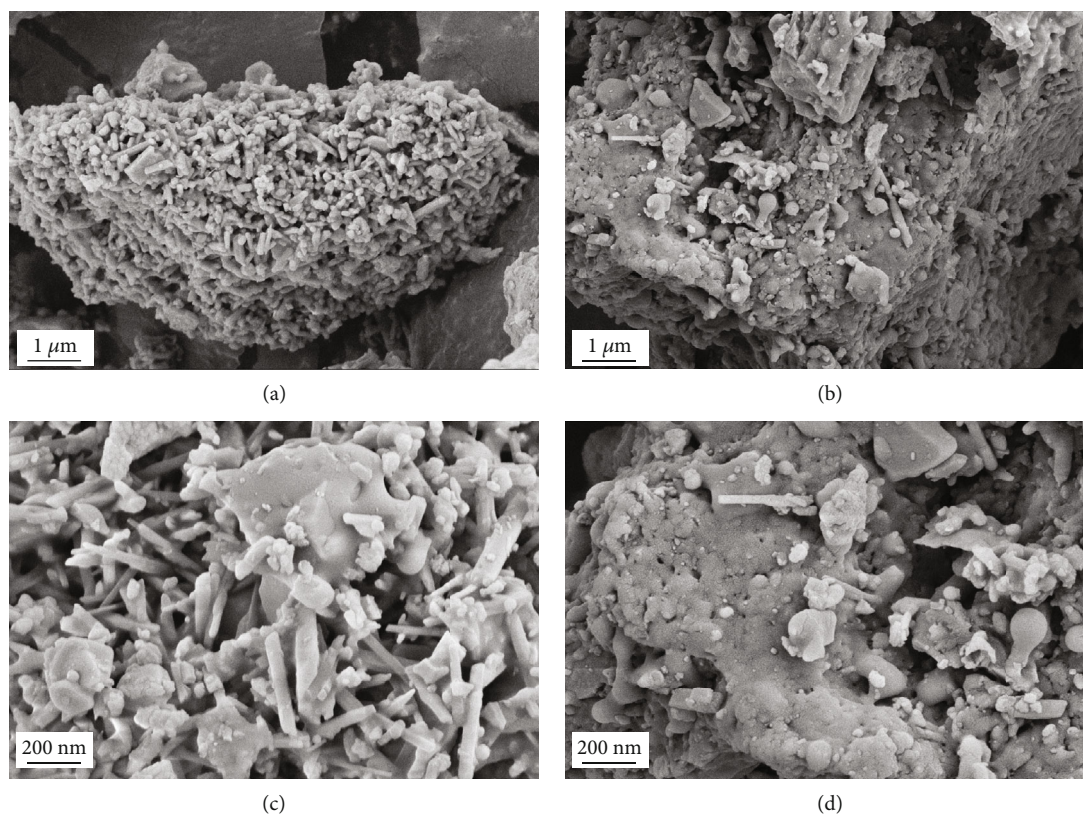


FIGURE 3: (a, b) Low-magnification (25.00 KX) and (c, d) high-magnification (50.00 KX) SEM images of RR-B and RR-C, respectively.

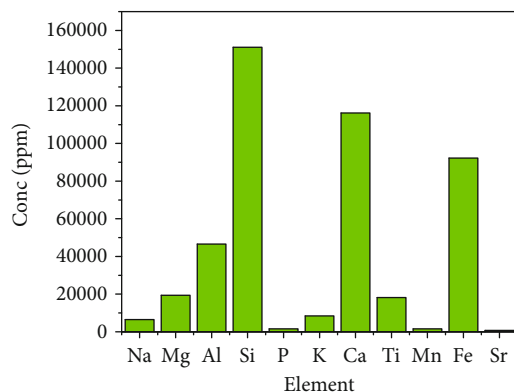


FIGURE 4: Elemental composition of red rock material calcined at a temperature of 1000°C.

adsorption ability; the latter is attributed to large surface area to volume ratio as per Table 2 compared to the rest.

**3.5.2. Effect of Calcination Temperature.** Among the five samples considered above, the best sample was 0.32–250  $\mu\text{m}$  particle size. This sample was then tested for another parameter that was calcination temperature. The effect of the RR calcination temperature on the removal of  $\text{H}_2\text{S}$  from biogas was evaluated as the REs of a raw sample and samples calcined at 500, 750, and 1000°C were considered in Figure 6. The highest temperature provides higher removal efficiency of about 66.5%, and this is due to the reason that high temperature causes some unwanted material/compounds (volatile)

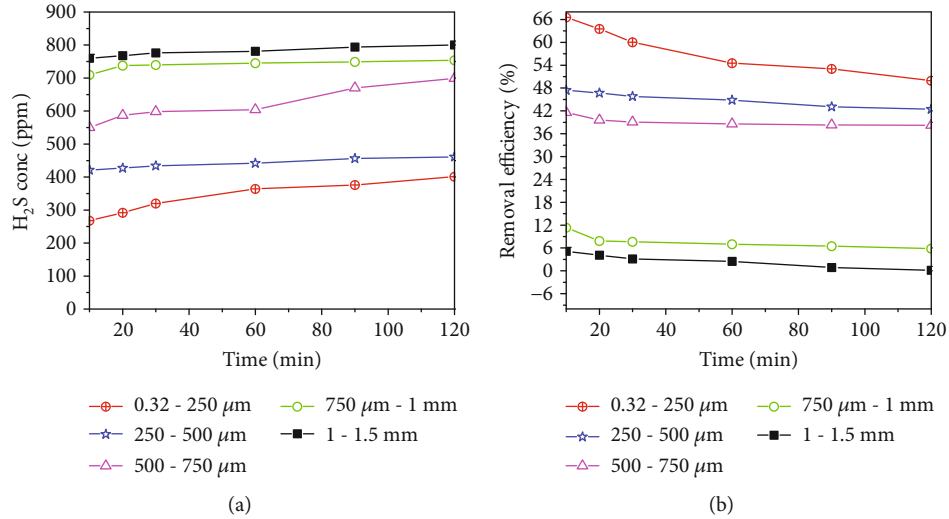
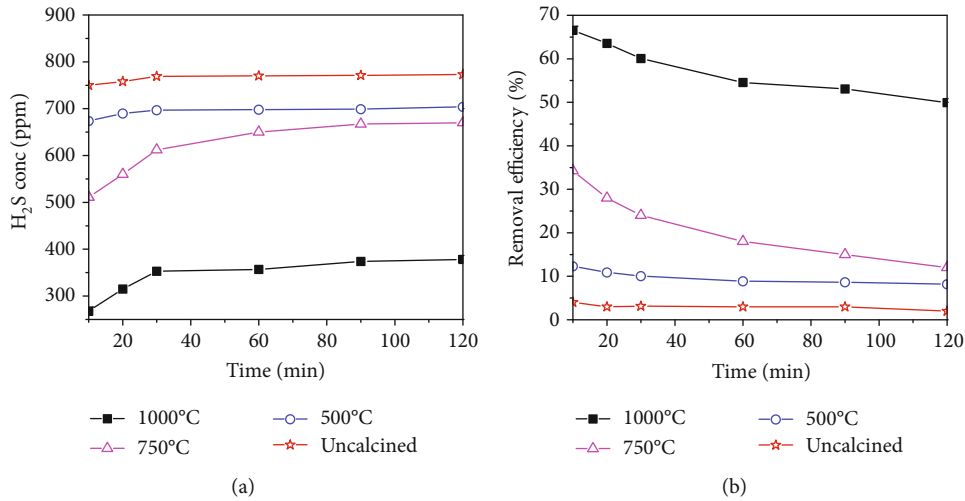
in the sample to evaporate and hence create more micropores for the hydrogen sulfide. The raw sample shows the removal efficiency of about 3.3% which is low compared to the calcined sample. This sample still contains some unwanted material like water; hence, they occupy the pores [34]. According to literature, higher temperature favors better sorption ability [35–37]. Therefore, sample 0.32–250  $\mu\text{m}$  calcined under a temperature of 1000°C was tested for the next parameter.

**3.5.3. Effect of Adsorbent Mass.** Sample with particle size 0.32–250  $\mu\text{m}$  calcined at 1000°C was tested for another parameter that is mass, as shown in Figure 7. When a higher amount of RR was used, then high adsorption capacity would be observed; this is in accordance to [38] while lowering the mass of RR on bed reactor decreases the amount of hydrogen sulfide adsorbed [31]. The removal efficiency of  $\text{H}_2\text{S}$  rises as the mass of adsorbent increases due to the increase in the interfacial external area for biogas to contact [31]. Therefore, hydrogen sulfide had more chance to contact with the adsorption site of RR material. From our study, the highest removal efficiency was obtained when 0.6 g of adsorbent was used. When the mass of adsorbent increased more than 0.6 g, there was no flowing of biogas due to the blocking of pores.

**3.5.4. Effect of Biogas Flow Rate.** Biogas flow rate influence on RR sorption ability was tested as showed in Figure 8, and particle size 0.32–250  $\mu\text{m}$  calcined at 1000°C was used. It was observed that the ability of red rock material to adsorb  $\text{H}_2\text{S}$

TABLE 3: The composition (wt%) of red rock sample calcined at 1000°C, pH of 10, and 0.32-250  $\mu\text{m}$ .

Compound	Na <sub>2</sub> O	MgO	Al <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>	P <sub>2</sub> O <sub>5</sub>	CaO	TiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	MnO
Conc. (%)	1.03	3.97	9.25	33.0	0.55	10.9	3.21	15.81	0.21

FIGURE 5: Effect of different particle sizes on the RR adsorption performance (a). H<sub>2</sub>S outlet concentration (left) and removal efficiency (right). Test conditions:  $m = 0.1$  g, FR = 0.06 m<sup>3</sup>/h,  $C_o = 801$  ppm, and  $T_c = 1000^\circ\text{C}$ .FIGURE 6: Effect of calcination temperature on the RR adsorption performance: H<sub>2</sub>S outlet concentration (a) and removal efficiency (b). Test conditions: mass = 0.1 g, FR = 0.06 m<sup>3</sup>/h, particle size = 0.32-250  $\mu\text{m}$ , and  $C_o = 779$  ppm.

was different at different flow rates. RR sample with a flow rate of 0.006 m<sup>3</sup>/h produced the maximum (RE) of about 95%. High adsorption of H<sub>2</sub>S was observed at low flow rate because adsorbent had more time to contact with the biogas. According to literature, adsorbent adsorption ability decreases as the biogas flow rate increases [34]. The contact time between the adsorbent and biogas is among crucial factors that determine the sample adsorption ability [39]. At high flow rate, the contact time between the adsorbent and the biogas decreases; hence, the H<sub>2</sub>S passes the adsorbent without being adsorbed; therefore, removal efficiency is low compared to the high flow rate. Plots for 0.006 m<sup>3</sup>/h and 0.012 m<sup>3</sup>/h are very close; probably this may be due to the

reason that adsorbent was too much compact together in the bed reactor when dealing with 0.012 m<sup>3</sup>/h; hence, biogas takes a long time in contact with the adsorbent; hence, the removal efficiency approximately equals to that of 0.006 m<sup>3</sup>/h.

Therefore, particle size, temperature, the mass of adsorbent, and flow rate were parameters used in this study, and the highest RE of about 95% was achieved for the sample calcined at  $T_c = 1000^\circ\text{C}$ , the mass of 0.6 g, and biogas flow rate of 0.006 m<sup>3</sup>/h.

**3.6. Regenerated Sample Performance.** After adsorption of hydrogen sulfide from biogas, the material was removed from the bed reactor and exposed to the atmospheric air

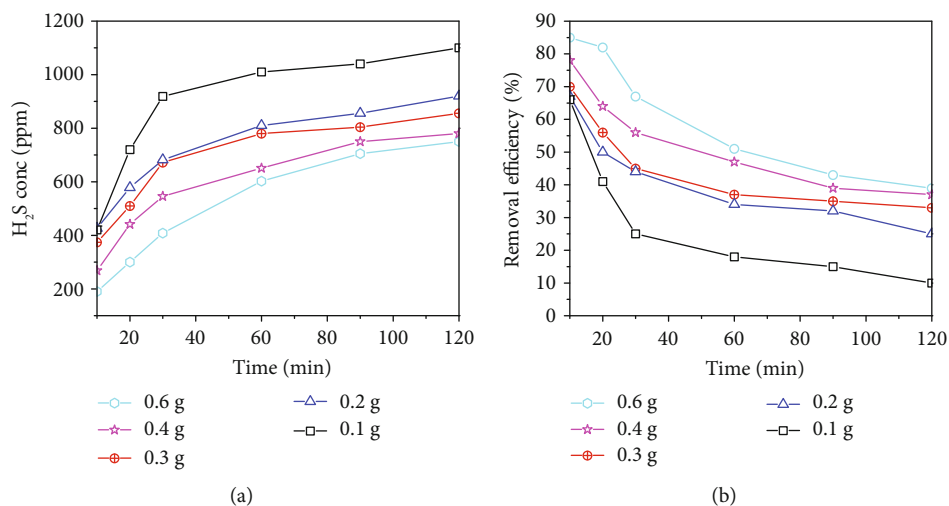


FIGURE 7: Effect of adsorbent mass on the RR adsorption performance: H<sub>2</sub>S outlet concentration (a) and removal efficiency (b). Test conditions:  $T_c = 1000^\circ\text{C}$ ,  $\text{FR} = 0.06 \text{ m}^3/\text{h}$ , particle size =  $0.32\text{-}250 \mu\text{m}$ , and  $C_o = 1230 \text{ ppm}$ .

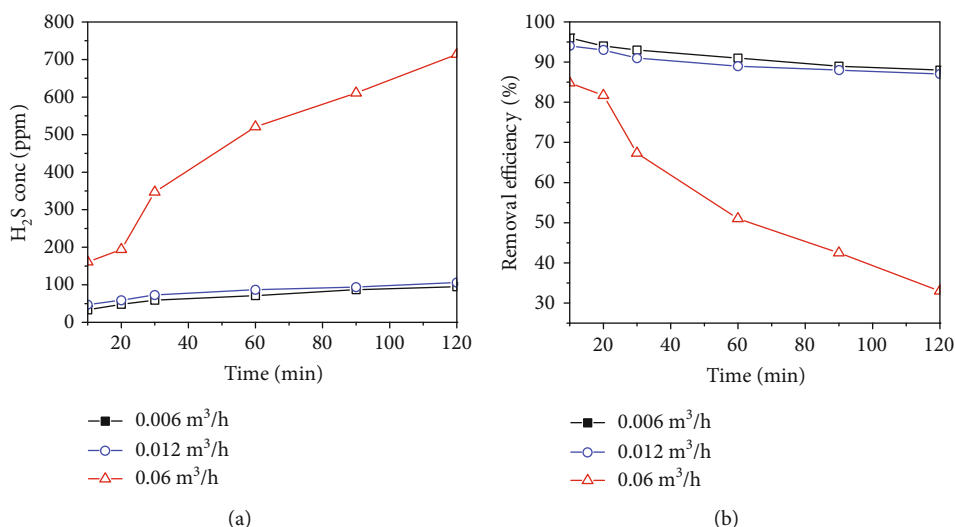


FIGURE 8: Effect of biogas flowrate on RR adsorption performance: H<sub>2</sub>S outlet concentration (a) and removal efficiency (b). Test conditions:  $m = 0.6 \text{ g}$ ,  $T_c = 1000^\circ\text{C}$ , particle size =  $0.32\text{-}250 \mu\text{m}$ , and  $C_o = 779 \text{ ppm}$ .

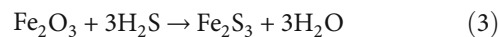
to lose the adsorbed hydrogen sulfide and gain oxygen hence iron oxide. The material was then returned to the bed reactor to continue with the sorption process as per Figures 9(a)–9(c).

Comparison between outlet concentration of original and the regenerated sample was made as showed in Figure 9(a). Original sample performs better than the regenerated sample, although the original sample adsorbs hydrogen sulfide for about 150 min before it saturates while regenerated sample adsorbs for 120 min. The regenerated material could not work for a longer time because it was already undergoing saturation; hence, it is partly starting to lose its adsorption ability.

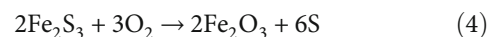
The removal efficiency of original and regenerated material was compared, as shown in Figure 9(b). It is seen that as time increases, the materials lose their adsorption ability. The original sample had an efficiency of 95% initially while the regenerated one showed RE of 93%.

Sorption capacity of the regenerated sample seems small, with a maximum value of  $0.12 \text{ g}/100 \text{ g}$ , due to the reason that the material already undergoes saturation while that of the original sample at the breakthrough time observed to be higher with maximum value  $0.37 \text{ g}/100 \text{ g}$  (see Figure 9(c)). Following this experiment, removal efficiency and sorption capacity decrease with the working time of adsorbent.

According to the literature [14], iron oxide was used as an adsorbent to adsorb hydrogen sulfide from biogas as per equations below:



Regeneration equation



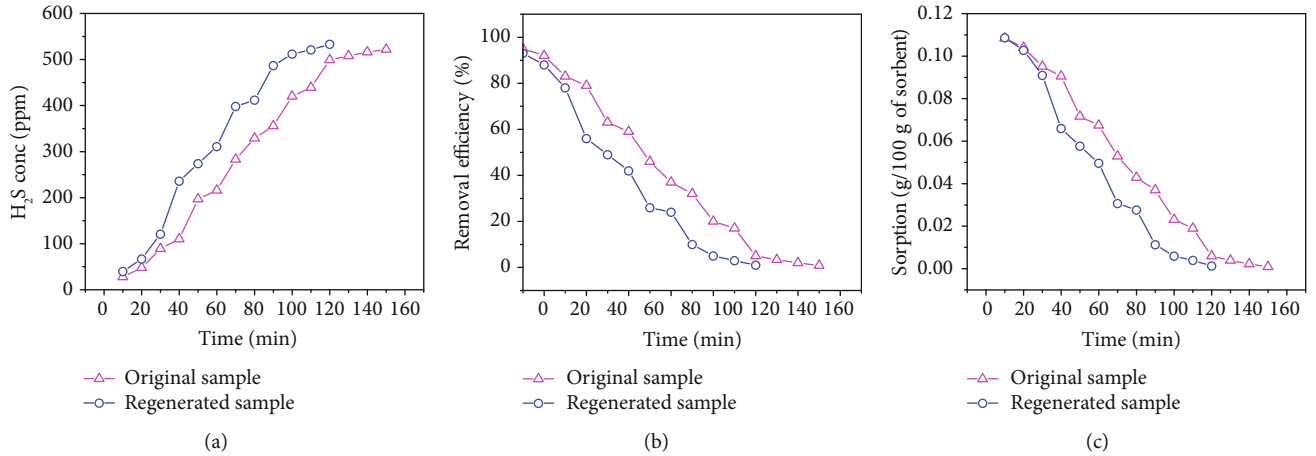


FIGURE 9: Adsorption performance comparison between original and regenerated samples. (a) H<sub>2</sub>S outlet concentration after filter. (b) RE. (c) SC. Test conditions:  $m = 0.6$  g,  $T_c = 1000^\circ\text{C}$ ,  $\text{FR} = 0.006$  m<sup>3</sup>/h, particle size = 0.32-250  $\mu\text{m}$ , and  $C_o = 539$  ppm.

TABLE 4: Evaluation of RR adsorbent with other materials reported in the literature.

Adsorbent	Mass (g)	Flowrate (m <sup>3</sup> /h)	Contact time (h)	RE (%)	SCg/100 g of sorbent	Ref
WHAC-1:1-650	1	0.024	2	93	—	[11]
Red mud soil	5	0.003	1.5	—	2.1	[22]
Fe/EDTA	—	0.0159	0.8	84.5	—	[42]
OLA-TP-850	1	0.12	1.5	96	1.0	[2]
Red rock	0.6	0.006	2.5	95	0.37	Current study

Equation (3) describes how RR materials in the form of Fe<sub>2</sub>O<sub>3</sub> adsorb the H<sub>2</sub>S from biogas while Equation (4) explains how RR material can be regenerated before the material loses its adsorption ability. During the regeneration process, the pore structure can be recovered, and a slight increase in surface area and the pore volume is usually noticed. The sulfate and elemental sulfur were the main sulfur species of H<sub>2</sub>S degradation [40]. The products formed during this process are of less toxic compared to the hydrogen sulfide that was adsorbed by the adsorbent. It is released to the environment and being used by sulfur-oxidizing bacteria. These bacteria can be found in a different environment as in freshwater marshes, deep in the ocean, and in the atmosphere [41]. Therefore, the regeneration process does not release H<sub>2</sub>S directly to the atmosphere; rather, it is an indirect way which will be used by the bacteria to obtain energy. Therefore, the regeneration process is efficient both in economic and environmental terms.

**3.7. Comparison of RR Adsorbent with Other Materials.** RR material was compared with other materials from the literature on the removal efficiency and ability to adsorb hydrogen sulfide from biogas (see Table 4). By using water hyacinth, activated carbon (AC) removal efficiency was 93%, where the contact time was about 2 hours [11]. Despite higher removal efficiency, but it is not locally available as compared to RR material. Additionally, by using red mud soil [22] sorption capacity obtained seems to be higher than this

study as the quantities of the material used were more significant compared to RR material through contact time was 1.5 h. Through this comparison, RR shows good performance as it demonstrates good removal efficiency and sorption capacity. Based on the literature, RR is suitable for biogas purification. We suggest that it could be more efficient if a porosity is increased through the addition of some pore-forming materials.

## 4. Conclusion

In this study, red rock materials were successfully used in the purification of biogas, especially H<sub>2</sub>S removal at ambient temperature. The XRF analysis showed the presence of iron(III) oxide, which facilitated the whole process of purification. BET analysis of the raw sample, calcined at 1000°C and utilized sample, showed the surface area of 546, 696, and 494 m<sup>2</sup>/g, respectively. On-site experiments were conducted on testing the performance of the RR materials, where the sample with particle size range 0.32–250  $\mu\text{m}$  calcined at 1000°C showed superior hydrogen sulfide (RE) of 95% at a low flow rate of 0.006 m<sup>3</sup>/h. During the regeneration process, regenerated material provided removal efficiency of about 93% while sorption capacity of the original and regenerated samples was 0.37 and 0.12 g/100 g of sorbent, respectively. We suggest the red rock potential for hydrogen sulfide removal could be enhanced if the material is used in pellet form or via the addition of some pore-forming materials.



## Data Availability

Data used to support these findings are available when they are required.

## Conflicts of Interest

The authors declared that no conflicts of interest concerning the publication of this paper.

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