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Thermo-flow performances of natural draft direct dry cooling system at ambient winds

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ABSTRACT

Natural draft direct dry cooling system (NDDDCS) uses the natural draft dry-cooling tower instead of axial flow fans, so can effectively reduce the power consumption, operating costs and also the noise caused by fans. In this work, two types of NDDDCS with horizontally arranged heat exchanger bundles (HAHEBs) and vertically arranged heat exchanger bundles (VAHEBs) are proposed respectively. Furthermore, the cooling delta apex angles from 60° to 180° are further investigated. The air-side velocity, pressure and temperature fields are presented and the heat rejections for various configurations of NDDDCS are calculated and compared. The results show that the cooling performance of NDDDCS with VAHEBs is superior to that with HAHEBs in any case, especially at high wind speeds. The VAHEBs with the apex angle of 150° have the best cooling performance, so can be recommended in the potential practical engineering of natural draft direct dry cooling system in power plants.

1. Introduction

Compared with wet cooling system, the dry cooling system can reduce the water loss caused by the evaporation and has been widely adopted by power plants in the arid regions [1,2]. As one of the dry cooling system, direct dry cooling system uses the air-cooled condenser (ACC) to take away the heat rejection from exhaust steam directly by cooling air. For the conventional ACC, it consists of dozens of condenser cells in the rectangular array, as shown in Fig. 1. For each condenser cell, the finned tube bundles are arranged in an A-frame form with the apex angle of about 60°. The axial flow fans are basically installed below the finned tube bundles, so that the ambient air can be driven to cool the exhaust steam from turbine. Nonetheless, it may suffer from the noise due to the turbulence and vibrations [3,4] as well as the operating costs from the high maintenance requirements, and also the power consumption. Additionally, ambient air is used instead of water as the cooling medium directly that the thermo-flow performances of ACC could be easily influenced by the ambient conditions, especially the crosswinds.

More attentions have been attracted to the impacts of crosswinds on the thermo-flow performances of ACC. Based on a representative 2 × 600 MW direct dry cooling system, Yang et al. [5,6] numerically investigated the wind impacts, finding that the crosswind may lead to the poor fan performance, exhaust air recirculation and mal-distribution of cooling air across the finned tube bundles. Liu et al. [7] simulated the hot air recirculation of air-cooled condenser under ambient winds, and concluded that the hot air recirculation is more sensitive to the wind direction and speed. Duvenhage and Kröger [8] reconfirmed that the crosswind blowing across the ACCs impairs the air flows driven by the fans and also strengthens the hot plume recirculation. Hotchkiss et al. [9] studied the effect of off-axis inflow on the performance of axial flow fans with various types of installation, pointing out that the fan efficiency can be reduced by crosswinds, while the fan power consumption not significantly affected. Bredell et al. [10] indicated that the inlet air flow distortions in a large air-cooled condenser are caused by the structures and crosswinds, besides the adjacent fans may result in the serious fan performance deterioration and volumetric effectiveness reduction, as well as fan blade vibration.

For restraining such unfavorable wind impacts on the thermo-flow performances of ACC, various measures have been proposed and deeply studied. Wang et al. [11] suggested the installation of a side board below or above the fan platform to restrain the hot plume recirculation. Zhang et al. [12] developed three types of windbreak meshes to weaken the adverse wind effects, concluding that the rectangle-type configuration can best prevent the periphery fans from suffering crosswinds. Gao et al. [13] recommended the air-flow guiding devices under the ACC platform to improve

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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)
k	turbulent kinetic energy ($m^2\,s^{-2}$)
f	flow loss coefficient
p	pressure (Pa)
Q	heat transfer rate (W)
T	temperature (K)
$\vec{v}$	velocity vector (m/s)
v	velocity magnitude (m/s)
z	height above the ground (m)

Greek symbols

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

Subscripts

b	base
f	fin
he	heat exchanger
i	air intake
N	net
o	outlet
p	peripheral
r	radiator
s	support
st	steam
t	turbulence
tt	tower throat
T	total
w	wind

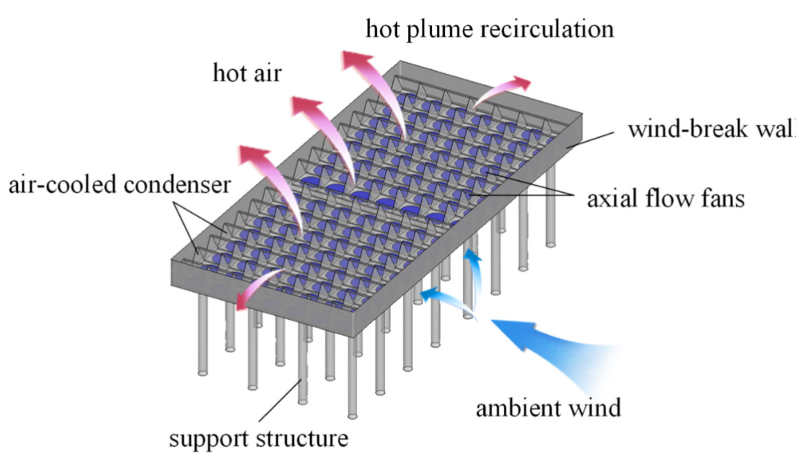

Fig. 1. Schematic of conventional direct dry cooing system.

the inlet air flow distortions of upwind fans. Gu et al. [14] studied the effects of various roof windbreak structures on the cooling performance of ACC and obtained the optimal geometries. Chen at al. [15] proposed a vertical configuration of air-cooled condenser to weaken the unfavorable wind effects and utilize the wind power, thus improve the cooling performance of dry cooling system conspicuously.

Different from the aforementioned direct dry cooling system with the ACC and axial flow fans, natural draft direct dry cooling system (NDDDCS) consists of the natural draft dry-cooling tower and ACC, which is similar to the natural draft indirect dry cooling system (NDIDCS) in geometric structure. For NDIDCS, some innovative structures have been suggested for the air-cooled heat exchanger and dry-cooling tower. Goodarzi and Ramezanpour [16] proposed a dry-cooling tower with the elliptical cross section to restrain the wind effects on dry cooling system, by which a better performance can be achieved than the traditional type. Kong et al. [17] recommended a bilaterally arranged air-cooled heat exchanger for NDIDCS, which is superior to the conventional circularly arranged configuration except for the wind speed higher than 14 m/s in the wind direction of 90°. Goodarzi [18] introduced a tower with the variable height to reduce the structural wind load without a considerable thermal performance deterioration. Additionally, Liao et al. [19] investigated the influence of the tower height to diameter ratio on the thermo-flow characteristics of dry cooling system, and proposed a lower value at high wind speeds.

In this work, the air-cooled condenser with a natural draft dry-cooling tower instead of large-scale axial flow fans will be developed. For this NDDDCS, the cooling air flows through the finned tube bundles by means of buoyancy force, resulting from the air density difference between the inside and outside of tower. With no axial flow fans, the fan power consumption could be completely saved. Moreover, even the capital cost is higher [20], the operating cost gets reduced compared to the conventional fan-driven alternative. Considering the air-cooled condenser layout, two types