Investigation into the positive effects of wind deflectors on natural draft wet cooling towers under crosswinds

Youliang Chen1*, Shi Cheng2, Pingyang Zi1, Zhongyuan Liu2, Rong Fan1

1Huadian Electric Power Research Institute Co., Ltd., No. 2 Xiyuan Ninth Road, Hangzhou 310030, China
2Jiangsu Huadian Kunshan Co-generation Co.Ltd, No. 6, Gaoding Road, Kunshan 215300, China
* Corresponding author’s e-mail: cyl_sdu@163.com

Abstract. In order to reduce the adverse effects of crosswinds on the intake air of natural draft counter-flow wet cooling towers, a new method of optimizing the air intake was introduced, that is installing wind deflectors in the circumferential direction of the air inlet, and for quantitative analysis of the uniformity of the circumferential air intake of the cooling tower, the air inlet uniformity factor was defined. Based on the thermal model experiment, the effect of installing the wind deflector on the inlet air and thermal performance of the wet cooling tower is studied under crosswind conditions. Through the comparative analysis of the air intake performance and cooling efficiency, two fundamental reasons for the influence of cross wind on the cooling performance are revealed: crosswinds not only reduce the amount of ventilation, but also destroy the uniformity of the circumferential air intake of the cooling tower. After installing the wind deflector to optimize the circumferential air intake, the ventilation volume is increased, the air intake uniformity coefficient is also greatly improved, the heat and mass transfer uniformity in the tower is enhanced, and the cooling efficiency is greatly improved.

1. Introduction

Naturally draft counter flow wet cooling towers are widely used in the cooling of circulating water at the cold end of steam turbines in thermal power plants and nuclear power plants. The circulating water from the condenser is sprayed out from the nozzle, and convection heat and mass transfer with the air entering the tower in the water distribution area, packing area and rain area in turn, and then return to the condenser to absorb heat after cooling. The performance of the cooling tower directly determines the vacuum of the condenser, which affects the power generation efficiency [1]. Therefore, it is of great significance to study its characteristics and improve its performance. There are three main methods for thermal calculation of cooling towers: Poppe, Merkel, and e-NTU. Kloppers et al. [2] conducted a comparative analysis and found that the calculation results of Merkel and e-NTU methods are basically the same, while Poppe method has the highest accuracy. Derksen et al. [3-5] found through the wind tunnel model experiments and numerical calculations that lateral wind severely affects the air flow field into the tower, and proposed to set up windproof walls at the upper air outlet of the cooling tower to reduce the windward side wind inlet and balance the cooling tower circumferential wind inlet. Al-Waked et al. [6-7] used the water droplet flow at a given speed to simulate the water film flow in the packing area. Through numerical calculation, it was found that when the lateral wind speed was 7.5 m/s, the temperature of the outgoing tower increased by 1.7 °C, and it is pointed out that the main cause is the non-uniform distribution of the air flow field in the tower due to crosswinds. The study also shows that...
the installation of pore windshields at the same time in and outside the rain area can reduce the water temperature of the tower by 0.5~1.0 °C. Hawlader [8] and Williamson [9] used algebraic and k-ε turbulence models to establish a two-dimensional axisymmetric numerical calculation model of the cooling tower, and studied the gas-water flow and heat and mass transfer inhomogeneity of the cooling tower. The impact of performance. Muangnoi [10] analyzed the performance of the cooling tower and found that the entropy production causes the circulating water to provide more effective energy than air. The effective energy loss at the top of the heat and mass transfer zone in the tower is large, and the effective energy loss at the bottom is small. In addition to the cooling tower body structure, environmental factors, especially outside crosswinds, will also have a greater impact on cooling performance [11-13].

In conclusion, previous studies have found that through the qualitative analysis, the presence of environmental crosswinds destroys the uniformity of the cooling tower circumferential air intake, reduces the amount of ventilation, and thus deteriorates the cooling performance. At present, most power plants reduce the adverse effects of cross wind on the thermal performance of cooling towers by arranging cross partitions in the rain area inside the cooling tower. In this article, the author will introduce a new method of optimizing the air intake of the cooling tower-install a wind deflector in the circumferential direction of the outer air inlet of the cooling tower, and more actively guide the uniform circumferential air intake of the cooling tower under crosswind conditions. Define the air inlet uniformity coefficient as a performance index to quantitatively evaluate the air inlet uniformity. Through the thermal model experiment, the influence of optimized air intake on the performance parameters of the cooling tower under cross-wind conditions was studied, and its mechanism was analyzed and discussed.

2. Model Test

2.1. Similarity Criterion

In order to make the experimental results of the model tower more realistic and guide the design, operation and optimization of the real tower, the principles of geometric similarity, airflow similarity and dynamic similarity must be satisfied between the model tower and the real tower.

The model tower is manufactured in a scale of 1:100 according to the reduction of the prototype tower. The size of the prototype tower is 37m×68m×85m (top outlet diameter × bottom diameter × height), air inlet height is 5 m, and the packing area is 3200 m². The size of the model tower is 370 mm×680 mm×850 mm, and the height of the air inlet is 50 mm. There is an optional frequency conversion fan at the top of the tower, which can make up for the lack of pumping power of the model tower itself. Wind tunnel experiments were conducted on the tower and its internal components to ensure similar resistance to the prototype tower.

2.2. Test System

The entire cooling tower model is made of transparent organic glass. During the experiment, first heat the circulating water in the constant temperature water tank to the set temperature, and then use the circulating water pump to pump the water into the buffer water tank. The circulating water will automatically flow into the cooling tower, pass through the water distribution area, the filling area and the rain area in turn, and convection heat and mass transfer will occur with the bottom-up air flow. After cooling, the circulating water falls into the collecting tank, flows back to the constant temperature water tank, and completes one cycle. This cycle is repeated.

In this thermal model experiment, a wind deflector is installed at the air inlet of the cooling tower. The wind deflector is a right-angled trapezoid with a thickness of 1 mm and a total of 36 pieces. It is evenly distributed in the circumferential direction of the air inlet. The interval between adjacent wind deflectors is 10°. In the following, BO and AO are used to indicate the operating conditions before and after the optimized air intake, respectively.
3. Results and discussion

3.1. Cooling efficiency

Cooling efficiency $\eta$ is the most commonly used cooling tower performance evaluation index, and its definition is:

$$\eta = \frac{T_{wi} - T_{wo}}{T_{wi} - T_{w}}$$

(1)

As shown in Fig. 1(a), before optimizing the air intake, the cooling efficiency increases first and then increases with the increase of the environmental crosswind, which is greatly affected by the crosswind. When $v_{cw}$ increased from 0 to 0.6 m/s, decreased from 15.93% to 14.41%, a decrease of nearly 10%; and when $v_{cw}$ continued to increase, $\eta$ rose again. After installing the air deflector at the air inlet of the cooling tower and optimizing the air intake, the overall change trend of the cooling efficiency is similar to that before optimizing the air intake, but the influence of the crosswind has been significantly weakened. Compared with before optimizing the air intake, the cooling efficiency of each side wind condition has been significantly improved, and the maximum decrease of the side wind is 4.27%. The change of cooling efficiency before and after optimizing the air intake is determined by the air intake performance of the cooling tower.

![Cooling efficiency before and after optimization](image_a)

![Inlet airflow uniformity coefficient](image_b)

![Airflow rate](image_c)

**Figure 1.** Crosswinds effect on NDWCT performance before and after inlet airflow optimization: (a) cooling efficiency, (b) inlet airflow uniformity coefficient, (c) airflow rate

3.2. Inlet air flow rate and uniformity coefficient

The ventilation volume $G$ represents the air intake performance of the cooling tower. The larger the ventilation volume, the better the cooling performance. According to the energy conservation between air and water, $G$ has the equation of

$$G = \frac{c_w \rho_w Q(T_{wi} - T_{wo})}{K \rho_l (i_{wi} - i_{w})}$$

(2)

where $K$ represents the sensible heat taken away by the evaporated water, and it is determined by the outlet water temperature.
At the same time, in order to quantitatively describe the uniformity of the air intake of the cooling tower, a new parameter is introduced—the air intake uniformity coefficient $C_u$, which is defined as

$$C_u = \frac{1}{n} \sum_{i=1}^{n} v_{a_i} - \frac{1}{n} \sum_{i=1}^{n} v_{a_i}^2$$

where $n$ is the quantity of measuring points, and $v_{a_i}$ is the inlet air velocity at the measuring point of $i$. $C_u$ is related to average velocity of inlet airflow and standard error, and demonstrates the degree of inlet airflow deviation.

According to the definition, $C_u$ ranges from 0 to 1. Theoretically, when there is no environmental crosswind, the cooling tower circumferential air intake is completely uniform, circumferential inlet airflow is totally even, and $C_u=1$. When there is crosswind, the circumferential air intake becomes uneven, and there is a difference in inlet air velocities at each measuring point. And when the crosswind is extremely large, the circumferential inlet wind speed inlet air velocity varies greatly, and $C_u$ tends to zero. When the amount of ventilation is fixed, the larger the $C_u$, the more uniform the heat and mass transfer strength in the tower, and the better the overall cooling performance. The greater the difference in mass intensity, the more weak heat transfer areas exist, the lower the cooling efficiency.

### Figure 2. Crosswinds effect on circumferential distribution of the NDWCT inlet air velocity:

(a) Before inlet airflow optimization, (b) After inlet airflow optimization

As can be seen from Figures 2(a), 2(b) and 1(c), before optimizing the air intake, the cooling tower circumferential air intake speed is basically the same when there is no cross wind, $C_u$ reaches 0.97, and the maximum $G$ is 165.27 m$^3$/h. When there is a crosswind, the air intake speed on the windward side increases, while the air intake speed on the leeward side decreases rapidly. The circumferential air intake gradually deviates from the windless condition, and both $C_u$ and $G$ decrease. When $v_{cw}$ increased to 0.6 m/s, leeward wind began to appear, $C_u$ decreased to 0.44, and $G$ reached a minimum value of 154.64 m$^3$/h, which was a decrease of 6.43% compared with no wind. When $v_{cw}$ exceeds 0.6 m/s, the uneven air inlet unevenness of the cooling tower is further aggravated, while the ventilation volume has a tendency to recover, $v_{cw} = 1.0$ m/s at $C_u = 0.3$, $G = 160.45$ m$^3$/h.

After installing the wind deflector at the air inlet, as shown in Figures 2(b), 1(b) and 1(c), the change trend of the circumferential air inlet of the cooling tower with the side wind is the same as before the optimized air inlet, but the windward and leeward sides The deviation of the face inlet air relative to the windless conditions is significantly reduced. In the studied wind speed range, there is no air outflow phenomenon, the air intake uniformity coefficient generally increases, and the ventilation volume also increases greatly. When $v_{cw} = 0.6$ m/s, $C_u = 0.65$, $G = 160.43$ m$^3$/h.

### 3.3. Relative variation of $\eta$ and $G$
Figure 3. Comparison between the relative variation of $\eta$ and $G$ under crosswind conditions

Figure 4. Comparison between the relative variation of $\eta$ and $G$ before and after inlet airflow optimization

Figure 3 is a comparison of the relative values of cooling efficiency and ventilation volume affected by crosswinds, where $\eta_0$ and $G_0$ are the reference values under windless conditions. Fig. 3 is the change curve of relative values of cooling efficiency and ventilation before and after optimizing air intake. It can be seen that under the influence of crosswinds, the relative change in cooling efficiency is greater than the amount of ventilation. For example, at $v_{cw} = 0.6 \text{ m/s}$, $\eta$ decreases 9.57%, while $G$ decreased by only 6.43% This shows that the reduction of ventilation is only one reason for the decrease in cooling performance, and the other reason is that the crosswind damages the uniformity of the circumferential air intake of the cooling tower, making the heat and mass transfer strength uneven throughout the tower, and ultimately worsening the cooling performance. Figure 4 shows that the relative change in cooling efficiency before and after optimizing the air intake is greater than the amount of ventilation. For example, when $v_{cw} = 0.6 \text{ m/s}$, $\eta$ increases 5.88%, while $G$ is only increased by 3.74%, which shows that the installation of wind deflector not only improves the amount of ventilation, but also enhances the uniformity of the air intake, making the heat exchange throughout the tower more uniform, thereby enhancing the cooling performance.

4. Conclusion

1) In this paper, by installing wind deflectors around the air inlet of the natural ventilation counter-flow wet cooling tower to optimize the air intake, and through the thermal model experiment, the variation of the cooling tower performance before and after the optimized air intake is studied by the crosswind. The results show that before optimizing the air intake, the side wind has a greater influence on the cooling performance, and the cooling efficiency first decreases and then rises as the side wind increases. After optimizing the air intake, the cooling efficiency of each side wind condition has been greatly improved, and its change with the side wind is more gentle. Installing a wind deflector can weaken the adverse effect of side wind on the cooling performance.

2) This paper defines the coefficient of uniformity of the inlet air $C_u$ to quantitatively describe the uniformity of the inlet air in the circumferential direction of the cooling tower. Analysis of the circumferential air intake test results shows that: when there is no wind, the circumferential air intake of the cooling tower is very uniform, $C_u$ is 0.97, and the ventilation volume $G$ is the largest; the presence of crosswinds makes the circumferential air intake deviate from the windless condition, and the air intake speed on the leeward side decreases rapidly or even appears Through the phenomenon of cross-wind, both $C_u$ and $G$ are greatly reduced. After installing the wind deflector, the circumferential air intake under cross-wind conditions is more uniform than before the optimized air intake, and both $C_u$ and $G$ have been greatly improved.

3) Through the comparative analysis of the cooling efficiency and the relative value of the ventilation amount under the cross-wind condition and before and after optimizing the air intake, it is revealed that the cross-wind affects the cooling performance in two aspects: first, the cross-wind reduces the ventilation; The wind destroys the uniformity of the air intake in the circumferential direction of the cooling tower, making the heat exchange intensity uneven in all parts of the tower, and ultimately
deteriorating the cooling performance. The installation of wind deflector can optimize these two aspects, thereby improving the cooling efficiency.

Acknowledgments
The authors would like to acknowledge the financial support received from the China Huadian Corporation Ltd.. The funding was provided through a science and technology project to Huadian Electric Power Research Institute Co., Ltd..

References
[1] Li Xiuyun, Yan Junjie, Lin Wanchao. Study on thermo-economics diagnosis method and index evaluation system for the cold-end system in steam power unit[J]. Proceedings of the CSEE, 2001, 21(9): 94-99.
[2] Kloppers J C, Kröger D G. A critical investigation into the heat and mass transfer analysis of counterflow wet-cooling towers[J]. International Journal of Heat and Mass Transfer, 2005, 48(3-4): 765-777.
[3] Derksen D D, Bender T J, Bergstrom D J, et al. Study on the effects of wind on the air intake flow rate of a cooling tower: Part 1. Wind tunnel study[J]. Journal of Wind Engineering and Industrial Aerodynamics, 1996, 64(1): 47-59.
[4] Bender T J, Bergstrom D J, Rezkallah K S. Study on the effects of wind on the air intake flow rate of a cooling tower: Part 2. Wind tunnel study[J]. Journal of Wind Engineering and Industrial Aerodynamics, 1996, 64(1): 61-72.
[5] Bender T J, Bergstrom D J, Rezkallah K S. Study on the effects of wind on the air intake flow rate of a cooling tower: Part 3. Numerical study[J]. Journal of Wind Engineering and Industrial Aerodynamics, 1996, 64(1): 73-88.
[6] Al-Waked R, Behnia M. CFD simulation of wet cooling towers[J]. Applied Thermal Engineering, 2006, 26(4): 382-395.
[7] Al-Waked R, Behnia M. Enhancing performance of wet cooling towers[J]. Energy Conversion and Management, 2007, 48(10): 2638-2648.
[8] Hawlader M N A, Liu B M. Numerical study of the thermalhydraulic performance of evaporative natural draft cooling towers[J]. Applied Thermal Engineering, 2002, 22(1): 41-59.
[9] Williamson N, Armfield S, Behnia M. Numerical simulation of flow in a natural draft wet cooling tower-the effect of radial thermofluid fields[J]. Applied Thermal Engineering, 2008, 28(2-3): 178-189.
[10] Muangnoi T, Asvapoositkul W, Wongwises S. An exergy analysis on the performance of a counterflow wet cooling tower[J]. Applied Thermal Engineering, 2007, 27(5-6): 910-917.
[11] Liu Zhiyun, Wang Dong, Lin Zonghu. Numerical analysis of the influence of side wind on the performance of the direct air cooling tower with natural ventilation[J]. Journal of Power Engineering, 2008, 28(6): 915-919.
[12] Zhang Xiaodong, Wang Qingzhao. Impact of side wind on the cooling performance of natural draft air cooling tower [J]. Electric Power, 1999, 32(6): 34-36, 47.
[13] Zhao Zhenguo, Shi Jinling, Wei Qingding, et al. The engineering improvement for weakening the bad effect of natural wind on the dry cooling towers[J]. Journal of Applied Sciences, 1998, 16(1): 112-120.