Title: CFD Numerical Simulations for Gas Separation Membrane Module Designs

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Hollow fiber membrane modules are widely used in gas separation applications, such as airplane on-board oxygen and fuel tank inert gas generation, biogas sweetening, separation of CO_2 from natural gas and flue gases etc. Air Liquide is an industry leader in the gas separation membrane research and manufacturing. To further develop the technology and enhance the gas separation efficiencies, it is critical to understand the gas flows inside the membrane modules and improve the fiber utilization through proper module designs. A computational fluid dynamics (CFD) model has been developed at Air Liquide to simulate the gas separation process in a membrane module that can visualize the pressure and different gas distributions, retentate and permeate flow fields, driving force distributions, etc. Information obtained are being used to analyse the separation efficiencies and guide the module design modifications.

The simulation model is developed based on general purpose CFD software FLUENT. The bore-side and the shell-side of a membrane module are modeled separately using different porous media domains. Both domains are meshed with exactly the same grid cells. The porosity of each domain is derived from the fiber dimensions and the local packing density. Gas flow resistances are calculated based on the appropriate pressure drop formulations. Gas mass transfer rates are calculated based on the local driving force and the gas permeance at each mesh cell of the module. The CFD model has been validated against experimental data on Air Liquide membrane modules and can be applied to both bore-feed and shell-feed configurations.

To illustrate the applications of the CFD simulations, a baseline module design is simulated together with several modifications to the baseline design. Results reveal the mechanisms of the performance improvements and show that the shell-side flow patterns are critical to the separation performance. Digital experiments using CFD provide a detailed understanding of fluid dynamics within the bundle that could be difficult to obtain experimentally. Results have proven to be very helpful in understanding the membrane module separation process for different configurations and to provide guidance for module designs. Module design becomes a more critical parameter as the module size increases and/or the intrinsic fiber performance improves.

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