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Heat transfer performance variations of condensers due to non-uniform air velocity distributions

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ABSTRACT

The heat transfer performance variations of condensers that are caused by non-uniform distributions of air flows are investigated using a numerical simulation method. A heat exchanger designed for the outdoor unit of a heat pump system is selected and represented using a numerical model. A non-uniform profile of the air velocity is constructed through measuring the air velocity at various locations on the outdoor unit. Numerical analyses are conducted for various refrigerant circuits and air flow conditions. The results demonstrate that the heat transfer capacity is reduced depending on the air flow rate and the refrigerant circuit configuration. It is also demonstrated that the capacity reduction rate is increased as the average air velocity decreases.

Variations des performances de transfert de chaleur de condenseurs dues à la non uniformité de la vitesse de l'air

Mots clés : Pompe à chaleur aérothermique ; Condenseur ; Distribution non uniforme ; Échangeur de chaleur ; Écoulement d'air

1. Introduction

The performance of air source heat pumps and air conditioners is significantly affected by the performance of the heat exchangers. Therefore, designers of refrigeration systems and heat pumps have made a concerted effort to evaluate and improve the heat exchanger performance (Cho et al., 2014; Kim, 2015; Kim et al., 2015; Lee and Jeong, 2014). The heat exchangers used in air source heat pumps and air conditioners usually have a thin rectangular slab shape. Air-side enthalpy measurement tunnels (code testers) are commonly used to evaluate the heat exchangers and a uniform distribution of the frontal air velocity is used in the evaluation (Yashar and Cho, 2007).

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Nomenclature

A	area [m^2]
C	constant
D	diameter [m]
F_p	fin pitch [m]
G	mass flux [kg m^{-2} s^{-1}]
L	length [m]
L_h	louver height [m]
L_p	louver pitch [m]
N	number of longitudinal tube row
P_l	longitudinal tube pitch [m]
P_t	transverse tube pitch [m]
Pr	Prandtl number, $\frac{c_p \cdot \mu}{k} = \frac{\upsilon}{\alpha}$
$\dot{Q}$	heat transfer rate [W]
R	thermal resistance [m^2 K W^{-1}]
Re	Reynolds number, $\frac{\rho \cdot V \cdot D}{\mu}$
T	temperature [K]
U	overall heat transfer coefficient [W m^{-2} K^{-1}]
V	velocity [m s^{-1}]
$\bar{V}$	average velocity [m s^{-1}]
f	Darcy friction factor
g	gravity acceleration [m s^{-2}]
h	convective heat transfer coefficient [W m^{-2} K^{-1}]
j	Colburn factor, $\mathrm{St} \cdot \mathrm{Pr}^{2/3}$
k	thermal conductivity [W m^{-1} K^{-1}]
η	overall surface efficiency
μ	viscosity [Pa s]
θ	angle [degree]
σ	core free-flow to frontal area ratio

Subscripts

LM	logarithmic mean
a	air
acc	acceleration
c	core or fin collar outside
cont	contact
exp	experiment
foul	fouling
fric	friction
grav	gravity
i	inner
in	inlet
m	mean
o	outer
out	outlet
pred	prediction
r	refrigerant

However, the air flows to the heat exchangers in real heat pumps and air conditioners have non-uniform air velocity distributions due to the fan, surrounding equipment, and chassis in which the heat exchanger matrix is mounted. Non-uniform air velocity distributions have been investigated because they influence the performance of the heat exchanger and refrigeration system (Lee and Jeong, 2014).

The non-uniform distribution of air flows affects the performance of heat exchangers. Zhang (2009) performed numerical simulations of an air-to-air heat exchanger and demonstrated that a non-uniform distribution of air flow decreases the heat transfer capacity of the heat exchanger. Mao et al. (2013) reported an increase in the fan power and a decrease in the heat transfer performance based on simulations of a condenser. In addition, non-uniform air flows also affect frost growth. Gong et al. (2008) reported that frost occurred earlier and the frost layer grew faster with increases in the degree of air flow maldistribution. They also reported that the performance of air source heat pump systems deteriorated as a result of the more frequent defrost operations due to the increased frost-block effect. The non-uniform distribution of the air flow affects the performance of the air source heat pump and refrigeration systems through inducing non-uniform distributions of the outlet exit temperature and mass flow rate at each refrigerant circuit of a heat exchanger. Domanski (1991) reported that a non-uniform air flow might induce non-uniform refrigeration flow rates and differences in the superheating degree at the outlet of each refrigerant circuit of an evaporator. Aganda et al. (2000) demonstrated that the effect of air maldistribution, which could lead to a reduction in the refrigerant mass flow through control of the thermostatic expansion valve, caused a loss of up to 38% in evaporator heat transfer performance. Meanwhile, non-uniform air flows appeared to have little effect on the heat exchanger performance in the studies conducted by Nair et al. (1998) and Lee and Oh (2004). An interesting observation was reported by Timoney and Foley (1994): they measured the transfer performance of a refrigerant evaporator and reported that the heat transfer duty and overall heat transfer coefficients were increased as the air flow non-uniformities were artificially introduced, while a constant mean air velocity was maintained. Based on this observation, they concluded that a uniform air flow was not an essential condition for achieving the best performance.

Despite the numerous previous works including those mentioned above, studies on non-uniform air flows in heat exchangers remain lacking. For example, heat exchanger design methods that consider the maldistribution of air flows are not well established. In order to determine countermeasures, the mechanism of the performance change due to the non-uniform air flow requires more investigation in quantitative and qualitative manners. This study was performed in order to examine how the maldistribution of air flows changes the performance of a fin-tube heat exchanger. A numerical simulation model was developed to evaluate the performance of a fin-tube heat exchanger, and this model was used to investigate how non-uniform air flows affect heat exchangers with various refrigerant circuitries. The non-uniform distribution of an air flow is affected by the fan motion, adjacent components, chassis, and bending of the heat exchanger matrix. The resultant air flow distribution was measured, and this profile was used to simulate its effects on the heat exchanger performance.