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Research Paper

Thermal performance analysis for high level water collecting wet cooling tower under crosswind conditions

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HIGHLIGHTS

- Field test was conducted on the high level water collecting wet cooling tower under crosswind conditions.
- The changing rules of water temperature drop and Merkel number were analyzed.
- The radius radio which can indicate the influence of crosswind was approximately 0.60 under 3.74 m/s.
- The thermal performance under $\theta_1 = 5^\circ$ condition were more superior than that under $\theta_2 = 35^\circ$ condition.
- At the same θ value, the higher the crosswind velocity is, the worse the thermal performance becomes.

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ABSTRACT

Field test was conducted on a high level water collecting wet cooling tower (HWCT) of a 1000 MW unit to investigate thermal performance under crosswind conditions. Firstly, the air temperature distribution above drift eliminators was analyzed, and then the changing rules of water temperature drop ΔT and Merkel number N were researched in this study. The results demonstrated that with the rising of crosswind velocity, crosswind appears an increasingly serious adverse effect on the thermal performance and uniformity of air temperature distribution inside tower. In this paper, χ_r stands for the radius radio which can indicate the influencing degree of crosswind, and χ_r is approximately 0.78 when the velocity is less than 2.11 m/s, but around 0.60 at 3.74 m/s. Additionally, the intersection angle θ between cross walls and crosswind direction is introduced to analyze the effect of crosswind direction. The testing results discovered that at the same crosswind velocity, the uniformity of air temperature distribution and thermal performance under $\theta_1 = 5^\circ$ condition are more superior to those under $\theta_2 = 35^\circ$ condition. When the crosswind velocity reaches to 3.74 m/s, under $\theta_1 = 5^\circ$ condition, compared with that of 0.28 m/s, ΔT and N reduce by 12.61% and 12.54%, respectively, however, under $\theta_2 = 35^\circ$ condition, their reductions reach to 15.34% and 13.58%, respectively. It can be obtained that the thermal performance of HWCTs is relatively more outstanding under the smaller θ and/or the lower crosswind velocity.

1. Introduction

As a key component of the cool-end system in thermal power plants or some nuclear power plants, the natural draft wet cooling towers (NDWCTs) play an important role, and their thermal performance directly affects the turbine back pressure and power generation efficiency. According to the characteristics of the water collecting mode, the NDWCTs can be classified into the usual wet cooling towers (UWCTs) [1] and the high level water collecting wet cooling towers (HWCTs) [2,3].

The HWCTs were firstly designed and used in a French nuclear power plant in 1980s. It is a kind of energy-saving cooling tower which can decrease the circulating water supply height and reduce pump power [4,5]. Recently, with the growing shortage of fossil energy, the requirements of energy-saving and emission reduction become increasingly urgent, more and more HWCTs have been put into operation. Due to the development time of HWCTs technology is relatively short, research on the HWCTs are very rare. Zhao and Li [6,7] conducted comparative study on the economic efficiency between the HWCTs and UWCTs. The results indicated that compared with the UWCTs, the HWCTs have higher initial cost but less annual operating cost, so the HWCTs is cost-effective in long-term operation. Lyn et al. [8] performed the experimental research on the airflow field in the water collecting devices, and obtained that the Venturi effects of water collecting devices can enlarge the air mass flow rate and enhance the thermal performance. Meanwhile, by terms of numerical computation, Lyn et al.

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[9] manifested that the non-uniform layout fillings lead to better cooling performance for the HWCTs. In brief, previous research work on the HWCTs mainly focused on the water collecting devices, fillings and economic analysis, and failed to pay attention to the thermal performance under crosswind conditions.

Actually, the crosswind continuously influences the heat and mass transfer performance during the operating course of NDWCTs, and further affects their cooling efficiency [10]. Therefore, it is extremely necessary to study the thermal performance under crosswind conditions both from an academic as well as an industrial point of view. For a long time, researches on the thermal performance of NDWCTs under crosswind conditions mainly divided into three parts which are numerical simulation [11–14], experimental research [15–19] and field test [20–26].

Al-Waked and Behnia [11–13] developed a CFD model of UWCTs, simulation results found that environmental crosswind affects seriously the cooling efficiency, and the circulating water temperature difference is less than 1 K for the whole span of crosswind velocity. Kashani et al. [14] also developed a numerical model to study the effect of inlet window deflectors on the performance of a UWCT subjected to crosswind. Results showed that crosswind has an adverse effect on the thermal performance, and the use of deflectors enhances the thermal efficiency up to 8.6% when wind velocity greater than 2 m/s.

Gao et al. [15,16] studied the effect of crosswind on the thermal performance of UWCTs by thermal-state model experiment. The experiment results indicated that crosswind affects the circumferential inflow air and generates vortex zones in both windward side and leeward side, and deteriorates the thermal performance. Chen et al. [17] also conducted experimental study on the effect of cross walls on the thermal performance of UWCTs under crosswind conditions, and the experimental researches showed that, at all crosswind velocities, the cross walls at a setting angle of 0° result in better performance than that at 45°, regardless of the cross walls shape. Wang et al. [18] reported experimental research on the guiding channel under crosswind conditions, and found that guiding channels with 70° setting angle lead to better cooling performance but also raise more circulating water consumption. Alavi et al. [19] investigated the heat transfer performance of UWCTs under crosswind conditions by using an innovative windcreator setup, and received that 0.48 m/s crosswind velocity is the critical crosswind velocity of the studied UWCTs.

So far, seldom research focused on the field test research on NDWCTs, especially on HWCTs. Zhang et al. [20,21] conducted field test on the UWCT of a 135 MW unit, and proposed the concept of air inlet deflection angle and air inlet uniformity coefficient. The test results showed that crosswind increases ventilation resistance, and destroys the uniformity of circumferential air inlet. By means of field test, Duan [22] developed the test method of three-dimensional thermal performance for large UWCTs, and found that the impacts of crosswind mainly include three aspects which are the additional resistance in air inlet zone, the additional draft in air outlet zone and the direct effect on heat transfer performance. Širok et al. [23,24] manufactured a robot which can move over the drift eliminators to measure the velocity and temperature field above the drift eliminators. Based on this study, they also came up with the thermovision method which enables quick detection of the local efficiency of cooling towers. Smrekar et al. [25] did the similar field experimental work, and obtained a lot of data by using a mobile unit, then established a cooling tower performance analysis model. Ardekani et al. [26] conducted field test on Heller-type cooling tower under crosswind conditions, the results indicated that the tower front cooling sectors embody better airflow distribution, compared to sectors parallel to wind direction, which can improve thermal performance by about 20% compared to still-air conditions.

As seen from above, the previous research on the HWCTs mainly paid attention to the numerical simulation and economic analysis, and did not investigate the thermal performance of HWCTs under crosswind conditions, especially lack of field test method. Meanwhile, the prior field test work only focused on the UWCTs. Actually, compared to the UWCTs, the HWCTs substitute water-collecting devices for the raining zone, the different structure results in the different effect mechanism of crosswind on the cooling towers, furthermore lead to different thermal performance under crosswind conditions.

In this paper, field test was conducted under various crosswind conditions. The main objective is to analyze the air temperature distribution inside HWCTs under different crosswind velocity and direction conditions, and then study the directly impact of crosswind on the thermal performance of HWCTs, finally reveal the changing rules of thermal performance under crosswind conditions. This study can lay the theoretical foundation for further energy-saving research and optimization design of the HWCTs.

2. Field test parts

2.1. Test purpose

In this study, the field test system for a HWCT was established to study the influence of crosswind on thermal performance. By measuring meteorological parameters and air/water temperature of different cooling zones under crosswind conditions, the main objective is to analyze the air temperature distribution inside HWCTs under different crosswind velocity and direction conditions, and then study the directly impact of crosswind on the thermal performance of HWCTs, including water temperature drop and Merkel number.

2.2. Field test description

This test was conducted in spring season, except for the system debugging time, the test process lasts for 10 days and the circulating water flowrate Q remains 69,553 t/h (around 19,320 kg/s) during the whole test period. The main geometrical dimensions of this HWCT are listed in Table 1. The operating and environmental conditions during the test process are shown in Table 2. Additionally, the monitored parameters and measuring instruments are shown in Table 3, including the environmental meteorological parameters, circulating water flowrate and temperature of different cooling zones.

The environmental meteorological parameters include inlet dry and wet bulb temperature, crosswind velocity and atmospheric pressure. All of the meteorological parameters are tested by the small-type meteorological station which settled at a height of 2.5 m and about 35 m away from the cooling tower.

2.3. Measuring points arrangement and monitoring system

Except for the inlet water temperature, there were four layers of temperature measuring points inside the tower which are air temperature above the drift eliminators, water temperature above the fillings, water temperature below the fillings and water temperature at collecting tanks layer. The schematic diagram of measuring points is shown in Fig. 1. There are six laps of measuring points on each layer which are shown in Fig. 2, and the radius of different laps and radius ratio are pointed out in Table 4. Here, R is the radius of tower inter wall on the drift eliminators layer.

Table 1
Main geometrical dimensions of the HWCT.

Subject	Value	Unit
Filling area	12800.00	m^2
Height of the tower	190.00	m
Height of the air inlet	14.85	m
Height of the throat	142.50	m
Diameter of the throat	84.04	m
Diameter of the outlet	86.87	m