INTERNATIONAL JOURNAL OF REFRIGERATION 73 (2017) 11–23

Available online at www.sciencedirect.com

ScienceDirect

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


INTERNATIONAL JOURNAL OF
refrigeration

Influence factors of flow distribution and a feeder tube compensation method in multi-circuit evaporators

Dandong Wang, Cichong Liu, Dengjia Yu, Jiangping Chen *

Institute of Refrigeration and Cryogenics, Shanghai Jiaotong University, Shanghai, China

ARTICLE INFO

Article history:
Received 27 May 2016
Received in revised form 7 September 2016
Accepted 8 September 2016
Available online 13 September 2016

Keywords:
Evaporator
Mal-distribution
Distributor
Two-phase flow
Computational fluid dynamics

ABSTRACT

This study investigates four influence factors of flow distribution in multi-circuit evaporators with distributor, including distributor inlet tube length, inclination angle, uneven airflow, and feeder tube length. Experimental tests and numerical simulations were carried out to evaluate the effect of these factors on superheat uniformity and refrigerant distribution performance. Additionally, a feeder tube compensation method for optimizing refrigerant distribution is presented that involves pressure drop fine-tuning of the feeder tube in each circuit coupled with a main expansion device to obtain more uniform superheat performance at all circuit outlets. To adopt this method, a model was developed to predict the best feeder tube length for each circuit. Experimental results show that when using feeder tubes with predicted lengths in condition of uneven airflow, the superheat uniformity was improved significantly, and up to 35% evaporator cooling capacity could be enhanced when airflow non-uniformity coefficient (F_{air}) was 0.6.

Facteurs d'influence de la distribution de l'écoulement et méthode de compensation de la conduite d'alimentation dans les évaporateurs multicircuits

Mots clés : Évaporateur ; Mauvaise distribution ; Distributeur ; Écoulement biphasé ; Mécanique des fluides numérique

1. Introduction

In recent years, the application of smaller diameter fin-tube evaporators ($\varnothing = 5$ mm) and parallel flow micro-channel evaporators has been increasingly popular for use in household and commercial air conditioner, allowing benefits of less weight and lower cost. In these evaporators, more evaporator circuits are required to decrease pressure drop and to avoid Coefficient of Performance (COP) loss. Therefore, it becomes important to solve the refrigerant mal-distribution problem that can occur among these circuits (Kærn et al., 2011; Li and Hrnjak, 2015). In general,

---

* *Corresponding author.* Institute of Refrigeration and Cryogenics, Shanghai Jiaotong University, Shanghai, China. Fax: +86-021-34206775.
E-mail address: jpchen_sjtu@163.com (J. Chen).

http://dx.doi.org/10.1016/j.ijrefrig.2016.09.011

Nomenclature

Roman

A	nozzle throat area $[\mathrm{m}^2]$
C	flow rate coefficient of nozzle
COP	coefficient of performance
CFD	computational fluid dynamics
D	inner tube diameter [m]
f	fraction factor
G	mass flux $[\mathrm{kg \cdot s^{-1} \cdot m^{-2}}]$
h	specific enthalpy $[\mathrm{kJ \cdot kg^{-1}}]$
L	length [m]
M	refrigerant mass flow rate $[\mathrm{kg \cdot h^{-1}}]$
P	pressure [Pa]
ΔP	differential pressure [Pa]
q	vapor quality
Q	air mass flow rate $[\mathrm{kg \cdot h^{-1}}]$
R	range [the maximum minus the minimum]
T	temperature [°C]
V	velocity $[\mathrm{m \cdot s^{-1}}]$
STD	standard deviation

Greek letters

λ	safety factor
μ	dynamic viscosity $[\mathrm{Pa \cdot s}]$
ξ	linear coefficient
ρ	density $[\mathrm{kg \cdot m^{-3}}]$
υ	specific volume $[\mathrm{m^3 \cdot kg^{-1}}]$

Subscripts

a	air
avg	average
ch	choking
c	condenser
e	evaporator
fd	feeder tube
i	the number of circuit
in	inlet
l	liquid
min	minimum
n	nozzle
out	outlet
sub	subcooling
Sup	superheat

a distributor and an expansion valve are positioned before the evaporator to divide the two-phase refrigerant into multi-circuits. However, the distributor is unable to effectively maintain similar superheat for all outlets due to variations in these circuits. For example, some circuits exit with a two-phase flow while the other circuits have superheated exit conditions, although the overall superheat is controlled by the expansion valve. Various factors can produce this flow mal-distribution problem: (1) uneven inlet airflow velocity or temperature distribution, (2) manufacture error or improper design of distributor, or (3) incorrect installation of the pipe, distributor, and evaporator.

Many studies have discussed the impact of air-side mal-distribution on evaporator performance. Domanski et al. (Domanski, 1991; Payne and Domanski, 2003) developed an evaporator model to study the effect of non-uniform airflow distribution in a plate-fin evaporator. They found a 25% cooling capacity decrease in extreme uneven airflow situations. Liang et al. (2001) investigated the effects of refrigerant circuitry on the performance of evaporators using a detailed evaporator model and found that the cooling capacity of the coil could be optimized and that 5% heat transfer area could be reduced by improving refrigerant circuiting design. Lee et al. (2003) concluded that for a parallel-cross flow evaporator, the convex, concave, and inclined types airflow reduces cooling capacity by 5.3%, 6.0%, and 3.0%, respectively, compared to uniform airflow. T'Joen et al. (2006) had similar findings for an air-to-water heat exchanger. Kærn et al. (2011) demonstrated that the uneven airflow distribution caused COP reduction of up to 43.2%, but this could be recovered by controlling the exit superheat at the same value over a wide range of airside mal-distribution. They also pointed out that similar superheat does not coincide with the best performance recovery.

Blecich (2015) experimentally investigated the effects of airflow nonuniformity on the thermal–hydraulic performance for a fin-and-tube heat exchanger with single-phase water flow. It revealed that in severely airflow maldistribution situation, the heat exchanger effectiveness was deteriorated up to 30% and the pressure drop was enhanced up to 90%. Yashar et al. (2014) performed an experimental and numerical study on inlet air distribution for slanted and A-shaped finned-tube heat exchangers. The airflow velocity measured by particle image velocimetry (PIV) shows highly nonuniform distribution for both heat exchangers. Computational fluid dynamics (CFD) results shows that the irregularities in the duct boundary or heat exchanger mounting changes airflow direction and cause mal-distribution.

Studies have also focused on distributor performance, both experimentally and through modeling. Aziz et al. (2012) studied the characteristics of flow pattern and deviation of air–water two-phase flow distribution through the distributor. Nakayama et al. (2000) studied experimentally the influence of the mixture chamber length and installation angle of jet distributor on the distribution performance and compared a modified and conventional distributor. Fay (2011) demonstrated the impact of the jet distributor's performance on the cooling capacity and system COP, and found that good distribution can improve cooling capacity by 5% and system COP by 4%. Li et al. (2002) adopted CFD simulation to study refrigerant distributor designs (flat base, cone base, round base, spherical base) and concluded that the distributor with spherical base is the best one to distribute two-phase refrigerant uniformly. Yoshioka et al. (2008) proposed a simple testing method to acquire information on the quality and flow rate for every evaporator branch, and conducted parameter optimization of reservoir distributor. Han et al. (2014) built an experiment test rig to measure mass flow rate and quality of four circuits with distributors. Experimental tests were then conducted to compare distribution performance among three types of distributors under different operating conditions.

In addition to evaporator and distributor optimization, there have been several studies of the benefit of maintaining individual superheat within each circuit. Domanski (1991) concluded that individual superheat control method with thermostatic