International Journal of Thermal Sciences 89 (2015) 234–244

Contents lists available at ScienceDirect

International Journal of Thermal Sciences

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

Overall thermal performance oriented numerical comparison between elliptical and circular finned-tube condensers

Lei Sun, Liang Yang, Liang-Liang Shao, Chun-Lu Zhang[*]

School of Mechanical Engineering, Tongji University, No.4800 Cao-An Highway, Shanghai 201804, China

ARTICLE INFO

Article history:
Received 1 April 2014
Received in revised form
16 September 2014
Accepted 12 November 2014
Available online

Keywords:
Condenser
Elliptical tube
Thermal performance
Model

ABSTRACT

This paper compares the overall thermal performance of refrigerant-to-air finned-tube condensers with elliptical and circular tubes. A distributed-parameter model of the circular-tube and the elliptical-tube condensers is developed and the prediction agrees well with the experimental data. The two type condensers are compared under different outlet subcoolings, air velocities, circuitries and refrigerants. Further, the condenser model is integrated with other component models to establish a system model, with which the tube shape effect on the system performance is evaluated. The results show that the air pressure drop and the heat transfer rate of elliptical-tube condensers are 20.0%–27.3% lower and −8.3% to 30.9% higher than those of circular-tube condensers, respectively. The superiority of elliptical-tube condensers could vanish if the refrigerant pressure drop is too large. The heat transfer rate improvement of elliptical-tube condensers can be promoted by increasing circuit number only at higher refrigerant pressure drop. Compared to circular-tube condensers, the system capacity improvement using elliptical-tube condensers can be as high as 21.3%–27.5% and the COP improvement ranges from 3.6% to 6.7%. Elliptical-tube condensers using R410A yield higher improvement of condenser heat transfer rate and system capacity than using R22 and R134a, while R134a has the most potential in system COP improvement.

1. Introduction

Nowadays the increasingly serious environmental and energy issues motivate the HVAC&R (heating, ventilating, air-conditioning and refrigeration) industry to utilize higher efficient components and systems. Finned-tube heat exchangers are widely used as refrigerant-to-air condensers in the air-conditioning and refrigeration systems. In finned-tube heat exchangers, the most-used tubes are the ones having the circular cross section. However, the elliptical tubes can offer some advantages over the circular ones, such as compactness, higher heat transfer coefficient and lower air side pressure drop. Therefore, it is reasonable to expect an increase of condenser performance as well as system efficiency by replacing circular tubes in air-cooled condenser with elliptical ones.

In fact, elliptical tubes have long been considered as an alternative of circular tubes in finned-tube heat exchangers. A number of studies have been conducted on the thermal characteristics of finned-tube heat exchangers with elliptical tubes. Through experiment, several researchers reported that the use of elliptical tubes reduced the air pressure drop substantially and enhanced the heat transfer [1–3]. Besides experimental approaches, numerical simulation has been often performed to investigate the flow and heat transfer phenomena in elliptical finned-tube heat exchangers. The numerical comparisons of the elliptical-tube and the circular-tube configurations were presented with different fin types, including the plain fin [4–7], the louvered fin [8,9] and the wavy fin [10]. A more detailed review on this topic can be found in our previous work [11].

Nevertheless, in most of the previous studies, only the air side thermal-hydraulic performance was compared between elliptical-tube and circular-tube heat exchangers. In other words, the influence of tube shape on the tube side performance was ignored. However, as reported by Min and Webb [12], using elliptical tubes will cause a substantial increase of tube side pressure drop. Our previous study also demonstrated that the impact of tube shape on the overall thermal-hydraulic performance of finned-tube heat exchangers is related with not only air side but also tube side flow conditions [11]. In refrigerant-to-air condensers, this impact could

---

[*] Corresponding author. Tel.: +86 136 71825 133.
E-mail address: chunlu.zhang@gmail.com (C.-L. Zhang).

http://dx.doi.org/10.1016/j.ijthermalsci.2014.11.017
1290-0729/

Nomenclature

A	surface area (m^2)
A_c	air side minimum cross flow area (m^2)
c_p	specific heat (J kg^{-1} K^{-1})
C	heat capacity rate (W K^{-1})
CAP	system capacity (W)
COP	coefficient of performance
C_r	$C_{\min}/C_{\max}$
D_i	tube inner diameter (m)
f	friction factor
G	mass flux (kg s^{-1} m^{-2})
G_{cross}	air mass flux based on A_c (kg s^{-1} m^{-2})
h	specific enthalpy of refrigerant (J kg^{-1})
L	element length (m)
m	mass flow rate (kg s^{-1})
N	number of circuits
NP	Normalized refrigerant pressure drop
NTU	number of transfer units
Δp	pressure drop (Pa)
Q	heat transfer rate (W)
Re_δ	Reynolds number based on fin pitch
RI	Relative improvement (%)
RR	Relative reduction of air pressure drop (%)
R_w	thermal resistance of tube wall (K W^{-1})
Sh	superheat (K)
Sc	subcooling at condenser outlet (K)
T	temperature (°C)
T_{cond}	condensing temperature (°C)
T_{evap}	Evaporating temperature (°C)
U	overall heat transfer coefficient (W m^{-2} K^{-1})
v_a	air frontal velocity (m s^{-1})
V	volumetric flow rate (m^{-3} s)
W	power (W)

Greek symbols

α	heat transfer coefficient (W m^{-2} K^{-1})
ε	effectiveness
η_f	fin efficiency
η_{fan}	fan overall efficiency
η_{is}	isentropic efficiency of compressor
η_s	fin surface efficiency
ρ	density (kg m^{-3})
σ	contraction ratio of cross section area

Subscripts

a	air
c	circular-tube condenser
com	compressor
cond	condenser
dis	discharge of compressor
e	elliptical-tube condenser
evap	evaporator
f	fin
fan	fan
in	inlet
is	isentropic process
m	mean value
max	maximum value
min	minimum value
out	outlet
r	refrigerant
sat	saturation
suc	suction of compressor

be more pronounced. Since the refrigerant pressure drop increases as the tube is flattened, the saturation temperature of refrigerant in condenser will decrease and thus the temperature difference between refrigerant and air becomes smaller, which is detrimental to the condenser performance. Therefore, it is imperative to compare the elliptical-tube and circular-tube condensers considering both the air and the refrigerant sides.

Furthermore, the existing studies about numerical comparison of the elliptical and circular finned-tube heat exchangers have typically been carried out through the computational fluid dynamics (CFD) approach. To avoid an unacceptable number of grids and thus to save computational resources, the CFD models usually just contained one heat transfer unit according to symmetry and periodicity of the geometrical configuration. Although the CFD models are perfectly suitable for investigation of the local heat transfer and fluid flow characteristics in finned-tube heat exchangers, the comparison result of local characteristics could be different from that of the whole heat exchanger. For example, the refrigerant circuitry plays a significant role on the condenser performance, but it cannot be analyzed using the CFD models. Fortunately, there are several distributed-parameter models available in literature that can be used to predict the whole condenser behavior. For detailed reviews of such models, one can refer to the work of Lee and Lam [13] and Singh et al. [14]. There is no doubt that these computer models have been successfully applied for circular-tube condensers with acceptable accuracy, yet investigation of elliptical-tube condensers using similar models is scarce in literature, not to mention the comparative study of the elliptical-tube and the circular-tube condensers.

The purpose of the present study is to more comprehensively compare the elliptical-tube and the circular-tube condensers. Different from the existing works, we focus on the entire condensers and are more concerned about the overall thermal performance. The comparison is firstly carried out at the component level under different outlet subcoolings, air velocities, circuitries and refrigerants using a detailed condenser model. Then, the comparison at the system level is performed to examine the tube shape effect on the system performance. The results show that in addition to the tube shape, the parameters we studied have significant impact on the condenser and system performance as well. The elliptical-tube condenser performance should be carefully evaluated at both component and system levels.

2. Numerical model

The main focus of the modeling is the condenser. The condenser model is a detailed effectiveness-NTU based distributed-parameter model. Meanwhile, at the system level, the ideal models are chosen for the evaporator and the expansion device. The efficiency models are applied for the compressor and the fan. The sketch of the condenser model is presented in Fig. 1. Note that the condenser model can be either standalone or integrated with other component models to comprise a system model. With the condenser