Thermal Radiation Modelling in a Tubular Solid Oxide Fuel Cell

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ABSTRACT

Thermal radiative heat transfer must be considered when modelling tubular solid oxide fuel cells (SOFCs):

❖Operating temperatures of 1050-1200K make radiation a dominant form of heat transfer in low speed flows, such as this one.

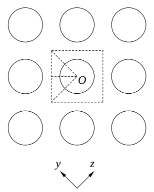
❖The tubular geometry gives larger path lengths than planar designs, which increases the influence of radiative heat transfer.

❖Several types of gases involved in the fuel stream participate in radiative heat transfer, while others do not.

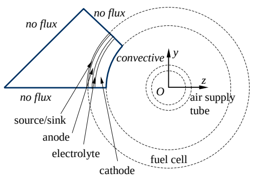
This is an ongoing study to determine the modelling requirements for solid oxide fuel cells. The effect of radiation is shown to be significant for the parameters chosen. Cathode channel air flow is also revealed to play a vital role in cell cooling.

SINGLE CELL MODEL

The model is a 1/8th symmetrical section of a 1.5m long Siemens Westinghouse tubular solid oxide fuel cell in the center of a stack. Fuel flow occurs over the anode surface and is simulated using the commercial computational fluid dynamics code, FLUENT. Heat transfer to the cathode air channel (annulus of cell) is approximated by a uniform convective boundary (T_{ref} = 1223K).



Top view of stack



Single cell with cross-section of model in blue

❖350mA/cm^2 (68% fuel utilization, single pass)

❖Prereformed fuel entering anode channel at 1023K

❖Fuel flow is laminar, consisting of H_2O, H_2, CO_2, CO

❖Radiation solved using the Discrete Ordinates (DO) method (2 theta divisions, 2 phi divisions)

❖Structured mesh built in GAMBIT (83,250 elements)

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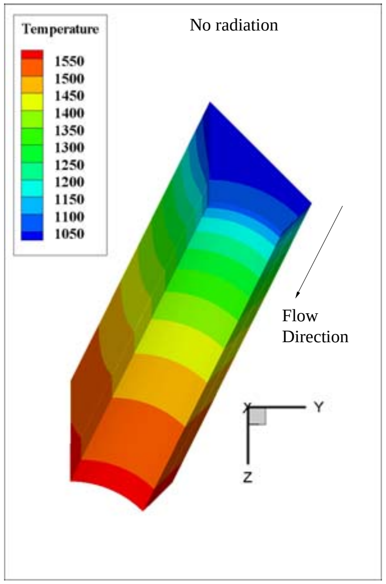
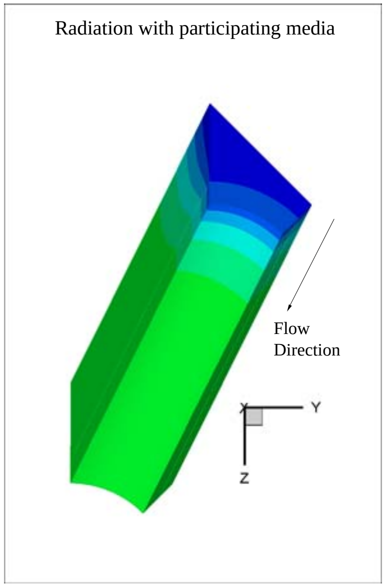
RADIATION EFFECTS

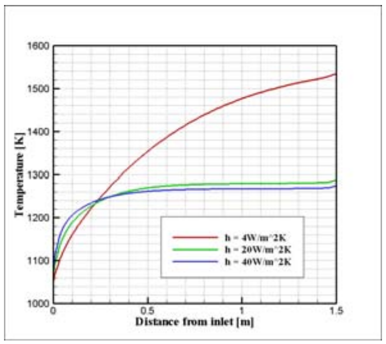
CFD Simulations

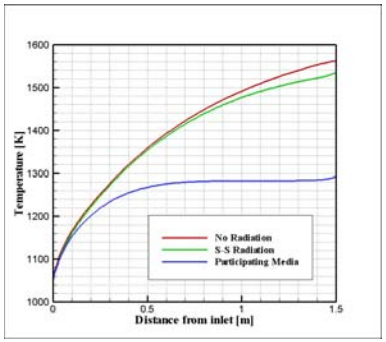
Anode flow over a 1.5m solid oxide fuel cell is shown below. The temperature profiles when no radiation is modelled (left), and when radiation with participating media is modelled (right) differ substantially. Lower overall temperature and smaller temperature gradients are a result.





Varying the convection coefficient (below, left) shows the sensitivity of the model to the cathode channel flow. It appears as though a limit exists, where increasing the convection further results in a diminishing return on cell cooling. The temperature profile is also affected by the complexity of the radiation model chosen (below, right). Radiation appears to aid in heat removal. In addition, the presence of gas participating in radiative heat transfer (CO_2 and H_2O) softens the temperature gradient along the cell.





Radiation, participating media, and internal flow all appear to reduce the operating temperature of the fuel cell, and should be included in a CFD model.

TRANSPORT PHYSICS

Fluid Properties

❖Temperature dependent species properties (thermal conductivity, viscosity, and specific heat capacity)

❖Leonard-Jones potential parameters were used when modelling multiphase diffusion using kinetic theory.

Fuel Cell Properties

❖From literature, density, thermal conductivity, and specific heat capacity were averaged to accurately represent the thermal properties of the solid components.

❖Heat generation is uniform over the fuel cell volume.

Parameters

❖Convection coefficient on cathode surface reduces the computational time incurred by modelling both air and fuel streams.

❖Absorption coefficient used in Discrete Ordinates (DO)

CONCLUSIONS AND FUTURE WORK

Radiation Modelling

❖When convection of heat from the cathode surface can be assumed minimal, radiation plays a dominant role in heat removal from the fuel cell surface.

❖Radiation and the influence of participating media help to reduce overall operating temperature, and smooth temperature gradients over the length of the cell.

Convection Boundary Condition

❖The physics of the air channel flow cannot be ignored, or simply approximated with parameters when accuracy is required. The heat balance of the fuel cell highly depends on the thermal convection from the cathode surface.

Future Work

The study will continue in the following directions:

❖Electrochemical model for non-uniform current density.

❖Implement a full anode/cathode flow CFD model.

❖Propose non-uniform heat generation in the fuel cell.

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