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Novel air-cooled condenser with V-frame cells and induced axial flow fans

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ABSTRACT

The thermo-flow performances of air-cooled condensers (ACCs) are basically deteriorated under wind conditions, so it is of great concerns to propose the measures against the adverse wind effects on air-cooled condensers. In this work, a novel reconstruction of ACCs combined the V-frame condenser cells with the induced axial flow fans, and a modified layout of the novel ACCs for a specific wind direction are proposed based on the direct dry cooling system in a 2×600 MW power plant. The CFD approach with a validation is applied to the performance investigation of the novel ACCs. The variable fields, mass flow rate, inlet air temperature and turbine back pressure for both the conventional and novel layouts of ACCs under different wind conditions are obtained and compared. The results show that the mass flow rates of the novel ACCs increase conspicuously compared with the conventional ACCs both in the absence and presence of winds. The flow distortions through the induced axial flow fans are greatly restrained and the inlet air temperature of the novel ACCs decreases, which lead to the improved thermo-flow performances of ACCs and reduced turbine back pressure of power generating unit.

1. Introduction

As an excellent water conservation technology, the direct dry cooling system with air-cooled condensers (ACCs) has been widely adopted in power plants at arid regions, which stands out from various heat sinks for the reason of minimal water consumption and no blowdown [1]. In addition to the thermal power station, ACCs are also widely applied to the cold ends of some industries, such as the refrigeration and air conditioning [2,3].

In practical engineering, most of ACCs are composed of dozens of condenser cells configured in a rectangular array. As the basic component of ACCs, the condenser cell is presented in the A-frame form with slant finned tube bundles on both sides of the roof, and an axial flow fan below. The ACCs platform is basically located at a certain height, ensuring sufficient amount of cooling air flow through the ACCs to take away the exhaust heat easily. But under wind conditions, the performances of the axial flow fans are deteriorated due to strong off-axis flows at their inlets, so it is generally considered that the crosswinds are always disadvantageous to the thermo-flow performances of ACCs.

More researches have been focused on the defects of the conventional ACCs in the A-frame style in windy days. By means of experimental and numerical methods, Duvenhage et al. [4] studied the adverse impacts of inlet distortions on the fan performance at different heights and distances of fan platforms, and proposed a fan inlet shroud configuration for optimal fan performance. With blades element theory, Thiart and von Backstrom [5] numerically investigated the crossflow impacts on the power consumption of axial flow fan, which basically agreed with the experimental results. With the actuator disc model, van Rooyen and Kroger [6] studied the ACC performance under wind conditions, concluding that the cooling efficiency decreases due to the off-axis inflow induced fan performance deterioration, other than the hot plume recirculation. Hotchkiss et al. [7] found that the torque characteristics at the outer portion of the fan blades are in charge of the fan power and efficiency. Duvenhage and Kroger [8] concluded that the crosswinds significantly deteriorate the performances of upwind fans with less air volume flow rate, and the hot plume recirculation becomes serious when the winds blow along the longitudinal axis of the ACCs. The work by Yang et al. [9,10] also confirmed the adverse wind effects on the upwind axial flow fans and the hot plume recirculation phenomenon.

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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	face 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

So far, many solutions have been put forward accordingly to deal with the crosswinds issues. With the purpose to restrain the hot plume recirculation flows, Wang et al. [11] proposed an outstretched windbreak board below or above the ACCs platform. Based on the result that the inlet flow loss is caused by the flow separation around the inlet lip of the fan ring, Meyer [12] recommended an additional walkway installed outside the ACCs platform and the dismantlement of the peripheral fan rings. Bredell et al. [13] investigated the effect of fan inlet flow loss on the fan performance, suggested the fan with a high hub-tip-ratio and the additional walkway. Yang et al. [14–16] proposed several measures such as the extended walkway, fan regulations, flow leading devices and novel arrays of ACCs to restrain the adverse effects of crosswinds. By setting a kind of deflectors to utilize the wind power, Gao et al. [17] pointed out that the higher the wind speed is, the more improved the ACC performances are. Owen and Kroger [18] suggested a porous screen in a cross shape on the ground below the fan platform to improve the performances of the upstream fans. By investigating the effects of windbreak mesh under windy conditions, Zhang et al. [19] recommended a rectangle-type windbreak mesh.

Besides the aforementioned accessory devices, some new configurations of ACCs are also recommended, which have a great advantage over the existing ones. Moore et al. [20] investigated a modular configured air-cooled condenser incorporated with low speed axial flow fans, which can be pre-assembled and allows the off-design operation of condenser. Instead of the large-scale axial flow fans, Butler and Grimes [21] proposed the modular air-cooled condenser with a small axial flow fan array and investigated the wind effects. By investigating the face velocity distributions of ACCs, Zhang et al. [22] proposed a V-frame condenser cell, which exhibits a favorable face velocity distribution opposite to the A-frame cell. Lee et al. [23,24] studied the thermo-flow performances of the VV-shaped condenser coils with an upper fan and a superior configuration was proposed.

As is well known, the inlet flow distortions of axial flow fans will definitely lead to the performance deterioration of ACCs under windy conditions, which is the defect of the conventional ACCs. In our previous work [25], a novel layout of vertically configured ACCs was proposed to improve the thermo-flow performances, which can utilize the kinetic energy of crosswinds. In this work, another novel layout of ACCs with the V-frame condenser cells and induced axial flow fans is proposed based on a 2×600 MW direct dry cooling power plant, by which the adverse wind effects on the induced axial flow fans can be effectively restrained. The thermo-flow performances of the novel ACCs and the turbine back pressure will be investigated and compared with the conventional ACCs, which can contribute to the design of air-cooled condensers in power plants.

2. Modeling and methods

2.1. Physical models

A typical 2×600 MW direct dry cooling power plant usually consists of two ACCs, with 56 (7×8) condenser cells arranged in a rectangular array for each ACC as shown in Fig. 1. For the condenser cell, it is in an A-frame form with an axial flow fan below as shown in Fig. 2(a). Under windy conditions, the off-axis flows, reverse flows and hot plume recirculation will deteriorate the thermo-flow performances of conventional ACCs. For the novel layout of ACCs proposed in this work, the condenser cell is constructed in a V-frame form with an induced axial flow fan on the top as shown in Fig. 2(b). The crosswinds blow towards the finned tube bundles and flow into the condenser cell chamber, so the off-axis flow is weakened at the inlet of the induced axial flow fan. The A-frame and novel V-frame layouts of ACCs are shown in Fig. 2 (c) and (d), in which the No. 1 ACC and No. 2 ACC are installed side by side, and the serial numbers of the condenser cells are pre-