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Numerical simulation on flow and heat transfer of fin structure in air-cooled heat exchanger

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HIGHLIGHTS

- Three types of wavy fin configurations were proposed to improve the air cooling capacity.
- The air-side flow and heat transfer were investigated by numerical simulation with experimental verifications.
- The periodic wavy fin performed the largest pressure drop as well as the best heat transfer.

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ABSTRACT

Fin-and-tubes as compact heat exchangers are primarily used in direct air-cooled condensers systems in power plants. Air-side flow and heat transfer characteristics of the fin-and-tubes play an important role in the performance of the condensers. In the present study, wavy fin configuration was proposed to improve the air cooling capacity. Investigation on heat transfer and pressure drop characteristics of fin-and-tubes with three kinds of different but closely related air-side fin configurations were made by numerical simulation. The effectiveness of air-side convergent–divergent channel in wavy fins was compared to straight channel in plain fins or continuous plain fins. The total heat transfer and pressure drop performances were assessed over a Reynolds number range based on hydraulic diameter of $440 < Re < 2800$. It is found that the air-side heat flux and heat transfer coefficient increase sharply for the wavy fin arrangement, whereas the continuous plain fin shows nearly the same heat flux and heat transfer coefficient to the plain fin. Results further indicate that the endwall temperature on the fins increases along the streamwise direction from the inlet to the outlet. The periodic convergent–divergent channel formed by wavy fins performs the largest pressure drop, which leads to the lowest overall performance despite of the best heat transfer.

1. Introduction

Air-cooled condensers are widely applied in power plants in the regions where water source is of shortage. The dominant thermal resistance for an air-cooled condenser is generally on the air side because of the high heat transfer rates of the condensation on the vapor side. As a result, to effectively improve the thermal performance of air-cooled heat exchangers, enhanced geometries of fin-and-tube bundles are often encountered in practical applications. There have been many experimental and numerical investigations on the heat transfer characteristics of fin-and-tube. Many fin patterns of fin-and-tube heat exchangers include continuous fin type, interrupted surfaces, and the enhanced surfaces with longitudinal vortex generators attract many researchers [1–8] on them.

The wavy fins are particularly attractive because of their simplicity of manufacture. It is believed that the more mixing could be obtained by forming self-sustained oscillations in periodic variable cross-section channels. A number of investigations on flow and heat transfer in variable cross-section channels without basic tubes were conducted by researchers. Goldstein and Sparrow [9] were among the first to study experimentally the local and average heat transfer characteristics for laminar, transitional, and turbulent flows in a corrugated wall channel using the naphthalene sublimation method. It was shown that, the heat transfer coefficients were only moderately larger than those for a parallel-plate channel in the case of low Reynolds number. However, the rates of heat transfer exceeded those for the straight channel by nearly a factor of three at turbulent Reynolds numbers. Sparrow et al. [10,11] conducted more experimental researches on the heat transfer characteristics and

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Nomenclature

A	area, m^2
c_f	pressure drop coefficient
c_p	heat rate capacity, kJ/(kg K)
d	diameter of basic tube, m
D	hydraulic diameter, m
h	heat transfer coefficient, W/(m^2 K)
H	height of fin, m
m	mass flow rate, kg/s
Nu	Nusselt number based on hydraulic diameter
P	pressure, N/m^2
Re	Reynolds number based on hydraulic diameter
s	distance between fins, m
T	temperature, K
u,v,w	velocity, m/s
V	velocity vector, m/s
W	width of fin or basic tube, m
x,y,z	Cartesian coordinates

Greek symbols

δ	thickness of fin or basic tube, m
Φ	wall heat flux, W
λ	thermal conductivity, W/(m K)
μ	dynamic viscosity of fluid, kg/(m s)
ρ	density of fluid, kg/m^3

Subscript

av	average
f	fin
in	quantity evaluated at inlet
max	quantity evaluated at maximum
min	quantity evaluated at minimum
out	quantity evaluated at outlet
p	period of wavy fin
t	flat tube
w	wall

flow resistance of periodic channels in variable Reynolds number ranges, subsequently. Nishimura et al. [12–15] conducted a series of experiments to study the flow characteristics and heat or mass transfer in sinusoidal wavy channels. No enhancement in mass transfer was observed at low Reynolds numbers, but the interactions between the recirculation zones and core flow can be found which lead to a remarkable increase in the heat transfer when the flow became unsteady as the Reynolds number increased above a critical value. Flow visualization experiment which was studied by Rush et al. [16] showed the flow patterns in sinusoidal wavy passages. It was found that instabilities were manifest near the channel exit at low Reynolds numbers and move toward the channel entrance as the Reynolds number increasing. Guzmán et al. [17,18] performed numerical simulations in convergent–divergent wavy channels to investigate the transition process from laminar to chaotic flow using a spectral element method. The physical models include fully developed, two-dimensional and three-dimensional flows. There were several other studies [19,20] related to the analogous problem on heat transfer or flow resistance in variable cross-section channels. The similar general conclusions could be obtained that at low Reynolds numbers there is not much heat transfer enhancement, but the occurrence of self-sustained flow regime at high Reynolds numbers leads to enhancement of heat transfer rates. A novel concept for convective heat transfer enhancement field, field synergy principle, was proposed by Guo and Tao et al. [21,22], which showed that the decrease of the interaction angle between the velocity and temperature gradient could enhance the heat transfer. The entransy theory and field synergy principle were used to not only analyze but also optimize some convective heat transfer processes [23–26], from which it could be explained reasonably that flow in the variable cross-section channel can enhance the heat transfer significantly.

Most of the aforementioned researches about the wavy channel only studied the flow and heat transfer in variable cross-section channel without basic tube. To study the heat transfer of the fin-and-tube more integrated, the basic tube should be taken into

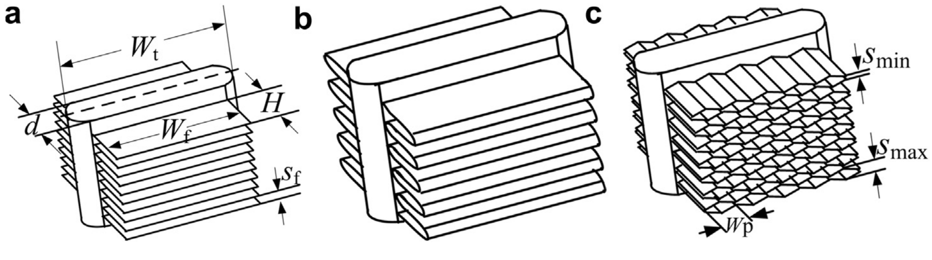

Fig. 1. Geometric diagram of three fin-and-tubes, (a) shape A; (b) shape B; (c) shape C.

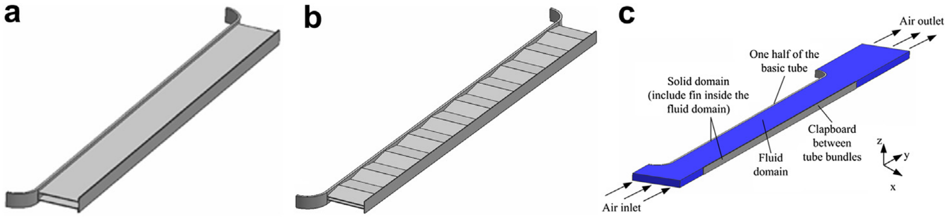

Fig. 2. Schematic diagram of computational domains and boundary conditions. (a) Computational domain of shape A or B; (b) computational domain of shape C; (c) boundary conditions of computational domains.