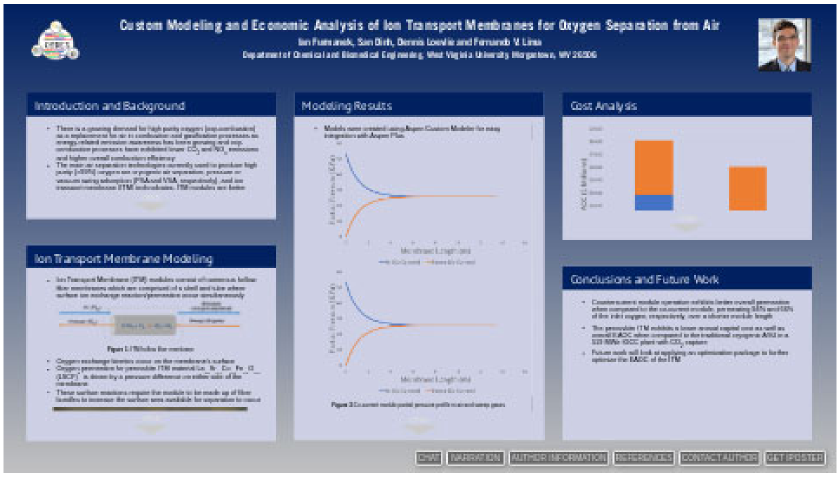
Custom Modeling and Economic Analysis of Ion Transport Membranes for Oxygen Separation from Air



Ian Furmanek, San Dinh, Dennis Loevlie and Fernando V. Lima

Department of Chemical and Biomedical Engineering, West Virginia University, Morgantown, WV 26506

PRESENTED AT:

2020 AIChE ANNUAL MEETING | ASC20 AIChE Annual Student Conference

INTRODUCTION AND BACKGROUND

- There is a growing demand for high purity oxygen (oxy-combustion) as a replacement for air in combustion and gasification processes as energy-related emission awareness has been growing and oxy-combustion processes have exhibited lower CO_2 and NO_x emissions and higher overall combustion efficiency
- The main air separation technologies currently used to produce high purity (>99%) oxygen are cryogenic air separation, pressure or vacuum swing adsorption (PSA and VSA, respectively), and ion transport membrane (ITM) technologies. ITM modules are better suited for integration into power cycles than PSA or VSA due to the high temperatures associated with these processes
- Approximately 4800 kmol/h of oxygen is required for a 519 MWe IGCC plant with CO_2 capture[1]

ION TRANSPORT MEMBRANE MODELING

- Ion Transport Membrane (ITM) modules consist of numerous hollow fiber membranes which are comprised of a shell and tube where surface ion exchange reaction/permeation occur simultaneously

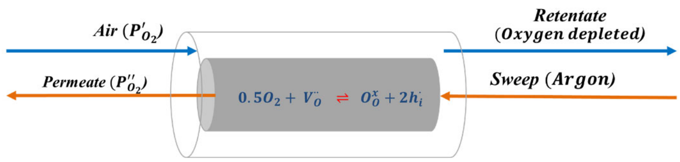


Figure 1: ITM hollow fiber membrane

- Oxygen exchange kinetics occur on the membrane's surface
- Oxygen permeation for perovskite ITM material $La_{0.6}Sr_{0.4}Co_{0.8}Fe_{0.2}O_{3-a}$ (LSCF)[2] is driven by a pressure difference on either side of the membrane
- These surface reactions require the module to be made up of fiber bundles to increase the surface area available for separation to occur

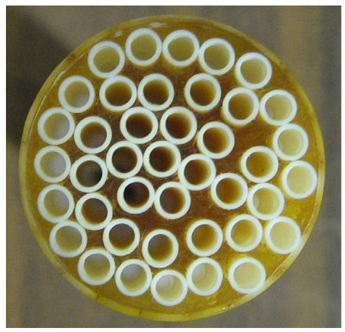


Figure 2: Hollow fiber module bundle

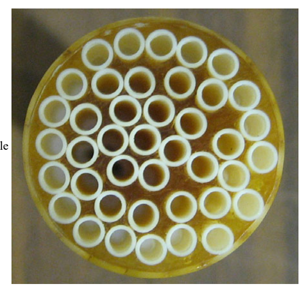


Table 1: Parameters for the costed countercurrent ITM module

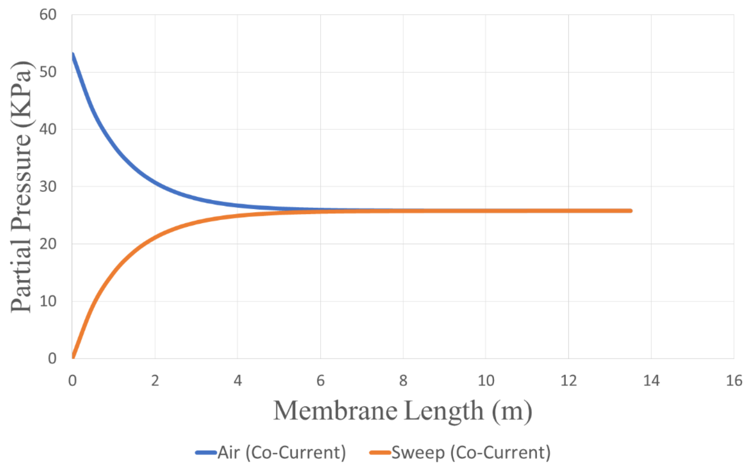
ITM Module	
Length (m)	4.4
Fiber tube diameter (mm)	2.28
Fiber shell diameter (mm)	2.92
Temperature (°C)	850
Air side pressure (bar)	2.535
Sweep gas pressure (bar)	1.022
Ratio sweep gas to air	1.06:1
Number of fibers	1.87×10^6
Oxygen permeation rate (mol/s)	1360

- The model was assumed to be isothermal, and previous simulations on ITM models exhibited a negligible pressure change along the length of the membrane

- Model was built in Aspen Custom Modeler which solved the model using a finite difference method and the model was validated using previous research and generated a percent error of 4%

MODELING RESULTS

- Models were created using Aspen Custom Modeler for easy integration with Aspen Plus



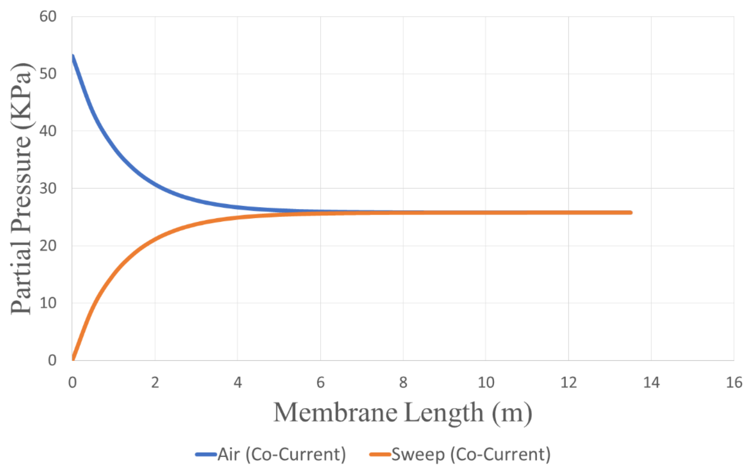
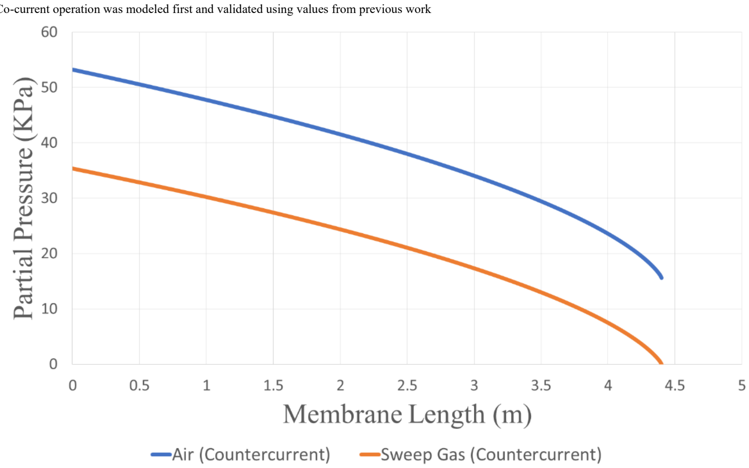


Figure 3:Co-current module partial pressure profile in air and sweep gases

- Co-current operation was modeled first and validated using values from previous work



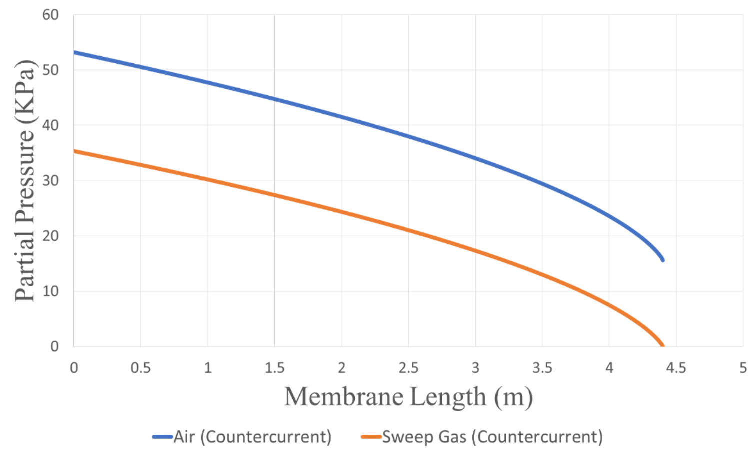


Figure 4: Countercurrent module partial pressure profile in air and sweep gases

- Both the co-current and countercurrent units are being used to process an inlet air stream of 24,800 kmol/h

COST ANALYSIS

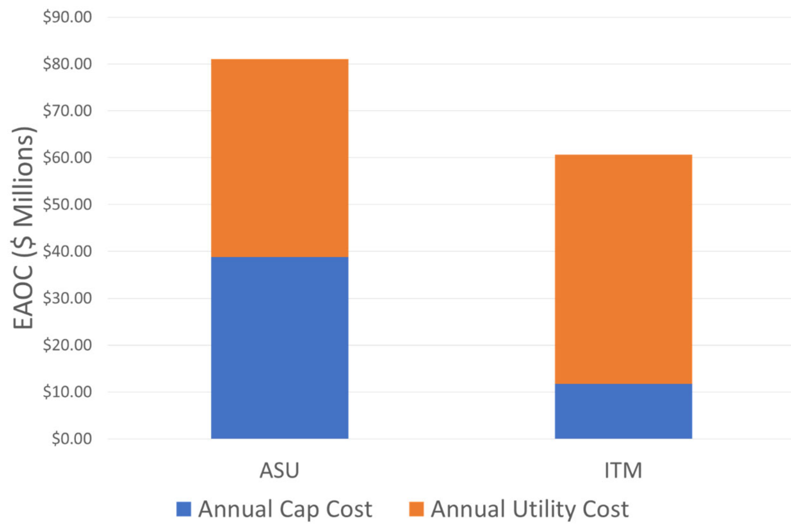


Figure 5: EAOC results for the ITM and traditional ASU for a 519 MWe IGCC plant with CO_2 capture

- ITM equipment was sized using Aspen Plus and costed using Capcost[3] while the ASU cost information was found in NETL report[1]

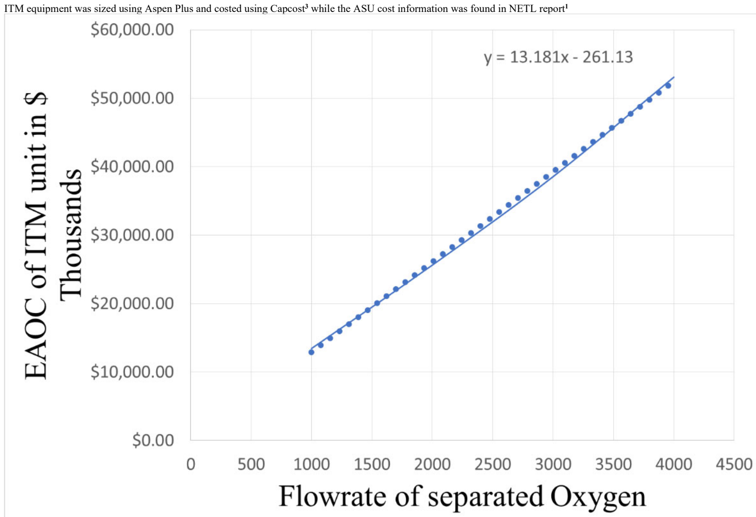


Figure 6: Change in the EAOC of an ITM air separation unit based on desired pure oxygen product

- EAOC (Equivalent Annual Operating Cost) was calculated at various flowrates to generate an equation relating the cost of ITM air separation to the amount of desired oxygen

CONCLUSIONS AND FUTURE WORK

- Countercurrent module operation exhibits better overall permeation when compared to the co-current module, permeating 94% and 66% of the inlet oxygen, respectively, over a shorter module length

- The perovskite ITM exhibits a lower annual capital cost as well as overall EAOC when compared to the traditional cryogenic ASU in a 519 MWe IGCC plant with CO_2 capture

- Future work will look at applying an optimization package to further optimize the EAOC of the ITM

AUTHOR INFORMATION

Hello, I am a senior engineering student from WVU working towards my bachelors in chemical engineering. I have worked with Dr. Lima in his CODES research group since the spring of my sophmore year and have been applying the membrane modeling skills learned through doing research to my work as a group leader for our senior design capstone.

You can find me on Linkedin at www.linkedin.com/in/ian-furmanek

REFERENCES

1. James, R., Kearins, D., Turner, M., Woods, M., Kuehn, N., Zoelle, A. (2019). Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity. doi:10.2172/1569246.
2. Tan, Xiaoyao, et al. "Mixed Conducting Ceramic Hollow-Fiber Membranes for Air Separation." AIChE Journal, vol. 51, no. 7, 9 May 2005, pp. 1991–2000.
3. Turton, R., J. A. Shaeiwitz, D. Bhattacharyya, and R. C. Bailie, Analysis, Synthesis, and Design of Chemical Processes, 5th ed., Prentice-Hall, 2018.

Acknowledgments: The authors of this report would like to gratefully acknowledge the National Science foundation and West Virginia University for their financial support of this research. Research sponsored through the NSF REU program funding under Dr. Lima's Control, Optimization and Design of Energy Systems (CODES) research group