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Development of a heterogeneous heat transfer model for open cell foams

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Highlights

- Gas/solid heat resistance can be the limiting heat transfer mechanism in foams
- Development of a heterogeneous heat transfer model
- Simulations of temperature profiles in low cell density foams

1. Introduction

Metallic cellular substrates are considered an enhanced catalyst support for non adiabatic applications; in contrast with packed beds the main heat transfer mechanism is heat conduction in the solid matrix. Previous studies on open cell foams showed an almost linear relationship between effective conductivity (k_{eff}) and the material conductivity. When dealing with conductive supports, however, often the wall heat transfer coefficient (h_{wall}) becomes the limiting resistance. In [1,2], correlations for the estimation of wall heat transfer coefficient h_{wall} are provided for loose foams, being inversely dependent of the foam cell diameter. In [3], CFD simulations were performed in order to assess the effect of the wall coefficient, comparing simulations where different fractions of wall were considered in perfect contact. Recently, Aghaei et al.[2] proposed a pseudo-homogeneous model for the estimation of the effective heat transfer parameters in high cell density foams, characterized by a very high surface area. However, extrapolation of this model to low cell density foams is questionable. In this contribution we propose an heterogeneous heat transfer model and we compare results with CFD simulations of sintered foams [3] and with experimental heat transfer data on wall-sintered and loosely fit foams.

2. Methods

Two sets of heat transfer data were collected in order to assess the effect of the foam-wall coupling. In the first set of experiment a foam sample was loosely loaded in a tubular reactor, while in the second case an aluminum foam was sintered to the reactor tube wall. The reactor was inserted in a thermostatic chamber and different gas flow rates of nitrogen or helium were fed. A temperature map inside foam sample was collected with 3 sliding thermocouples at different radial coordinates (central, lateral, wall). In the heterogeneous model, energy balances of the gas and solid phase were solved with finite differences in axial direction and orthogonal collocations in the radial direction. Solid conductivity was estimated with correlation proposed in [2], while gas/solid interphase heat transfer coefficient was derived from mass transfer analysis in open cell foams in view of the Chilton – Colburn analogy.

3. Results and discussion

To validate the 2D heterogeneous model, a comparison with CFD simulations for sintered foams [3] and is reported in Figure 1. Very close predictions of the radial average temperature along the axial coordinate are obtained for both helium and nitrogen flow in the case of perfect wall contact – i.e. with infinite wall heat transfer coefficient.

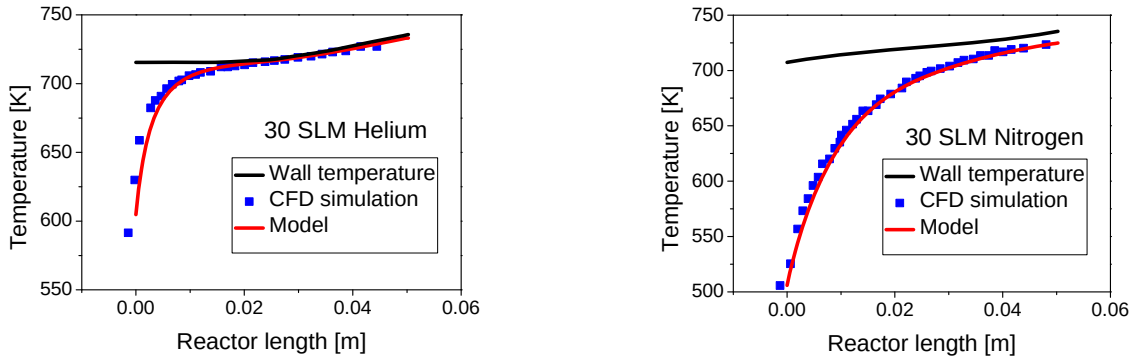

Figure 1. Comparison of radial average temperature profiles for CFD (symbols) [3] and heterogeneous model (lines) at 30 SLM and T_{oven} 773 K. Case of sintered foam.

Figure 2 (A) shows the comparison of temperature profiles calculated with the heterogeneous model with the experimental results obtained for a loose foam. The model matches well the experimental data with a wall heat transfer coefficient, h_{wall}= 106 W/m^2/K obtained from the correlation reported in [2]. Figure 2(B) instead shows a comparison of the measured temperature profiles for a sintered foam with those calculated by the model with a fitting value of h_{wall}=366 W/m^2/K. Sintering procedure lead to an increase of the wall heat transfer coefficient of almost three times with respect to loose foams.

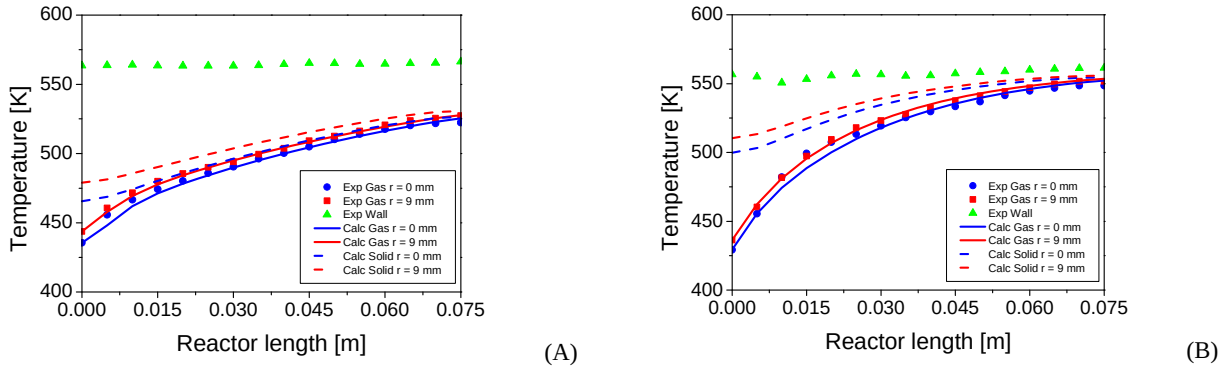

Figure 2. Temperature profiles at 30 SLM Nitrogen, T_{oven} 573 K, loosely fit foam (A) and sintered foam (B) symbols = experimental data, lines = model fit

4. Conclusions

We present the development of an heterogeneous 2D heat transfer model for open cell foams. This model has been validated against both CFD and experimental data. With this model it is possible to account for gas/solid limitations, that can be relevant for overall heat transfer performances of cellular substrates with low cell density. The model was used to quantify the strongly beneficial effect of wall sintering on the overall heat transfer performances of open cell foams.

Acknowledgment

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Keywords
Heat transfer intensification; open cell foams , mathematical modeling