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Dynamic modeling and simulation of a double-effect absorption heat pump

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ABSTRACT

This paper presents a new dynamic model to study the transient thermochemical behavior of a double-effect absorption heat pump (DEAHP). It has been designed according to the experience with an experimental DEAHP totally integrated into a solar-assisted multi-effect distillation (MED) plant set up at CIEMAT – Plataforma Solar de Almería (PSA). The non-linear first-principles model was implemented using the equation-based object-oriented Modelica modeling language and is based on a mathematical formulation that describes the main heat and mass transfer phenomena in this kind of facilities. A modular and hierarchical modeling methodology has allowed a graphical modeling development. Submodels that wrap the different physical phenomena are interconnected between them, thus making a three level deep hierarchy. All the submodels have been calibrated and validated with experimental data. The numerical predictions show a good agreement with measured data.

Modélisation dynamique et simulation d’une pompe à chaleur double-effet à absorption

Mots clés : Bromure de lithium ; Transitions de phase ; Film tombant ; Modélisation orientée objet ; Modelica

1. Introduction

One of the industry demands is to improve the efficiency of the processes by reducing its energy cost. Recovering the rejected energy from industrial processes and returning it to the process is one possible way to increase the energy efficiency. The main hurdle is that the low temperature of the recovered energy prevents from reusing it as the main energy source of the process.

A heat pump is a thermal machine that transfers heat from a low temperature to a high temperature source. According to the second law of thermodynamics, an external energy input is required to make this heat transfer possible. The nature of this input determines the technology of the heat pump. If it is heat, absorption technology is the most extended.

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Nomenclature

A	Area (m^2)
Ar	Archimedes number (dimensionless)
C_p	Specific heat capacity at constant pressure ($J \cdot kg^{-1} \cdot K^{-1}$)
C_R	Rohsenow correlation coefficient (dimensionless)
D	Diameter (m)
F	Apparent wet area fraction (dimensionless)
g	Gravitational acceleration ($m \cdot s^{-2}$)
H	Enthalpy (J)
h	Specific enthalpy ($J \cdot kg^{-1}$)
L	Latent heat of vaporization ($J \cdot kg^{-1}$)
l	Length (m)
m	Mass (kg)
N	Number (dimensionless)
Nu	Nusselt number (dimensionless)
n	Nusselt correlation coefficient (dimensionless)
n_R	Rohsenow correlation coefficient (dimensionless)
K	Mass gas constant ($J \cdot K^{-1} \cdot kg^{-1}$)
k	Thermal conductivity ($W \cdot m^{-1} \cdot K^{-1}$)
Pr	Prandl number (dimensionless)
p	Pressure (Pa)
Q	Heat (J)
q	Heat per area ($J \cdot m^{-2}$)
Re	Reynolds number (dimensionless)
r	Radius (m)
T	Temperature (K)
V	Volume (m^3)
w	Mass fraction (dimensionless)
y	Proportional number (dimensionless)

Greek symbols

α	Heat transfer coefficient ($W \cdot m^{-2} \cdot K^{-1}$)
η	heat exchanger factor (dimensionless)
θ	Heat exchanger factor (dimensionless)
μ	Dynamic viscosity ($kg \cdot m^{-1} \cdot s^{-1}$)
ν	Kinematic viscosity ($m^2 \cdot s^{-1}$)
ρ	Density ($kg \cdot m^{-3}$)

Newton's notation is used for time derivatives.
The bold terms depict the differential operator for a continuous time state.

Subscripts

A	Area
ag	Falling film absorber/generator
av	Average
bc	Horizontal tube bundle condenser
c	Falling film condenser
col	Column
cond	Condensate
cr	Crosses in the vessel
e	Falling film evaporator
ev	Evaporated
ext	External
ff	Falling film evaporator or condenser
fg	Flooded generator
fl	Flash
g	Gas volume
he	Heat exchanger
hw	Hot water
in	Inlet
int	Internal
l	Liquid
mea	Measured
nom	Nominal
out	Outlet
onset	Onset
p	Pressure flow
par	Parallel pipes
pp	Pipe
pt	Phase transition
row	Row
s	Surface
sim	Simulated
sl	Saturated liquid
st	Storage
sv	Saturated vapor
T	Total
tk	Tank
top	Top
tv	Tree-way valve
V	Volume
va	Valve
w	Pipe wall
water	Water
wet	Wet

Nevertheless if the input is work, vapor compression technology is the most usual choice.

The multi-effect distillation (MED) process is a good example of an industrial process which can be enhanced by a heat pump. Some theoretical analysis of integrating a DEAHP into solar-assisted MED processes has shown better performance than with other types of heat pumps (Alarcón-Padilla et al., 2010). The high coefficient of performance (COP) and its flexibility at part-load operation without a COP reduction are the main advantages of this technology. Lithium bromide and water ($LiBr/H_2O$) are the preferred working fluids due to the operating range of temperatures of the process. This kind of heat pumps is the focus of this work.

Absorption heat pumps (AHP) are systems with a high thermal inertia; therefore, its dynamic is rather slow compared to similar capacity compression heat pumps. This has a special relevance at starting-up and at part-load operation. The complicated interaction between the device and its thermal sources limits the operating conditions at transient stages. The hard controlability of the plant is caused by this problem. Process modeling and simulation provide knowledge about the physical phenomena and give detailed information about the thermal behavior that may be useful in order to improve the efficiency of the machine over a wide range of operating conditions without experimentation at the real plant. Also, dynamic modeling is a subject of particular importance for