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A novel layout of air-cooled condensers to improve thermo-flow performances

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HIGHLIGHTS

- A novel vertical arrangement of air-cooled condensers is proposed.
- Novel air-cooled condenser flow rate markedly increases compared with the current.
- Inlet air temperature of novel air-cooled condensers equals to ambient temperature.
- Novel ACCs utilize wind power to improve the thermo-flow performances.
- Novel ACCs can be applied to the direct dry cooling system design in power plants.

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ABSTRACT

Ambient winds are generally unfavorable to the thermo-flow performances of air-cooled condensers in power plants. More emphases are placed to weaken the negative effects of ambient winds, but no layout alternative of air-cooled condensers is considered. In this work, a novel vertical arrangement of air-cooled condensers is proposed on the basis of a 2 × 600 MW direct dry cooling power plant, which can weaken the adverse wind effects and utilize the wind power to improve the cooling capacity of air-cooled condensers. By means of the CFD simulation and experimental validation, the flow and temperature fields of cooling air for the vertically arranged air-cooled condensers at ambient winds are obtained. The mass flow rate, inlet air temperature and turbine back pressure are computed and compared with the traditional air-cooled condensers. The results show that the flow rate of the novel air-cooled condensers increases conspicuously compared with the current ones both in the absence and presence of winds. In the wind directions of 60° and 90°, the off-axis flow distortions of axial flow fans are greatly weakened and the average inlet air temperature of the novel air-cooled condensers is reduced and almost equals the ambient temperature. The thermo-flow performances of the air-cooled condensers are improved, thus the turbine back pressure is reduced by the novel layout of air-cooled condensers.

1. Introduction

Due to the great advantage of water conservation, direct dry cooling system has been widely applied to power plants in arid areas. Tawney et al. [1] studied the power plant heat sink, pointing out that the minimal water usage requirement and no blowdown disposal are the main merits of the direct dry cooling system with air-cooled condensers (ACCs). Barigozzi et al. [2,3] optimized the combined wet and dry cooling system, by which the performance of the waste-to-energy cogeneration plant was improved. Not only in the thermal power industry, is air-cooled condenser also commonly used in other fields, such as the air conditioning and refrigeration industries [4,5].

An extremely similar configuration has been adopted for the existing direct dry cooling system. That is, the air-cooled condenser consists of dozens of condenser cells in a rectangular array. The condenser cell is basically configured in the shape of an A-frame plume chamber with horizontally arranged A-frame finned tube bundles and an axial flow fan below. In order that the ambient air can flow easily across the finned tube bundles to take away the heat rejection from the turbine exhaust steam, the air-cooled condenser should be elevated to an enough height. The higher the air-cooled condenser platform is, the easier the ambient air

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Nomenclature

A	heat transfer surface area (m^2)
C	constant in turbulence model
c_{pa}	specific heat of air ($J\ kg^{-1}\ K^{-1}$)
e	exponent of the wind speed in the power-law equation
g_n	polynomial coefficient for the tangential velocity
h	convection heat transfer coefficient ($W\ m^{-2}\ K^{-1}$)
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
k	turbulent kinetic energy ($m^2\ s^{-2}$)
k_L	flow loss coefficient
K	overall heat transfer coefficient ($W\ m^{-2}\ K^{-1}$)
m	mass flow rate ($kg\ s^{-1}$)
N	number
p	pressure (Pa)
q	heat flux ($W\ m^{-2}$)
r_n	polynomial coefficient of non-dimensional loss coefficient
S	source term
t	temperature (°C)
t_s	temperature of saturated steam (°C)
t_w	wall temperature of radiator (°C)
u_f	frontal velocity ($m\ s^{-1}$)
u_j	component of velocity ($m\ s^{-1}$)
u_w	wind speed ($m\ s^{-1}$)
x_j	Cartesian coordinate (m)
z	height above the ground (m)

Greek symbols

ε	turbulence dissipation rate ($m^2\ s^{-3}$)
μ	dynamic viscosity ($kg\ m^{-1}\ s^{-1}$)
μ_t	turbulent viscosity ($kg\ m^{-1}\ s^{-1}$)
ρ	density ($kg\ m^{-3}$)
Γ	diffusion coefficient ($kg\ m^{-1}\ s^{-1}$)
Φ	heat rejection (W)
φ	scalar variable

Subscripts

1	inlet
2	outlet
a	air
avg	average
f	frontal
s	steam
w	wind
wa	water
θ	peripheral direction

flow through the axial flow fan is. Even so, the strong crosswinds in the horizontal direction are difficult to pass perpendicularly across the axial flow fans. Therefore, it is generally accepted that the ambient winds play unfavorable roles in the thermo-flow performances of air-cooled condensers.

More attentions have been attracted to the impacts of the A-frame plume chamber and axial flow fan configurations, as well as the crosswinds on the thermo-flow performances of air-cooled condensers. Salta and Kroger [6] experimentally studied the effects of the height and distance of fan platforms on the volumetric effectiveness of a single fan or multiple fans, finding that the effectiveness increases with increasing the platform height, and the inlet flow distortions occur in the periphery fans. By using the actuator disc model, Thiart and von Backstrom [7] studied the impacts of the inlet flow distortion on the axial flow fan performance. van Rooyen and Kroger [8] studied the air-cooled condenser performance at ambient winds with the actuator disc model, concluded that the off-axis inflow results in poor performances of the fan and condenser. Hotchkiss et al. [9] investigated the axial flow fan performance by using the actuator disc fan model as well. Duvenhage and Kroger [10] pointed out that the upwind condenser cells are mainly affected and the hot plume recirculation occurs at the side condenser cells when the crosswind blows along the longitudinal axis of air-cooled condensers. The work by Yang et al. [11,12] also proved the wind effects on the upwind condenser cells and hot plume recirculation flows.

Various measures against the adverse impacts of crosswinds were proposed accordingly. Wang et al. [13] suggested the installation of a side board below or above the fan platform to restrain the hot plume recirculation. Meyer [14] 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. [15] also suggested the walkway to increase the flow rate through the periphery fans. Yang et al. [16,17] proposed three wind-break wall configurations to weaken the off-axis flow distortion and reduce the inlet air temperature, and suggested flow leading devices below the platform to improve the peripheral fan performance and reduce the hot plume recirculation. Gao et al. [18] studied the effect of deflecting plates below the platform on the heat transfer performance of air-cooled condensers under windy conditions. Owen and Kroger [19] suggested porous wind screens in a cross-type arrangement below the platform to increase the air-cooled condenser performance. Yang et al. [20] proposed a trapezoidal array of air-cooled condensers to restrain the reverse flows in the upwind condenser cells and hot plume recirculation.

Recently, various novel constructions of air-cooled condensers are proposed, which have many advantages over the traditional air-cooled condensers. O'Donovan et al. [21–23] presented a novel modular air-cooled condenser mainly used in solar or thermoelectric power plants, which can be pre-assembled with small controlled axial flow fans. Butler and Grimes [24] studied the wind effect on the modular air-cooled condenser and proposed the optimal condenser configuration. Zhang et al. [25] 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. [26,27] proposed a VV-shaped finned-tube condenser coils with an upper fan, which can effectively improve the heat transfer performance.

The aforementioned works mainly focus on the additional accessories of air-cooled condensers such as the walkway, windbreak wall and flow leading plates. Even though some novel configurations of air-cooled condensers are proposed, they only aims at overcoming the shortcomings of traditional air-cooled condensers rather than improving the thermo-flow performances at ambient winds. As is well known, the off-axis flow distortion basically results in the performance deterioration of air-cooled condensers in the absence of winds, which is the weakness of the current air-cooled condenser layout in nature. Under windy conditions, this disadvantage of the air-cooled condenser layout becomes more