Optimization of Membrane Networks-Superstructures*

Ernest West**, Nina Wright**, Miguel Bagajewicz, Debora Faria

(*)This work was done was as part of the capstone Chemical Engineering class at the University of Oklahoma, (**) Capstone Undergraduate students

The natural gas industry is one of the largest industries in the United States with 10,000 companies producing an annual revenue of $100 billion dollars per year. Actual natural gas processing is the largest application of industrial gas separation. Membranes have been introduced as an alternative to traditional natural gas processing. In the interest of conserving energy costs and environmental concerns membranes offer a new exciting alternative to traditional natural gas processing. As the future of membranes in natural gas processing is becoming more certain, the necessity of more efficient designs of membrane networks becomes more important and vital. The most efficient membrane networks will be decided using a mathematical superstructure model. The superstructure will be able to eliminate inefficient membrane networks, from all possible layout plans.

The mathematical model that was used to produce the given results were modelled from a hollow fiber membrane using permeabilities of CO_2, CH_4, H_2S, and heavier through a cellulose acetate membrane. An objective function was developed using the capital and operating costs of running a membrane network considering costs such as membrane and compressor costs. The efficiency of the compressors was assumed to be 70%, the cost of the membrane housing was $200/m^2, the cost of the compressors was $1000/ kW of required power, the working capital investment was assumed to be 10% of the fixed capital, and the amount of the capital cost that must be paid back each year is 27% of the total.

Operating costs were developed similarly, with the cost of membrane replacement priced at a cost of $30/m^2/yr, the cost of maintenance had a weight factor of 5%, the cost of the natural gas was assumed to be $35/Mm^3 and was used as a penalty cost in the composition in the permeate, the operating days are 300 days/yr, and the feed has a rate of 10 mole/s.

The conditions for the feed was a total flow rate of 10 mol/s (around .7 MMSCFD) with a composition of 73% methane, 19% carbon dioxide, 1% hydrogen sulfide, and 7% ethane. The condition for the final retentate was a final composition of 2% carbon dioxide or less.

The final model was run while minimizing the objective function, using a mixed integer non-linear programming and a solver called CPLEX. A mixed integer linear program was used as well in order to determine an initial guess for a reasonable value of the objective function.

The most efficient two membrane network with four components was determined to be $67,863/year with a total membrane area of 160 m^2. The resulting membrane network is also in parallel, with recycle streams from both the retentate of the first membrane to the feed of the second membrane, while a fraction of the permeate of the second membrane is recycled to the feed of the first membrane. The results are comparable to literature values found in Qi and Henson, however discrepancies are afforded to the fact that the model in Qi and Henson are modeled on spiral bound membranes as opposed to hollow fiber membranes.

The model was successful in determining a local minimum of membrane networks, but the determination of a global minimum remains uncertain as the model was forced to use recycle streams using initial guesses that were input at the General Algebraic Modeling System (GAMS) interface using a closed loop function. The infeasible solutions were eliminated as potential solutions, and the lowest valued feasible solutions were then determined as the minimum value solution to the objective function.