ANTWI, S.W., GIWA, A. and GOBINA, E. 2022. Direct oxygen air capture using pressure-driven ion transport membranes: membrane support evaluation. In *Techconnect briefs 2022: papers from 2022 TechConnect world innovation conference and expo, 13-15 June 2022, Washington, USA*. Danville: TechConnect [online], pages 63-66. Available from: https://briefs.techconnect.org/wp-content/volumes/TCB2022/pdf/329.pdf

Direct oxygen air capture using pressure-driven ion transport membranes: membrane support evaluation.

ANTWI, S.W., GIWA, A. and GOBINA, E.

2022

Oxygen Air Capture Using Pressure-Driven Ion Transport Membranes: Evaluation of the Support

[1]**Samuel Wisdom Antwi,** [2]**Ayo Giwa and and** [1]**Edward Gobina**
[1] Centre of Excellence for Process Integration and Membrane Technology (CPIMT), School of Engineering, Robert Gordon University, Garthdee Road, ABERDEEN, AB10 7GJ, UK, Tel: +441224262348
(*Corresponding author: e.gobina@rgu.ac.uk)
[2] McAlpha, Inc., 205 - 279 Midpark Way SE, Calgary, ALBERTA T2X 1M2, CANADA, Tel: +1 403 969 9062, email: a.giwa@mcalpha.com

ABSTRACT

As membrane technology has progressed in separation processes, it earns the attentiveness from industrial and academic to investigate the practicality of membrane in gas separation. This presentation centres on building ceramic membranes to yield oxygen as prospective relief for the existing air separation techniques. Different materials can accomplish this, and membrane structures will be characterised and tested. Optimisation of membrane permeation and selectivity /yield of chemical reactions will take place through catalytic activation. Air transport and separation through flaw-free ease transport membranes constructed on mixed oxide ceramic membranes is analysed in methodical diverse composition for air (oxygen and nitrogen) separation. Oxygen transit in the membrane eased through selective and reversive interaction of oxygen and ion transport ceramic layer through bond interaction. A continuous and thin discriminatory layer formed on the substrate as mixed oxide ceramic has a perfect affinity for oxygen ions. The addition of a calculated number of other constituents facilitates the separation fulfilment of the membrane and limit feed pressure. This research generates a prospective membrane material in a modest state for oxygen and nitrogen separation. Categorisation of the membranes will be carried out based on thermal, mechanical, porosity, pore size dispensation, sorption, morphology, and permeation properties—the built membrane ordered for coating absorption, nanoparticles loading and a specific number of coatings. The proposed technique is uncomplicated and productive concerning cost.

Keywords: air separation, oxygen production, membrane, ion transport, pressure

1 INTRODUCTION AND BACKGROUND THEORY

In the chemical and medical fields, oxygen-enriched air plays a vital role in their operation for instance, the sewage treatment plant operates the combustion process [1]. Lately, delight was ensued in fired combustion engine by enriching the natural gas and coal; this is achievable through instigating oxygen gas into the stages of combustion to lower the consumption rate of fuel and improved situated oxygen gas for a perfect quality of air [2]. Currently, commercial production of oxygen-enriched air is achieved by cryogenic distillation and pressure swing adsorption, respectively. Whereas pressure swing adsorption is a medium scute production technology with significant sterility of oxygen gas generation tonnage of 20 to 100 tons daily, cryogenic distillation is a high-flake generation technology with daily manufacturing tonnage above 100 tonnes of potent sterility oxygen gas [3]. These technologies have been operated for over 70 years in the industry; they still experience some snag. The function of these two technologies demands intensive energy use and large built-up, which does not make them economically advantageous. As membrane techniques progress is expected to cater for oxygen gas production scale at the range of 10 to 25 tons daily, with the sterility of 25 to 99% [4]. A membrane is corporal barricade consisting of a semi-permeable medium permitting some constituent to pass through while preventing others (Figure 1). The pervade is the feed section that goes across the membrane, and the retentate is the section of the feed turned down by the membrane. The flux, which is expressed by the permeation and selectivity of the membrane, gives the ideal performance of the membrane; the pressure difference, possible electrochemical potential content is the steering power across the membrane [5,6].

In the gas separation process, a membrane is a hurdle position between two folds allowing preferential permeation of one gas, in contrast, the others remain on the feed surge. This fastidious permeation exists because of the steering force, that is, gas constituent partial pressure.

The membrane segregation process presents more benefits over other traditional gas separation technologies. They do not need the craving for extra chemical and do not require any energy-intensive stage transformation processes [8]. Furthermore, the requisite process appliance is straightforward, with no mobile parts, concise, simple to run and control, and easy to scale up. Various types of membrane processes have been build depending on diverse separation concept covering the vast scope of particles and molecules.

Mostly, inorganic membranes are the perfect candidate for oxygen production. These can be categorized into dense and porous membranes, respectively. Under inorganic membranes, ceramic membranes champion gas separation to necessitate oxygen generation. Ceramic membranes are an engrossing substitute for standard oxygen production technology [8]. These materials competent of partition oxygen in continuous mode by facile diffusion via the structure lattice above 700 degrees Celsius have inspired much watchfulness over the years, as simple, cleaner, and economically friendly as shown in Figure 1.

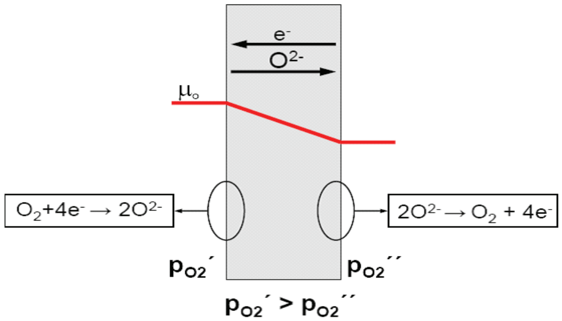

Figure 1: Schematic representation of the transport process of oxygen through a membrane with different oxygen partial pressure PO_2‘>PO_2" on both surfaces.

1.1 Membrane Technology

Membrane techniques have become conducive to the traditional separation processes; pressure swing adsorption and cryogenic distillation in gas segregation because it calls for less energy diction and fewer capital expenses [21]. For membrane techniques, abduct atmospheric air into the membrane lattice, and by their diffusivity and solubility variation, gas will be segregated accordingly. Upstream will occupied by oxygen because of its high diffusivity, and downstream filled by nitrogen. The daily membrane segregation process can yield 25 to 100% clean oxygen and a generation rate of around 10 to 25 tonnes. Membrane development leans on many strands like the type of membrane. Phase inversion techniques are procedures to build a membrane. This method is a conventional structure of polymer dope solvent inside a solid-state via the solvent-nonsolvent substitute. This method is applied in making flat sheet and hollow fibre membranes; though, this rests on the set-up devices. The polymer dope solvent deluge in a non-solvent stiffening bath, first granting the solvent-nonsolvent transpose to establish; the demising action occurs here [22]. Also, the phase segregation transpires through solvent evaporation within the coagulation bath, permitting polymer solidification. The converse process has been enacted and sued most dense-structured membrane manufacturing for the separation network. Hollow fibre membrane and nanofiber membrane possess separate production procedures [23].

1.2 Ceramic membrane

The ceramic membrane has a positive impact on oxygen separation from the air due to its infinite selectivity. The oxygen molecules in the form of oxygen ions invade from enormous mass pressure to the patch of lower partial pressure when a partial pressures deviation is deployed to oxygen via a dense membrane as no other ions are projected to oxygen. As a result, limitless selectivity. There are five levels for oxygen imbue via the membrane [24]. The interactivity links the oxygen molecules and hollow oxygen lot on the surface of the membrane, which entails massive partial pressure of oxygen gas and hence trigger mass oxygen transfer from more excellent pressure gas stream to the membrane surface and oxygen mass from the surface low-pressure gas sweep.

2 METHODOLOGY

Inorganic powders, the mixture and homogeneity of the powder dissolution, the drying and the sintering state have an appreciable impact on the standard of the porous support. Slurry preparation, shaping into a green structure and final sintering at extreme temperature. Pressurised pure gas separated through the membranes at different pressures. The membrane surface is upgraded for highly efficient separation, and then separation is repeated to achieve oxygen-enriched air. The flow rates and gauge pressure values were noted. Membrane techniques have become conducive to the traditional separation processes; pressure swing adsorption and cryogenic distillation.

2.1 Experimental Design

Laboratory experiments on gas permeation were conducted for Air, Nitrogen, Oxygen and Carbon Dioxides in a radial ceramic membrane of 200nm pore size at different Pressure and temperature conditions.

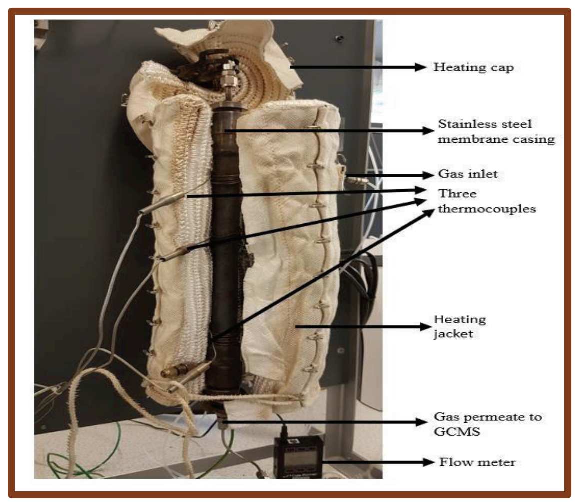

Figure 2: Photograph of the membrane permeator enclosed in the heating jacket.

2.2 Oxygen transport through membranes

Figure 1: illustrate the oxygen segregation via ceramic membrane with oxygen diffusion through dense ceramic membranes can come up if there is a steering force that physically array as an oxygen partial pressure deviation between the feed flow and permeates stream. Oxygen movement implies five continuous steps regarding membrane operation [24].

Stage 1- feed segment gas transport: The oxygen molecules are conveyed from the gas state to the membrane surface via gas-to-gas diffusion. **Stage 2**- dissociation on feed segment: Due to the catalytic impact of the ceramic material, the oxygen molecules soak the surface of the membrane and uncouple. **Stage 3**- Oxygen transport through the porous ceramic support network, driven by oxygen partial pressure gradient via the membrane. In the support there is no electrons or ions transferred across the support. However, once the LaO.58SrO.4CoO.2FeO.8O^{3-}delta (LSCF) or BaO.5SrO.5CoO.8FeO.2O^{3-}delta (BSCF) perovskite layer is formed on the support electrons and oxygen ions will traverse in opposing directions across the membrane resulting pure oxygen production. **Stage 4**- there is no association on the permeate segment: the oxygen molecules leave the surface of the membrane. **Stage 5**- permeate segment gas transport: The oxygen molecules are moved to the permeate flow via gas-to-gas diffusion. Stages 1-5 will be modified once the ionic layer is formed on the support.

2.3 Impact

This technology will boost the medical, chemical and energy industries to have more accessible oxygen at a lower cost as shown in Figure 4 in intensive care.

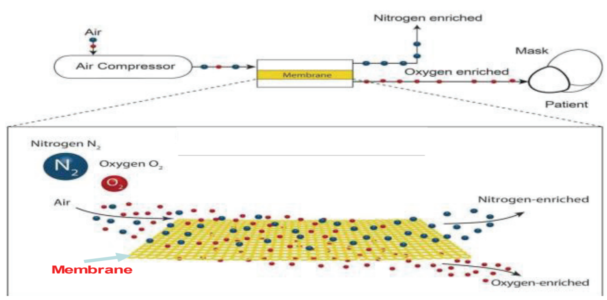

Figure 3: Air O_2 capture for intensive care

3 RESULT AND DISCUSSION

An increase in flow rate and volume of gas permeated as the Pressure increased, as shown in Figure 4. Analyses of the initial behaviour of the gas with the membrane and the possible flow regime that exist in the separation process is shown in B. Oxygen ions gained maximum preferential permeation through the membrane. Doping gamma-alumina ceramic membrane with LaSrGaFe coating may possibly create a cat-ion vacancy in the membrane support. The oxygen ions may tend to fill but rather permeate through the membrane's micropores.

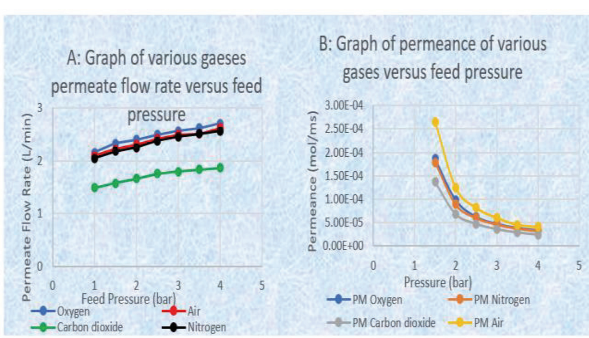

Figure 4: Graph (A) of Feed pressure (bar) versus Permeate Flow rate (L/min) and Graph (B) The flux of various gases against pressure on the regular scale.

3.1 Oxygen Selectivity

The oxygen selectivity of the uncoated membrane was determenied using the following equation.

$$O_{2st} = \frac{O_{pm}}{N_{pm}} \quad (1)$$

Where O_{2st} is the oxygen selectivity, O_{pm} and N_{pm} are the oxygen permeance and nitogen permeance respectively. The target of this project is to obtain oxygen selectivity of 21% to 100% , from table 1 the oxygen selectivity is far below the the targetted selectivity and hence the need to modify (coat) the membrane to improve oxygen permeation to reach the targetted selectivity. This support will be subject to diverse temperature (100 to 1100 degree celcius to assure its mechanical stability and higher oxygen purity.

Feed Pressure	Temperature	Oxygen Permeance	Nitrogen Permeance	Oxygen Selectivity
1.5	22.57	1.86E-04	1.79E-04	1.039
2.0	22.5	9.16E-05	8.81E-05	1.04
2.5	22.48	6.23E-05	5.98E-05	1.042
3.0	22.44	4.74E-05	4.61E-05	1.028
3.5	22.38	3.87E-05	3.73E-05	1.038
4.0	22.33	3.36E-05	3.21E-05	1.047

Table 1: Oxygen selectivity

4 CONCLUSION

As shown in Table 1. the support does not possess much oxygen selectivity and is mostly based on the inverse of viscosity. Thus, flow is dominated by viscous flow. Ceramic membrane possesses the needed competence for air separation, conducive pore size for gases, defiance to intense temperature and chemical infects, and compatibility with oxygen. Rising flow rate and volume of gas pervaded as the pressure added up, deducing that the pressure gradient is the steering force. The para-magnetic characteristics of the membrane material grant oxygen the ultimate value over nitrogen and other air components. Membrane techniques can generate oxygen-enriched air in a low-cost approach to rescue medical and industrial combustion operations costs. The homogeneous membrane can boost the economic and energy proficiency of the medical and energy division.
For great sterility, high tonnage oxygen making for next-generation consumption of the desegrated power plant, ceramic membrane process stands as the most convenient option compared to other traditional technologies. This project displayed that ceramic membrane technology can yield oxygen-enriched air in a low-cost model to rescue fuel, medical expenses, and industrial combustion. This project is solely laboratory work, and some of the practical experiments are yet to trigger and hence fewer data to analyse and conclude. The ceramic membrane is suitable

for air separation, favourable pore size for gases, resistance to high temperature and chemical attack coupled with its oxygen affinity. The para-magnetic behaviour of the membrane material gave oxygen the perfect advantage over nitrogen and other air constituents, which are non-magnetic.

REFERENCES

[1] Chong, K.C., Lai, S.O., Thiam, H.S., Teoh, H.C. and Heng, S.L., 2016. Recent progress of oxygen/nitrogen separation using membrane technology. J. Eng. Sci. Technol, 11, pp.1016-1030.

[2] Stafford, T.M., 2015. Indoor air quality and academic performance. Journal of Environmental Economics and Management, 70, pp.34-50.

[3] Smith, A.R. and Klosek, J., 2001. A review of air separation technologies and their integration with energy conversion processes. Fuel processing technology, 70(2), pp.115-134.

[4] Sanders, D.F., Smith, Z.P., Guo, R., Robeson, L.M., McGrath, J.E., Paul, D.R. and Freeman, B.D., 2013. Energy-efficient polymeric gas separation membranes for a sustainable future: A review. Polymer, 54(18), pp.4729-4761.

[5] Nanofiltration Separations Part 1 (Nanotechnology),” The-Crankshaft Publishing. [Online]. Available: http://what-when-how.com/nanoscience andnanotechnology/ nanofiltration-separations-part-1-nanotechnology/. [Accessed: 23- Mar-2021].

[6] Serdijn, W.A. and Mulder, J. eds., 2013. Research perspectives on dynamic translinear and log-domain circuits (Vol. 550). Springer Science & Business Media.

[7] Wang, L., Dou, R., Bai, M. Li, Y. Hall, D. and Chen, L, A case study of mechanical properties of perovskite-structured Ba0.5Sr0.5Co0.8Fe02O3−δ oxygen transport membrane 2018, J EUR CERAM SOC, 38(2) pp 647-653.

[8] , 2010. Functionalized copolyimide membranes for the separation of gaseous and liquid mixtures. Beilstein journal of organic chemistry, 6(1), pp.789-800.

[9] Gobina, E. (2006). Apparatus and Methods for Separating Gases. The United States Granted Patent No. US 7048778, May 23, 2006.

[10] Chong, K.C., Lai, S.O., Thiam, H.S., Teoh, H.C. and Heng, S.L., 2016. Recent progress of oxygen/nitrogen separation using membrane technology. J. Eng. Sci. Technol, 11, pp.1016-1030.

[11] Hu, T., Zhou, H., Peng, H. and Jiang, H., 2018. Nitrogen production by efficiently removing oxygen from air using a perovskite hollow-fiber membrane with porous catalytic layer. Frontiers in chemistry, 6, p.329.

[12] García Fayos, J., 2017. Development Of Ceramic Miec Membranes for Oxygen Separation: Application in Catalytic Industrial Processes (Doctoral dissertation, Universitat Politècnica de València).

[13] S. Baumann, W. A. Meulenberg, H. P. Buchkremer, Manufacturing strategies for asymmetric ceramic membranes for efficient separation of oxygen from air. Journal of the European Ceramic Society, 33 (2013) 1251-1261.

[14] Castillo, R., 2011. Thermodynamic analysis of a hard coal oxyfuel power plant with high temperature three-end membrane for air separation. Applied Energy, 88(5), pp.1480-1493.

[15] Takahashi, T., Esaka, T. and Iwahara, H., 1976. Electrical conduction in the sintered oxides of the system Bi2O3 BaO. Journal of Solid State Chemistry, 16(3-4), pp.317-323.

[16] Cales, B. and Baumard, J.F., 1982. Oxygen semipermeability and electronic conductivity in calcia-stabilized zirconia. Journal of Materials Science, 17(11), pp.3243-3248.

[17] Cales, B. and Baumard, J.F., 1984. Mixed Conduction and Defect Structure of ZrO2-CeO2-Y 2 O 3 Solid Solutions. Journal of the Electrochemical Society, 131(10), p.2407.

[18] Chakma, A. and Tontiwachwuthikul, P.T., 1999. CO [sub2] separation from combustion gas streams by chemical reactive solvents.

[19] Göttlicher, G. and Pruschek, R., 1997. Comparison of CO2 removal systems for fossil-fuelled power plant processes. Energy Conversion and Management, 38, pp.S173-S178.

[20] Sunarti, A.R. and Ahmad, A.L., 2015. Performances of Automated Control System for Membrane Gas Absorption: Optimization Study. Jounal of Advanced Research in Applied Mechanics, 6, pp.1-20.

[21] Lu, G.Q., Da Costa, J.D., Duke, M., Giessler, S., Socolow, R., Williams, R.H. and Kreutz, T., 2007. Inorganic membranes for hydrogen.

[22] Ahmad, F.N., Sazali, N. and Othman, M.H.D., 2019. Review on Development of Oxygen/Nitrogen Separations Technologies. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, 63(2), pp.249-259.

[23] Lee, R. J., Z. A. Jawad, A. L. Ahmad, J. Q. Ngo, and Han Bing Chua. "Improvement of CO2/N2 separation performance by polymer matrix cellulose acetate butyrate." In IOP Conference Series: Materials Science and Engineering, vol. 206, no. 1, p. 012072. IOP Publishing, 2017.

[24] Spahis, N., Dellali, M. and Mahmoudi, H., 2012. Synthesis and characterisation of polymeric/activated carbon membranes. Procedia Engineering, 33, pp.47-51.

[25] Tan, X. and Li, K., 2002. Modeling of air separation in a LSCF hollow-fiber membrane module. AIChE Journal, 48(7), pp.1469-1477.