Thermal Modeling of a Honeycomb Reformer Including Radiative Heat Transfer

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Abstract

Reformer and catalytic burners are common components in fuel cell systems, crucial for efficient preparation of fuel and exhaust gases of the fuel cell stack. Modeling has been proved as a valuable tool in the design and optimization process to ensure a safe, efficient and enduring operation of the reactors. Subject of the modeling is the thermal management together with fluidic behavior and reaction engineering. In the presented case a cylindrical reformer unit from a SOFC-system, converting methane to hydrogen and carbon-monoxide, with a catalytic honeycomb (cordierite) structure was analyzed in a model obeying free (turbulent) and porous flow, convective and conductive heat transfer and chemical reaction. The model consists of an axisymmetric representation of the inlet-zone, the catalytic body and the outlet zone (figure 1). To reduce the computational demands the honeycomb structure with its huge number of parallel rectangular channels was simplified as an anisotropic, porous, continuous media with permeability, volume specific heat transfer coefficient and inner surface parameters adapted to reflect its channel structure. The temperature in the reactor reaches up to 900°C. In this temperature range thermal radiation is an import mode for heat transport and should be included into the model, to characterize the radiative interaction of the honeycomb with the housing in the gas entrance and exhaust chambers, resulting in a redistribution of heat between housing, catalyst body and gas. COMSOL Multiphysics® offers surface-to-surface and participating media interfaces to account for thermal radiation. Both modes were problematic in our case due to the anisotropic, porous approach for the honeycomb. A surface to surface approach does neglect the participation of inner surfaces of the channels beneath the honeycomb body end faces. The participating media mode of COMSOL Multiphysics® only allows for isotropic transparent material while the honeycomb in our case was unidirectional isotropic. We there developed a separate 1D-description for radiative heat transport, with 2 opposite rays interacting with a semitransparent porous media. We tested and confirmed the validity of the approach by comparison of a corresponding 1D-model with a detailed thermal 3D-model of a single honeycomb channel with surface-to surface radiation and radiative interaction to the external environment by its open ends (figure 2). We used the verification to adapt the effective adsorption coefficient of the honeycomb material (figure 3). Finally the 1D radiation model was introduced into the 2D axisymmetric reformer model and coupled to a surface-to-surface mode in the inlet and outlet chamber. The model results reveal a strong influence of the consideration of thermal radiation on the temperature distribution of the reformer (figure 4). The presented model for radiative heat interaction in a semitransparent porous medium with unidirectional anisotropy proved to be an efficient approach for analyses of high temperature reactor devices, taking

advantage from the specific, flexible multiphysics capabilities of the COMSOL Multiphysics® code.

Reference

P. D. Ronney – Summary of radiation in participating media (Home page: http://ronney.usc.edu)

Figures used in the abstract

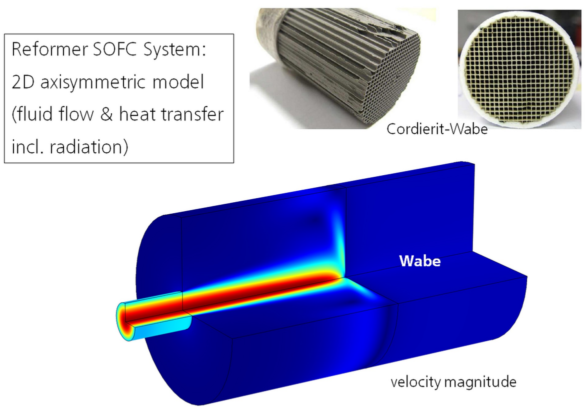

Figure 1: Model geometry with gas chambers and honeycomb body

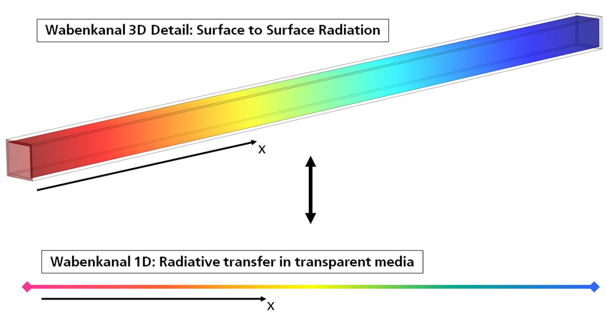

Figure 2: 3D (top) thermal S2S-radiation model of a honeycomb channel used to verify 1D model (bottom)

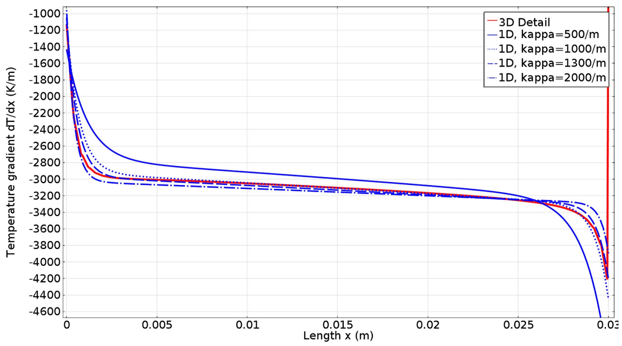

Figure 3: Comparison of 1D model results with variation for adsorption coefficient kappa to 3D-model result for axial gradient of T

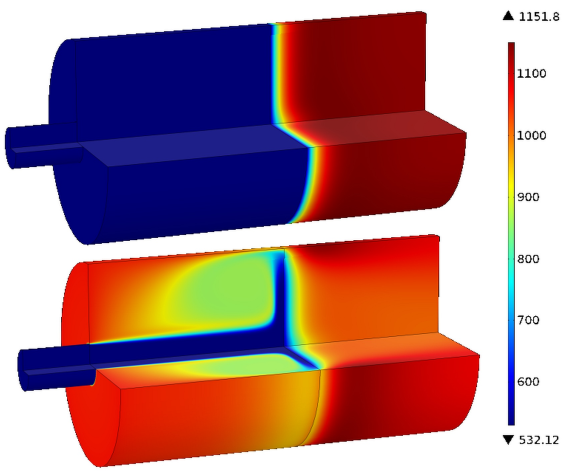

Figure 4: Model results for gas temperature for model without (top) and with (bottom, discussed 1D radiation approach) consideration of thermal radiation