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An Initial Study of Single Gas Permeation using a Commercial Alumina membrane

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Abstract—An initial study has been conducted using a commercially available alumina membrane. The study is based on single gas permeation method involving He, O₂, CO₂ and N₂. The effect of trans membrane pressure drop, gas molecular mass, kinetic diameter, permselectivity and permeance were observed and discussed. Helium showed a faster flowrate through the membrane and the order of flow was He>O₂>N₂>CO₂. The experiment was conducted at constant room temperature.

Keywords—Alumina membrane, kinetic diameter, molecular mass, permselectivity

I. INTRODUCTION

CURRENTLY membrane technology is being viewed as an interesting area of research in the world. This could be in the oil and gas sectors, environmental sector and so on. The membrane technology may involve the separation of individual gases or liquids from a mixture or processes involving separation of gas or vapour mixtures^{1,2}. The permeation experiment is a vital process in membrane technology that helps in the exploration of the flow characteristics of various gas molecules through a membrane³. There are different factors that may determine the rate of

flow of gases through a membrane. These factors could be the molecular weight of the gases, kinetic diameter, the gas concentrations, or the affinity of the gas for the membrane. Different types of gas transport mechanism come into play and pressure difference across the membrane is used as the driving force for transport⁴.

In this study, the flowrates of the gases through the membrane will also be critically evaluated. Transport mechanisms could be deduced from a graph of flowrates plotted against gauge pressures⁵.

Equation 1 could be used to calculate the membrane's selectivity factor or preferably called the Knudsen separation factor⁶ of two or more gases⁵.

$$\alpha_{a/b} = \frac{F_a}{F_b} \sqrt{\frac{M_b}{M_a}} \quad (1)$$

Where

- α Knudsen separation factor
- F Flowrate (mol/s)
- a gas of interest
- b other gas (es)

II. EXPERIMENTAL

The membrane used was supplied by Ceramiques Techniques et industrielles (CTI SA) France. It is a commercially made ceramic membrane tube of permeable length of 3.18cm. The inner and outer diameters were 0.07cm and 0.1cm respectively. The single gases used for the permeation analysis were helium (He), oxygen (O₂), nitrogen (N₂) and carbondioxide (CO₂).

Figure 1 shows the experimental set up for the permeation test. The setup consists of the delivery system for the different gases, the membrane reactor, pressure gauge and flow meter. The membrane was sealed inside the membrane reactor prior to the analysis. The gas flowrate were controlled with the control valve located before the gauge pressure. The digital gauges measured the pressure at which the gases flowed into the membrane reactor. The flow meter connected to the permeate port measured the flow rate of the permeate gas. The atmospheric pressure represents the pressure at the permeate end, this is because the permeate side is open to the atmosphere. The permeation test was carried out at a constant room temperature of 298K.

The permeance of the gas is obtained from the mathematical expression in (2)⁶.

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$$Q_i = \frac{F_i}{A \Delta P_i} \quad (2)$$

Where

Q_i Permeance ($\text{mols}^{-1}\text{m}^{-2}\text{Pa}^{-1}$ of gas i)

F_i Flowrate (mols^{-1}) of gas i

A Surface area of the membrane (m^2)

ΔP_i Pressure difference of gas i across the membrane (Pa)

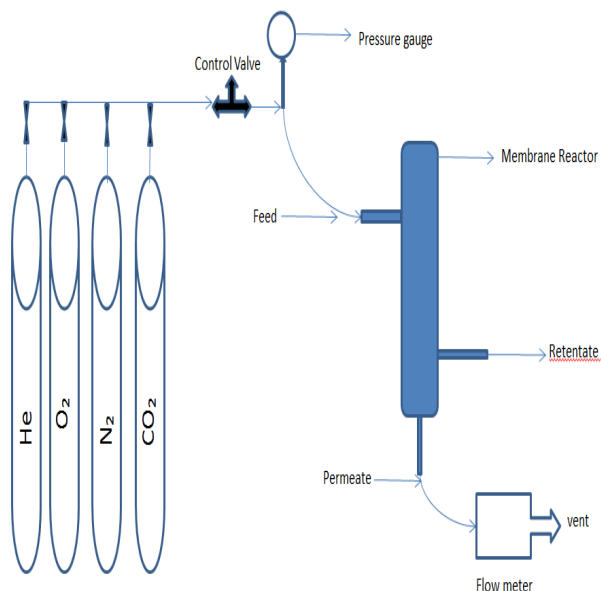


Fig 1 Schematic diagram of the experimental setup

III. RESULTS AND DISCUSSION

The flowrates of helium (He), oxygen (O_2), nitrogen (N_2) and carbon dioxide (CO_2) single gases versus the gauge pressure were studied at 298K. Figure 2 shows the graph plotted in respect to this. It was observed that there was a proportional rise in flowrate as the pressure increased. Helium gas showed the highest flow rate with respect to the other gases, while the rate of flow of CO_2 was the slowest. This results indicated that the permeation of the gases is dependant on their molecular weight. Table 1 shows the molecular weights of the gases. CO_2 is heavier than Helium.

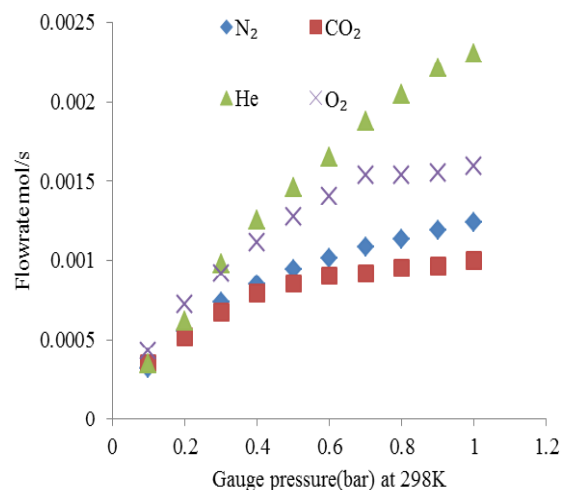


Fig 2 Flowrates of He, N_2 , O_2 and CO_2 against gauge pressure

The nature of the flowrate of the gases also showed that the gas flow was not only dependant on the molecular weight but also on the kinetic diameter of the gases. Based on molecular weight, it is expected that N_2 should flow faster than O_2 , but the reverse was the case, O_2 showed a higher flow rate than N_2 . Table 1 shows the kinetic diameter of the gases and it will be used to explain the behaviour of O_2 and N_2 .

Table I Molecular weight and Kinetic diameter of gases

Gases	Molecular mass	Kinetic Diameter
He	4	2.6
O_2	32	3.0
N_2	28	3.64
CO_2	44	3.30

In table 1, it is seen that O_2 has a smaller kinetic diameter than that of N_2 . This means that, though O_2 is heavier than nitrogen, it is actually smaller in molecular size and tend to diffuse through the membrane faster than nitrogen ⁷. The rate of flow of O_2 is determined by this lower kinetic size.

Fig 3 shows the effect of kinetic diameter on the rate of flow of gases through the membrane at a pressure of 0.45 bar.

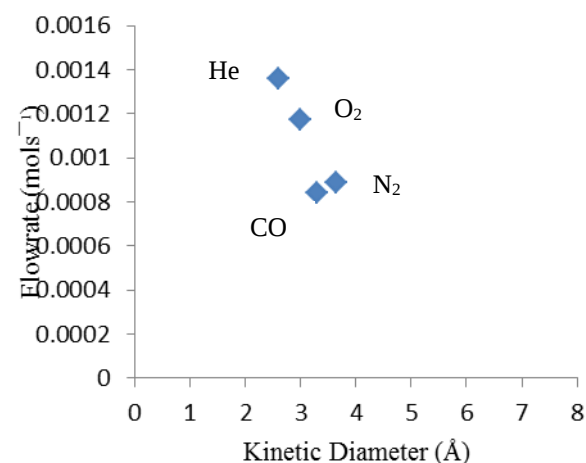


Fig 3 Flowrates of He, N_2 , O_2 and CO_2 against kinetic diameter (Å)

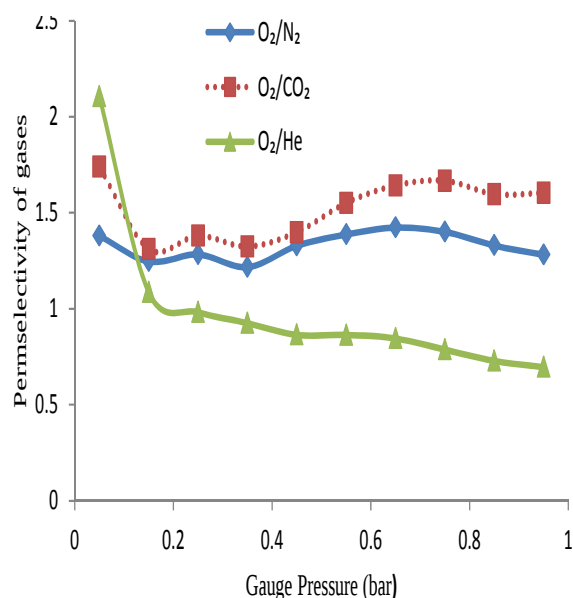


Fig 4 Permselectivity of gases against gauge pressure (bar)

In fig 4, the permselectivity for O_2 against N_2 , CO_2 against He are presented. Table IIa shows the permeabilities of the gases at 0.95 bar gauge pressure and Table IIb shows the experimental and the theoretical selectivities obtained. From the results, the experimental values were greater than the theoretical and this implies there is selectivity of the gases in relation to the membrane. Knudsen mode of gas transport exist here.

Table IIa shows the permeability ($\text{mols}^{-1}\text{m}^{-2}\text{Pa}^{-1}$) at 0.95bar gauge feed pressure.

Gauge Pressure (bar)	O_2	N_2	CO_2	He
0.95	$2.632\text{e-}3$	$2.055\text{e-}3$	$1.642\text{e-}3$	$3.784\text{e-}3$

Table IIb shows the experimental and theoretical selectivities at 0.95bar gauge feed pressure.

Experimal selectivity, α			Theoretical Selectivity, α		
O_2/N_2	O_2/CO_2	O_2/He	α_{O_2/N_2}	α_{O_2/CO_2}	$\alpha_{O_2/He}$
1.280	1.60	0.695	0.707	1.25	0.378

In fig 5, the gas permeance was plotted against the gauge pressure. From the results obtained, as the gauge pressure was increased, there occurred an initial steep drop then a gradual drop in permeability.

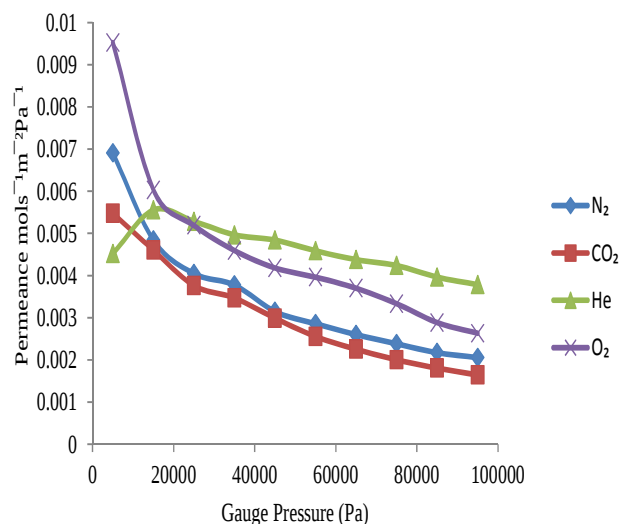


Fig 5 Permeance against gauge pressure (Pa)

IV. CONCLUSION

Gas permeation test is an interesting way of an initial study on a membrane. Valuable information which could be used in understanding membrane performance can be derived from the results obtained. From the permselectivity graph, the experimental selectivity was greater than the theoretical value and this concludes that the molecules collided more with the membrane walls than among themselves.

NOMENCLATURE

- α Knudsen separation factor
- a Gas of interest
- A Surface area of the membrane (m^2)
- b Other gas (es)
- F_i Flowrate (mols^{-1}) of gas i
- F Flowrate (mol/s)
- i Gas of interest
- ΔP_i Pressure difference of gas i across the membrane (Pa)
- Q_i Permeance ($\text{mols}^{-1}\text{m}^{-2}\text{Pa}^{-1}$ of gas i)

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