A 3D topology optimization model of the cathode air supply channel in planar solid oxide fuel cell

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A 3D topology optimization model is developed to design the geometry of an air supply channel in solid oxide fuel cell (SOFC). The net electrical energy generation (i.e., the total electrical energy generated minus the energy cost of pumping air) of the cathode is maximized by altering the path of the oxygen gas transport in a medium Reynolds number (1<Re<100), modifying the air-cathode interface (ionic transfer interface) and adjusting the path of oxygen ion diffusion in the cathode.

Previous work by the authors used a simplified 2D model to explore the effect of altering the shape of the cross section of the channel, based on the classic rectangular channel used in current planar SOFC applications. Ignoring the oxygen gas transport, the model was reduced to a 2D oxygen ion diffusion problem with a design-dependent ionic transfer boundary condition. That simplification is only valid when oxygen gas supply is saturated and the energy cost associated with pumping air is not significant. These limitations motivate the 3D coupled model developed in this work.

The air flow in the channel with design-dependent geometry is modeled using a mixed formulation of the momentum equation. The resulting velocity field is used as a known parameter in the calculation of the oxygen gas transport. The oxygen gas transport is described by the convection-diffusion equation and is coupled with the oxygen ion diffusion by a design-dependent ionic transfer boundary condition. Although the 3D model can accommodate several design concepts, only two design strategies are explored in this work, focusing on the concepts that are easier to manufacture.

In the first strategy we look for improved solutions by changing the cross section of the channel. A second strategy consists of placing a series of porous cathode barriers, uniformly spaced along the air flow direction. In this strategy we design the microstructure of the barriers. Both designs are geometrically periodic in the air flow direction. From the periodicity, the air flow is expected to be periodic. Moreover, given the low oxygen gas consumption in planar SOFC applications, the oxygen gas transport can also be assumed to vary periodically, with a small decay. The periodic repeating portion of the channel is designated as a periodic cell. It is selected as the analysis domain and is modeled using a finite element method. Effective “densities” with values between 0 and 1 are used to describe the presence of cathode material (value 1) or free air flow path (value 0). Design-dependent boundary conditions are modeled as functions of the element densities. The optimal geometry of the cross section of the channel (strategy 1) and the optimal microstructure of the barriers (strategy 2) are identified by a standard, density based topology optimization method. Numerical examples are provided to discuss the effects of different cathode material properties, different periodic lengths and different thicknesses of the cathode barriers.

Key words: planar solid oxide fuel cell, topology optimization, 3D coupled model