available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/ijrefrig

www.iifiir.org

ELSEVIER

Simulation model for complex refrigeration systems based on two-phase fluid network – Part I: Model development

Shuangquan Shao, Wenxing Shi, Xianting Li, Qisen Yan*

Department of Building Science, School of Architecture, Tsinghua University, Beijing 100084, China

ARTICLE INFO

Article history:
Received 29 March 2007
Received in revised form
19 June 2007
Accepted 2 July 2007
Published online 24 July 2007

Keywords:
Refrigeration system
Refrigeration
Heat pump
Air conditioning
Modelling
Simulation
Performance
Parameter
Refrigeration circuit

ABSTRACT

Some complex refrigeration and heat pump systems with several condensers and evaporators have been developed for different kinds of application. Traditional simulation models were developed for systems in certain operating modes and they failed in modeling the complex refrigeration systems with uncertainties of heat exchangers function and refrigerant flowing direction. In order to predict the performance of complex refrigeration systems, a simulation model is presented based on the two-phase fluid network. The model is consisted of distributed-parameter model of heat exchangers and connecting tubes, map-based model of inverter compressor and electronic expansion valve (EEV). Based on the characteristic of refrigeration system and fluid network, the three conservation equations, i.e. energy, momentum and mass equations, are solved iteratively. This model can deal with the uncertainty of refrigerant flow direction by separating the solving process of the components and the fluid network model, and therefore can simulate different kinds of complex refrigeration systems in different operating modes and conditions. The model is validated by the experimental data of an inverter air conditioner in heating/cooling operating modes and it shows the error of the model is mainly determined by the error of submodels of components in calculating heat transfer and pressure loss. The model is applied for performance analysis of three kinds of complex refrigeration systems in the accompanying article [Shi W.X., Shao, S.Q., Li, X.T., Yan, Q.S., 2008. Simulation model for complex heat pump systems based on two-phase fluid network: part II – model applications, International Journal of Refrigeration 31 (3), 500–509.].

Modèle pour la simulation des systèmes frigorifiques complexes fondés sur un réseau de fluide diphasique - Partie I : développement du modèle

Mots clés : Système frigorifique ; Réfrigération ; Pompe à chaleur ; Conditionnement d'air ; Modélisation ; Simulation ; Performance ; Paramètre ; Circuit frigorifique

* *Corresponding author.* Tel.: +86 10 62785860; fax: +86 10 62773461.
E-mail address: xtingli@tsinghua.edu.cn (X. Li).
0140-7007/$ – see front matter
doi:10.1016/j.ijrefrig.2007.07.001

Nomenclature

$\mathbf{A}$	base node–branch relationship matrix (–)
$\mathbf{A}_{\mathrm{I}}$	inlet node–branch relationship matrix (–)
$\mathbf{A}_{\mathrm{O}}$	outlet node–branch relationship matrix (–)
A_i	inner section area of tube (–)
A_{EEV}	flow area of EEV (m^2)
C_b	pressure drop coefficient of return bend tube (–)
C_d	mass flow rate coefficient of EEV (–)
C_p	specific heat ($kJ\,kg^{-1}\,K^{-1}$)
d	diameter of tube (m)
d_i	inner diameter of tube (m)
e_H	relative difference of enthalpy (–)
e_P	relative difference of pressure (–)
e_R	relative difference of mass flow rate (–)
f	compressor frequency (Hz)
g	gravity acceleration ($m\,s^{-2}$)
h	specific enthalpy of refrigerant ($kJ\,kg^{-1}$)
Δh	enthalpy difference of branches ($kJ\,kg^{-1}$)
i_j	indicator of refrigerant flowing direction (–)
k	heat transfer coefficient ($kW\,m^{-2}\,K^{-1}$)
L	length of tube (m)
m	refrigerant charge (kg)
$\dot{m}$	mass flow rate of refrigerant ($kg\,s^{-1}$)
$\dot{m}_{comp}$	refrigerant mass flow rate of compressor ($kg\,s^{-1}$)
n	number of heat exchanger
N_B	number of branch (–)
N_L	number of loop (–)
N_N	number of node (–)
P	pressure (Pa)
Δp	pressure difference (Pa)
Δp_y	pressure increase cause by some equipment in the branch (Pa)
Q	heat transfer rate (kW)
r	relative mass flow rate (–)
s	equivalent pressure loss coefficient (–)
T	temperature (°C)
ΔT	temperature difference (°C)
T_1	suction temperature (°C)
T_c	condensation temperature (°C)
T_e	evaporation temperature (°C)
w_y	power input (kW)
Δz	head difference (m)
ε_H	acceptable error of relative difference of enthalpy (–)
ε_M	acceptable error of total charge amount of refrigerant (kg)
ε_P	acceptable error of relative difference of pressure (–)
ε_R	acceptable error of relative difference of mass flow rate (–)
ρ	density of refrigerant ($kg\,m^{-3}$)

Subscripts

a	acceleration loss
f	friction loss
g	gravity loss
i	inner side of tube
I	inlet
O	outlet

Superscripts

′	new values
T	transpose of matrix

1. Introduction

Heat pump systems have been widely used in the last decade since they have been the necessities of life at home and in public areas due to the large demand for comfort in modern society. The conception of refrigeration or heat pump system has now developed from simple system with only one evaporator and one condenser to complex systems with several evaporators and condensers, even compressors. To facilitate more flexible and multi-purpose uses, complex refrigeration systems with a variable speed compressor or a group of constant speed compressors connected in parallel, an outdoor unit with a group of heat exchangers, and/or several indoor units have been developed (Qureshi and Tassou, 1996; Field, 2002; Masuda et al., 1991; Lijima et al., 1991; Ito and Miura, 2000; Shao et al., 2003a, 2004a; Ji et al., 2003; Chua et al., 2002). A multi-unit air conditioner is the system that could distribute cooling/heating capacity to different spaces, which is consisted of a number of indoor units and only one outdoor unit as shown in Fig. 1 (Masuda et al., 1991; Lijima et al., 1991). Some heat pumps were developed to use different kinds of heat sources simultaneously, such as a heat pump using water and air as heat sources in parallel (Ito and Miura, 2000). A heat pump with several heat exchangers in series or in parallel to produce domestic hot water was also developed (Shao et al., 2004a; Ji et al., 2003), where some heat exchangers are for domestic hot water and the others are for cooling or heating. Another such kind of complex system named multi-unit heat pump dehumidifier (Chua et al., 2002; Shao et al., 2003a) was developed, which has two condensers in parallel. One condenser is placed outdoor and the other is placed at back of the evaporator to recover part of the condensing heat and to keep the temperature of air passed through the evaporator.

Although the cycle principle of complex refrigeration system is the same as the simple one, we can see from the above-mentioned complex refrigeration systems that the major features of complex refrigeration system are as following: (1) Complexity – more components, more influencing factors, more operating modes for different purposes and more complex pipeline. (2) Uncertainty – the functions of the components are dissimilar in different operating conditions and the refrigerant flowing directions in the pipeline are uncertain even in the same operating mode. (3) Internal coupling – the complex refrigeration system is a closed one and cannot be solved by the method of simple refrigeration system because many components are coupled each other. These features make it difficult to conduct performance analysis, optimal design and to determine control strategy of complex system.