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Research Paper

Wind leading to improve cooling performance of natural draft air-cooled condenser

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HIGHLIGHTS

- Windbreakers are proposed and studied for natural draft air-cooled condenser (NDACC).
- Heat rejection of NDACC rises with windbreakers, especially at high wind speeds.
- Case B reduces uneven airflow distributions locally, but has little thermal benefits.
- With more windbreakers, cases E and F have nearly same best cooling performances.
- Case F windbreakers are recommended considering the robust and economic operation.

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ABSTRACT

Natural draft air-cooled condenser (NDACC) has been adopted in chemical and power plants owing to its superior energy-efficient operation to the traditional fan-driven air-cooled condenser. However, the cooling capability of NDACC is generally impaired by ambient winds, which incur the unbalanced airflow distributions through the condenser cells. So, the wind flow fields are organized in this research to restrain the adverse wind effects. By numerical simulations, five types of windbreakers are studied and compared with the no-windbreaker case. The air velocity, pressure and temperature distributions, and the specific air flow rates of condenser cells as well as heat rejections of cooling sectors are analyzed. Furthermore, the three-dimensional path lines are additionally presented to highlight the leading effects of windbreakers, airflow inside the tower, and flow discharge at the tower outlet. The results show that, appropriate windbreaker configurations can effectively improve the cooling performance of NDACC, especially at high wind speeds, while the windbreaker arrangement inside the condenser cells plays a negligible role in the overall cooling performance. Besides, the cases with 12 and 48 exterior windbreak walls achieve almost the same best performances. In consideration of the system robustness and economy, the case with 48 exterior windbreakers can be recommended in the future engineering application.

1. Introduction

In arid places, natural draft direct dry cooling system has been adopted by some power and chemical plants thanks to its superiority in water conservation [1–3]. The large-scale air-cooled condenser around the tower base incorporates dozens of condenser cells, which are formed by vertically arranged A-frame cooling columns with the common apex angle of 60° to fully utilize the area covered. For the heat transfer process of cooling system, the exhaust steam flows into the vertically arranged condenser cells, and rejects its latent heat to the cooling air driven by the buoyancy force from the dry cooling tower. However, similar to the indirect dry cooling system, the cooling performance of such a system is basically susceptible to the ambient conditions, especially the crosswinds. Therefore, it is essential to investigate the thermo-flow improvements of natural draft air-cooled condenser under the wind conditions.

The adverse wind effects on the airflow and heat transfer performances of natural draft indirect dry cooling system have been thoroughly investigated [4–9], and the relevant proposals of lifting the cooling efficiency, such as changing the layout of heat exchanger or cooling tower [2,10–15], pre-cooling of air [16–18], as well as water flow redistribution [19,20], were deeply studied. But as a matter of fact, it is the windbreakers with different structures that have always been regarded as the most practical accessories in power plants. Wang et al.

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Nomenclature

A	heat transfer area (m^2)
C	constant in turbulence model
D	diameter (m)
e	exponent of the wind speed in the power-law equation
g	gravitational acceleration ($m\,s^{-2}$)
G	turbulence kinetic energy generation ($m^2\,s^{-2}$)
h	convection heat transfer coefficient ($W\,m^{-2}\,K^{-1}$)
h_n	polynomial coefficient for the convection heat transfer coefficient
H	height (m)
I	thermal improvement index (%)
k	turbulent kinetic energy ($m^2\,s^{-2}$)
f	flow loss coefficient
L	length (m)
m	mass flow rate ($kg\,s^{-1}$)
N	number
p	pressure (Pa)
Q	heat rejection (W)
S	source term
t	temperature (K)
v_j	component of velocity (m/s)
v	velocity magnitude (m/s)
V	volume (m^3)
x_j	Cartesian coordinate (m)
z	height (m)

Greek symbols

α	apex angle (°)
Γ	diffusion coefficient ($kg\,m^{-1}\,s^{-1}$)
ε	turbulence dissipation rate ($m^2\,s^{-3}$)
η	cooling efficiency (%)
μ	dynamic viscosity ($kg\,m^{-1}\,s^{-1}$)
ρ	density ($kg\,m^{-3}$)
σ	turbulent Prandtl number
φ	scalar variable

Subscripts

a	air
b	base
cc	cooling column
o	out
f	fin
r	radiator
s	steam
t	tower
tt	tower throat
T	turbulence
w	wind
z	height

[21] suggested three windbreaker configurations, finding that the windbreaker combined with an enclosure shows most effective to cripple the adverse wind effects. Based on the natural draft dry cooling system with vertical heat exchanger, Ma et al. [22] pointed out that the setting angle of the windbreakers should be equal to air inflow deviation. Zhao et al. [23] recommended the windbreakers be installed around the tower inlet circumferentially and uniformly, so that the tangential air flow could be introduced toward the radial direction. Zhai and Fu [24] suggested the windbreakers be placed at the lateral sides of the air-cooled heat exchanger perpendicular to the crosswinds. Chen et al. [25] proposed the interior and exterior, as well as the combined windbreakers, finding that the exterior windbreakers are superior to the interior in the thermo-flow performances of cooling system. Gu et al. [26] compared the heat transfer characteristics of natural draft dry cooling system with four different windbreak configurations, finding that the wind-break wall is the most optimal structure. Lu et al. [27] proposed a tri-blade-like windbreak configuration for a small natural draft dry cooling system with horizontal heat exchanger, indicating that the cooling performance is most improved with the windbreaks placed in the attack angle of 0°.

It's worth noting that, the emphases of the aforementioned research are mainly placed upon the impacts of crosswinds on the cooling performance of natural draft indirect dry cooling system and the measures against the adverse wind effects. Furthermore, the deteriorated performance of natural draft dry cooling system basically originates from the unbalanced air flows through finned tube bundles under ambient winds, so improving the flow distribution outside the cooling tower by windbreakers is an effective way to recover the overall performance of cooling system. On account of these issues, this work will focus on the effects of exterior windbreakers outside the tower and the interior windbreakers inside the air-cooled condenser cells for a typical natural draft air-cooled condenser, compared with the no-windbreaker ones. The thermo-flow performances of NDACC with various windbreakers are clarified under crosswinds, which may contribute to the optimal design of windbreakers in practical engineering.

2. Modeling

2.1. Physical model

On the basis of a 600 MW power generating unit, the natural draft direct dry cooling system consisting of the hyperbolic tower shell and vertically arranged air-cooled condenser is schematically shown in Fig. 1(a). The delta-type condenser cell as the heat transfer unit comprises two cooling columns with the apex angle of 60°, and each column is 10 × 11 m in length and height respectively, as observed in Fig. 1(b). The wave-finned flat-tube is commonly accepted as the basic heat transfer element of air-cooled condenser in power plants. Table 1 lists the specific geometric parameters of the dry cooling tower and air-cooled condenser. During the thermo-flow process of natural draft direct dry cooling system as shown in Fig. 2, the cooling air takes away the rejected heat of exhausted steam when flowing through the heat exchanger bundles, and then gets discharged by the buoyance force of tower. The temperature of exhausted steam inside the finned tube of condenser cell is assumed constant with neglecting the inlet pressure loss and flow resistance.

For flexible control of steam flow rate in practical engineering, the condenser cells are equally divided into 12 sectors. Under windy conditions, the unbalanced distribution of cooling air is formed when flowing across the large-scale circular condenser, which results in the reduced cooling efficiency of dry cooling system, as shown in Fig. 3. In order to restrain such adverse wind effects, five types of windbreakers arranged inside or outside the air-cooled condenser cells are proposed, as shown in Fig. 4(a) together with the no-windbreaker configuration named as case A. The exterior windbreakers are set as 30 m in length and 11 m in height, while for the interior ones, the sizes are 9 m and 11 m respectively. For simplification, the air-cooled condensers with 48 interior windbreakers for all condenser cells, 2 exterior windbreakers at the lateral sides, 4 exterior windbreakers with the intersection angle of 90°, 12 exterior windbreakers with the intersection angle of 30°, and 48 exterior windbreakers with the intersection angle of 7.5°, are termed as case B, case C, case D, case E, case F respectively, as shown in Fig. 4(b).