International Journal of Heat and Mass Transfer 116 (2018) 1085–1095

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

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

Experimental study on heat transfer and pressure drop characteristics of fin-and-tube surface with four convex-strips around each tube

Xiao-Yu Li, Zhao-Hui Li, Wen-Quan Tao *

Key Laboratory of Thermo-Fluid Science and Engineering of MOE, Xi'an Jiaotong University, Xi'an, Shaanxi 710049, China

A R T I C L E   I N F O

Article history:
Received 1 June 2017
Received in revised form 17 August 2017
Accepted 19 September 2017
Available online 4 October 2017

Keywords:
Heat transfer enhancement
Pressure drop
Convex fin
Experimental correlation
Air cooler

A B S T R A C T

In the present study, heat transfer and friction characteristics of heat transfer exchanger with a new type of enhanced fin – convex fin was experimentally investigated. For comparison, a plain-fin heat transfer surface with the same dimension was also tested. At low Reynolds number the airside convective heat transfer coefficient of the convex-fin is 25% higher than that of the plain-fin. At high Reynolds number the heat transfer coefficients of the convex-fin is slightly higher than the heat transfer coefficient of the plain fin. The pressure drop of the new enhanced fin increases by 16%. The convex-fin is suitable for enhancing heat transfer at low and middle velocity condition commonly encountered in air-cooling industry.

1. Introduction

Finned tube heat exchangers have been widely used in various engineering fields such as heating, ventilation, air conditioning and refrigeration (HVAC&R) systems. In an air-cooling fin-and-tube heat exchanger, heat transfers from the air flowing outside tubes to the liquid flowing inside the tubes. Because the heat transfer capability of air is very poor due to its low thermal conductivity and density, over 90% of the total thermal resistance from air to liquid lies on the air side. Therefore a series of fin-surfaces have been developed. Broadly speaking, they can be classified into following four groups, namely, (1) plain plate fin; (2) wave fin; (3) interrupted fin, including strip fin and louvered fin and (4) fin with vortex generators. A brief review of these four kinds of fins is given below.

A lot of studies, both experimental and numerical, have been conducted on the air heat transfer and pressure drop performance for the above-mentioned types of fin-and-tube surfaces. References examples include: [1–3] for plain plate fin, [4–7] for wavy-fin, [8–19] for interrupted fin and [20–26] for fin with vortex generators. Wang et al [1] performed experimental studies on the air side performance on 18 samples with plain fin configurations and found out the effect of fin pitch, tube rows and tube diameter on heat transfer and friction characteristics. Then in Reference [2] Wang and co-workers used the data of 74 samples to develop a correlation for fin-and-tube heat exchanger with plain fin. The correlation can predict more than 85% experimental data with the deviation less than 15%. He et al. [3] performed numerical investigation for plate fin-and-tube heat exchanger. Five parameters including Reynolds number, fin pitch, longitudinal tube pitch, spanwise tube pitch and tube row number were examined. The results were analyzed and well described from the view point of field synergy principle. Wang et al. [4] also performed a series of extensive experiments on pressure drop and heat transfer of wavy fin-and-tube heat exchangers. Eighteen samples with different parameters were measured. The result shows that the heat transfer characteristics are independent of fin pitch; the number of tube row has negligible effect on friction factors and the heat transfer coefficients for wavy fin are 55% to 70% higher than that of plain fin. Tao [5–7] and co-workers performed a series of numerical simulation of heat exchangers with wavy fin surface. In Reference [5] numerical studies for wavy fin heat exchanger with two different shapes of tubes (circular and elliptic) were carried out. The result shows that the heat transfer coefficient of elliptic tubes is increased by 30% and the increase of friction factor is only 10%. In [6] the prediction results of Nusselt number, friction factor and fin efficiency calculated by numerical simulation were compared with two experimental correlations. They found that the fin efficiency of wavy fin is larger than that of plain fin and with the increase of *Re* the effects of wavy angle are more and more significant. In [7] the authors examined the effect of four different parameters including Reynolds number, fin pitch, tube row number and wavy angle. The result shows that *Re* and wavy angles have

* Corresponding author.
E-mail address: wqtao@mail.xjtu.edu.cn (W.-Q. Tao).

https://doi.org/10.1016/j.ijheatmasstransfer.2017.09.076
0017-9310/

Nomenclature

A	heat transfer area (m^2)
A_c	minimum free-flow area (m^2)
D_c	tube diameter, including fin collar thickness (m)
D_h	$4A_cL/A$, hydraulic diameter (m)
F_f, F_j	enhance factor
F_p	fin pitch (m)
f	friction factor
G	mass flow rate (kg/s)
g	gravity (m/s^2)
H	effective tube height (m)
h	heat transfer coefficient (W/m^2 K)
h_{fg}	latent heat (kJ/kg)
j	the Colburn factor
k	overall heat transfer coefficient (W/m^2 K)
L	depth of the heat exchanger (m)
P_l	longitudinal tube pitch (m)
P_t	transverse tube pitch (m)
r	radius of the tube
R	thermal resistance (K/W)
S_S	breadth of a slit in the direction of airflow (m)
S_W	width of slit (m)
T	temperature (°C)
t	time (s)
u_m	maximum velocity (m/s)
V	volume (m^3)
X_L	$\sqrt{(P_t/2)^2 + P_l^2}/2$ geometric parameter (m)
X_M	$P_t/2$ geometric parameter (m)

Greek symbols

Δp	pressure drop (Pa)
δ	thickness (m)
η	fin efficiency
η_o	surface efficiency
λ	thermal conductivity (W/m K)
μ	dynamic viscosity (kg/m s)
ν	kinematic viscosity (m^2/s)
ρ	density (kg/m^3)
σ	contraction ratio of cross-sectional area
Φ	heat transfer rate (W)

Subscripts

a	air
c	convex fin
cor	by correlation
exp	by experiment
f	fin
i	tubeside
in	airside inlet
m	mean
o	airside
out	airside outlet
p	plain-fin
t	tube
w	water

positive effect on heat transfer and the other two factors have negative effect. All these results are agreeable very well with the field synergy principle. The first study related to slit fin was conducted by Nakayama and Xu [8]. They presented test results for three samples, and proposed a correlation based on these results. After 1999 lots of works on interrupted fin surface have been presented. Wang et al. [9] tested as many as 49 samples of louvered fin-and-tube heat exchangers and developed the correlations for louvered fin. Yun and Lee [10] investigated the performance of interrupted surfaces of multi-tube row with different shape and recommended an optimal fin shape for air conditioners. Kang and Kim [11] found that under the same fan power hybrid fin with strips at fin sheet of rear row are more effective than that with strips at whole fin sheet. Lozza and Merlo [12] performed experimental investigation on different kinds of fin surface including plain fin, wavy fin, louvered fin and winglet fin. Their experiments show that louvered fins provide the best heat exchanger performance. Cheng et al. [13] performed a numerical investigation on four types of plain and strip fin surfaces. The results show that among three types of strip fin designed by “front sparse and rear dense”, the fin which behaves the best has the least synergy angle between velocity and fluid temperature gradient. Qu et al. [14] also performed a numerical computation on four types of strip fin surfaces and their results show that enhancement structures placed in the rear part of the fin can be more effective compared with that placed in the frontal part. Zhou and Tao [15] found that at the same frontal velocity the full slotted fin surface have the highest heat transfer rate but at the identical pumping power the slotted fin surface with strips mainly located in the rear part behaves the best. Jin et al. [16,17] first discussed in the literature the convergence criteria of numerical simulation for fin-and-tube structures and observed the turning *Re* number below which slotted fin performs worse than plain fin. Tao et al. [18] studied five types of slit fins and concluded that the slit fin has the best heat transfer performance when the thermal resistance is uniformly distributed. Kim and Cho [19] experimentally investigated on slit fin and plain fin heat exchangers with 5.3 mm tube diameter. Results reveal that slit fin has higher *j* factor and *j/f* ratio. Fiebig et al. [20] performed experiments to investigate the effect of wing-type vortex generators on the performance of heat exchanger. Fin with a pair of vortex generators behind each tube can increase the heat transfer by 55–65% and pressure drop by 20–45%. In 1995, Jacobi and Shah [21] reviewed the previous works of vortex generators and indicated that a deeper understanding of the flow and heat transfer interactions is needed to identify promising implementations for specific applications. Joardar and Jacobi [22] numerically studied the flow and heat transfer characteristics for surface enhanced by an array of delta-winglet vortex generators. Their investigation show that the winglet vortex generators significantly enhance the local heat transfer on the downstream tube and fin surface and 3 vortex generators inline arrangement structure can enhance the heat transfer by 32% with the pressure drop increase by the same scale. Wu and Tao [23] reveal that the heat transfer enhancement mechanism of the longitudinal vortex generator is the improvement of synergy between velocity and fluid temperature gradient. They also found that the attack angle of 45 °has better enhancement effect compared with the attack angle of 30°. Tian et al. [24] compared the performance of fin with rectangular and delta winglet pair. There are two main conclusions in their study: the first is that the delta winglet pair has better performance; the second is that for rectangular winglet pair the common-flow-down configuration has a better performance than that of common-flow-up. He and Zhang [25] summarized the papers from 1990s to 2000s in the study on vortex generator techniques. They conclude that further investigation should be focus on finding out the best arrangement of the vortex generators for different heat exchangers. Li et al. [26] proposed a new kind of plain fin with twelve winglets arranged around each tube. Their numerical simulation proved that the proposed fin