



Low pressure biomethane gas adsorption by activated carbon

Sirichai Koonaphapdeelert ^a, James Moran ^{b,*}, Pruk Aggarangsi ^{b,c}, Asira Bunkham ^c

^a Department of Environmental Engineering, Faculty of Engineering, Chiang Mai University, Chiang Mai 50200, Thailand

^b Department of Mechanical Engineering, Faculty of Engineering, Chiang Mai University, Chiang Mai 50200, Thailand

^c Energy Research and Development Institute, Chiang Mai University, Chiang Mai 50200, Thailand



ARTICLE INFO

Article history:

Received 17 October 2017

Revised 30 January 2018

Accepted 30 January 2018

Available online 22 February 2018

Keywords:

Biomethane

Activated carbon

Biomethane storage

Gas adsorption

Activated alumina

Molecular sieves

ABSTRACT

The objective of this research is to study the adsorption of biomethane gas by several different adsorbents. The ultimate goal was to create a cost effective and safe fuel tank for use in domestic cooking applications in rural Thailand. Biomethane is a cleaned and upgraded fuel derived from biogas. It contains a minimum of 80% methane (v/v) with the remainder composed mostly of carbon dioxide. Specifically, the effects of pressure and temperature on the biomethane adsorption capacity of five different adsorbents in a 28 l tank were studied. The pressure ranged between 3 and 9 MPa while the temperature range was 15–25 °C. The results showed that the adsorbent, Activated Carbon 3, had the highest biomethane adsorption capability. At higher pressures, greater biomethane adsorption was observed with the highest adsorption value of 164.3 ± 0.5 g/l obtained at 9 MPa. Temperature had a smaller effect with higher temperatures producing less adsorption. At 9 MPa, as the temperature increased from 15 to 25 °C, the adsorbed biomethane decreased by 8%. The degradation in performance of the adsorbent was investigated and found to be negligible over 500 filling/emptying cycles. The selective adsorption of methane over the other biomethane constituents was investigated and also found to be negligible over 500 cycles. The Langmuir adsorption model was applied to estimate the maximum absorption capacity of each adsorbent.

© 2018 International Energy Initiative. Published by Elsevier Inc. All rights reserved.

Introduction

At present, natural gas in vehicles (NGV or CNG) must store the gas at high pressures, up to 20 MPa (200 bar). Filling a CNG tank requires an expensive multistage compression facility. In addition to safety concerns, the necessary tank wall thickness is expensive and heavy (Energy Research and Development Institute, 2013). There would be significant advantages to storing an equal amount of gas, in the same volume at lower pressures. Adsorbed Natural Gas (ANG) is a promising technology which offers a path to this solution (Zhang, Walawender, & Fan, 2010).

ANG is based on adsorption technology. Adsorption is the adhesion of atoms or molecules from a liquid or gas, the adsorbate, to a surface, the adsorbent. This process creates a film of the adsorbate on the adsorbent. Atomic bonds between adjacent layers of the adsorbate and adsorbent hold the adsorbate in place. ANG is natural gas which is stored at relatively low pressures in a tank filled with an adsorbent (ANGP, 2012). Known adsorbents include charcoal, silica and treated alumina (Rouquerol, Rouquerol, & Sing, 1999). Adsorption technology is used in multiple industries, from air storage, petrochemicals and gas processing to waste water treatment.

An important adsorbent parameter is the specific surface area (m^2/g). Wang et al. (2011) found that for gas adsorption, the

average pore size was an important parameter as well as the specific surface area. According to Tan and Gubbins (1990), Matranga, Meyers, and Glandt (1992) Chen, Shan, Wong, and Tan (1997) the highest methane density adsorbed was if the average porous diameter is between 11.2 and 11.4 Å. Matranga et al. (1992) used a Monte Carlo technique to calculate an optimal porosity of 11.4 Å for activated carbon in the adsorption of natural gas at a pressure of 3.4 MPa at 27 °C.

Another adsorbent is zeolite molecular sieves, which are crystalline oxides of silicon (SiO_4) and aluminum atoms (AlO_4). This is an inorganic adsorbent which mimics naturally occurring compounds. They can be found in pollution control applications such as in mining to adsorb heavy metals. In the natural gas industry, zeolites can filter out water, sulfur and carbon dioxide (Li, Li, & Yu, 2017).

Another commonly used adsorbent is activated carbon which has the highest gas storage density compared to other adsorbents. Lozano-Castello, Alcaniz-Monge, De la Casa-Lillo, Cazorla-Amoros, and Linares-Solano (2002) studied methane adsorption on different activated carbon materials, with the goal of finding the optimal carbon material for methane storage. They analyzed the micropore volume, micropore size distribution (MPSD) and packing density with respect to methane adsorption and desorption. It was found that the activated carbon had the ability to adsorb methane up to 166 times its volume. Herath and De Alwis (2015) investigated the properties of different activated carbons produced in Sri Lanka. Matranga et al. (1992) and Chiew, Brown, You, Judd, and Briggs (2011) have demonstrated that

* Corresponding author.

E-mail address: james@dome.eng.cmu.ac.th (J. Moran).

ANG can contain two to three time more natural gas at 1/6th the normal CNG pressure.

Although methane adsorption has been studied and continues to be studied in depth, there are less studies on the adsorbed storage of multi component gases, [Himeno, Komatsu, and Fujita \(2005\)](#). Biomethane is derived from biogas, which has been cleaned of hydrogen sulfide and processed to increase the methane percentage. Biomethane is a gas mixture containing at least 80% methane and other gases such as carbon dioxide, oxygen and nitrogen, [Koonaphadeelert, Kanta, and Aggarangsi \(2011\)](#). In cooking applications methane stoves must be modified to accommodate biomethane gas ([Suwansri et al., 2015](#)). These auxiliary gases may have an effect on the adsorption characteristics of biomethane compared to pure methane. [Yuan, Zhu, Lin, and Zhao \(2015\)](#) examined methane recovery with carbon dioxide through molecular dynamics simulations. [Feroldi, Neves, Bach, and Alves \(2016\)](#) reviews the latest research on ANG for biogas and biomethane applications revealing a lack of direct experimental evidence for both gases. One issue is that if one gas component is adsorbed selectively stronger and does not desorb equally then the net effect is the progressive filling of the micropores with this gas, [Isabel, Lopes, Pedro, and José \(2008\)](#).

Therefore, the focus of this research is on the adsorption characteristics of biomethane. How pressure and temperature effect the quantity of biomethane adsorbed by five different adsorbents is investigated. The mass of biomethane adsorbed at pressures between 3 and 9 MPa, was compared with the mass of bio-methane stored in a regular gas tank at 20 MPa. Cycle tests and exit methane analysis were performed to investigate any gas selectivity from the adsorbent.

Absorbents

[Table 1](#) compares various commercially available activated carbons ability to adsorb methane, [Menon and Komarneni \(1998\)](#) and [Quinn, MacDonald, and Sosin \(1994\)](#). As the activated carbon's specific surface area increases so does its methane adsorption capacity. Kansai Maxsorb, which has a specific surface area of 2,671 m^2/g , absorbs up to 164 mg/g of methane at 3.5 MPa and 25 °C.

The average porosities of activated carbons are typically <20 Angstrom's, which suits the molecular size of methane, 3.751 Å and carbon dioxide, 3.615 Å ([Kurniawan, Bhatia, & Rudolph, 2006](#)). [Parkyns and Quinn \(1995\)](#) found that the ability to adsorb methane increases linearly with the increase of specific surface area so long as the pore volume is small.

For the experiments in this paper, three types of activated carbon, called activated carbon 1, activated carbon 2 and activated carbon 3 respectively were selected as adsorbents. Their relevant properties are shown in [Table 2](#). Activated carbon 1 and 2 were synthesized locally from organic coconut shells. The making of both these activated carbons can be divided into two sub sequencing steps. First, a pyrolysis process was performed by heating the crushed coconut shell in order to vaporize volatile compounds from the raw materials. Bio-oil and syngas were

the by-products of this carbonization stage. Carbon dioxide was heated to 600 °C and fed into a furnace to flush the air out. Then the crushed coconut shells with the average size of 50–100 mm were fed into the furnace and heated at a rate of 20 °C/min until reaching 600 °C. The pyrolysis took place for 2 h before the fully pyrolyzed char was transferred to the second step. In this step, surface activation was carried out in a fluidized-bed reactor with steam as the activator. The reactor was heated to 850–1000 °C at a rate of 50 °C/min and then the biochar was reacted with steam for 1 h to produce activated carbon. In this process, all organic materials were entirely removed from the elemental carbon structure. Some carbon layers reacted to produce carbon dioxide and hydrogen gas, leaving behind open pores in the activated carbon. Finally the products were taken out and left to cool down to room temperature. The reactor temperature during steam activation was found to be a major factor affecting the porosity and surface area of the produced activated carbons. Activated Carbon 3 was purchased commercially. It was made from pinewood using chemical surface activation to achieve higher specific surface area. The process details can be found in the patent ([Sudhakar, Beckler, Miller, & Patel, 1994](#)).

Another adsorbent used was activated Alumina. This is a popular adsorbent because it is inexpensive. It has a small particle size can be easily prepared. Its surface is highly polar which makes it suitable for adsorbing polar molecules such as steam ([Ouchi, Hamamoto, Mori, Takata, & Etoh, 2014](#)).

The last adsorbent used was the inorganic adsorbent, Zeolite 13X. Its properties are also shown in [Table 2](#). These properties were experimentally obtained from the Department of Industrial Chemistry at Chiang Mai University. The average radius of porosity was calculated by the Barret-Joyner-Halenda (BJH) method ([Brunauer, Emmett, & Teller, 1938](#)) which tests the evaporation of nitrogen from the adsorbent at a constant temperature. It uses the modified Kelvin equation to relate the amount of adsorbate removed.

Methodology

This goal of this research is to determine the quantity of biomethane adsorbed by activated carbon as the temperature and pressure varies. To this end, a standard CNG Type 1, 28 l tank was used as a biogas adsorption system for experimental purposes as shown in [Fig. 1](#).

The biomethane used in this study contained a minimum of 80% methane by volume. It was produced in the facilities of the Energy Research and Development Institute in Chiang Mai. Its gas components were obtained using gas chromatography. The full details of its chemical composition are shown in [Table 3](#).

Experimental setup

Test method

Two Type-1 CNG tanks, with working volumes of 28 l, were stored in a constant temperature water bath, see [Fig. 2](#). These are tanks 4 and 5 in [Fig. 3](#). Tank 4 was empty and tank 5 filled completely with whichever adsorbent was being tested. Initially both tanks were evacuated with a vacuum pump, to a vacuum of –50 kPa, before each test. Biomethane was fed from a gas backup system, [Fig. 3](#) - tanks numbered 1, into tank number 4, which was kept at a constant temperature and pressure. This allowed the initial mass to be calculated from Eq. (1). Then, this gas was fed into the gas adsorption tank, tank number 5. The pressure in the adsorption tank was monitored and when it reached a certain level the flow was stopped. The pressures tested in this paper were 3, 5, 7 and 9 MPa. The temperatures tested were 15 °C, 20 °C and 25 °C. When the flow was stopped the pressure was recorded in the original gas tank and the final mass inside the tank was calculated from Eq. (2). The difference between the initial and final mass is the mass

Table 1

Ability to adsorb methane with various activated carbons at 3.5 MPa and 25 °C.

Source: ^aMenon and Komarneni (1998), ^bParkyns and Quinn (1995), ^cQuinn et al. (1994) and ^dRios et al. (2011).

Activated carbon	Specific surface area (m^2/g)	Methane adsorption amount (g/l)
Norit WX6 ^c	445	34.1
Calgon BPL ^c	1030	33
Norit R1 ^b	1240	32
Kureha BAC ^a	1350	58.4
WV1050 ^d	1615	58.5
Kansai Maxsorb ^a	2671	164

Download English Version:

<https://daneshyari.com/en/article/7453643>

Download Persian Version:

<https://daneshyari.com/article/7453643>

[Daneshyari.com](https://daneshyari.com)