International Journal of Heat and Mass Transfer 118 (2018) 1022–1039

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

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

Effects of geometric structures of air deflectors on thermo-flow performances of air-cooled condenser

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ARTICLE INFO

Article history:
Received 5 September 2017
Received in revised form 3 November 2017
Accepted 14 November 2017

Keywords:
Air-cooled condenser
Flow and heat transfer
Ambient winds
Air deflector
Reverse flow
Turbine back pressure

ABSTRACT

Ambient winds may deteriorate the thermo-flow performances of air-cooled condenser (ACC) in power plants, so it is of benefit to the energy efficient operation of ACC to propose measures against adverse wind effects. In this work, the air deflectors installed under the fan platform of ACCs are proposed on the basis of a 2×300 MW direct dry cooling power plant. The flow and temperature fields of cooling air are obtained and analyzed for the air deflectors with various geometric parameters. The air mass flow rate and turbine back pressure are computed and compared with the original ACCs. The results show that the thermo-flow performances of ACCs are significantly influenced by the width, pitch, inclination angle and number of air deflectors, and get improved due to the restrained reverse flows in windward condenser cells. In most cases, the wide and more air deflectors are preferred, but the moderate pitch is recommended to improve the ACC performances. Moreover, the 45° inclination of air deflectors is superior to others in restraining the adverse wind effects.

1. Introduction

Due to great water conversation advantage, direct dry cooling system is becoming more and more popular among various cooling systems of power generating unit in arid areas. For direct dry cooling system, the ambient air is impelled by axial flow fans to flow across air-cooled condenser (ACC), taking away the heat rejection from exhaust steam. As a result, the ambient conditions, especially ambient winds, play important roles in ACC performance [1].

It has been well documented that ambient winds may lead to the inlet flow distortion and increased inlet air temperature of fans, so deteriorate the thermo-flow performances of ACCs. By wind tunnel experiments, Gu et al. [2] found that the hot air recirculation caused by the interference from neighboring buildings and structures can significantly reduce the ACC efficiency. Also, the wind speed and direction, the ACC platform height both affect the hot air recirculation. Yang et al. [3] numerically investigated the performances of the ACC as a whole, the condenser cells and fin-tube bundles under various wind conditions, finding that the thermo-flow performances of the downstream condenser cells are generally superior to those at the upwind due to the weakened adverse wind impacts along the wind direction. Duvenhage et al. [4] studied the inlet flow distortions of fans, pointed out that the platform height and fan inlet shrouds both play significant roles in the fan performance. Bredell et al. [5] simulated the flow fields of fans in ACCs, finding that the uneven inlet air distribution may cause the fan blade to stall, and the off-axis inflow reduces the static pressure. He et al. [6] investigated the air temperatures under different wind conditions, pointing out that the fan inlet temperature rising attributes to the diffusion effect and reverse irrigation. Yang et al. [7] found that the reversed flows in the upwind condenser cells lead to the high inlet air temperature, but the wind effect decays rapidly along the wind direction due to the combined hot plume discharge and ambient winds. Owen and Kröger [8] proved that the plume recirculation flows result in the increased local inlet air temperature at higher wind speeds. Liu et al. [9] pointed out that the hot air recirculation is related to the wind speed and direction.

To weaken the adverse wind impacts, various measures were suggested. Meyer [10] proposed the walkway at the platform edge and the removal of periphery fan inlet section to reduce the flow losses near the fan inlet. Bredell et al. [5] also suggested the walkway to increase the flow rate through the periphery fans. Owen et al. [11] found that the installation of wind screens in a cross-type way under the ACC platform is always beneficial to the performance of upstream fans under windy conditions. Yang et al. [12,13] proposed three wind-break wall configurations to weaken the off-axis flow distortion and reduce the inlet air temperature, and suggested the flow leading devices below the platform to

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https://doi.org/10.1016/j.ijheatmasstransfer.2017.11.071
0017-9310/

Nomenclature

A	heat transfer surface area (m^2); major axis of base tube (mm)
B	minor axis of base tube (mm)
C	constant in turbulence model
D	diameter of fan (m)
e	exponent in the power-law equation of wind speed
g	gravitational acceleration ($m\ s^{-2}$)
g_n	polynomial coefficient for the tangential velocity
h	convection heat transfer coefficient ($W\ m^{-2}\ K^{-1}$)
H	fin height (mm)
h_n	polynomial coefficient for the convection heat transfer coefficient
h_s	enthalpy of the exhaust steam ($J\ kg^{-1}$)
h_{wa}	enthalpy of the condensate ($J\ kg^{-1}$)
I	turbulence intensity; percent of improvement
k	turbulent kinetic energy ($m^2\ s^{-2}$)
k_L	flow loss coefficient
m	mass flow rate ($kg\ s^{-1}$)
N	number
p	pressure (Pa)
P	pith (m)
q	heat flux ($W\ m^{-2}$)
Q	heat transfer rate (kW)
r_n	polynomial coefficient of non-dimensional loss coefficient
S	source term in generic equation
t	temperature (°C)
u	velocity (m/s)
u_j	component of velocity (m/s)
W	width (mm or m)
x_j	coordinate in j direction (m)
z	height above the ground (m)

Greek symbols

Γ	diffusion coefficient ($m^2\ s^{-1}$)
Φ	heat rejection (W)
θ	air deflector inclination angle (°)
ε	turbulence dissipation rate ($m^2\ s^{-3}$)
μ	dynamic viscosity ($kg^{-1}\ m^{-1}\ s^{-1}$)
μ_t	turbulent viscosity ($kg\ m^{-1}\ s^{-1}$)
μ_e	$\mu + \mu_t$ effective viscosity ($kg\ m^{-1}\ s^{-1}$)
ρ	density ($kg\ m^{-3}$)
σ	minimum flow to face area ratio
φ	scalar variable

Subscripts

1	inlet
2	outlet
a	air
am	air mass flow rate
ad	air deflector
ave	average
f	frontal; fin
o	original
s	steam
w	wind
wa	water

improve the peripheral fan performance and reduce the hot plume recirculation. Wang et al. [14] suggested a side board below or above the fan platform to restrain the hot plume recirculation. Gao et al. [15] proposed the installation of deflecting plates under the platform to reduce the flow distortion at the fan inlet. Zhang and Chen [16] proposed a windbreak mesh below the fan platform and outside the fan steel supporting structure to improve the ACC performance, and recommended the rectangle-type windbreak mesh. Gu et al. [17] proposed a roof windbreak system to weaken the adverse wind effects, which plays a key role in the ACC performance. Yang et al. [18] proposed a trapezoidal array of air-cooled condensers to restrain the reverse flows in the upwind condenser cells and hot plume recirculation. Chen et al. [19] studied the performance of a novel layout of ACCs, finding that the flow rate increases conspicuously compared with the conventional ones both in the absence and presence of winds. Chen et al. [20] also proposed a reconstruction of ACCs combined the V-frame condenser cells with the induced axial flow fans to weaken the adverse wind effects. Kong et al. [21] proposed a novel circular array of ACCs, finding that the hot plume recirculation flows and reverse flows of peripheral condenser cells are greatly weakened. Kong et al. [22] also studied a hybrid ventilation direct dry cooling system utilizing the buoyancy force from the cooling tower, which can avoid the hot plume recirculation of peripheral condenser cells.

The aforementioned measures against the adverse wind impacts mainly focus on the accessories and new configurations of ACCs. Although the air deflectors are proposed [15], only the wind speed and direction, and the incline angle of deflectors are considered. In this work, the impacts of air deflectors under the windward fan platform on the thermal-flow characteristics of ACCs in a representative 2×300 MW direct dry cooling power plant are numerically investigated, where the width, inclination angle, number of air deflectors are all taken into account. Besides, the position of air deflectors is also different from previous work [15]. It can contribute to the energy efficient operation of air-cooled condensers under windy conditions.

2. Numerical modeling

2.1. Physical model

A typical 2×300 MW direct dry cooling power plant is schematically shown in Fig. 1(a), which consists of two ACCs with each containing 30 (5×6) condenser cells. The turbine and boiler houses, as well as the chimney near the air-cooled condensers are taken into consideration, but other buildings are neglected. Each condenser cell comprises an axial flow fan and two intersecting wave-finned flat tube bundles as depicted in Fig. 1(b). Based on the real parameters in practical engineering, Fig. 1(c) and Fig. 1(d) show the axial flow fan and the structure details of the wave-finned flat tube, with the main geometric parameters listed in Table 1. The layout of the two ACCs and air deflectors colored by red[1] are shown in Fig. 2(a), where the fans with green colors are in the first row or column locating at the windward. The air deflectors are installed below the steel supporting of windward fans, as shown in Fig. 2(b), with the geometric parameters listed in Table 2. To avoid unrealistic flow effects caused by the domain boundaries on the flow across the ACCs, the physical domain should be set large enough, which is shown in Fig. 3. For investigating the influence of the air deflectors on the performance of ACCs, only the prevailing wind is taken into consideration, as shown in Fig. 3.

[1] For interpretation of color in Figs. 2 and 8, the reader is referred to the web version of this article.