3D-Printed Packings for Solvent-based absorbers

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Abstract

The advent of additive manufacturing, including 3D-printing, allows fabrication of new geometries and reactor configurations not previously considered for carbon capture. These new reactors can be designed for intensified mass transfer and heat transfer, potentially reducing the volume and capital cost of equipment. Gyroid and gyroid-like surfaces are some of the most promising geometries made available through additive manufacturing. They consist of two or more interpenetrating volume domains separated by a continuously curving wall. An example is shown in Figure 1.

Femmer et al. [1] recently showed that gyroid-like heat exchangers offer order-of-magnitude enhancement in heat exchange per unit surface area compared to conventional tube and plate designs. The continuously turning flow paths of the structures can interrupt boundary layers and help move fluid to the walls for enhanced transport. As a result, similar enhancement is expected for mass transfer in membrane systems.

In this research, we evaluate two concepts applying 3D-printed, gyroid-like geometries to CO_2 absorption in solvent-based post-combustion capture systems. The first concept, an intercooled packing, puts solvent and flue gas in one volume domain of the gyroid, while a cooling fluid flows through the other. This concept is especially useful for water-lean solvents, which tend to have lower

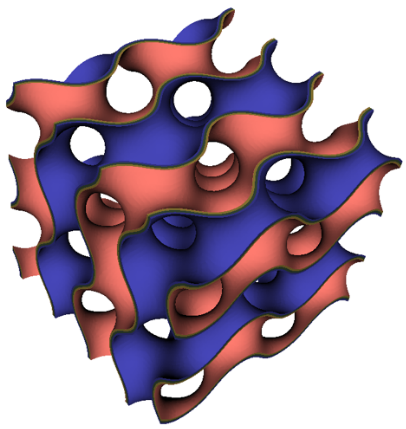

Figure 1: Rendering of a gyroid. The block contains 4x4x4 unit cells of the gyroid or "Schoen G" geometry. The red and blue domains are separate but interpenetrating volumes.

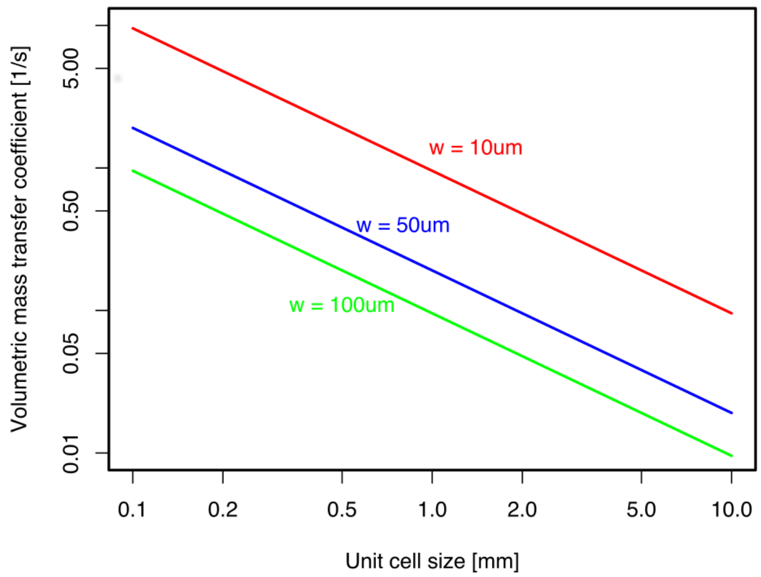

Figure 2: Calculated volumetric mass transfer coefficient, Kla, in a gas/liquid membrane reactor with Schwarz-D geometry. "w" is the thickness of the membrane wall. Permeability is assumed to be 3000 barrer (typical for silicones), and mass transfer is assumed to be limited by transport across the membrane.

heat capacity and more difficulty with temperature bulges in the absorber than conventional aqueous solvents. A packing with continuous, integrated cooling could both enhance rich solvent loading and reduce the overall size of the absorber. We evaluate the exchange area and flow rate of cooling fluid needed per unit of packing for a representative water-lean solvent. One of the benefits of the gyroid geometries is that the relative sizes of the volume domains can be adjusted to accommodate different flows in each, and so an optimized variant of the gyroid is calculated. The resulting reactors can be printed in stainless steel or a chemically-compatible plastic.

Another concept is to use the gyroid as a membrane reactor. Flue gas flows in one volume domain and solvent flows in the other. The wall of the structure is a CO_2-permeable silicone. The wall introduces resistance to mass transfer, but also increases interfacial area and liquid-side mixing compared to conventional packed towers. Figure 2 shows example model results for a Schwarz-D type reactor with solid silicone walls and a fast-reacting solvent. We find that volumetric mass transfer coefficients can surpass typical values for packed towers with aqueous amines at the small size scales. In our lab, we have recently demonstrated printing of gyroids in silicone with wall thicknesses as small as 10 um and unit cells down to 100 um.

We calculate volumetric mass transfer coefficients for additional geometries and several representative solvents. We consider several membrane materials for which we have demonstrated printing and account for different permeabilities and practical size scales. Results are compared with values for conventional towers from the literature. The performance of gyroid-type membrane reactors and intercooled packings for improved absorbers in post-combustion CO_2 capture is evaluated.