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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, $O_2$, $CO_2$ and $N_2$. The effect of trans membrane pressure drop, gas molecular mass, kinectic diameter, permselectivity and permeance were observed and discussed. Helium showed a faster flowrate through the membrane and the order of flow was He>$O_2$>$N_2$>$CO_2$. 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 membrane [3].

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 transport [4].

In this sudy, 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 pressures [5].

Equation 1 could be used to calculate the membrane's selectivity factor or preferrably called the Knudsen seperation factor $\alpha$ of two or more gases [5].

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

Where

$\alpha$ 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 sinlge gases used for the permeation analysis were helium (He) , oxygen ($O_2$), nitrogen ($N_2$) and carbondioxide ($CO_2$).

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 ($mols^{-1}m^{-2}Pa^{-1}$ of gas $i$)
$F_i$ Flowrate ($mols^{-1}$) of gas $i$
$A$ Surface area of the membrane ($m^2$)
$\Delta P_i$ Pressure difference of gas I across the membrane (Pa)

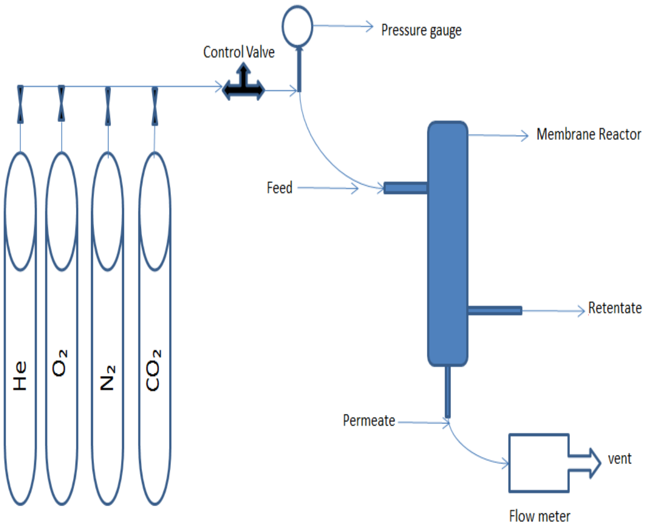


Fig 1 Schematic diagram of the experimental setup

## 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.

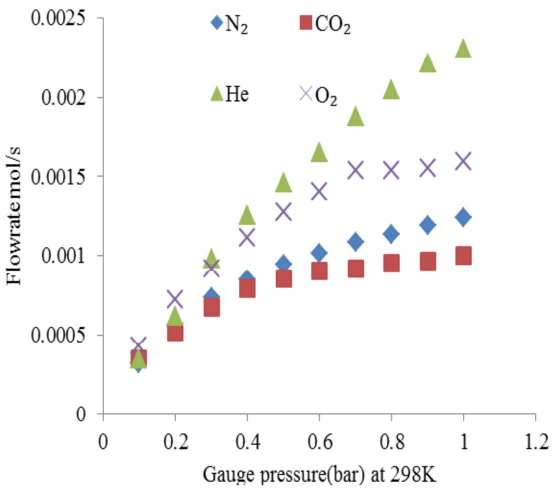


Fig 2 Flowrates of He, $N_2$,$O_2$ and $CO_2$ against gauge pressure

The nature of the flowrate of the gases also showed that the gas flow was not only depepndant 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.

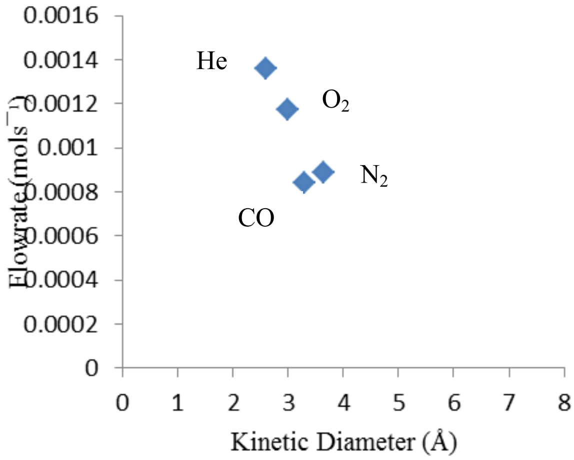


Fig 3 Flowrates of He, $N_2$,$O_2$ and $CO_2$ against kinetic diameter (Å)

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 theoritical selectivities obtained. From the results, the experimental values were greater than the theoritical and this implies there is selectivity of the gases in relation to the membrane. Knudsen mode of gas transport exist here.

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.

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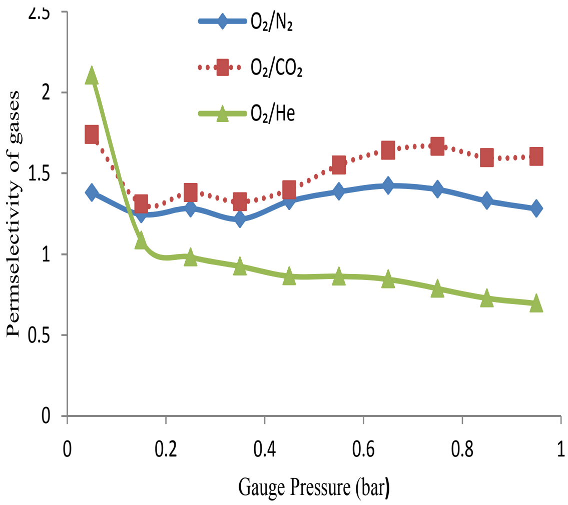


Fig 4 Permselectivity of gases againt gauge pressure (bar)

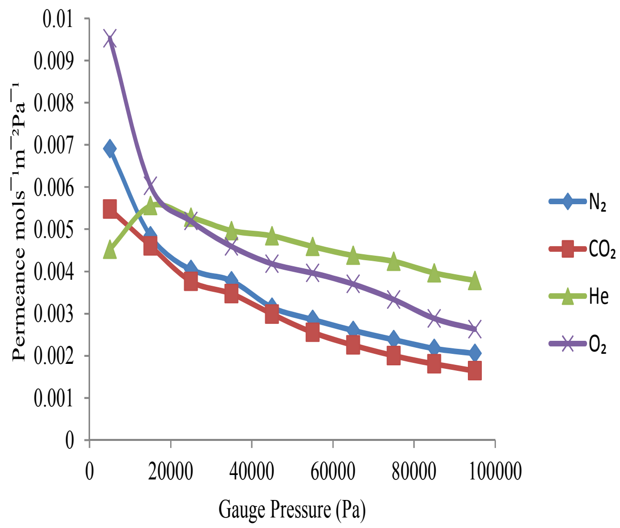


Fig 5 Permeance against gauge pressure (Pa)

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

| Gauge Pressure (bar) | $O_2$ | $N_2$ | $CO_2$ | He |
|---|---|---|---|---|
| 0.95 | 2.632e-3 | 2.055e-3 | 1.642e-3 | 3.784e-3 |

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

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

## 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
$\Delta P_i$ Pressure difference of gas $_i$ across the membrane (Pa)
$Q_i$ Permeance (mols$^{-1}$m$^{-2}$Pa$^{-1}$ of gas $_i$)

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