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Research Paper

Direct dry cooling system through hybrid ventilation for improving cooling efficiency in power plants

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HIGHLIGHTS

- Hybrid ventilation direct dry cooling systems (C-HVDDCS and R-HVDDCS) are proposed.
- Hot plume recirculation is avoided completely for both C-HVDDCS and R-HVDDCS.
- Reversed flows in upwind condenser cells are effectively restrained for C-HVDDCS.
- HVDDCS can improve cooling efficiency greatly compared with conventional ACCs.
- C-HVDDCS shows the optimum thermo-flow performances under various ambient conditions.

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ABSTRACT

The thermo-flow performances of conventional air-cooled condenser (ACC) using mechanical ventilation are basically susceptible to ambient winds due to its geometrical flaws, so more attentions have been paid to weakening such unfavorable effects, but the hybrid ventilation has never been considered. Based on representative 2 × 600 MW power generating units, two types of hybrid ventilation direct dry cooling systems (HVDDCS) utilizing the buoyancy force from the cooling tower, circular-type and rectangular-type, are developed. Furthermore, the thermo-flow performances in three wind directions of 0°, 45° and 90° are presented and compared with the conventional ACCs. The results show that the hot plume recirculation of the peripheral condenser cells for HVDDCS can be avoided, thus the inlet air temperature of air-cooled condensers is reduced. For circular HVDDCS, the reversed flows in upwind condenser cells are much weakened, leading to increased heat rejection and improved cooling performance in any case. In the wind direction of 0°, the rectangular HVDDCS shows a superior performance to those in the wind directions of 45° and 90°, so it is applicable to the region with a prevailing wind direction. The HVDDCS could be recommended for the potential engineering application thanks to its more energy efficient performance.

1. Introduction

Direct dry cooling system has been widely applied to power plants throughout the arid regions short of water resources, whereby ambient air is used instead of water as the cooling medium directly [1]. The conventional air-cooled condenser in a power plant consists of dozens of condenser cells in a rectangular array. For each condenser cell, the finned tube bundles are arranged in the A-frame form with an axial flow fan below, so that ambient air can be driven to pass through the finned tube bundles to remove the heat rejection from exhaust steam. However, under the wind conditions, the cooling air shows difficult to pass perpendicularly across the axial flow fans. Therefore, the current ACCs are basically susceptible to ambient winds due to its geometrical flaws [2].

In past decades, the wind effects have been thoroughly investigated on the thermo-flow performances of the conventional ACCs. Yang et al. [3] numerically studied the impacts of wind speed and direction on the thermo-flow performances of air-cooled condensers in a power plant, proving that the wind effects on the upwind condenser cells and hot plume recirculation flows play key roles in performance deterioration. Duvenhage and Kröger [4] studied the wind effects on the fan performance and exhaust plume recirculation in air-cooled condensers, finding that the crosswind across the ACCs reduces the air flow rate, and also

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Nomenclature

A	heat transfer area (m^2)
C	constant in turbulence model
e	exponent of the wind speed in the power-law equation
f_n	polynomial coefficient for the pressure rise of fan
g_n	polynomial coefficient for the tangential velocity
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	enthalpy ($J\ kg^{-1}$)
I	turbulence intensity
k	turbulent kinetic energy ($m^2\ s^{-2}$)
k_L	flow loss coefficient
m	mass flow rate (kg/s)
P	pressure (Pa)
Q	heat transfer rate (W)
r_n	polynomial coefficient of non-dimensional loss coefficient
S	source term
T	temperature (K)
v_j	component of velocity (m/s)
v	velocity magnitude (m/s)
x_j	Cartesian coordinate (m)
z	height above the ground (m)

Greek symbols

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 ($kg\ m^{-1}\ s^{-1}$)
φ	scalar variable

Subscripts

a	air
avg	average
c	condenser
r	radiator
s	steam
T	turbulence
wa	saturated water
θ	tangential direction

strengthens the exhaust plume recirculation. Gu et al. [5] investigated the hot plume recirculation by a wind tunnel experiment, showing that the wind speed and direction, as well as the platform height all show significant impacts. By numerical simulation, Hotchkiss et al. [6] investigated the cross-flow effects on the performance of axial flow fans, concluding that the fan efficiency is reduced and fan-blade loading is affected by the cross-flow induced off-axis inflow. The aforementioned works all prove that the ambient winds may significantly cripple the cooling efficiency of conventional ACCs.

In order to weaken such wind impacts on the thermo-flow performances of ACCs, various measures have been proposed. Wang et al. [7] investigated the air flow and temperature fields in a power plant, and suggested the installation of a side board below or above the fan platform to restrain the hot plume recirculation. Zhang et al. [8] suggested three types of windbreak meshes to weaken the wind adverse effects, finding that the windbreak mesh in a rectangle-type configuration can well prevent the periphery fans from suffering winds. Gao et al. [9] suggested the air-flow guiding devices under the air-cooled condenser platform to improve the inlet flow distortions of upwind fans. Gu et al. [10] studied the effects of various roof windbreak structures on the cooling performances of ACCs and obtained the optimal geometries. What's more, Bredell et al. [11] and Yang et al. [12] proposed to extend the inner and outer walkways, which can effectively improve the cooling capability of ACCs.

As a matter of fact, it is the rectangular array configuration of the conventional ACCs that deteriorates the thermo-flow performances of the windward as well as the periphery condenser cells under the wind conditions, so some novel constructions of air-cooled condenser have been investigated recently. Zhang et al. [13] proposed a "V" frame condenser cell to form 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. [14,15] studied the VV-shaped finned-tube condenser coils with an upper fan, which can effectively improve the heat transfer performance. Chen et al. [16] suggested a novel layout of air-cooled condensers, by which the air flow rate increases conspicuously compared with the conventional ACCs. Yang et al. [17] investigated a trapezoidal array of air-cooled condenser to restrain the adverse wind impacts.

As also well known, the cooling performance of conventional ACC drops sharply at high ambient temperatures, due to the reduced temperature difference between the exhaust steam and ambient air. In general, if the ambient temperature increases by 10 °C, the net power efficiency will be reduced by about 4.2%. Considering this, Bustamante et al. [18] proposed two hybrid wet-dry cooling systems at high ambient temperatures, pointing out that the hybrid cooling can improve the ACC performance with a minimal water consumption. Besides, Heyns [19] introduced a direct air cooled dry-wet dephlegmator condenser at different ambient temperatures and achieved a measureable enhancement in cooling performance at the high ambient temperature.

Conclusively, although the conventional ACC shows the superiority to wet cooling system, it suffers the low thermal efficiency from ambient winds as well as its own configuration defects. Furthermore, the aforementioned researches mostly focused on the auxiliary facilities such as the air flow leading plates, windbreak wall and walkway. Even though some novel proposals of ACCs have been investigated, has never the hybrid ventilation technology been studied before. In this research, two direct dry cooling systems through hybrid ventilation are suggested based on 2 × 600 MW power generating units, which may enhance the cooling performance of the current fan-driven ACCs by adding cooling tower shell over the heat exchanger platform. For the innovative HVDDCS, the cooling tower increases the buoyancy force of cooling air, which helps more air flow through the air-cooled condensers and then take away more heat. Besides, the hot plume recirculation of peripheral condenser cells can also be eliminated thoroughly. In consequence, the HVDDCS will improve the thermal efficiency of the cold end system substantially since the turbine back pressure can be much reduced. As further noticed, the proposed HVDDCS can allow fewer heat exchanger areas than conventional ACCs and also smaller tower shell than natural draft dry cooling system (NDDCS) to meet the cooling requirement, therefore may reduce the capital cost for its potential engineering application. This investigation of HVDDCS can be beneficial to the design optimization of direct dry cooling system in power plants.