Gas Separation by Membranes

Membrane technology in gas separation and purification has grown exponentially since they were first introduced about 30 years ago. Compared to other conventional gas separation processes such as cryogenic distillation and absorption, membrane technology provides advantages like the simplicity of operation, ease of scale-up, smaller footprints and, low operating and capital cost. In membrane gas separation, a gas mixture that is fed to the unit gets split into two streams: permeate and retentate which either can be the product depending on the application. Some of the main applications of membrane technology are:

N_2/O_2 separation in Nitrogen/Oxygen generation

H_2 removal from purge gas in Ammonia production

H_2/CO_2 separation in SMR (Steam Methane Reformers)

H_2/H_2S separation in Hydrotreatment

H_2/light hydrocarbons in Hydrocrackers

Recovery of helium from rejected gas streams in Natural gas processing [1, 2, 3].

Membranes used in gas separation can be divided into two major groups: inorganic (metals, ceramics, …) and organic (polymers). Although inorganic membrane can be more selective than polymers, it is difficult to produce defect-free thin films, which makes them more expensive to make [4]. Some of the polymers that are used in membrane technologies are: polyimide (PI), cellulose acetate (CA), polyetherimide (PEI), and Polyethersulfone (PES) [2].

The separation in polymeric membranes is usually explained by the solution-diffusion model. According to this model, the gas molecules are first adsorbed on the polymer surface, diffuse through the polymer and desorb on the other side. The membrane unit usually works between two pressures: feed pressure and permeate. Permeate pressure is always lower than the feed pressure. [1, 2, 4]. Permeability and selectivity are two major factors that should be considered when choosing a membrane for a specific gas separation/purification purpose.

Membrane Modules

A module is a building block of a membrane which can be flat or tubular. Different types of membrane modules are shown in table 1. As it can be seen from the provided data, hollow fiber membranes have the largest packing density. They are a bundle of capillary tubes which are arranged parallel to each other. Permeates gas can be collected in the housing of the fibers or pass to into membrane bore [3]. A schematic of a hollow fiber membrane module is shown in figure 1.

Table 1- Membrane Modules

Module Type	Module Configuration	Packing Density(m^2/m^3)
Flat Sheet	Plate-and-frame	100-400
Flat Sheet	Spirally-wound	300-1000
Tubular	Hollow fiber	10,000-30,000
Tubular	Tubular	N/A

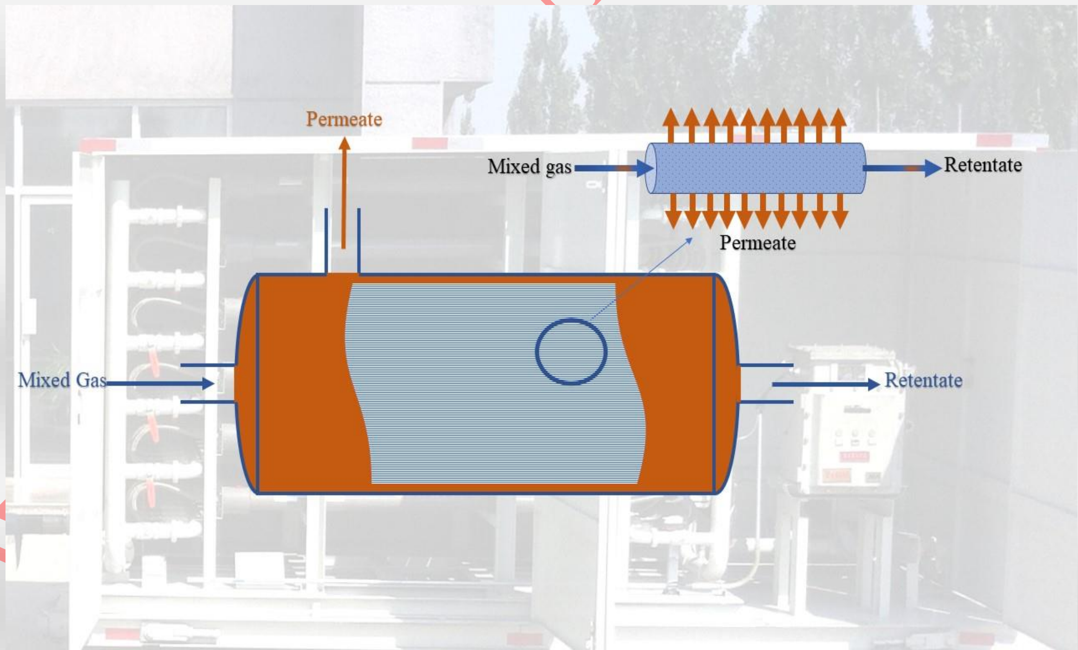

Figure 1-Membrane Gas Separation Unit

Performance of a Membrane Unit:

The key parameters in a membrane performance are selectivity, permeability, and durability. Effective gas separation (high purity and high capacity) requires membranes with high selectivity and permeability. However, there is a tradeoff between these parameters. In other words, a membrane with a higher selectivity has a lower permeability and vice versa [5]. The most favorable combination of these two parameters is represented by a correlation which is known by Robeson upper bound or gas separation trade-off limit. The correlation is used in the development of high-performance membranes [6]. The correlation is defined by equation 1[7]:

$$\alpha_{A/B} = \frac{\beta_{A/B}}{P_A^{\lambda_{A/B}}} \qquad \text{Eq. 1}$$

In the above equation, α_(A/B) is selectivity, P_A is permeability and the other two parameters (β_(A/B) 〖and λ〗_(A/B)) are empirical parameters which are a function of the gas pair in binary mixtures. The upper bound correlation for different gas pairs has been reported in the literature [7, 8]. According to diffusion-solution theory, gas permeability (PA) is a function of gas diffusivity (DA) and solubility (SA) and is defined by equation 2[7]:

$$P_A = D_A \times S_A \qquad \text{Eq. 2}$$

And gas selectivity ($\alpha_{A/B}$) is defined by equation 3 [7]:

$$\alpha_{A/B} = \frac{P_A}{P_B} \qquad \text{Eq. 3}$$

The diffusion coefficient is a function of the size of the penetrant size, flexibility of chains and the free volume in the membrane polymer. The solubility coefficient is a function of gas condensability (critical temperature, normal boiling point, …), the gas-polymer interactions and morphological features of the polymer [9].

References:

1. Paola Bernardo, Gabriele Clarizia, *30 Years of Membrane Technology for Gas Separation*, Chemical Engineering Transactions, **2013**, 32, 1999-2004

2. Xiao Yuan Chen, Serge Kaliaguine and Denis Rodrigue, *A Comparison between Several Commercial Polymer Hollow Fiber Membranes for Gas Separation*, Journal of Membrane and Separation Technology, **2017**, 6, 1-15

3. S. Sridhar, Sharifah Bee and Suresh K. Bhargava*, Membrane-based Gas Separation: Principle, Applications and Future Potential*, **2014**, (https://www.researchgate.net/publication/265295121)

4. Yousef Alqaheem, Abdulaziz Alomair,Mari Vinoba, and Andrés Pérez, *Polymeric Gas-Separation Membranes for Petroleum Refining*, International Journal of Polymer Science, **2017**, Article ID 4250927

5. Ismail, A.F., Norida, R., and Sunarti, A.R, *Latest development on the membrane formation for gas separation*, Songklanakarin J. Sci. Technol., **2002**, 24(Suppl.) 1025-1043

6. K. C. Chong, S. O. Lai, H. S. Thiam, H. C. Teoh, S. L. Heng, *Recent Progress of Oxygen/Nitrogen Separation Using Membrane Technology*, Journal of Engineering Science and Technology, **2016,** 11(7), 1016 – 1030

7. Brandon W. Rowe, Lloyd M. Robeson, Benny D. Freeman, Donald R. Paul*, Influence of temperature on the upper bound: Theoretical considerations and comparison with experimental results*, Journal of Membrane Science, **2010**, 360, 58–69

8. Lloyd M. Robeson, *The upper bound revisited*, Journal of Membrane Science, **2008**, 320 390–400

9. David F. Sanders, Zachary P. Smith, Ruilan Guo, Lloyd M. Robeson, James E. McGrath,

Donald R. Paul, Benny D. Freeman, *Energy-efficient polymeric gas separation membranes for a sustainable future: A review*, Polymer, **2013**, 54, 4729-4761

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