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Research Paper

Improved flow and heat transfer characteristics for heat exchanger by using a new humped wavy fin

Xilong Zhang [a,*], Yichun Wang [b], Min Li [a], Sidong Wang [b], Xiaolong Li [b]

[a] School of Automobile and Transportation, Qingdao University of Technology, Qingdao 266520, China
[b] School of Mechanical Engineering, Beijing Institute of Technology, Beijing 100081, China

HIGHLIGHTS

- The recirculation phenomenon completely disappears in valley by using the humped fin.
- The flow in humped fin duct can easily get into a turbulence state at a low *Re*.
- Low velocity areas near suction side and valley are small and uniform in humped duct.
- The *JF* factors of different humped fins are higher than that of triangular fins.
- The *AFSA* first decreases and later increases with the increasing of humped radius.

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ABSTRACT

A novel humped wavy fin is presented in this paper. The flow and heat transfer characteristics for humped wavy fins with different humped radii (R = 0.3, 0.5, 0.7 and 0.9 mm) and Reynolds numbers ($500 \leq Re \leq 5000$) are studied numerically and experimentally. Results show that the overall thermal-hydraulic characteristics for humped fin patterns with different R are better than that of triangular fin. The recirculation Phenomena in the valley regions completely disappear for either laminar or turbulent flows by using the humped fin. The areas of separation zones near the suction side are smaller and more uniformly, and the core flow encounters a smaller resistance along the flow direction. The directions of the secondary flows in left half and right half regions are clockwise and anticlockwise respectively in both fin patterns at low Re, but the secondary flow disappears at a relatively high Re. Besides, the humped fin pattern can easily get into the turbulence state at a low Re. The JF factor first increases and later decreases while R increases from 0.3 mm to 0.9 mm, and when R = 0.5 mm, the duct has the highest JF. Using the filed synergy principle we can see the average field synergy angle first decreases and later increases with the increasing of R.

1. Introduction

The major thermal resistance of heat exchanger is on the air side; hence, it is useful and efficient by using slit, offset-strip and louver fins to raise the heat transfer performance. Those fins can reduce the thickness of boundary layer and produce the vortices or the secondary flow, which would enhance the convective heat transfer intensity. However, an obvious blockage effect happens after long term operation in practical applications by exploiting the fins. For this reason, wavy fins are still the most frequently used construction in vehicles and refrigerating systems.

Instead of restarting the boundary layer and inducing vortices to cause mixing in slit and louver fins, the flow is mixed in the wavy fins duct through shear-layer instabilities and the generation of secondary flow. The effect of fin pitch, number of tube rows, fin thickness, wavelength ratio, amplitude and air velocity for heat transfer and friction characteristics of wavy fins were studied by a lot of researchers [1–4]. Recently, Aliabadi et al. did a lot of work for wavy fin-and-flat tube heat exchangers. At first, they experimentally investigated the influence of sinusoidal wavy-surface plate-fin geometries, such as wave length (l = 10, 20 and 40 mm) and wave amplitude (a = 0.5, 1.0 and 2.0 mm), on laminar and transition airflows [5]. In the same year, they tested three different wavy fin arrangements (perforations, winglets and nanofluids) in a closed loop and concluded that the winged wavy plate-fins have best thermal-hydraulic performance factor [6]. And after that, they

* Corresponding author.
E-mail address: beibitpap@hotmail.com (X. Zhang).

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Nomenclature

A	surface area [m^2]
A_C	the channel flow cross section [m^2]
b_f	fin width [m]
c_p	specific heat capacity [J/kg·K]
D_h	hydraulic diameter [m]
h	heat transfer coefficient [W/m^2·K]
h_f	fin height [m]
L	fin core length [m]
L_C	the flow wetting perimeter [m]
Δp	pressure difference through fin core [Pa]
Q	heat transfer rate [W]
R	humped radius [m]
S_f	fin wavelength [m]
T	temperature [K]
ΔT	temperature difference [K]
U, u	velocity [m/s]
X, Y, Z	coordinate axis
Greek letters	
α	intersection angle [°]
θ	field synergy angle [°]
λ	thermal conductivity [W/m·K]
μ	dynamic viscosity [kg/m·s]
ρ	density [kg/m^3]
Dimensionless	
f	friction factor
j	Colburn factor
JF	thermal-hydraulic performance factor
Nu	Nusselt number
Pr	Prandtl number
Re	Reynolds number
St	Stanton number
Subscripts	
A	inlet air
B	outlet air
C	inlet water
D	outlet water
ln	logarithm
m	mean value

also came up with a novel wavy based configuration called corrugated/vortex-generator plate-fin (CVGPF). They found that the CVGPF channel has the best thermal-hydraulic performances that of the corrugated plate-fin and vortex-generator plate-fin under the same geometrical and conditions [7]. Later, Ranganayakulu et al. [8] using a single-blow transient test technique to investigate the convective heat transfer and pressure drop of the wavy and offset fins in a heat exchanger.

Actually, it is hoped that the local heat transfer coefficient would increase dramatically along the corrugated (wavy) duct; however, relatively lower heat transfer regions appear at the valley and the suction side of the duct. This phenomenon was revealed by a numerical visualization conducted by McNab et al. [9]. They stated that flow separation (burbling) and recirculating flow were induced at the peak (apex) and valley when the air flow passed through the duct, which is shown in Fig. 1. In other words, the air flow is interfered at the turning points (valley and peak) presenting recirculation flow and separation/reattachment. Similar conclusions were also described by Hwang et al. [10]. Except for triangular (herringbone) wavy fin pattern, as is shown in Fig. 1, smooth wavy fin pattern is also used in the heat exchanger. But the pressure drop between the inlet and outlet of the duct increases violently by using the triangular wavy fin, when comparing to smooth wavy fin. A remarkable reduction in pressure drop by smoothing the sharp edges of the triangular wavy fin was experimentally demonstrated by Sparrow et al. [11]. Islamoglu et al. [12], Asako et al. [13] and Zhang et al. [14] also came to the same conclusion that rounding the apex of the triangular wavy fin lead to a significant decrease in pressure drop. Dong et al.

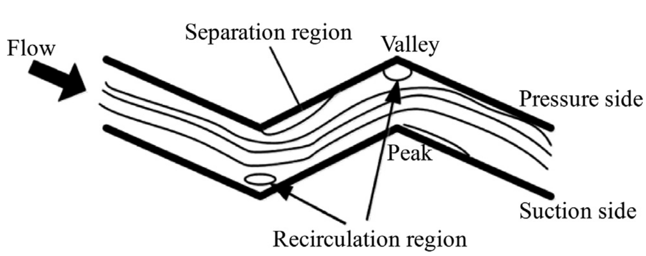

Fig. 1. Low heat transfer regions at the valley and suction side of the duct [6].

[15] experimental and numerical studied the convection heat transfer and pressure drop for three different wavy fin profiles including triangular, sinusoidal and triangular round corner, and they also used the field synergy principle to explain the enhancement heat transfer mechanism.

To overcome the above drawbacks, this paper comes up with a new wavy fin pattern having humped configurations at both valley and peak called humped wavy fin pattern. This paper depicts a specific experimental and numerical studies of flow characteristic and heat transfer perform for humped wavy fin. The accuracy of three-dimensional models is validated through the comparison of the j and f factors curves between experimental and numerical results. A parametric study using various humped radii (0.3 mm, 0.5 mm, 0.7 mm and 0.9 mm) and the Reynolds numbers range from 500 to 5000 are discussed here. Besides, the mechanism of enhancement heat transfer of the humped wavy fin is explained in the point view of field synergy principle [16].

2. Experimental system and data reduction

2.1. Physical model

The geometric characteristics and coordinates of wavy-fin-tube heat exchangers with triangular and humped wavy configurations are described in Fig. 2(a) and (b) respectively. The triangular and humped ducts are compose of ten pairs of pressure and suction sides walls, and they all have five times wavy length. The specific parameters of the two type wavy ducts are shown in Table 1. The two configures, triangular and humped wavy fins, have the same fin wavelength (S_f), fin height (h_f), fin width (b_f), intersection angle (α) and fin core length (L). The structures of humped wavy fins are changing with different humped radii R which ranges from 0.3 mm to 0.9 mm. The two type heat exchangers have the same dimensions, 260 mm × 230 mm × 40 mm, are all made of aluminum.

2.2. Experimental setup

The wind tunnel setup for the two type wavy configurations consists of heat exchangers, air and water loops, data acquisition