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Transient modeling of a flash tank vapor injection heat pump system – Part I: Model development

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ABSTRACT

This two-part article explores the dynamic behavior of a flash tank vapor injection heat pump system from a numerical simulation perspective. Part I provides a first-principles model describing the transient heat transfer and flow phenomena of the system with detailed modeling techniques for each component. The vapor injection scroll compressor is analyzed with the internal heat transfer between the refrigerant and metallic parts taken into account. Lumped-parameter models are developed for the flash tank and expansion devices. Heat exchangers are modeled using a finite volume approach and accounting for the complex tube circuitry. The separated flow model without interfacial exchange is utilized for two-phase flows in order to incorporate an appropriate void fraction model so that a more accurate prediction for refrigerant mass distribution can be achieved. The modular nature of the component models allows flexibility in the system configuration. Transient simulations are carried out for start-up and shut-down operations. A detailed comparison of model predictions against experimental data is presented in the companion paper.

Modélisation transitoire d'un systéme de pompe à chaleur à injection de vapeur à partir d'un réservoir à vaporisation instantanée – Partie I: développement du modéle

Mots clés : Transitoire ; Modélisation ; Injection de vapeur ; Ecoulement diphasique ; Réservoir intermédiaire ; Modelica

1. Introduction

Flash tank vapor injection (FTVI) system has been gaining popularity since it was first introduced to the market in late 1970s (Umezu and Suma, 1984). Its applications have increased considerably in order to satisfy various needs, such as heating, cooling and refrigeration (Baek et al., 2008; Cho et al., 2009; Scarcella and Chen, 2010). Compared to the conventional systems without vapor injection, FTVI systems are operated under lower discharge temperatures and have higher performance in energy efficiency. Moreover, these systems are able to adjust the capacity by altering the vapor injection ratio (Winandy and Lebrun, 2002). Experimental

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Nomenclature

Symbols

a_1–a_3	curve fitting constants [-]
A	area [m^2]
b_1–b_5	curve fitting constants [-]
c_0–c_3	curve fitting constants [-]
c_p	specific heat [J kg^{-1} K^{-1}]
C_v	discharge coefficient [-]
d	diameter [m]
e_{sh}	error between the measured superheat and the set point [K]
f	pressure drop coefficient [-]
F	spring force [N]
G	mass flux [kg m^{-2}]
h	enthalpy [J kg^{-1}]
$\overline{h}$	mass flow weighted enthalpy [J kg^{-1}]
$\overline{h}_{FT}$	mass-based refrigerant mean enthalpy in flash tank [J kg^{-1}]
$\overline{h}_{\rho}$	density weighted enthalpy [J kg^{-1}]
H	height [m]
K	PID gain [-]
Le	Lewis number [-]
$\dot{m}$	mass flow rate [kg s^{-1}]
M	mass [kg]
n	polytropic index [-]
N	motor speed [min^{-1}]
p	pressure [N m^{-2}]
P	perimeter [m]
q	heat transfer rate [W]
q''	heat flux [W m^{-2}]
R	thermal resistance [K W^{-1}]
t	time [s]
T	temperature [K]
u	velocity [m s^{-1}]
V	volume [m^3]
$\dot{V}$	volumetric flow rate [m^3 s^{-1}]
$\dot{W}$	power [W]
x	flow quality [-]
$\hat{x}$	static quality [-]
y	spring deflection [m]
Δ	difference
Δy	segment length along the direction of air flow [m]
Δz	segment length along the direction of refrigerant flow [m]

Greek letters

α	heat transfer coefficient [W m^{-2} K^{-1}] or mass transfer coefficient [kg s^{-1} m^{-2}]
β	angle [degree]
ε	emissivity [-]
γ	void fraction [-]
η	efficiency [-]
φ	valve opening fraction [-]
κ	spring constant [N m^{-1}]
μ	dynamic viscosity [kg m^{-1} s^{-1}]
ρ	density [kg m^{-3}]
σ	Boltzmann constant [m^2 kg^2 s^{-2} K^{-1}]
τ	time constant [s] or wall shear stress [N m^{-1}]
ω	humidity ratio [kg H$_2$O/kg dry air]
ξ_{shf}	fraction of mechanical loss at the shaft [-]
ζ	built-in volume ratio of the first stage [-]

Subscripts

a	air
als	between ambient and compressor lower-shell
amb	ambient
aus	between ambient and compressor upper-shell
b	sensor bulb of TXV
c	correction
comp	compression
cs	cold stream
d	derivative
diaph	diaphragm of TXV
dis	discharge
disp	displacement
eo	evaporator outlet
eq	equalization
exp	expansion device
f	saturated liquid
face	frontal face
fg	liquid to gas
fin	fin
FT	flash tank
g	saturated vapor
h	mass flow weighted
hcs	between hot stream and cold stream
hs	hot stream
i	integral
in	inlet
inj	injected flow
int	intermediate stage
liq	liquid
lo	liquid outlet
ls	compressor lower-shell
m	motor or mass transfer
max	maximum
mech	mechanical
mix	mixing
nom	nominal
o	external
offset	offset
ori	orifice of TXV
out	outlet
p	proportional
pin	pin of TXV
r	refrigerant
rated	rating conditioning
rev	reversing valve
rls	between refrigerant and compressor lower-shell
rm	between refrigerant and compressor motor
rscr	between refrigerant and compressor scroll set
rshf	between refrigerant and compressor shaft
sat	saturation
scr	scroll set
sh	superheat