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Effect mechanism of air deflectors on the cooling performance of dry cooling tower with vertical delta radiators under crosswind

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ABSTRACT

To study the effect mechanism of air deflectors on dry cooling tower, a three dimensional numerical model was established, with full consideration of the delta structure. The accuracy and credibility of dry cooling tower numerical model were validated. By numerical model, the average air static pressure and the average radial inflow air velocity were computed and analyzed at delta air entry, sector air entry and exit faces. By the air inflow deviation angle θ_d, the effect of air deflectors on the aerodynamic field around tower was analyzed. The water exit temperatures of θ_{-1} columns, θ_{+2} columns and cooling sectors were also presented to clarify the effect of air deflectors. It was found that the air deflectors improved the aerodynamic field around cooling columns. The reduced air inflow deviation degree at delta entry improved the cooling performance of deteriorated columns. Referring to the radial inflow air velocity u_{ra} and the air inflow deviation degree at delta entry, the effect mechanism of air deflectors are clarified under crosswind.

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1. Introduction

As key cooling equipment, the performance of natural draft cooling tower is very critical to the running economy of thermal power plant. The performance of cooling tower is up to its structure, size, heat transfer mode, and ambient meteorological conditions, especially ambient crosswind. With high cooling efficiency, the natural draft wet cooling tower (NDWCT) is used widely, but evaporating large amount of water. So in arid regions with rich coal, the natural draft dry cooling tower (NDDCT) is more feasible with the water saving advantage. And then the study about improving the cooling performance of NDDCT, especially under crosswind impact, is very essential.

According to the radiator position and layout mode, the NDDCT is divided into the NDDCT with horizontal A-frame radiators in its inlet cross section (NDDCTH) and the NDDCT with vertical delta radiators around its circumference (NDDCTV). Du Preeze and Kröger [1] compared the two dry cooling towers and indicated that the initial cost of NDDCTV was less but its cooling performance was more susceptible to the ambient crosswind. By numerical study on NDDCTH, du Preeze and Kröger [2] pointed out that the low speed crosswind had little adverse effect on the performance of NDDCTH, but the high speed crosswind was very adverse for NDDCTH. At 12 m/s crosswind, the cross wall erected beneath tower could reduce the distortion of aerodynamic field around the horizontal radiators and then improve the performance of NDDCTH effectively.

Al-Waked [3,4] reconfirmed the crosswind adverse impact on the cooling performance of NDDCTH, and indicated that the low static pressure at tower laterals reduced the air mass inflow rate there. Meanwhile, Al-Waked [4] suggested that installing air deflectors outside could redirect the airflow into radiators, especially at tower laterals, while installing cross wall could redirect the approaching air up into the upper radiators and generate a low pressure zone behind, which helped the leeward air inflow. By CFD model for a small NDDCTH, Lu et al. [5] quantified the adverse impact of crosswind and indicated that the windbreak walls beneath tower could guide air through the upper radiators and reverse the crosswind adverse impact into positive.

With the advantage of less initial cost [2], NDDCTVs are increasing gradually, especially in northwest China. But the NDDCTV is more susceptible to the ambient crosswind impact than NDDCTH, the study about the effect mechanism of air deflectors and cross walls on NDDCTV is very significant and necessary.

By wind tunnel experiments, Wei et al. [6] pointed out that the unfavorable pressure distribution around tower air inlet under crosswind could drop the mean draft velocity and deteriorate the

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Nomenclature

A_v	specific surface area, m^2
c_w	constant pressure specific heat, kJ/(kg °C)
dQ	heat transfer rate, kW
dV	micro volume, m^3
dz, d$-z$	micro height, m
k	turbulent kinetic energy per unit mass, J/kg
h	local heat transfer coefficient, W/(m^2 °C)
k_u	pressure drop coefficient, 1/m
m_a	air mass flow rate, kg/s
m_w	equivalent water mass flow rate per unit area in cooling column, kg/(m^2 s)
M_w	molecular weight of air with humidity, kg/kg mol
p_a	average air static pressure, Pa
$S_{\varphi i}$	internal source term of air governing equation
S_{φ}	energy or momentum source term of air governing equation caused by radiator
t_a	local air temperature, °C
t_w	local water temperature, °C
t_{w2}	exit water temperature of NDDCTV, °C
$\vec{u}$	air velocity vector, m/s
u_c	ambient natural crosswind velocity, m/s
u_n	face air velocity, m/s
u_{ref}	reference crosswind velocity, m/s
u_r	radial inflow air velocity, m/s

Greek symbols

α	profile index of ambient crosswind speed
Γ_{φ}	diffusion coefficient for air variable φ
Δp	air pressure drop through a cooling delta, Pa
Δt_w	water temperature drop, °C
θ	circumferential angle, °
θ_d	air inflow deviation angle, °
ε	turbulent dissipation rate, m^2/s^3
ρ	air density, kg/m^3
φ	evaluated variable for air flow

Subscripts

a	air or average
$\theta-1$	the cooling column θ_{-1} with the less circumferential angle in one delta
$\theta+2$	the cooling column θ_{+2} with the bigger circumferential angle in one delta
o	outer
i	inner
$s1$	cooling sector 1
$s2$	cooling sector 2
$s3$	cooling sector 3
$s4$	cooling sector 4
$s5$	cooling sector 5
w	water

cooling performance of NDDCTV. Leene [7] suggested that installing appropriate windbreak devices around tower air inlet could reduce the crosswind adverse impact. By an annular volume to represent the delta radiators in numerical model, Su et al. [8] indicated that under crosswind both the large tangential air velocity and the low static air pressure at tower flanks reduced the corresponding air flow rate and deteriorated the radiator cooling performance there. Also by representing the delta radiators as an annular volume numerically, Zhai and Fu [9] suggested that placing windbreak walls at tower flanks could recover about 50% of the reduced cooling capacity for its hindering the tangential air flow at tower flanks. By a similar numerical method, Goodarzi [10] proposed a radiator type windbreak wall to substitute for the solid windbreak wall so as to improve the cooling performance of NDDCTV by full use of the cooling potential of the blowing wind. Meanwhile, Goodarzi also optimized the exit configuration of NDDCTV [11] and its cross section shape [12].

By an annular infinite thin face to replace the delta radiators arranged circumferentially [13], Yang et al. [14] established the numerical models for the air side flow and heat transfer of two NDDCTVs in a power plant, and studied the crosswind impact on the two NDDCTVs. From the view of radiators delta layout, Yang et al. [15] also studied the crosswind effect on the cooling performance of different cooling deltas and analyzed the dimensional characteristics of crosswind effect, but adopting two infinite thin faces to represent the two cooling columns of a delta.

The above numerical models [8–12,14,15] used for the radiators of NDDCTV have larger structure discrepancies with the real delta type radiators. Besides, the water temperature used for heat transfer computation in those models is only the mean water temperature in a separate radiator unit, e.g. a cooling delta [15]. So the impact of crosswind and windbreak walls on NDDCTV cannot be studied in more detail. In fact, the air flow mal-distribution between the two columns of a delta accounts partly for the crosswind adverse impact [16]. By a two-dimensional (2D) model for cooling deltas, du Preeze and Kröger [2] found that the air mass flow rate through the upside column of a delta decreased greatly for the inclined air inflow caused by crosswind. Then the studied minimum unit for NDDCTV's cooling performance should be the cooling columns, rather than the deltas.

By numerical simulation, Al-Waked and Behnia [17] indicated that installing windbreak walls around tower air inlet could enhance the cooling performance of NDWCTH under crosswind. Zhao et al. [18] studied the cross wall effect on NDWCT under crosswind numerically and suggested the cross wall shape and location. By experiments, Chen et al. [19] also studied the effect of cross wall on NDWCT and suggested an optimal setting angle. Meanwhile, Wang et al. [20] suggested the optimized setting angle about 70° for the air deflectors around NDWCT.

As the discrepancies exist among NDDCTH, NDDCTV and NDWCT, the effect mechanisms of windbreak walls on the aerodynamic field, the local heat transfer rate and the total cooling performance are different from each other. To improve the cooling performance of NDDCTV more effectively, this paper developed a three-dimensional (3D) numerical model based on Fluent [23], with full consideration of the air deflectors, the delta structure, the column three dimensions, the real water two passes and the local water temperature. In this paper, the effect and its mechanism of air deflectors on the cooling performance of NDDCTV are studied and clarified from columns in detail.

2. Numerical model

2.1. NDDCTV and corresponding air deflectors

As shown in Fig. 1, the studied tower is 172 m high, with the radiator outside diameter of 152 m, a tower shell bottom height of 27.5 m, and a top outlet diameter of 98.022 m. The vertical cooling columns are arranged circumferentially around tower in a delta form with the apex angle about 46.58° between the two columns of a delta, as shown in Fig. 2. For the nearly axial-symmetrical structure of NDDCTV, only a half of tower was taken to study the

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