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Research Paper

Numerical simulation study of a novel, truncated cone-shaped air-cooled unit

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HIGHLIGHTS

- TCACC is considered to reduce the high temperature region of ACC.
- The effects on the heat transfer between different porosity of TCACC are studied.
- Two types of baffle are installed to improve the TCACC performance.
- The baffle type 5b shows evident advantage for safe and economical operation.

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ABSTRACT

The Λ-frame air-cooled condenser (ΛACC) is widely applied by people, but it is also the main reason of the uneven distribution of internal air flow and temperature field in the air-cooled condenser (ACC). In order to solve these problems and make the air-cooled unit running more economically, safely and efficiently, heat transfer characteristics of new types of ACC are researched, which is of significance for improving traditional direct air cooling technology. Taking the 600 MW unit model of a thermal power plant as the comparative object, innovation is made to change the heat transfer surface of Λ-frame into truncated cone-shaped. By means of the numerical simulation, the relationship between the flow and heat transfer characteristics and the top baffle porosity of the truncated cone-shaped air-cooled condenser (TCACC) is studied, and the optimal baffle porosity for heat transfer and safety is got. Then, the effect of the shapes of baffle on the heat transfer characteristics of the TCACC is studied, and the shapes of which are optimized. Comparisons for a series of ACCs in different fan inlet air volumes and temperatures are made, and the optimized ACC is obtained for heat transfer and safety finally. All these we have done are going to provide some significant theory evidence for improving of direct air cooling technology.

1. Introduction

Saving-water can be achieved by Λ-frame air-cooled condenser (ΛACC) in a great extent, which typically reduces a plant's water usage by approximately 99% comparing to the wet-cooled ones with the same unit capacity [1]. Due to the condition of "abundance of coal, but short of water" in north China, the use of ΛACCs is popular as a thermal power generating unit cooling method. The air-cooled coal-fired power generating units in operation have been more than 80GW, occupying 13% of the total installed capacity of the coal-fired power generating units. Most of them are large scale direct air-cooled units above 300 MW, including a majority of 600 MW power generating unit [2].

ΛACC systems are comprised of an array of air-cooled heat exchanger units which condense the turbine exhaust in finned tube bundles. At present, ambient air is forced over Λ-frame finned tube bundles by means of an axial flow fan located beneath each condenser cell in Fig. 1. However, the performance of ΛACCs are involved a series of factors, including the flow and pressure field, the inlet ambient temperature of fans, and the physical properties of the ΛACC (such as proximity to the ground surface and nearby structures).

For improving the flow field and exchange heat effectiveness, lots of researches conducting experimental or numerical methods are investigated in recent decade.

Various of baffles were appeared frequently thereafter. Zhang et al. [3,4] studied the effect of windbreak mesh which was arranged below the ACC platform and outside the ΛACC steel supporting structure, and they proposed a installation of swirl device at the outlet of an axial fan. Owen and Maulbetsch et al. [5,6]

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Nomenclature

ΛACC	Λ-frame air-cooled condenser
ACC	air-cooled condenser
TCACC	truncated cone-shaped air-cooled condenser
CFD	computational fluid dynamics
TCACCB	TCACC with baffle bowl shaped
TCACCC	TCACC with baffle cylinder shaped
T	temperature [K]
p	air pressure [Pa]
u	velocity in some direction [m/s]
u'	pulsation velocity in some direction [m/s]
x_i	space coordinate component
c_p	heat capacity of constant pressure [$J \cdot kg^{-1} \cdot K^{-1}$]
g	acceleration [$m \cdot s^{-2}$]
$C_{1\varepsilon}$, $C_{2\varepsilon}$, $C_{3\varepsilon}$	constants of turbulence
k	turbulence kinetic energy [$m^2 \cdot s^{-2}$]
G_k	turbulent kinetic energy [$m^2 \cdot s^{-2}$]
G_b	turbulent kinetic energy [$m^2 \cdot s^{-2}$]
S_i	momentum source [$N \cdot s^{-2}$]
D_{ij}, C_{ij}	defined matrixes
C_2	inertial resistance coefficient matrix
Δp_f	pressure drop across the finned tube bundles [Pa]
u_f	axial velocity across the finned tube bundles [m/s]
l_z	heat exchanger thickness [m]
Q	heat load [W]
U	the overall Heat transfer coefficient [$W \cdot m^{-2} \cdot K^{-1}$]
A	both sides of the heat exchanger area [m^2]
Δt_m	logarithmic average temperature difference [K]
D_s	flow rate of the exhaust steam [$kg \cdot s^{-1}$]
h_s	enthalpy of the exhaust steam [$W \cdot m^{-2} \cdot K^{-1}$]
h_w	saturated water enthalpy of the assume the turbine back pressure [$W \cdot m^{-2} \cdot K^{-1}$]
Δt_a	air temperature rise [K]
t_{a1}	air temperatures of ACC inlet [K]
t_{a2}	air temperatures of ACC outlet [K]
t_c	turbine exhaust steam temperature [K]
D_a	cooling air flow rate [$kg \cdot s^{-1}$]
K	heat transfer coefficient [$W \cdot m^{-2} \cdot K^{-1}$]
S	surface area of ACC [m^2]
Δp_c	turbine exhaust pressure variation of ACCs [kPa]
H	vertical height [m]
R	spherical radius [m]
P	installation position [m]

Greek symbols

ρ	air density [$kg \cdot m^{-3}$]
μ	dynamic viscosity [Pa·s]
β	thermal expansion coefficient [K^{-1}]
σ_k, σ_T, σ_ε, μ_t	constants of turbulence
ε	dissipation of turbulence kinetic energy [$m^2 \cdot s^{-3}$]
ω	viscosity coefficient matrix
δ_{tp}	temperature drop of exhaust steam pipe [K]
δ_t	terminal temperature difference [K]

Subscripts

ref	reference value
i	component value, equates 1, 2 and 3
j	component value, equates 1, 2 and 3
a	air
s	steam

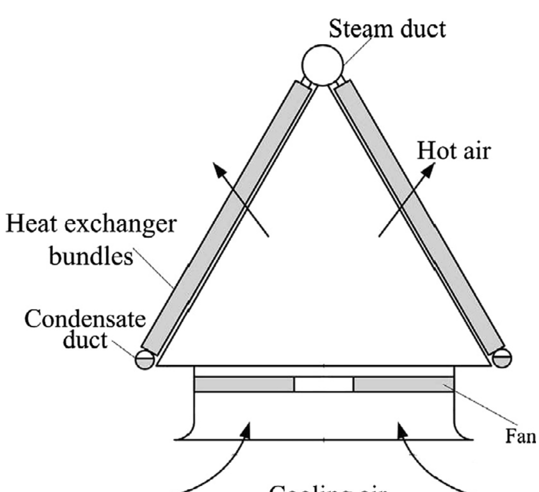

Fig. 1. The structure of ΛACC.

indicated that increased fan inlet temperatures are most severe at moderate wind speeds but tend to decrease and level-off at higher wind speeds. By conducting the numerical simulation, aforementioned could make a better air flow, improve the effect of heat transfer. VanRooyen et al. [7] demonstrated that the performance of the air-cooled steam condensers is sensitive to the wind conditions and high ambient temperature. Liu et al. [8] demonstrated that the hot air recirculation is caused by the ambient wind speed and its flow direction. Gao et al. [9] and Yang et al. [10] obtained a measure to improve ΛACC performance by installing diffuser orifice plate under the ΛACC platform. The investigation revealed the adverse impacts of ambient wind were weakened effectively. Owen et al. [11] suggested porous wind screens in a cross-type arrangement below the platform to increase the air-cooled condenser performance. Meyer [12] proposed a walkway at the edge of the fan platform and the removal of the periphery fan inlet section to reduce the inlet flow losses. Bredell et al. [13] also suggested the walkway to increase the flow rate through the periphery fans. Yang et al. [14] proposed three wind-break wall configurations to weaken the off-axis flow distortion and reduce the inlet air temperature, and achieved the better face velocity uniformity.

The aforementioned works mainly focus on the improvement of the velocity field and temperature field by accessories such as the baffles, diffuser orifice plate, windbreak mesh. However, the methods mentioned above don't resolve the practical problems in Λ-frame condenser cells radically. And only few researches were found to change the basic frame. Zhang et al. [15] proposed a V-frame condenser cell to create a favorable face velocity distribution, in which the axial flow fan is installed under the intersection of two finned-tube bundles rather than the centroid of cell chamber. Lee et al. [16,17] proposed a VV-shaped finned-tube condenser coils with an upper fan, which can effectively improve the heat transfer performance. O'Donovan et al. [18,19] studied on the losses in a full-scale ACC circular tube bundle and investigated a novel modular air-cooled condenser. A new trapezoidal array of ACCs is studied by Yang et al. [20] and a novel vertical arrangement is proposed by Chen et al. [21] can improve the thermo-flow