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Research paper

Effects of windbreak mesh on thermo-flow characteristics of air-cooled steam condenser under windy conditions

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HIGHLIGHTS

- A windbreak mesh is considered to improve ACSC performance under windy conditions.
- The wind tunnel test is applied to determine the windbreak mesh loss coefficient.
- The effects of windbreak mesh are numerically investigated.
- The windbreak mesh in rectangle-type configuration shows the best performance.

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ABSTRACT

Ambient wind has adverse impacts on the thermal-flow characteristics of air-cooled steam condenser (ACSC). A windbreak mesh is arranged below the ACSC platform and outside the ACSC steel supporting structure to improve ACSC performance, and its effects are numerically investigated. The windbreak mesh in a rectangle-type configuration improves the volumetric effectiveness of almost all periphery fans because of the protection effect. It also increases the volumetric effectiveness of most inner fans at $+X$ wind direction, while it has little effect on inner fans at $+Y$ wind direction because main buildings locating upstream of the ACSC weaken the protection effect of windbreak mesh. In addition, the windbreak mesh has the greatest effect on inlet air temperatures of windward fans at $+X$ wind direction because of the alleviation of reversed flow, while the inlet air temperatures of periphery fans locating in Row 1 and Row 8 decrease obviously at $+Y$ wind direction as a result of hot air recirculation mitigated by windbreak mesh. Obviously, the total ACSC heat transfer effectiveness is improved by windbreak mesh under windy conditions. Compared with grid-type and cross-type configurations, the windbreak mesh in rectangle-type configuration can protect the periphery fans to avoid suffering ambient wind to the greatest extent, and it consequently shows the best performance in general.

1. Introduction

Economic and environmental restrictions have resulted in an increase in the installation of air-cooled steam condensers (ACSCs) in direct cooled power plants located in arid regions. The use of air as the cooling medium means the ACSC performance is directly influenced by ambient wind conditions [1].

It is well documented that ambient wind has a negative effect on ACSC performance as a result of reducing fan performance and increasing ambient temperature. In the numerical studies of ACSC, Duvenhage and Kröger [2] found that cross wind significantly reduces the air flow rate in the upwind condenser cells. It indicated that there exists a negative pressure region under the ACSC platform, especially at the inlet of windward fans, which decreases fan performance greatly [3,4]. Owen [5] numerically investigated the air flow field about and through a particular air-cooled condenser under windy conditions, and found that reduced fan performance due to distorted flow at the inlet of the upstream fans is the primary contributor to the reduction in ACSC performance associated with increased wind speed. Another contributor to the ACSC performance reduction under windy conditions is hot air recirculation. Owen and Kröger [5] showed that hot air recirculation increases with wind speed. In an experimental investigation of the same ACSC, Maulbetsch and DiFilippo [6,7] indicated that increased fan inlet temperatures are most severe at moderate wind speeds but tend to decrease and level-off at higher wind

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Nomenclature

ACSC	air-cooled steam condenser
b	exponent of the wind speed in power-law equation
c_{pa}	isobaric specific heat of air (J kg^{-1} K^{-1})
C_2	pressure-jump coefficient
$C_{1\varepsilon}$, $C_{2\varepsilon}$, $C_{3\varepsilon}$	$k-\varepsilon$ model constants
C_i	inertial loss coefficient
C_μ	empirical constant of 0.09
e	specific energy (J kg^{-1})
g	gravitational acceleration (m s^{-2})
G_b	turbulence kinetic energy generation due to buoyancy (m^2 s^{-2})
G_k	turbulence kinetic energy generation due to mean velocity gradients (m^2 s^{-2})
h	specific enthalpy (J kg^{-1})
I	turbulence intensity
k	turbulence kinetic energy (m^2 s^{-2})
l_{wm}	windbreak mesh thickness (m)
l_z	heat exchanger thickness (m)
m	mass flow rate (kg s^{-1})
NTU	number of transfer units
p	pressure (Pa)
Δp	pressure drop (Pa)
Δp_f	fan pressure rise (Pa)
Q	heat transfer rate (W)
S_i	momentum source (N m^{-3})
T	temperature (K)
v	air velocity (m s^{-1})
v_{avg}	mean flow velocity (m s^{-1})
v_{10}	wind speed at 10 m height (m s^{-1})
v_f	axial velocity across a fan surface (m s^{-1})
v_w	wind speed (m s^{-1})
v_{wm}	velocity across the windbreak mesh (m s^{-1})
V	volumetric flow rate (m^3 s^{-1})
x_i	Cartesian coordinate (m)
z	height above the ground (m)

Greek symbols

$1/\alpha_i$	viscous loss coefficient
α_{wm}	windbreak mesh permeability
ρ	density (kg m^{-3})
μ	dynamic viscosity (kg m^{-1} s^{-1})
ε	turbulence kinetic energy dissipation rate (m^2 s^{-3})
τ	stress tensor (J m^{-3})
σ	turbulent Prandtl number
ε_{ij}	heat transfer effectiveness of No.(i,j) exchanger
η_{ACSC}	overall ACSC heat transfer effectiveness
ξ_{wm}	loss coefficient of windbreak mesh

Subscripts

a	air
avg	average
ftb	finned tube bundles
id	ideal
ij	No.(i,j) exchanger
eff	effective
t	turbulent
v	vapor
wm	windbreak mesh

speeds. Gu [8] investigated the phenomenon of recirculation at different wind directions, wind speeds and ACSC platform heights through wind tunnel experiments. It was found that the effects from the wind conditions and ACSC platform height are significant for the recirculation. Wang [9] and Liu [10] simulated the hot air recirculation respectively, and proposed some constructive suggestions to reduce the recirculation. Yang [11] found that the reversed flows happened in the upwind condenser cells lead to the high inlet air temperature, worsening the cooling capability of air at high wind speeds. He [12] found that the recirculation is not the only reason to raise air temperatures at the inlets of axial fans. It was found that the phenomenon of diffusion effect as well as reverse irrigation is also significant to raise the air temperatures at the fan inlets.

To weaken the adverse impacts of ambient wind on the thermal-flow characteristics of ACSC, various measures had been proposed, such as the extensions of the inner and outer walkways [13,14] at the fan platform height, the elevation of the wind-break wall [13], the promotion of the windward fan rotating speed [15], and the installation of flow guiding devices below the ACSC platform [16,17]. Furthermore, Owen [2] investigated the effect of porous wind screen installed in a cross-type arrangement below the fan platform and found the wind screen configuration can improve ACSC performance.

The measures to alleviate the adverse impacts of ambient wind have already been investigated by the aforementioned research. However, the measure of installing a windbreak mesh to improve ACSC performance is still not reported. Furthermore, the pressure drop across the windbreak mesh is not known, which may affect the accuracy of numerical model. In this paper, the impact of a windbreak mesh upon the thermal-flow characteristics of ACSC in a representative 600 MW direct air cooled power plant are numerically investigated. The windbreak mesh is 45% area open to flow and is arranged in a rectangle-type configuration below the ACSC platform and outside the ACSC steel supporting structure. The wind tunnel test setup is applied to determine the windbreak mesh material loss coefficient, which guarantees to obtain reliable numerical results. Other different variations of windbreak mesh configurations, grid-type and cross-type, are also numerically investigated to find the optimal configuration.

2. Numerical models

2.1. Physical model and computational grids

The influence of ambient wind on the performance of ACSC is investigated based on the numerical model of a typical 600 MW direct air cooled power plant. Fig. 1 presents the layout of the ACSC containing 56(8 × 7) condenser cells and main buildings consisting of the boiler and turbine houses. The representative structure of condenser cell is shown in Fig. 2(a). It mainly consists of an axial flow fan, 9.15 m in diameter and a series of finned tube heat exchanger bundles. The cooling air is accelerated towards the A-frame plenum chamber by the fan, and then it is heated as flowing through the finned tube heat exchanger bundles. As a result, the heat rejection of the exhaust is carried away by cooling air. As the purpose of this study is to investigate fan performance and system performance, A-frame plenum chamber is simplified as a rectangular box [3–5], as shown in Fig. 2(b). The effects of the simplified model and an actual A-frame heat exchanger model on heat transfer rate of condenser cell under the windless operating condition are investigated. The results show that the difference between the two heat exchanger models is only 0.72%, which confirms that the simplified model is reliable enough.