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Research Paper

Fresh breeze cuts down one-third ventilation rate of a natural draft dry cooling tower: A hot state modelling

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HIGHLIGHTS

- Cooling performance of a NDDCT in 660 MW power plant was studied under crosswind.
- Experiments were conducted with a scaling NDDCT model in a wind tunnel.
- Radiator model was heated and its resistance met the first order profile.
- Outlet velocities, inlet/outlet pressures of the scaling model were measured.
- Cross ventilation and lowest ventilation rate were found in fresh breeze condition.

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ABSTRACT

The natural draft dry cooling tower (NDDCT) has been increasingly used in power generation for its merits of excellent water-saving, high energy saving, simple maintenance and long life service. To study the performance of a newly installed 660 MW NDDCT under crosswind condition, a model with scale of 1:200 was built according to the scaling law of geometric similarity. The experiments were set up in self-similar region with high Reynolds to meet momentum similarity, while meeting the scaling law of Froude and Euler numbers. A first order law radiator resistance model is also proposed and verified by a systematic test. The exponent law profile of wind velocity above the ground was built and verified by experimental data. On the ground of a constant heating rate bases, the flow field inside the NDDCT and the ventilation rate were investigated at the crosswind range of 0–20 m/s.

1. Introduction

The development of natural draft dry cooling technology is of significance for the thermal power plants for its merits of stable operation, low maintenance cost and water saving [1]. In the cooling system, the natural draft dry cooling tower (NDDCT) is the main component. Around the circumference or inside the NDDCT, some heat exchanger bundles are installed [2]. The heat transfer between the air and heat exchanger bundles depends on the ventilation rate of the tower and the flow field inside and surrounding the NDDCT.

Previous studies, mostly by computational fluid dynamics (CFD) simulation, found that the cooling performance of NDDCT is sensitive to ambient crosswind, which may severely change the surrounding and inside flow fields [3]. Numerical results showed that the crosswind at 20 m/s may decrease the ventilation rate by 36%, and increase the temperature of circulating water by 7 °C [3]. In addition, the crosswind could cause a 7.5 °C increment of the air temperature inside the tower [4], or more than 25% decrement of the heat transfer efficiency [5].

A few experimental studies have been conducted on the cooling performance of NDDCT [8–11], and they can be divided into cold state tests and the hot state tests. In the cold state tests, NDDCT model is used and the upward air flow in the tower is artificially introduced from the top outlet [6], or the bottom of the tower [7], or at the throat [8] of NDDCT model, depending on installation position of the draft fans. Obviously, these three kinds of air flow induction emulate only part of flow field in the tower, while interfering the other parts.

To assess the effect of crosswind on the cooling performance, the cold tests were usually conducted in a wind tunnel using a

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Nomenclature

a	the exponent of the wind velocity profile
d	spacing mm
D	throat diameter m
Eu	Euler number
Fr	Froude number
g	gravity m^2/s
H	height m
l	width of the resistance pieces mm
L	characteristic size m
L	length m
n	number
NDDCT	natural draft dry cooling tower
P	pressure kPa
Q	the overall heat released from the radiators MW
q	mass flow rate kg/s
r	radius value m
Re	Reynolds number
RH	relative humidity%
S	the momentum source term kg/(m·s)
T	temperature K
U	characteristic velocity m/s
V	velocity m/s
$\bar{v}$	average velocity m/s
$\vec{v}$	velocity vector m/s
W	width m
Z	the vertical height m

Greek letters

α	permeability m/s
β	air compressibility coefficient
Δ	delta, the difference
δ	thickness of the resistance pieces
ε	turbulent dissipation
∇	hamiltonian
ρ	air density kg/m
μ	dynamic viscosity $N{\cdot}m/s^2$
ν	kinematic viscosity m^2/s

Subscripts

a	environmental air parameter
b	the standard reference altitude
c	critical
d / - d	design
i	direction variable
in	inlet of the NDDCT
loc	local
m	mass
out	outlet of the NDDCT
t	tunnel

scaled-down model. For examples, Zhai et al. [9–10] studied the cooling performance for a NDDCT of 125 m tall using a model with scale of 1:640 in a small wind tunnel with a cross section of 0.8 m (W) × 0.6 m (H). Wang [11] studied the cooling performance of two NDDCTs with models scaled down by 1:380 and 1:500 respectively in an open type low-speed wind tunnel with a test section of 1.2 m (W) × 1 m (H) × 2 m (L). In both studies, the ventilating air flow was induced from the top of the tower. This kind of ventilation setting certainly can induce some interference of outside flow field.

Wei et al. [4] did the hot state tests to directly mimic the natural draft ventilation by introducing hot circulating water system to the heat exchangers placed in a NDDCT model. The NDDCT they studied was of 125 m high and the model was scaled down in 1:200 [4]. The hot state test rig was placed in a boundary layer tunnel. However, limited by the bench scale, it was hard to generate a measureable natural draft upward in-tower flow. In the experiments, the scaling law of same Froude number was mainly considered. They only measured the cooling air velocity field at the inlet but not the heated air after the radiators of the NDDCT model. In addition, they introduced a dimensionless wind effect coefficient as the function of inlet wind velocity, air temperature, cooling water temperature etc. to describe the influence of the crosswind, while no correlation was reported.

The other drawback of the previous studies was the emulation of flow resistance of the radiators or the heat exchangers placed at the entrance or inside of the NDDCT. This resistance was basically treated as a local flow resistance [12–14]. Recently, however, it was treated as a polynomial function of velocity [15–18]. Theoretically, in laminar flow region, the flow resistance is controlled by viscos force, exhibiting a first-order variation with the local velocity, and only in turbulent flow region, it is controlled by inertial force, showing a second-order variation with the local velocity [19–20]. Thus, to accurately assess the cooling performance of NDDCT under crosswind condition, it is important to investigate the flow pattern among the radiator fins, and keep the resistance characteristics of the radiator same as the baseline NDDCT.

In order to better understand and predict the cooling performance of a large NDDCT installed in a 2 × 660 MW power plant under crosswind condition, a hot state test rig with a NDDCT model was set up. The experiments were conducted in a wind tunnel. The NDDCT model was designed according to the scaling laws and the inlet air was heated up. The crosswind velocity profile and flow resistant of radiators were carefully setup.

2. Experimental approaches

2.1. Experimental system

The schematic diagram of the experimental system is shown in Fig. 1. The NDDCT model was built up according to the scaling laws of geometry, Froude number, Euler Number, and momentum, with also considering the scaling law of Reynolds number to keep the mainstream flow in self-similar region. The Reynolds similarity criterion is explained as Eq. (1), where the characteristic velocity, $\boldsymbol{U}$, and characteristic size, $\boldsymbol{L}$, refer to the outlet velocity of the tower and the diameter of the tower outlet. First, the air velocity in the NDDCT model was selected according to Froude similarity criterion of Eq. (2), which shares the same characteristic size and velocity with Eq. (1). Then, with consideration of the material of the model, a safe temperature range of the heated air was selected. Consequently, the ranges of overall ventilation mass flow rate and the heating power rate were determined. With optimized ventilation mass flow rate, heating power rate and air temperature, then the flow resistance of the NDDCT model was designed according to the Euler scaling law in Eq. (3), where the characteristic velocity, $\boldsymbol{V}_{in}$, refers to the inlet velocity of the tower on wind free condition, and the pressure difference $\Delta\boldsymbol{P}$ refers to the system resistance. Thereafter, the dimensions of the resistance pieces, including the adjacent spacing, were designed to meet the constraints of flow resistance, material properties, processing and displacement.