

Original Research Article

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Biogas Purification using Coconut Shell Based Granular Activated Carbon by Pressure Swing Adsorption

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ABSTRACT

Biogas is one of the most important renewable energy source. Biogas normally contains 55 – 65% methane (CH₄) and 45 – 55% carbon dioxide (CO₂) and trace amounts of hydrogen sulphide (H₂S). Raw biogas cannot be used as vehicle fuel as it contains CO₂ and H₂S which lowers the calorific value and causes corrosion to the storage vessel respectively. Enriching the biogas by removing CO₂ and H₂S will significantly improve the quality of biogas. The application of biogas either as cooking fuel or engine fuel chooses the type of purification method. In this work biogas enrichment using coconut shell derived granular activated carbon as CO₂ adsorbent by pressure swing adsorption (PSA) technique was investigated. The adsorption of CO₂ by the adsorbent with varying pressure from 1 to 10 bar were experimentally examined. The results indicated that with increase in pressure adsorption also increases. Activated carbon (AC) showed adsorption affinity towards both CO₂ and CH₄ at lower pressure. As the pressure increases the material showed little higher affinity towards CO₂ than CH₄. The maximum methane content obtained after adsorption and CO₂ reduction percent found to be 73.9 % and 44.7 % at 8 bar pressure respectively. The material showed lower biogas separation ability in terms of lower CH₄ enrichment and lower CO₂ reduction. So the selected AC cannot be used for biogas enrichment but it can be used for single gas adsorption.

Keywords

Biogas purification, Activated carbon, Pressure swing adsorption, Carbon dioxide, Methane.

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Introduction

Biogas from anaerobic digestion of waste material is a great source for future energy needs. It is a very important source of renewable methane (Tippayawong and Thanompongchart, 2010). Biogas has low heating value (6.5 kWh/Nm³), which is approximately half that of the natural gas value (Bauer *et al.*, 2013). Biogas can be directly used for thermal applications or if it is upgraded, it can be used as a vehicle fuel and can replace natural gas. After methane enrichment and compression it can be used as vehicle fuel just like CNG (Vijay *et al.*, 2006).

So enrichment of biogas is needed to convert the biogas into portable form.

A lot of processes are available for enrichment of methane content in biogas by removing significant amount of carbon dioxide (CO₂) and hydrogen sulfide (H₂S). Commonly CO₂ removal processes also remove H₂S.

These include absorption into liquid (physical/chemical), adsorption on solid surface, membrane separation, cryogenic separation

and chemical conversion. Selection of the appropriate process for a particular application depends on the scale of intended operation, composition of the gas to be treated, degree of purity required and the need for CO₂ recovery (MENS report, 2001).

Adsorption is one of the most economical methods of CO₂ separation from biogas that has been commercialized (Grande, 2011). Among the technologies for adsorption, the pressure swing adsorption (PSA) has gained interest in the separation and capture of CO₂, due to its reduced costs in energy and resources, when compared to conventional separation methods, such as absorption and distillation (Kapdi *et al.*, 2005; Huang *et al.*, 2006).

PSA provides high efficiency in terms of high methane enrichment. In PSA maximum of 99% pure methane can be achieved in the pressure range of 4 to 8 bar (Urban *et al.*, 2009). This technique works on the principle of physical adsorption.

The gas molecules will be adsorbed on the adsorbent surface under pressure and when the pressure is reduced the adsorbed gases will be released. The success of this technology lies in choosing the appropriate adsorbent material which selectively adsorb the particular gas species of concern. This posts the requirement of efficient and cost effective adsorbent that is made from locally available material. Activated carbon is one of the most widely used adsorbents because of its higher adsorptive capacity (Hung *et al.*, 2005). AC has high surface area and porosity which makes it suitable for variety of applications.

The aim of this work was to test the coconut shell derived activated carbon which is available commercially for its ability on biogas purification and also to test the CO₂ reduction capability of that material.

Materials and Methods

Selection and characterization of adsorbent

Selection of the adsorbent material is based on the properties like high surface area, total pore volume and high adsorption ability. Based on the above properties, coconut shell based granular activated carbon was selected as the adsorbent which was procured from The Jacobi Carbons India Private Limited, Coimbatore. The specification of the material was presented in table 1. From table 1 it is clear to see that the porosity of AC is 42% and this pore volume mainly consists of mesopores and micropores. For PSA design and operation the porosity should be in the range of 0.3 to 0.5 (Jain *et al.*, 2003). This property suggests that the material can be used for gas adsorption process. The surface morphology was studied using Quanta 250 electron microscope, FEI, Netherlands.

Experimental Setup

The adsorption experiments were performed in a lab scale PSA column with height and diameter of 1 m and 0.3 m respectively. Packing height of the column was 0.6 m. Pall rings was provided in alternate layers in the PSA column with the adsorbent for easy distribution of gas over the cross sectional area of the column. Pall rings covers half of the total packing volume and it was provided in alternate layers with the adsorbent. The packing height of 0.6 m was subdivided into 6 parts each with the height of 0.1 m. For packing the materials inside the column and to ensure partitioning of the packing materials, porous plates with 2 mm diameter holes were provided in between the materials at every 0.1 m intervals, schematic of the setup shown in figure 1. The biogas which needs to be treated compressed to desired pressure and sent through the bottom and enriched gas was collected at the top of the column. The experiment was carried out with

the biogas inlet pressure range of 1 to 10 bar and at a room temperature of 30°C. The fraction of gas components after adsorption was analyzed using GC, Nucon 5765. To

evaluate the adsorption of CO₂ on the adsorbent, percent of CO₂ reduction was calculated as follows:

$$\text{CO}_2 \text{ reduction, \%} = \frac{(\text{CO}_2 \text{ content of the raw biogas} - \text{CO}_2 \text{ content of the scrubbed biogas})}{\text{CO}_2 \text{ content of the raw biogas}} \times 100$$

Results and Discussion

Surface characterization by SEM

SEM image of selected AC is shown in figure 2. It can be seen from the micrographs that the external surface of the adsorbent has lot of holes and cracks with varying in size. The surface is uneven and small size pores covers maximum of its pore volume than large pores. It can be inferred from SEM image that material is suitable for gas adsorption purpose.

Effect of biogas inlet pressure on CO₂ reduction

The experiment for analyzing the biogas purification ability of AC using PSA system was carried out with the pressure range of 1 to 10 bar. Table 2 shows the percentages of CO₂ and CH₄ gases after adsorption. The biogas initially had 47 % of CO₂ and 51 % of CH₄. From 1 to 8 bar there was a slight increase of CH₄ %. So with increase in pressure, CH₄ enrichment also increases. After 8 bar there

was a decrease in CH₄ enrichment. Initial lower methane content may due to insufficient pressure for the adsorption of CO₂ into the pores of the material and if the pressure is increased adsorption of CO₂ molecules into the pores of material increases.

But when the pressure further increases the adsorbed gas may be carried away with the outlet gas so the CH₄ content in the outlet gas decreases. In this process, maximum methane content of 73.9 % was achieved at 8 bar pressure.

Figure 3 shows the CO₂ reduction percent with respect to biogas inlet pressure. As the pressure increases CO₂ reduction also increases. Minimum and maximum CO₂ adsorption found to be 11% and 45% at 1 bar and 8 bar respectively. Low reduction of CO₂ may due to the fact that both CO₂ and CH₄ were absorbed by the material (Rios *et al.*, 2013) and when the pressure increases, the material showed slight increase in adsorption of CO₂ than CH₄.

Table.1 Specification of AC

Properties	Value
Form	Granules
Size	2.5 mm
Pore size	15 to 20 Å
Bulk density	484 kg.m ⁻³
Porosity	0.42

Table.2 Final CH₄ content after adsorption (Initial CO₂ = 47%, CH₄ =51%)

Pressure, bar	CH ₄ final, %
1	57.8
2	60
3	63.1
4	65
5	66.6
6	69.6
7	72.8
8	73.9
9	72.4
10	71.5

Fig.1 Schematic illustration of PSA unit

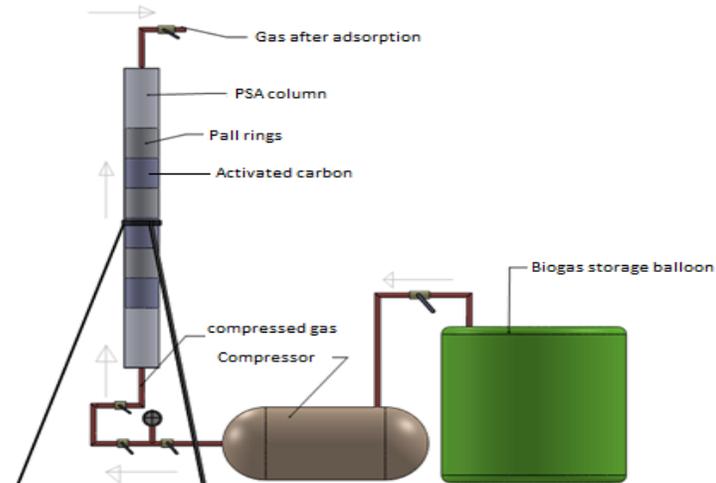


Fig.2 SEM image of AC

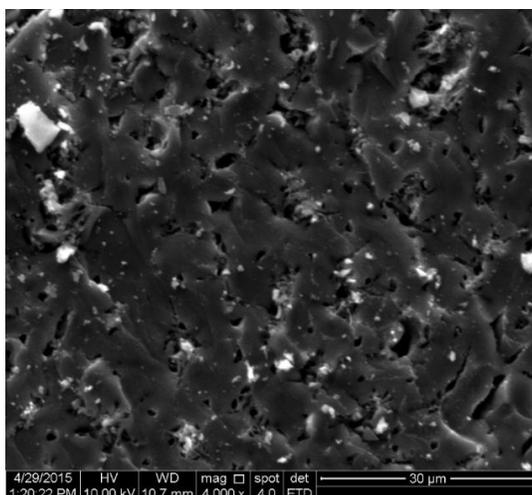
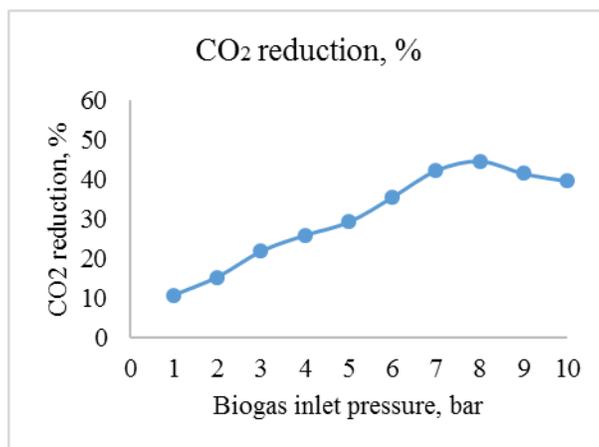


Fig.3 Effect of biogas inlet pressure on CO₂ reduction



There is an initial and preferential filling of high-energy sites for which the more strongly adsorbed component (CO₂) is even more preferred in the competition for the sites than when competing for energetically weaker adsorption sites (Rios *et al.*, 2013). The competitive nature of the two gas species was seen at higher pressure. Since CO₂ is more strongly held by the adsorbent, it tends to displace the previously adsorbed CH₄ (Foeth *et al.*, 1994).

During adsorption the molecules dimension play an important role. The pore size of the material cavities is selective factor for the adsorbed molecules. As the pore size of activated carbon (15 to 20 Å) is greater than the molecule diameter of the gas species CO₂ (3.4 Å) and CH₄ (3.8 Å) the selective adsorption was not accomplished and the material adsorbs both CO₂ and CH₄ results in less methane content in the product gas (Bonenfant *et al.*, 2008).

In conclusion, the study was conducted to evaluate the suitability of AC for biogas purification. The material showed adsorption affinity towards both CO₂ and CH₄ at all pressure. Even though the material exhibited slightly higher adsorption of CO₂ than CH₄, the maximum CO₂ reduction was only 45%.

This indicates that the material has lower ability in purification of biogas. But the selected material showed better adsorption capacity of gases so it can be used for areas where single gas adsorption is required like CO₂ capturing or for methane storage.

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