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A dynamic simulation model for transient absorption chiller performance. Part I: The model

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ABSTRACT

This paper is the first of two which presents the development of a dynamic model for single-effect LiBr/water absorption chillers. The model is based on external and internal steady-state enthalpy balances for each main component. Dynamic behaviour is implemented via mass storage terms in the absorber and generator, thermal heat storage terms in all vessels and a delay time in the solution cycle. A special feature is that the thermal capacity is partly connected to external and partly to internal process temperatures.
In this paper, the model is presented in detail. For verification, the model has been compared to experimental data. The dynamic agreement between experiment and simulation is very good with dynamic deviations around 10 s. General functionality of the model and a more detailed comparison with experimental data are presented in Part II of this paper.

Modèle de simulation dynamique utilisé pour la performance transitoire d'un refroidisseur de liquide. Partie I : le modèle

Mots clés : Refroidisseur de liquide ; Système à absorption ; Eau-bromure de lithium ; Modélisation ; Performance ; Régime transitoire ; Comparaison ; Expérimentation

1. Introduction

The dynamic model of an absorption chiller allows the simulation of its transient behaviour for changing input conditions or design parameters. This is important because absorption chillers usually have a high thermal mass, consisting of their internal heat exchangers, the absorbing solution and the externally supplied heat transfer media. The dynamics of an absorption chiller are therefore rather slow compared to similar capacity compression chillers. The time to achieve a new steady-state with all parameters after a change of input conditions is about 15 min for the chiller presented in this paper.

If the chiller is implemented in a complex heat supply/cooling demand system, e.g. a solar thermal or waste-heat

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Nomenclature

Variables

A	area (m^2)
A	Duehring factor (°C)
B	Duehring factor (–)
c	specific heat capacity ($kJ\,kg^{-1}\,K^{-1}$)
c	number of simulation steps representing time constants for transport delay (–)
D	dew point temperature (°C)
g	gravity constant ($N\,m^2\,kg^{-2}$)
h	height difference between generator outlet and absorber inlet (m)
h	enthalpy ($kJ\,kg^{-1}$)
l	specific heat of solution ($kJ\,kg^{-1}$)
$m,\dot{m}$	mass flow rate ($kg\,s^{-1}$)
M	mass (kg)
p	pressure (Pa)
$Q,\dot{Q}$	heat flux (kW)
r	evaporation enthalpy ($kJ\,kg^{-1}$)
R	gas constant for water vapour ($J\,kg^{-1}$)
T	temperature (°C)
t	time (s)
UA	heat transfer coefficient ($kW\,K^{-1}$)
x	solution mass fraction ($kg_{Salt}\,kg_{Sol}^{-1}$)
X	mole ratio (–)
z	solution level in generator sump (m)

Greek letters

η	effectiveness (–)
ρ	density ($kg\,m^{-3}$)
Δ	difference (–)
ϑ	temperature (°C)

Indices

A	Absorber
C	Condenser
d	Duehring
E	Evaporator
ext	external
G	Generator
i	simulation time interval
in	inlet
int	internal
meas	measured
p	pump
p, pc	at constant pressure
s	strong
sim	simulated
sol	solution
st	storage
SHX	solution heat exchanger
sG	strong solution leaving the generator tube bundle
sA	strong solution leaving the generator sump and entering the absorber
t	tube
tb	tube bundle
out	outlet
v	vapour
w	water, weak
wA	weak solution leaving the absorber tube bundle
wG	weak solution leaving the absorber sump and entering the generator
X	general index for vessels ($X = A, C, E, G$)
*	time delay of solution at generator and absorber inlet

driven system, the simulation of the chiller is usually being done using steady-state models. They simulate the chiller assuming constant operating conditions and allow the determination of internal and external cycle parameters, such as heat exchanger sizes, pump flow rates, temperatures and heat flows. However, steady-state models do not provide time-dependent information on the thermal behaviour of absorption chillers and are therefore not suitable for transient system simulations. In contrast, the model presented in this work allows the simulation of the dynamic chiller behaviour. It extends the range of applicable models for transient system simulations, where the time constants of the chiller significantly influence the system performance.

Research on dynamic system behaviour was carried out for both LiBr/water and water/NH_3 heat pumps, chillers and components of such. Most complete are the recent papers by Bian et al. (2005), and Jeong et al. (1998). Bian et al. (2005) have performed a transient simulation of an absorption chiller. They present a chiller model that can be run using variable time steps for the simulation. It includes a temperature change term of each heat exchanger per time step as well as a mass storage term in the generator, i.e. a part of the strong solution is being stored in the generator in each time step. The model has been verified with experimental data and shows good agreement in the transiency of the thermal behaviour, even if absolute values do not exactly match.

Jeong et al. (1998) present the dynamic simulation of a steam-driven LiBr/water absorption heat pump for the use of low-grade waste heat. The model assumes storage terms with thermal capacities and solution mass storage in the vessels. Solution and vapour mass flow rates are calculated in proportion to pressure differences between vessels. The heat transfer coefficients as well as the simulation time step are assumed to be constant. The model has been verified with good agreement using operational data for an absorption chiller.

The dynamic model presented here simulates the reaction of the absorption chiller on a change of external conditions. In contrast to the approach in the cited references above, a simpler model structure was chosen in order to learn more about the most important interdependencies in a direct manner. For instance, emphasis is on the fact that the thermal storage terms respond partly to the temperatures of the external fluids and partly to the internal process streams and these effects are separated. In contrast to this, the steady-state was incorporated very coarsely only, because time-consuming iterations were to be avoided. The model has been developed for and verified on the 10 kW absorption chiller manufactured by Phoenix SonnenWaerme AG (Kohlenbach, 2006).