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Modelling and Simulation of a closed Adsorption System for Thermal Energy Storage Applications

1. Introduction

Energy storages are gaining more importance. Especially thermochemical energy storages show high potential. The main advantages are:

- High energy storage density
- Negligible heat losses

In the field of seasonal storage of solar-thermal energy, concepts based on closed adsorption systems are promising (e.g. EU-Project COMTES).

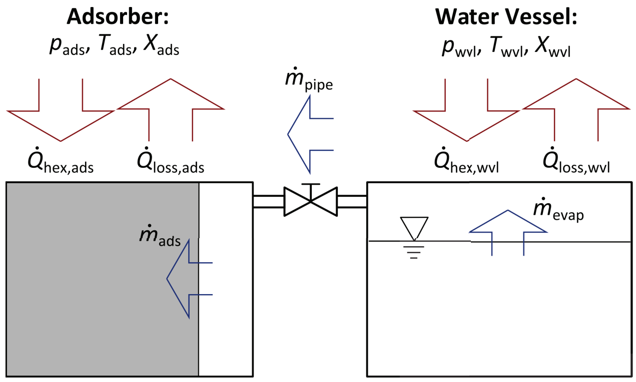
2. System Description

The examined system consists of:

- Two vessels with internal heat exchangers
- Vessels are connected via pipe, initially evacuated and vacuum-sealed → 3 phases
- Adsorption pair: water vapour ↔ zeolite

The phase change processes (ad- and desorption in the adsorber; evaporation and condensation in the water vessel) depend on the:

- heat flow in or out of the vessels
- current thermodynamic states in the vessels
- controlled vapour mass flow through the pipe



3. Simplified Modelling

A simplified 0-dimensional model is useful for a first equation-based similitude analysis. The main simplifications and assumptions are:

- Spatial dependencies of the state variables p, T, X in the vessels are neglected.
- The temperature differences between vapour and zeolite/condensate is negligible.
- Pipe mass flow and heat exchangers heat flows of two similar systems are also similar.

4. Similitude Analysis

Transformation of the governing equations for the simplified model into a non-dimensional form yields 32 non-dimensional parameters. These non-dimensional parameters can be reduced to 6 dimensional scaling constraints per vessel:

Constraint	Adsorber	WVL
$\gamma_{ads/wvl,1} =$	$k_{ads} t_{per}$	$\frac{k_{evap} t_{per}}{m_{wat,all}}$
$\gamma_{ads/wvl,2} =$	$\frac{V_{vap,ads}}{m_{zeo,dry}}$	$\frac{V_{wvl}}{m_{wat,all}}$
$\gamma_{ads/wvl,3} =$	$\frac{m_{wat,all}}{m_{zeo,dry}}$	$\frac{\Delta \dot{m}_{pipe,max}}{k_{loss,wvl}}$
$\gamma_{ads/wvl,4} =$	$\frac{t_{per} k_{loss,ads}}{m_{zeo,dry}}$	$\frac{t_{per} k_{loss,wvl}}{m_{wat,all}}$
$\gamma_{ads/wvl,5} =$	$\frac{\Delta \dot{Q}_{hex,ads,max}}{k_{loss,ads}}$	$\frac{\Delta \dot{Q}_{hex,wvl,max}}{k_{loss,wvl}}$
$\gamma_{ads/wvl,6} =$	$T_{amb,ads}$	$T_{amb,wvl}$

5. Advanced Modelling Approach

The motivation for an advanced modelling approach can be summarized as follows:

- Strong coupling of the macroscopic heat and mass transfer with the microscopic adsorption/ reaction kinetics and transport phenomena
- Classical models for porous flow (Darcy law) might not be applicable for low pressure processes (e.g. closed adsorption systems)

→Multi-Scale-Approach (Micro, Meso, Macro)

This contains:

- Direct numerical simulations on the meso scale
- Coupling the macro simulation with the results from the meso scale simulations in a proper way

Outlook: Advanced model should allow for specific optimization (heat and mass transfer).

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