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Experimental research of the guiding channels effect on the thermal performance of wet cooling towers subjected to crosswinds – Air guiding effect on cooling tower

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ABSTRACT

The thermal performance of a natural-draft wet cooling tower model with inlet airflow guiding channels under crosswinds conditions was monitored and experimented. Three patterns of the air guiding channels with different setting angles (including 60°, 70° and 80°) were tested under various crosswinds velocities. The results show that the air flow rate and the cooling efficiency increase remarkably after the inlet air is directed. On the basis of testing data, some thermal performance parameters including the Lewis factor, the heat and mass transfer coefficient were also calculated and analysed. The results indicate that the Lewis factor ranges from 0.95 to 1.15, which is in accordance with the data of other literatures. Besides, it is found that the optimum setting angle for the air guiding channels is 70°, and it does not change with the channel quantity which ranges from 18 to 88. However, it should be noticed that although the guiding channels with 70° setting angle lead to better cooling performance, they may cause more circulating water consumption.

1. Introduction

Cooling towers are widely used for extracting heat from warm water to the atmosphere in most power stations, refrigeration and air conditioning industries. They can be classified by means of contacting mode into dry and wet types. Moreover, they can also be classified by the driving force of air stream as mechanical-draft and natural-draft types. Usually the natural-draft wet cooling towers (NDWCT) are mostly utilized in large-scale power stations. Heat rejection in NDWCT includes not only convection between water droplets/film and the surrounding air stream, but also evaporation which allows a portion of water with latent heat to evaporate into the moving air stream. Large savings in fuel cost can be made by improving the performance of cooling tower which in turn can reduce the turbine back pressure and increase the power generation efficiency.

There are many literatures concerning the heat transfer process and thermal performance of the tower. Williamson et al. [1], Hawlader and Liu [2] proposed two-dimensional axisymmetric models employing Lagrangian form for water liquid phase combined with algebraic turbulence model to study the non-uniformities and thermal parameters across the tower. Kloppers and Kroger [3,4] described the development history of Lewis factor and its effect on the prediction of thermal parameters of NDWCTS, and also presented an empirical equation to calculate the pressure drop across the fill accurately over a wide range of operating conditions. Fisenko et al. [5] introduced a new mathematical model of NDWCT and reported that their model described experimental data in the literature with an error less than 3%, but the model cannot be used in winter or under strong wind conditions.

In addition, many other methods were developed to predict and analyse the tower performance. Hosoz et al. [6] applied artificial neural networks (ANN) to predict the performance of a NDWCT. The predictions turned out to be agreeable with low statistical errors. Muangnoi et al. [7] presented a mathematical model which can calculate the exergy of air and water to analyse the exergy destruction of different parts of a cooling tower. The study revealed that the greatest exergy destruction exists near the air inlet of the tower. Qi et al. [8] developed a one-dimensional model to analyse the heat and mass transfer process of a shower cooling tower, and applied ANN to predict the outlet water temperature of the tower. Smrekar et al. [9] investigated the effect of water distribution system on the heat transfer performance of a mechanical-draft cooling tower. The aerodynamic fields in the tower was measured and analysed to get a reasonable water distribution mode which can minimize the exergy destruction in the tower.

As the performance of cooling tower is greatly affected by environmental conditions, especially by crosswinds, many researchers have investigated the crosswinds effect and developed some methods to improve the cooling capacity. Waked and Behnia [10] introduced a three-dimensional CFD model to simulate the performance

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Nomenclature

A	filling area (m^2)
c_p	specific heat at constant pressure (kJ/(kg K))
Fr_Δ	the density Froude number
g	gravity acceleration (m/s^2)
G	mass flow rate of air (kg/s)
h	specific enthalpy of air (kJ/kg)
L	characteristic dimension (m)
Le_f	Lewis factor
m	mass flow rate of water (kg/s)
N	cooling number
p_a	atmospheric pressure (Pa)
Q	heat rejection (kJ/s)
T	temperature (°C)
v	velocity (m/s)
V	filling volume (m^3)

Greek symbols

α	angle (°)
β_h	heat transfer coefficient (kW/(m^2 K))
β_m	mass transfer coefficient (kg/(m^2 s))
ρ	density (kg/m^3)
η	cooling efficiency
Φ	relative humidity of air
χ	moisture content (kg/kg)

Subscripts

a	air stream
avg	average value
c	crosswinds
dry	dry bulb
i	inlet
o	outlet
M	model
P	prototype
s	saturation
w	water
wet	wet bulb

of NDWCT under different crosswinds and operating conditions. The results confirm that crosswind that has a velocity less than 7.5 m/s is adverse to the heat transfer performance. Preez and Kroger [11] used a CFD code to study the effect of the arrangement mode for the heat exchanger bundles on the cooling performance of a dry tower. Then wind-break walls were developed to diminish the disadvantage of crosswinds. Zhai and Fu [12], Bender et al. [13–15] did cold state model tests in wind tunnel combined with corresponding numerical simulation to investigate the effect of crosswinds on the air intake flow rate of a mechanical-draft counter flow cooling tower. Wind-break walls were introduced to improve the unfavorable non-uniformity of air intake around the tower caused by crosswinds. Besides, the optimal scale of wind-break walls was discussed in detail. However, the cold tests in wind tunnel were not able to reflect the thermo-hydraulic character of the tower. Gao et al. [16] did hot model tests to investigate the effect of crosswinds on heat transfer performance of NDWCT.

As seen from above, the present studies focus mostly on heat transfer performance of cooling tower, and few refer to thermo-hydraulic performance improvement of NDWCT to weaken the disadvantage caused by crosswinds. However, the reduction of the adverse effect of crosswinds can considerably improve the cooling efficiency and power generation efficiency. In this paper, the inlet air guiding method was introduced to reduce the crosswinds effect, and the related model test was performed. After fixing some plates around the air inlet circumference, the formed air guiding channels can affect the inlet air flow rate and its direction. Therefore, the cooling performance of NDWCT could be enhanced by changing the air guiding channels, such as changing the quantity, the shape and the setting angle of the guiding plates.

2. Model experiment

2.1. Test objective

The hot test of a NDWCT model with air guiding channels was performed to investigate the thermo-hydraulic character of cooling tower under different crosswinds conditions. Air guiding plates were fixed around the air inlet circumference of the tower to reduce the crosswinds disadvantage. By measuring the temperature of circulating water and air stream across the tower, the thermal parameters of heat transfer could be calculated. Then the optimal installation mode for the guiding channels could be concluded. It is useful for NDWCT modification and can help the cooling tower operate with maximum cooling capacity under crosswinds.

2.2. Model similarity criterion

The NDWCT model used in this paper is made of plexiglass with a scale of 1:100 to the prototype. The dimension of the model tower is about 37 cm × 68 cm × 85 cm (top outlet diameter × bottom diameter × height). Fig. 1 shows the schematic structure of the model tower.

According to kinematic similarity, the air velocity ratio of the model should be equal to that of the prototype [17], that is,

$$\left(\frac{v_{ao}}{v_{co}}\right)_P = \left(\frac{v_{ao}}{v_{co}}\right)_M \quad (1)$$

where v_{ao} is the outlet air velocity, v_{co} – the crosswinds velocity at the top outlet, P – prototype tower, M – model tower. In addition, the thermo-dynamic similarity has to be taken into consideration. It is impossible for the model test to conform to both Reynolds criterion and Froude criterion at the same time. Because people pay more attention to the thermo-hydraulic characteristic in hot test, it is not the Reynolds number but the density Froude number Fr_Δ to be concerned, that is,

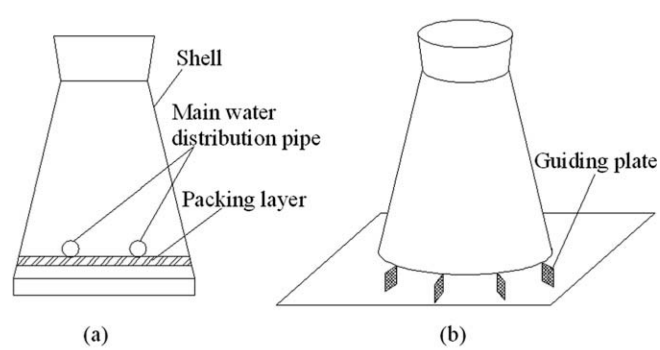

Fig. 1. Schematic structure of model tower.