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Testing membranes for separation of CO2 from small molecules in landfill gas.

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TESTING MEMBRANES FOR SEPARATION OF CO_2 FROM SMALL MOLECULES IN LANDFILL GAS

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ABSTRACT

The present work is focusing on the utilization of previously fabricated membrane (synthesized in 3 days as reported in our previous work) to study the effect of hydrocarbons and its durability at the previously optimized conditions. Subsequently, gas permeation study was conducted on ceramic membranes in CO_2 separation from small gas molecules present in biogas and it was found that the permeance of CO_2, N_2, and CH_4 decreased in the order of 15 nm > 200 nm > 6,000 nm, according to the decrease in porosity of the membranes.

Keywords: Membrane, Pore size, Porosity, Permeance, Biogas

INTRODUCTION

Over the last few decades, much research has been done on the CO_2 separation especially in biogas upgrading to biomethane [**1**]. The presence of CO_2 in the biogas reduces the calorific value of the raw gas methane recovery during the combustion and other downstream processes [**2**]. Similarly, the presence of CO_2 decreases the heating value of natural gas and causes equipment corrosion in the existence of water [**3**]. Meanwhile, membrane separation technology has received much attention in CO_2 separation mainly due to its advantages compared to the conventional separation technologies [**4**]. Inorganic membranes are generally favored in the CO_2 separation among the membrane materials over polymeric membranes due to their specific unique characteristics, including well-specified pores, the molecular filtering property, ability to sustain logetivity and wide pore size availability [**5, 6**].

MATERIALS AND METHODS

The ceramic membrane have been used as received without any modifications and typically made of aluminum oxide**,** titanium oxide, and zirconium oxide which all belong to the group of inorganic materials and are stable under CO_2 and water vapours conditions of biogas. They consisted of three mean pore sizes each namely: 15 nm, 200 nm and 6,000 nm (Outside Diameter 25 mm 7 cnx, pore diameter = 6 000nm, length : 368 mm, glazed section on either end: 25 mm, chemical composition : TiO_2, thickness - 1st layer TiO_2 (0.1-0.2μm), 2nd layer Al_2O_3 (15nm) respectively. The crystallinity and morphology of the membrane were characterized using an X-ray diffractometer (Bruker D8 Advance) and field emission scanning electron microscopy (Zeiss Supra 55 VP). Permeation experiments and stability tests were conducted for CH_4 and CO_2 using the flow rig shown in Figure 1. These membranes are to be scaled up for the prototype-module for use as the reference base materials. The membrane components were sealed in the proof-of-concept (PoC)-module and tested under realistic operating conditions of 50 – 100 C and pressure drops of 1 – 5 bars. Initially, the membrane sample was degassed for at least 16 hours by holding both upstream and downstream under vacuum with a series of valves closed and to select a small downstream volume or opened to select a large volume. The system leak rate was determined by manipulating a particular valve for at least 1 hour and measuring the rate of downstream pressure rise. Next, the upstream was pressurized by enabling the MFCs, opening and/or closing specific valves/valve, and placing other desired valves/valve into feedback mode. To ensure steady-state conditions, flux measurements were made after waiting a period of at least 60 mins.

RESULTS AND CONCLUSIONS

Highly permeable membrane materials show chemical instability against CO_2 and other landfill gas components. This project addresses this challenge by developing highly stable eco-friendly ceramic microporous membranes and a proof-

of-concept (PoC) module for integrated CO_2 capture in landfill will be carried out using the setup shown in Figure 1. Results have shown that there is a link between porosity and pores size on membrane permeance (Figure 2). This important result will enable the investigation of four possible loadings of affinity material on the membrane and up to two flow designs using computational fluid dynamics (CFD), finite element method stress analysis (FESA) and incorporating various transport mechanisms. After evaluating the advantages and disadvantages of each pore size and porosity, we have selected the 200 nm as the most promising one. The new designs will comprise up to two asymmetric membranes on opposite side of an interlayer that provide both mechanical stability and flow channels for the biogas. The components will be configured in a tubular metal housing forming the permeator. In collaboration with our Project collaborators, we will also identify and produce a wide range of materials at the lab scale for high throughput and stability. The applications of these type of membranes are wide in range and the team will in the future focus the membrane technology demonstration on an microporous CO_2 transport mechanisms including surface flow that has superior performance regarding high CO_2 permeability, infinite methane selectivity, and high thermal, chemical and mechanical stability. Furthermore, our intention is in the development of additional optimised membranes using both standard Al_2O_3 and multiple phase membranes. Highly stable materials that will be identified by project partners will also be considered for use with technologies like integrated catalytic membrane reactors for producing chemical energy carriers such as ammonia, hydrogen and other aspects of the developing energy transition leading to net-zero. In addition to CO_2-capture and methane upgrading, this technology can be applied to the field of CO_2-utilisation, waste destruction or pure gas separation. The deliverables of this project will benefit members of the scientific community working on gas separation membranes and and other industries in the circular economy where carbon capture is important such as fossil power exhaust gas, fossil fuel upgrading in refinery flue gas and in iron and steel plants. It will also benefit the wider public through climate change mitigation.

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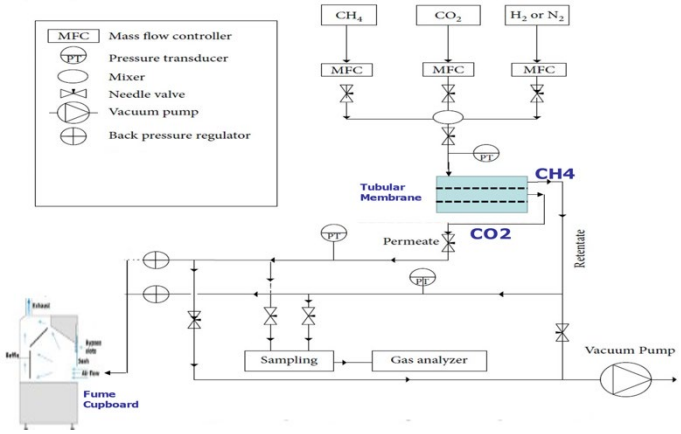

Figure 1: Schematic of the laboratory gas permeation set up

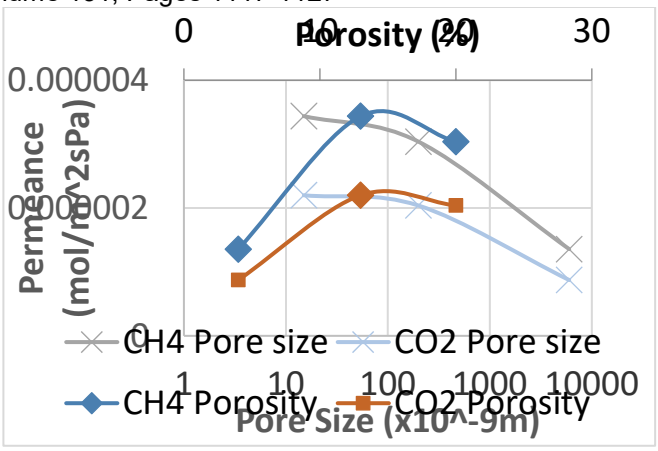

Figure 2: Permeance vs membrane pore size and porosity at 3 bar at 100 degrees celsius