SCALE-UP OF MOLTEN CARBONATE FUEL CELLS FOR CARBON CAPTURE

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Abstract

Carbonate fuel cells offer an elegant solution to the dual energy challenge of extending energy access while reducing carbon emissions. Unlike most carbon capture technologies that are energy intensive, the carbonate fuel cell actually co-produces electricity while concentrating CO_2 from dilute streams like refinery emissions or natural gas combined cycle power plants. To effectively deploy the fuel cell at such challenging conditions, careful attention must be paid to managing heat and mass transfer to maximize performance.

Keywords

Carbonate Fuel Cell, Carbon Capture, Methane Reforming.

Introduction

To economically sequester or utilize CO_2 from dilute sources such as industrial emissions or power generation, technologies for concentrating CO_2 are required. Unfortunately, commercially available technologies are capital and energy intensive, reducing their effectiveness in limiting emissions. The advantage of the carbonate fuel cell is that it can effectively concentrate CO_2 and simultaneously produce electricity. This example of process intensification takes advantage of the electrochemical reaction to drive a desirable separation. While carbonate fuel cells have been deployed commercially by our joint development partner FuelCell Energy, application under the strenuous conditions of carbon capture requires a reengineering of the fuel cell stack from the ground up.

Results

Utilizing model-guided and parallel development strategies, we are working across a number of process scales to understand the electrochemistry and process fundamentals. A technology stack with commercially sized repeat components is the main tool utilized to evaluate the scale up challenges of mass transfer and thermal management. To date, we have designed and built two such stacks. The second of these adapted many insights from the lab scale fundamentals research to design a cathode current collector that reduced the "carbonate gap" which arises from CO_2 mass transfer limitations in the fuel cell cathode. This carbonate gap was responsible for reduced carbon capture efficiency and voltage. With a redesigned current collector, the mass transfer limitation induced carbonate gap was reduced by >60% while simultaneously increasing voltage by >25 mV.

Additionally, because of the exothermic nature of the electrochemical reactions and heat generation from electrical resistivity, thermal management is critical. Endothermic steam methane reforming is used to heat balance the fuel cell stack and provide the hydrogen which maintains the driving force for the carbonate mass transfer. Carefully co-locating the heat generation and consumption reactions is critical to reducing thermal gradients rather than

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exacerbating them. A modeling approach was utilized to design a methane reforming catalyst pattern that could reduce thermal gradients by ~40% within the fuel cell stack and allow for improved electrochemical performance.

In addition to continued improvements to the CO_2 mass transfer and thermal management, next generation designs are being considered that have altered cathode and anode flow patterns. The first two stacks had a cross-flow arrangement that is mechanically easier to construct at scale, but that results in a spatial mismatch between areas of CO_2 and H_2 concentration as well between areas of max heat generation and consumption. Models are again playing a leading role in outlining the potential advantages of alternative flow patterns. Because these advantages rely on achieving well distributed and aligned flow, detailed CFD is being combined with the larger process models to choose among many potential mechanical designs of the cells while avoiding the time and cost of building and testing each alternative.

Conclusions

The dual challenge of extending the benefits of energy access and mitigating risks from carbon emissions is daunting but not insurmountable. The carbonate fuel cell solves one of the biggest issues of carbon capture technology, parasitic energy usage, by actually co-producing electricity along with capturing CO_2. The deployment of this unique reactive separation technology, however, relies on careful engineering to properly manage the heat and mass transfer during scale-up. Development of fundamentals based models have been key in guiding the scale up and experimental design by highlighting the key mass and heat transfer issues and guiding solutions. Going forward, the model guided design approach will be key in matching process conditions and hardware design to specific carbon capture applications as each application presents unique challenges of economics and feed composition.