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A study of gas diffusion characteristics on nano-structured ceramic membranes.

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A Study of Gas Diffusion Characteristics on Nano-Structured Ceramic Membranes

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Abstract

The use of membranes for gas upgrading has increasingly become of interest as it has shown great potential for efficient and affective gas purification and a pathway to green energy. The emission of greenhouse gases to the atmosphere has detrimental effects on the economy in terms of global warming which has led to many natural disasters, heat waves, food shortage, loss of life and property. To combat this, studies of capturing and utilizing greenhouse gases are ongoing. In this paper, the study of biogas components (methane and carbon dioxide) diffusion through membranes are studied to employ its use as a solution for the challenge. The study involved the use of membranes of different pore sizes (15, 200 and 6000nm) to ascertain the flow characteristics and regime of the gases under different operating conditions. Single gas permeation tests were conducted, and the results show the flow of gases is dependent on factors including molecular weight, kinematic diameter and viscosity of the gas components. It was observed that pressure has a greater influence on the gas flow through membranes compared to temperature with the effect of pore size having the greatest impact. The flux of methane through the membrane is greater than that of carbon dioxide in regular pore geometry and depicts a greater potential for upgrading of biogas.

Keywords: Biogas, upgrading, emissions, nano-structured, membrane, carbon capture

Introduction

Greenhouse gas emissions (GHGs) and its effects have been a matter of global concern over the past decade(1). With growing energy demands to support developing economies, there has been a challenge of harnessing and utilizing renewable energy to meet these demands. Despite the effect of global warming and the problems associated with it, the use of fossil fuels is still increasing. This problem has negatively impacted the climate because the carbon dioxide evolved from burning fossils are increasing the GHGs. A possible cause of this problem is the technical difficulty of capturing and utilizing the GHGs. Thus, this study investigates a method of channeling biogas for use as a renewable energy source using membrane technology which could remedy the situation(2). Biogas is a mixture of mainly carbon dioxide (CO_2) and methane (CH_4) which is evolved from food waste, animal waste, sewage and municipal waste that have decomposed under certain conditions of temperature and pressure(3). Biogas holds a promising future to solving these challenges as it utilizes these gases as a renewable fuel to meet economic demand and prevent emissions that cause global warming.

In this article, nano-structured membranes would be utilized for the biogas upgrading process. Upgraded biogas can be used as an alternative energy source to fulfil global energy demands. Ceramic nanostructured membranes are chosen due to their versatility (for use in separation and reaction processes), high stability, long life-span, compact size, low energy demand, high efficiency and high resistance to aggressive chemical environment/harsh environmental conditions of temperature and pressure which prevail in industry(4).

Methodology

The membranes used for this experiment were inserted into an insulated reactor chamber. Permeation tests for the sample gases were carried out to study the behaviour of the methane/carbon dioxide and the selectivity of the membranes for each gas. The membranes were investigated under different conditions of temperature and pressure which were stabilized during each test run, this was confirmed using a pressure gauge and temperature indicator which was connected to various points of the reactor chamber. Tests were performed at various operating conditions. The outlet gas flow estimates how much methane versus carbon dioxide is evolved in order to figure out how well the membrane will separate the gases in an industrial application.

Figure 1 Experimental set-up showing all equipment including; pressure gauge(1), membrane module covered with heating tape(2), gas regulator(3), gas cylinder(4), heat regulator(5), volumetric meter(6) and temperature indicator(7)

Results and Discussion

Both CH4 and CO2 were passed through the membrane, but the flux of CH4 is significantly higher therefore this means that CO2 collides with the pore walls more than CH4 and thus loses momentum and absolute velocity to the wall; this can be attributed to the kinetic diameter of CO2 which is larger than that of CH4 and also shows molecular weight dependency which is representative of Knudsen mechanism.

The tables below show separation factors for the gases using different membranes and at varied temperature ranges. The separation factor was calculated based on the ratio of flow of

each gas which was obtained from experiments whilst the theoretical (Knudsen) separation factor is defined by (5):

Where MWB AND MWA are the molecular weights of B and A respectively.

$$\propto_{A/B} = \sqrt{\frac{MW_B}{MW_A}}$$

15nm membrane with inlet Pressure of 1 bar	
Ideal Knudsen Value	1.66
Experimental Knudsen Value at 298K	1.59
Experimental Knudsen Value at 323K	1.59
Experimental Knudsen Value at 343K	1.60
Experimental Knudsen Value at 373K	1.61

Conditions of 373K and 1 bar	
Ideal Knudsen Value	1.66
Experimental Knudsen Value using 15nm membrane	1.61
Experimental Knudsen Value using 200nm membrane	1.56
Experimental Knudsen Value using 6000nm membrane	1.55

This shows that pore size has a greater influence on the gas flow through membranes compared to temperature within this range. The flux of methane through the membrane is greater than that of carbon dioxide in regular pore geometry and depicts a great potential for separation/upgrading of biogas which is a mixture of both. Results also show that flux is dependent on the gas molecular weight, kinematic viscosity and viscosity as the heavier, larger and more viscous gas CO_2 did not pass through the membrane as quickly as the lighter, smaller and less viscous CH_4 gas.

It can also be seen that the separation factor increases with decreasing pore size as the 6000nm membrane show low selectivity compared to the 15nm membranes, this is attributed to the smaller pores that restrict the flow of carbon dioxide. These results show that by tuning the pore size of the membranes below 15nm, a greater separation efficiency can be achieved.

Conclusion

The experiments show that pore size has a greater influence on the gas flow through membranes compared to temperature with no significant changes in the graphs from 20 – 100oC. The flux of methane through the membrane is greater than that of carbon dioxide in regular pore geometry due to factors including molecular weight, kinematic diameter and viscosity of the gas components. This depicts a greater potential for separation/upgrading of biogas.

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