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Experimental study of the effect of air inlet angle on the air-side performance for cross-flow finned oval-tube heat exchangers

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A B S T R A C T

An experimental system was built to study the heat transfer and resistance characteristics of two finned oval-tube heat exchangers (HE1: Double rows of tubes, HE2: Three rows of tubes.) inclined towards the air incoming flow direction. Four air inlet angles (90°, 60°, 45° and 30°) are investigated separately to acquire the heat transfer and pressure drop performances for Reynolds number ranging from 1300 to 13,000. The experimental correlations of Nusselt number and resistance coefficient of the air side are obtained, and the comprehensive comparisons of heat transfer performance are carried out. The results show that whether the heat transfer performance for heat exchangers positioned obliquely is improved or not is depended on not only their inclined angles, but also their structures.

1. Introduction

The heat exchanger sometimes is necessary to be positioned obliquely to save space, and the entrance air flow direction is not orthogonal to the heat exchanger surface in many applications. There is a widespread application that the air inlet direction is not orthogonal to the radiator, or the radiator is a vertical layout, horizontal or inclined arrangement. The air incoming flow direction has an important effect on the heat transfer and flow friction characteristics of air cooling tower.

As described by Kröger [1], the finned tube bundles in large air-cooled condensers may be sloped at some angle up to 60° with the horizontal or A-frame (Fig. 1) in order to save land area. So most of the air-cooled heat exchangers are always arranged with inclined angles. A picture of the surface indirect air-cooled radiator mounted inside the air-cooled tower [2] is shown in Fig. 2a, and the partial enlarged drawing of the apex angle of the above air-cooled radiator is presented in Fig. 2b, where three representative apex angles (α = 120°, 90°, and 60°) are simply drawn as an example. From Fig. 2, it can be found that more land area will be saved if the apex angles vary from 120°, 90° to 60° in the radial direction of a cooling tower. However, this arrangement has a higher air-side pressure drop [1]. So in consideration of the land area, cooling efficiency and the loss of pressure, a proper apex angle must be chosen in an air-cooled tower according to the practical engineering conditions.

It is well known that circular tubes are used in most of finned tube heat exchangers. Kayansayan [3], Wang et al. [4–7], Tang et al. [8,9], Xie et al. [10] and Ma et al.[11] studied the finned round-tube heat exchangers, and Xie et al. [12] and Zeng et al. [13] optimized them through genetic algorithm and Taguchi method, respectively. Meanwhile, it is found that using the finned oval-tube can not only effectively reduce the fluid flow resistance in the fin side, but also cut down the energy consumption [14–16]. During the last decades, many researchers have paid attention on the investigation of finned oval-tube heat exchangers [17–20].

A heat transfer enhancement study of cross-flow heat exchangers with oval tubes and multiple delta winglets was accomplished to determine the flow structure and heat transfer in a rectangular channel using a body fitted grid and a finite-volume method [21]. It was confirmed that combinations of oval tubes and the winglet pairs improve the heat transfer significantly, especially in the dead water zone. The air side performance for fin-and-tube heat exchangers having circular and oval configuration was numerically studied by Leu et al. [15]. It can be concluded that a 10% decrease of heat transfer performance and a 41% decrease of pressure drop for oval tube configuration for a fixed louver length (6.25 mm) and louver angle (14°). Jang and Yang [14] investigated the heat transfer and resistance performance of the finned tube heat exchangers with circular tubes or oval tubes with experimental and numerical methods. Their experimental results showed that the mean heat transfer coefficient of an elliptical finned tube was 35–50% of the circular finned tube with the same tube perimeter, while the pressure drop of the finned oval-tube was only 25–30% of the circular one under dry conditions. Erek et al. [16] studied the influence of

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Nomenclature

A	area, m^2
A_{min}	minimum circulation area, m^2
A_o	total heat transfer area of the air side, m^2
a	outer length of the major axis, m
b	outer length of the minor axis, m
c_p	specific heat at constant pressure, J kg^{-1} K^{-1}
D	equivalent diameter of the ellipse, m
D_c	fin collar outside diameter, $D_c = D_o + 2\delta$, m
D_i	tube inside diameter, m
D_o	tube outside diameter, m
E	thermal balance error, %
f	friction factor
F_h	fin height, m
F_l	fin length, m
F_s	fin spacing, m
F_w	fin width, m
h	heat transfer coefficients, W m^{-2} K^{-1}
k	overall heat transfer coefficient, W m^{-2} K^{-1}
L	total length of tubes, m
l	length, m
m	mass flow rate, kg s^{-1}
N	number of tube rows
N_t	number of tubes
Nu	Nusselt number
P_l	longitudinal tube pitch, m
P_t	transverse tube pitch, m
Q	heat transfer rate, W
q	volume flow rate, m^3 h^{-1}
Re_{Dc}	Reynolds number, $Re_{Dc} = \rho\ v_{max}\ D_c/\mu$
T	temperature, K
v	velocity of water, m s^{-1}
v_{fr}	air frontal velocity, m s^{-1}
v_{max}	maximum air velocity, m s^{-1}

Greek symbols

α	apex angle, °
δ	thickness, m
ΔT	temperature difference, K
ΔT_m	log mean temperature difference, K
η_f	fin efficiency
η_o	overall surface efficiency
θ	air inlet angle, °
λ	coefficient of heat conductivity, W m^{-1} K^{-1}
μ	dynamic viscosity, kg m^{-1} s^{-1}
ρ	density, kg m^{-3}
ψ	correction factor of temperature difference

Subscripts

a	air
f	fin
i	water side
m	mean value
o	air side
t	tube
w	water

the geometry parameters on the heat transfer of straight fin-and-tube heat exchangers with Computational Fluid Dynamics (CFD) technology. Their results indicated that the heat transfer would be enhanced while the pressure drop could be reduced by increasing the ellipticity of an elliptical finned tube. O'Brien et al. [22,23] tested the local heat transfer and pressure drop for finned tube heat exchangers with oval tubes and vortex generators. It was concluded that the addition of the single winglet pair to the oval-tube geometry produced significant heat transfer enhancement, averaging 38% higher than the oval-tube, no-winglet case, while the friction factor only increase less than 10%.

The mixed convection from an elliptical tube at different angles of attack placed in a fluctuating free stream was numerically studied by Ahmad and Badr [24]. It was shown that increasing the angle of inclination from 0° to 90° tends to enhance the vortex shedding and the heat transfer rates. Abd-Elhady et al. [25] investigated the influence of the apex angle of cone-shaped tubes on particulate fouling of heat exchangers. It was concluded that not only the attached cones intensified the flow around the tubes, but also the particles depositing on the top of the tubes of the heat exchanger could be removed by the air flow if the apex angle of the cone-shaped tubes was smaller than 90°.

The heat transfer characteristics and fluid flow structure of fin-and-oval-tube heat exchangers with longitudinal vortex generators (LVGs) were numerically studied and analyzed based on the field synergy principle [19]. Their results indicated that the reduction of the intersection angle between the velocity field and the temperature field was one of the essential factors influencing the heat transfer enhancement. Hasan and Sirén [17] studied the plain circular and oval tube evaporatively cooled heat exchangers. It was confirmed that the ratio (j_m/f) of the oval tube was 1.93–1.96 times than that of the circular tube which meant that the oval tube had a better overall thermal–hydraulic performance. Yoon et al. [26] investigated the diverse laminar flow characteristics of the vortices generated by an inclined square cylinder in channel flow to enhance the heat transfer capacity.

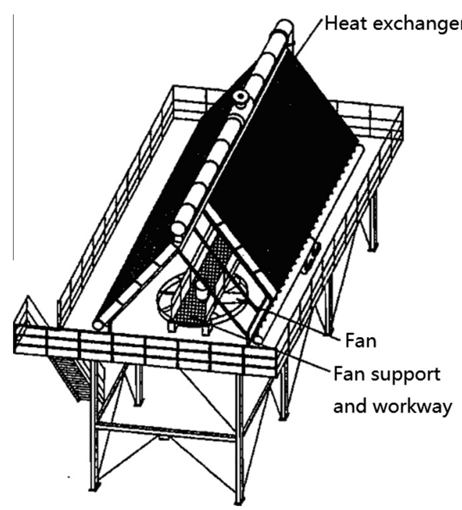

Fig. 1. A frame air-cooled condenser [1].

In the heat exchanger application fields, the structure optimization and performance prediction is a significant problem for designers and engineers. And there may be plenty of applications of finned oval-tube heat exchangers in the field of engineering operations. However, there are many researches on finned round-tube heat exchangers with different types of fins [3,4,6–11,27–29], while few on finned oval-tube heat exchangers.