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Simulation of water sorption dynamics in adsorption chillers: One, two and four layers of loose silica grains

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ABSTRACT

This paper presents a mathematical model of coupled heat and mass transfer in multi-layers of loose adsorbent grains under realistic conditions of adsorption heat transformation (AHT) cycle. The model allows a simulation of the adsorption dynamics in the adsorbent layer which consists of a low number of loose adsorbent grains ($1 \le n \le 4$).

Firstly, the model was validated by comparison with the kinetics of isothermal water adsorption on a single spherical grain, initiated by a small pressure drop, for which an analytical solution is well-known.

Afterwards, the model was applied to simulate non-isothermal water dynamics for adsorbent-heat exchanger configurations of one, two and four layers of loose grains of Fuji silica type RD. The grains are located on a metal support subjected to a fast variation of temperature as it takes place during isobaric phases of AHT cycle. The system of partial differential equations was solved by using the COMSOL Multiphysics® simulation environment.

The calculated sorption dynamics is in a good accordance with the experimental data obtained for $n = 1$, 2 and 4 under the same boundary conditions. Moreover, the model was used to simulate the ad/desorption process for different grain sizes (0.45, 0.85 and 1.7 mm).

The input parameters which ensure the best data fitting were compared with those experimentally determined for Fuji silica type RD as well as with the input data of other heat and mass transfer models presented in the literature. The developed model gives a powerful tool for accurate simulation of dynamic features for the AHT units with practically interesting configuration of the adsorber/heat exchanger which utilizes a low number of loose adsorbent grains. Moreover, useful information about radial and axial distributions of the temperature and vapour concentration can be obtained for both gas and solid phases. Finally, the specific cooling power of AHT cycle was estimated and recommendations on the cycle dynamic optimization were made.

1. Introduction

Adsorption dynamics dictates the compactness of adsorption heat transformers (AHTs) and is a subject of careful optimization. The dynamics depends on many factors among which the most important is the configuration of "adsorbent – heat exchanger" (Ad-HEx). Two main concepts were suggested in literature [1–6]: a) loose adsorbent grains in contact with HEx surface, and b) HEx surface coated with a consolidated adsorbent layer. Here, we analyze the former configuration because it is very simple to realize and ensures a good vapour transport in the adsorbent layer [7]. On the other hand, this configuration is considered to suffer from a poor heat transfer due to the high thermal resistance in the adsorbent bed as well as between the adsorbent grains and the HEx surface. Despite this, the loose grain configuration has been successfully realized in several prototypes of adsorption chillers and heat pumps [8–13]. For instance, loose grains of a composite sorbent SWS-9L ($LiNO_3$/silica KSK) of 0.25–0.50 mm in size were embedded inside a compact heat exchanger of a finned flat-tube type, so that 2–4 grains could be housed in a 1 mm gap between the fins [12].

In addition, the dynamics of water ad- and desorption for the configuration "*n*-layers of loose grains of a silica Fuji RD" has recently been studied for $n = 2$ and $n = 4$ by a Large Temperature Jump (LTJ) method [14] under the four sets of boundary temperatures same as those used for $n = 1$ in Ref. [15]. The water adsorption

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