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To cite this article: Wen Cai *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **295** 012051

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Evaluation and Verification Method of Cooling Capacity of Counterflow Natural Ventilation Cooling Tower

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Abstract. The cooling tower cooling capacity evaluation method is the core of the performance test of the counterflow natural ventilation cooling tower. The existing cooling water temperature comparison method is very cumbersome and does not enumerate detailed calculation cases and steps, which makes the tester unable to verify the accuracy of his calculation. Aimed at the problems existing in the existing cooling tower cooling capacity evaluation method, a cooling capacity evaluation and checking method for the counterflow natural ventilation cooling tower is proposed, which simplifies the calculation task of the existing cooling water temperature comparison method. At the same time, the method can self-check and verify the accuracy of each step calculation, which is a useful supplement to the existing cooling tower cooling capacity evaluation method.

1. Introduction

The cooling tower cooling capacity evaluation method is the core part of the performance test of the counterflow natural ventilation cooling tower. The industry standard generally recommends the cooling water temperature comparison method and the cooling water quantity comparison method, such as "NDGJ 89-1989 Industrial Cooling Tower Test Technical Regulations", "DLT1027- 2006 Industrial Cooling Tower Test Procedures and CECS-2000 Cooling Tower Test and Acceptance Procedures [1-3].

Due to the large uncertainty of the air flow measurement in the tower, the performance test of the on-site cooling tower mostly uses the cooling water temperature comparison method. The existing cooling water temperature comparison method is calculated based on the measured performance parameters, design or manufacturing unit to provide the cooling tower thermal performance curve or formula. Firstly, the temperature difference Δt_d of the cooling water under the measured parameters is calculated, and then compared with the measured temperature difference Δt_t of the measured cooling water under the working condition to obtain the cooling capacity η . Obviously, the method needs to evaluate each test condition one by one, and then takes the average value of the cooling capacity of each working condition as the final test result, the calculation task is very heavy; at the same time, several standards only give the approximate solution of the cooling water temperature comparison method. The steps, without enumerating detailed calculation cases and steps, make it impossible for the tester to verify the accuracy of their calculations [4].



2. Evaluation methods and indicators

According to the performance data of the counterflow natural ventilation cooling tower, the thermal performance curve and formula of the cooling tower test are obtained; According to the design of the air parameters of the tower, the design of the tower water temperature, the design of the tower water temperature and the design of the cooling tower thermal performance curve or formula, the design gas-water ratio and the design cooling number are iteratively calculated, and the tower water temperature correction curve and formula are obtained. Through the drawing and calling design parameters, the accuracy of the above calculation process is checked; According to the design working condition parameters and the cooling tower test thermal performance curve, the tower water temperature and the cooling water temperature difference Δt_r are corrected to the design inlet air parameters, the design inlet water temperature and the design gas-water ratio state; Then, the corrected calculation result is compared with the designed cooling water temperature difference Δt_d under the design condition to obtain the cooling capacity η of the cooling tower, and the cooling capacity is evaluated.

If the cooling capacity η reaches 95% and above, it should be considered as meeting the design requirements; if the cooling capacity η reaches 105% or more, it should be considered as exceeding the design requirements.

$$\eta = \frac{\Delta t_r}{\Delta t_d} \times 100\% \quad (1)$$

Where: η is the measured cooling capacity calculated according to the measured cooling water temperature, %; Δt_r is the cooling water temperature difference, °C; corrected to the design working condition; Δt_d is the designed cooling water temperature difference, °C.

3. Test case analysis

The circulating cooling water system of a power station adopts an expanded unit circulating water supply system with a natural ventilation cooling tower. The unit is equipped with two circulating water pumps and a 10000m² natural ventilation cooling tower. In spring and autumn, both circulating pumps are operated. In winter, one pump runs. In order to understand the cooling tower cooling line energy, the field performance test of the counterflow natural ventilation cooling tower was completed according to the relevant test standards.

The steps for the evaluation and verification of the tower are as follows:

1) First, the test data is compiled; then, the thermal performance formula of the cooling tower test under the test conditions is obtained by the Simpson approximation integration method:

$$N = 2.488 \times \lambda^{0.6504}$$

2) According to the design conditions meteorological parameters (atmospheric pressure, inlet air dry/wet bulb temperature), design tower water temperature, design tower water temperature and design cooling tower thermal performance formula, and taking the temperature of the tower air wet bulb as the independent variable, the corresponding cooling number is calculated by the Simpson approximate integral method; At the same time, the calculated gas-water ratio is substituted into the design cooling tower thermal performance formula to obtain the converted cooling number; with the relative error of less than 0.001 as the goal, the design gas-water ratio and design cooling number are calculated iteratively [5].

Table 1. Design gas-water ratio and design cooling number.

| Project name | Symbo l | Design value | Calculated value |
|---------------------------------------------------|----------------|-----------------|---------------------|
| Atmospheric pressure (kPa) | P ₀ | 99.992 | 99.992 |
| Air dry bulb temperature into the tower (°C) | θ_1 | 29.80 | 29.80 |
| Air wet bulb temperature into the tower (°C) | τ_1 | 26.50 | 26.50 |
| Circulating water temperature into the tower (°C) | t ₁ | 40.96 | 40.96 |
| Air wet bulb temperature out of the tower (°C) | τ_2 | not given | 38.14 |

| Project name | Symbo l | Design value | Calculated value |
|-----------------------------------------------------|------------|----------------------------------|---------------------|
| Circulating water temperature out of the tower (°C) | t_2 | 31.89 | 31.89 |
| Gas-water ratio | λ | not given | 0.578 |
| Cooling number | N | not given | 1.645 |
| Design cooling tower thermal performance formula | | $N = 2.35 \times \lambda^{0.65}$ | |

3) Assuming five different gas-water ratios, the design gas-water ratio is within the assumed gas-water ratio range; According to the design conditions meteorological parameters (atmospheric pressure, inlet air dry/wet bulb temperature), design tower water temperature and design tower water temperature, and taking the air wet bulb temperature as the independent variable, the Simpson approximate integral method is used to calculate the gas-water ratio; According to the calculated steam-water ratio and the assumed gas-water ratio deviation less than 0.001, the number of coolings under the assumed gas-water ratio is iteratively calculated; Furthermore, from five sets of assumed gas-water ratios and cooling numbers, the cooling tower operating characteristic curve and formula are obtained and fitted, as shown in Fig. 1. Taking the gas-water ratio as the abscissa and the cooling number as the ordinate, the cooling tower working characteristic curve and the design cooling tower thermal performance curve are drawn respectively; The intersection point of the two is the cooling tower operating point, the gas-water ratio and the cooling number at the intersection are read, and compared with the design gas-water ratio and the cooling number calculated in the iterative step 2 (the relative error should be less than 1%) to verify The accuracy of the relevant calculations in steps 2 and 3 [6].

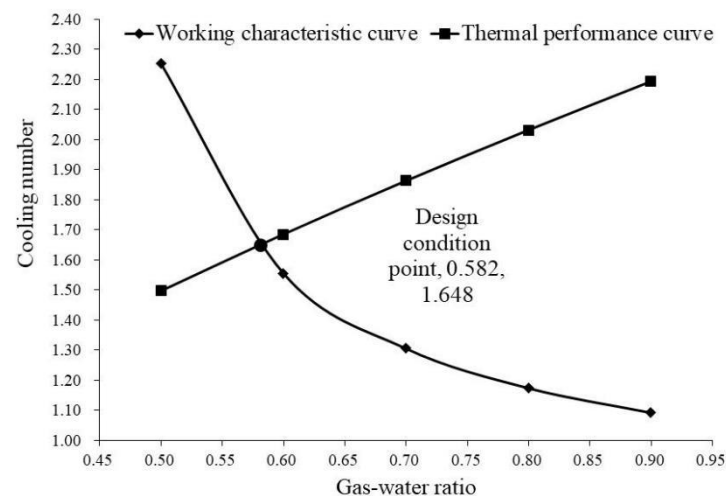


Figure 1. Cooling tower design gas-water ratio and cooling number verification.

4) Assuming the water temperature of the three towers, the tower water temperature is designed to be within the assumed tower water temperature range; According to the design conditions meteorological parameters (atmospheric pressure, inlet air dry/wet bulb temperature), design tower water temperature and assumed tower water temperature, and taking the tower air wet bulb temperature as the independent variable, the Simpson approximate integral method is used to calculate the gas-water ratio; According to the calculated steam-water ratio and the assumed gas-water ratio deviation less than 0.001, the number of coolings under the assumed gas-water ratio is iteratively calculated; Furthermore, from the three groups of assumed tower water temperature and cooling number, the correction curve and formula of the tower water temperature to the cooling number are obtained and fitted: $\tau_2 = 0.636313 \times N^2 - 3.6699 \times N + 36.20688$. The correction curve of the inlet water temperature to the cooling number is shown in Fig. 2.

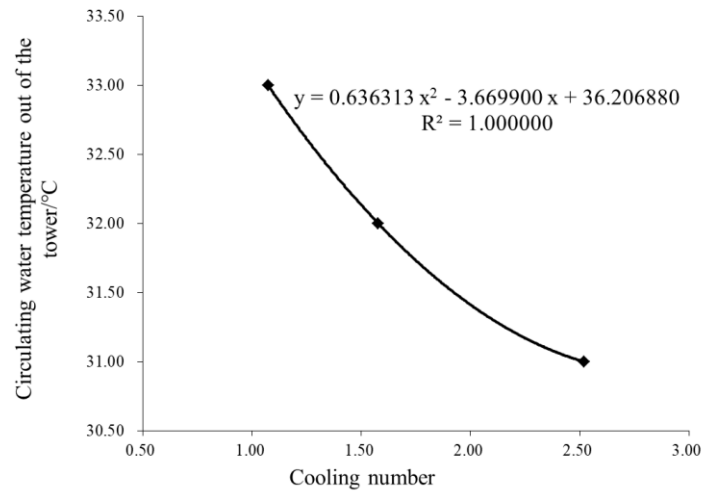


Figure 2. Correction curve fitting of tower water temperature τ_2 to cooling number N .

The design cooling number calculated in the iterative step 2 is substituted into the cooling water correction formula of the tower water temperature to obtain the corresponding tower water temperature. The calculated tower water temperature is compared with the designed tower water temperature (relative error should be less than 1%) to verify the accuracy of the tower water temperature correction curve for the cooling number.

Table 2. Circulating water temperature out of the tower.

| Project name | Design value (°C) | Conversion value (°C) | Deviation (%) |
|------------------------------------------------|----------------------|--------------------------|------------------|
| Circulating water temperature out of the tower | 31.8900 | 31.8913 | 0.004 |

5) According to the design working condition parameters and the cooling tower test thermal performance curve, the tower water temperature and the cooling water temperature difference Δt_r are corrected to the design inlet air parameters, the design inlet water temperature and the design gas-water ratio; The result is compared with the design cooling water temperature difference Δt_d under the design condition, and the cooling capacity η of the cooling tower is calculated according to the formula (1). If the cooling capacity η reaches 95% and above, it should be considered as meeting the design requirements; if the cooling capacity η reaches 105% or more, it should be considered as exceeding the design requirements.

Table 3. Cooling capacity.

| Project name | Design value | Calculated value |
|---------------------------------------------------------------|-------------------------------------|------------------|
| Air dry bulb temperature into the tower (°C) | 29.8 | 29.8 |
| Air wet bulb temperature into the tower (°C) | 26.5 | 26.5 |
| Atmospheric pressure (Pa) | 99992 | 99992 |
| Circulating water volume ($\text{m}^3 \cdot \text{h}^{-1}$) | 66960 | 66960 |
| Test thermodynamic performance equation | $N = 2.488 \times \lambda^{0.6504}$ | |
| Circulating water temperature into the tower (°C) | 40.96 | 40.96 |
| Circulating water temperature out of the tower (°C) | 31.89 | 31.75 |
| Water temperature difference (°C) | 9.07 | 9.21 |

| Project name | Design value | Calculated value |
|----------------------|-----------------------------------------------------|-----------------------------------------------|
| Cooling capacity (%) | $\eta = \frac{\Delta t_r}{\Delta t_d} \times 100\%$ | $= \frac{9.21}{9.07} \times 100\% = 101.59\%$ |

4. Conclusion

The cooling tower cooling capacity evaluation method is the core of the performance test of the counterflow natural ventilation cooling tower. Aimed at the shortcomings of existing cooling tower cooling capacity evaluation methods, a method for evaluating and verifying the cooling capacity of the counterflow natural ventilation cooling tower with simplified calculation and self-checking function is proposed, and the implementation steps are explained through specific case.

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