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Modelling of an adsorption chiller for dynamic system simulation

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Adsorption chillers are periodically working chillers with fast temperature changes at the outlets of the hydraulic loops at the beginning of a new adsorption cycle. The scope of the current study is to predict the consequences of these temperature changes for the components in the hydraulic system in order to optimize the system's design. Therefore, a model of an adsorption chiller has been created in the object-oriented simulation language Modelica. The model follows a component approach for each part of the chiller based on fundamental equations for heat and mass transfer. Compared to an effective model all equations have a physical significance. Simulation results are validated by measurement values coming from an adsorption chiller tested. Measured temperatures and volume flows at the inlet of the hydraulic loops are given as input to the simulation model. The simulated output temperatures show good agreement with measured temperatures, heating and cooling power and coefficient of performance (COP).

Modélisation d'un refroidisseur à adsorption pour un système dynamique de simulation

Mots clés : Système à adsorption ; Modélisation ; Simulation ; Performance ; Paramètre ; Matériau ; Adsorbant

1. Introduction

When aiming at better control strategies for air conditioning systems with adsorption chillers it is important to understand the dynamic behavior of the hydraulic system. Dynamic simulations can help to predict the consequences of changes to the other components in the hydraulic system. Adsorption chillers are highly dynamic components with temperature variations of 30 K at the outlets on a minute time scale. This is due to the switching process of the adsorber between the adsorption and desorption phases. As a first step to system simulation a model for the adsorption chiller has been created. It is designed in the simulation language Modelica (Modelica Association, 2005) which offers a variety of public

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Nomenclature

A	adsorption potential ($\mathrm{J\,kg^{-1}}$)
A	surface ($\mathrm{m^2}$)
d	tube diameter (m)
E	internal energy (J)
H	enthalpy (J)
h	specific enthalpy ($\mathrm{J\,kg^{-1}}$)
h	convective heat transfer coefficient ($\mathrm{W\,m^{-2}\,K^{-1}}$)
L	length (m)
m	mass (kg)
Nu	Nusselt number
p	pressure (Pa)
Pr	Prandtl number
Q	heat (J)
R	specific gas constant ($\mathrm{J\,kg^{-1}\,K^{-1}}$)
Re	Reynolds number
S	statistical variable (arbitrary unit)
T	temperature (K)
U	overall heat transfer coefficient ($\mathrm{W\,m^{-2}\,K^{-1}}$)
w	velocity ($\mathrm{m\,s^{-1}}$)
W	adsorption volume ($\mathrm{m^3\,kg^{-1}}$)
x	adsorption loading ($\mathrm{kg_{ref}\,kg_{ad}^{-1}}$)

Greek symbols

α	linear expansion coefficient ($\mathrm{m\,K^{-1}}$)
β	global pressure drop coefficient ($\mathrm{s\,m^{-1}}$)
Δ	difference
ζ	friction factor (ms)

Subscripts and superscripts

ad	adsorbent
C	condenser
chilled	chilled water
D	desorber
e	evaporation
E	evaporator
fin	fins
gl	globes
hot	hot water
in	incoming
norm	normalized
meas	measured
out	out flow
p	constant pressure
ref	refrigerant
sat	saturation
sim	simulated

libraries for system simulation and a graphical user interface where components can easily be connected to each other. Modelica is characterized by three properties:

- equation solver, no sequential code is needed
- object-oriented, reusable classes
- models can be linked by connectors

The Modelica standard library and the Modelica_Fluid library (Casella et al., 2006) are used as base for this work. The standard Modelica library offers a media library where the physical properties of water in the two phase regime are described according to the IAPWS-IF97 standard (IAPWS, 1997). Moreover, a simple water model with constant properties is used to describe the medium in the pipes. All hydraulic ports of the chiller fulfill the standard as defined in the Modelica_Fluid library and therefore offer good reusability. Modelica comes with a lot of standard connectors to combine different models. From an abstract point of view the connectors should always consist of couples of variables, a flow variable for the conservation equation and a state variable describing the corresponding driving force. Two connectors were used in this work.

- Fluid connector (for pure substance media)

  flow variables: $\dot{m}, \dot{H}$
  state variables: p, h

- Thermal connector

  flow variable: $\dot{Q}$
  state variable: T

For the work presented in this article two library packages were created. The first package is a library for adsorption materials. So far, all embedded materials modeled are using Dubinin's approach (Dubinin, 1975). This means only one function must be given from measurements to derive fundamental adsorption properties (equilibrium conditions, specific adsorption enthalpy). The second package contains the models for the components. The main models are a model for the piping, a model for the vacuum vessels and a model for the controller. The vacuum vessels consist of two adsorbers, a condenser and an evaporator. All vacuum vessel components have a similar structure: a model to describe the heat exchanger and a model for mass transfer of either condensation, evaporation or ad/desorption.

2. Description of the model

The following will describe the most important equations in the two packages beginning with the adsorption material package.

2.1. *Adsorption material properties*

The physical properties of the adsorption material in terms of adsorption enthalpy and equilibrium conditions for temperature T, pressure p and load x are described according to Dubinin's theory (Dubinin, 1975). The theory states that the properties can be derived from one equation

$$W = f(A) \tag{1}$$

in which W is the adsorption volume that describes how much refrigerant can be adsorbed onto the adsorbent surface. Therefore, it is proportional to the load