Extended Frequency Response Analysis for Loading and Temperature Dependent Heat and Mass Transfer Evaluation in Adsorbent Coatings

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Abstract

The combination of heat and mass transfer (HMT) phenomena and sorption equilibria are governing the adsorption dynamics. Their thorough understanding is crucial for the improvement of power density on appliance level. HMT phenomena are often difficult to distinguish, especially regarding the dependency on loading and temperature, i.e. the thermodynamic state of the adsorbent. In this contribution a frequency response (FR) analysis extended by manometrical equilibrium measurements is presented as a novel method for measuring both, adsorption equilibrium and HMT, in a single measurement for the example of an aluminium fumarate coating with water as refrigerant. This includes the direct measurement of the adsorption equilibrium derivatives for adsorption enthalpy evaluation. The thermal conductivity of the samples was identified as about 0.07 W/(m K), and the LDF time constant between 0.1 and 3 s^{-1} at 40 °C with a U-shaped loading dependency and an Arrhenius-type temperature dependency. The heat transfer coefficient h for the contact between coating and support was identified to $\geq 4 \times 10^3$ W/(m^2K). The method is validated by comparing a measured large temperature jump experiment to the results from a non-linear simulation informed solely by these parameters obtained from the new FR-based method.

Keywords: adsorption dynamics; heat and mass transfer; frequency response analysis; adsorption equilibrium, adsorption enthalpy; aluminium fumarate; metal organic framework

Introduction

The increase of volume specific cooling power – thus reduction of specific costs – while keeping a reasonably high COP is one of the major development challenges for adsorption chillers [1]. Further performance increase can be reached through model based design and optimization which is more cost-effective than empiric trial-and-error prototyping of adsorption heat exchangers (Ad-HX) [2]. However, model based design requires detailed knowledge of a) relevant physical heat and mass mechanisms and the corresponding transfer coefficients, b) the adsorption equilibria, c) the adsorption enthalpy and d) the specific heat capacities, allowing for models with explicit dependency on design parameters like heat exchanger geometry, layer thicknesses and particle sizes. In this work we propose a comprehensive approach to gain most of this data from small representative Ad-HX cut-outs based on the FR analysis [3, 4].

As example material we use aluminium fumarate, a metal–organic framework (MOF) that exhibits adsorption equilibrium properties fitting well to low-driving-temperature applications [5] like data centre cooling driven by heat yielded from water cooled CPUs [6].

Discussion and Results

Sample plates (5x5 cm²) were coated (A_{ct} = 18.9 cm²) with different thicknesses (140, 240, 610 µm) and placed on a temperature-controlled plate in a variable-volume vacuum chamber.

The integrated measurement procedure consists of absolute adsorption equilibrium measurements by manometric uptake measurements, differential adsorption equilibrium measurements by small step-wise volume and temperature variations around an equilibrium point, and thermal frequency response measurements at the same equilibrium point through sinusoidal volume variations while measuring pressure and surface-temperature responses.

The measured FR, i.e. amplitude and phase shift at different variation, could be well reproduced with a Laplace-transformed model with 1-D-discretised heat transfer and LDF-simplified micro level mass transfer. This allowed to identify the loading and temperature dependent transport parameters (Figure 1). Macropore mass transfer and thermal contact resistance to the support showed to be irrelevant for the overall dynamics. Adsorption equilibrium and enthalpy results were published recently [4], detailed FR results will be available in due course [3].

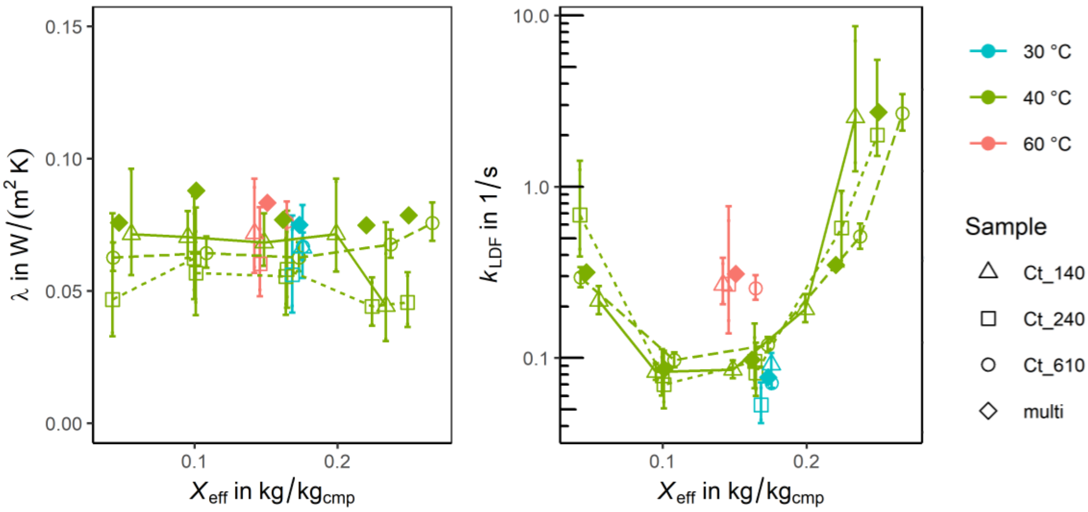

Figure 1: Estimated thermal conductivity λ and micro-level LDF-coefficient k_{LDF} over X_{eff}, the loading with respect to the dry coating mass for different coating thicknesses. Lines are only meant as guides to the eye.

Conclusions

The extended FRA was developed as a new method for the evaluation of heat and mass transfer parameters in an unprecedented resolution of the temperature and loading dependency. As the underlying models explicitly include geometrical parameters, the results may be directly used for design and optimisation of Ad-HX for adsorption heat pumps and chillers.

References

[1] L. Schnabel, G. Füldner, A. Velte, E. Laurenz, P. Bendix, H. Kummer, U. Wittstadt, in *Innovative Heat Exchangers* (Eds: H.-J. Bart, S. Scholl), Springer International Publishing. Cham **2018**.

[2] S. Graf, S. Eibel, F. Lanzerath, A. Bardow, *Energy Technol.* **2020**, 1901130. DOI: 10.1002/ente.201901130.

[3] E. Laurenz, G. Füldner, A. Velte, L. Schnabel, G. Schmitz, *International Journal of Heat and Mass Transfer* **2021**, *accepted*.

[4] E. Laurenz, G. Füldner, L. Schnabel, G. Schmitz, *Energies* **2020**, *13 (11)*, 3003. DOI: 10.3390/en13113003.

[5] D. Lenzen, J. Zhao, S.-J. Ernst, M. Wahiduzzaman, A. Ken Inge, D. Fröhlich, H. Xu, H.-J. Bart, C. Janiak, S. Henninger, G. Maurin, X. Zou, N. Stock, *Nature communications* **2019**, *10 (1)*, 3025. DOI: 10.1038/s41467-019-10960-0.

[6] T. Wilde, M. Ott, A. Auweter, I. Meijer, P. Ruch, M. Hilger, S. Kuhnert, H. Huber, in *Proceedings* **2017**.