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Performance enhancement for the natural draft dry cooling tower under crosswind condition by optimizing the water distribution

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ABSTRACT

Crosswind is a big challenge to the cooling performance of natural draft dry cooling towers (NDDCTs) and has attracted a lot of attention in previous research. This study proposed a new method to increase the performance of NDDCT under crosswind conditions by optimizing the hot water mass flow rate in the air-cooled heat exchangers. The 20 m UQ Gatton NDDCT was selected as a case study to test and validate this method. The cooling performance of this cooling tower under crosswind condition was evaluated by the 3-D CFD model. The results show that the crosswind redistributes the air flow and result in a non-uniform heat exchanger performance. By optimizing the hot water mass flow rate among the heat exchanger bundles, the cold fluids and hot fluids of the air-cooled heat exchanger can be better matched. The cooling performance of the NDDCT is increased by 18% when the crosswind speed is 4 m/s.

1. Introduction

For every thermal power plant, the cooling tower is an indispensable part and its performance will significantly influence the efficiency of the whole system [1]. Natural draft dry cooling towers (NDDCTs) are widely utilized in the power plants of water deficient areas throughout the world for more than fifty years [2]. Though the construction shape and the heat exchanger arrangement may different, the fundamental mechanism is the same. Ambient air is used for heat transfer medium instead of water evaporation as in wet cooling towers. The density difference of the air inside and outside of the cooling tower generates a "buoyancy effect", which keeps the hot air inside the tower rising and sucks the external cool air into the tower. This so called natural draft effect takes the heat away to achieve cooling [3].

This cooling technology could save a lot of water and has a lower maintenance cost but also faces two big challenges: hot ambient temperature and the crosswind [4–8] – both have negative effects on the cooling performance. The driving force of the heat transfer process is the temperature difference between the air and the hot water and the driving force of the air flow in the cooling tower is the density difference between the air inside and outside of the tower. So the NDDCT performance is seriously reduced at the high ambient temperature. As another ambient effect, crosswinds could also cause a significant performance drop by disturbing the natural draft processes [2]. Compared with high ambient air temperature issue, crosswind effects are much more complex and difficult to predict. So the research of crosswind effect on NDDCT has achieved a lot of attention in previous cooling tower research. The crosswind has more significant effect on shorter NDDCTs proposed for renewable power plants, such as the NDDCT proposed by the authors for the Concentrating Solar Thermal (CST) Power plant configuration being developed by the Australian Solar Thermal Research Initiative (ASTRI). This is another reason why the topic has started attracting attention in recent years due to increased interest in renewable thermal power generation.

Kröger [2] summarized the early industrial data about the crosswind effect on the NDDCTs. In this book, Kröger presented the tower performance of the Gagarin power plant, Rugeley power plant, and Grootvlei power plant in different crosswind conditions. The crosswind velocity, air inlet temperature and the water outlet temperature were recorded in the publication. The performance of all tested NDDCTs subject to crosswinds decreased with the increasing wind speed for a given heat rejection rate. Wei et al. [9] studied the unfavorable effects of crosswind on a 125 m NDDCT. In their research, the authors pointed out that when crosswind speed was about 6 m/s, the draft velocity of the cooling tower decreased about 20%. Su et al. investigated the fluid flow and the temperature distribution of the dry-cooling tower under crosswind [10]. The results without crosswind have been compared against those obtained with crosswind, at the crosswind speeds of 5 m/s

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Nomenclature

A	area (m^2)
C	inertial resistance factor
C_p	specific heat ($J\,kg^{-1}\,K^{-1}$)
C_D	drag coefficient
d	diameter (m)
e	effectiveness of the air-cooled heat exchanger
h	empirical heat transfer ($W\,m^{-2}\,K^{-1}$)
H	height, elevation (m)
K	flow resistance
L	length (m)
m	mass flow rate (kg/s)
n	number
P	pressure (Pa)
Q	heat transfer rate (W)
q	heat flux ($W\,m^{-2}$)
r	water/air mass flow ratio
Re	Reynolds number
T	temperature (°C)
v	velocity scalar (m/s)

Greek letters

α	permeability
ε	turbulent kinetic energy dissipation ($m^2\,s^{-3}$)
η	efficiency
κ	turbulent kinetic energy ($m^2\,s^{-2}$)
ρ	density, mean density ($kg\,m^{-3}$)
μ	viscosity ($kg\,m^{-1}\,s^{-1}$)

Vectors

$\vec{F}$	force
$\vec{v}$	velocity
$\hat{i}, \hat{j}, \hat{k}$	unit vectors of x-, y-, z-direction in Cartesian coordinate system

Subscripts

a, w	air side, water side
cw	crosswind
e	effective
i, o	inside or inlet, outside or outlet
opt	with optimization
t	tube
ref	reference

and 10 m/s. Based on the simulation result, the authors explained how the crosswind affects the cooling performance of the tower. Al-Waked and Benhia [11] analysed the performance of the NDDCT under crosswind using a three-dimensional CFD study. As reported by the authors, the crosswind velocity has a significant effect on the cooling performance of the NDDCT. The cooling performance dropped by 30% when the wind velocity is larger than 10 m/s. For different air temperatures, the crosswind effect manifests itself in the same manner. Yang et al. [12] simulated the crosswind effects of a NDDCT with vertically arranged heat exchanger bundles. The thermo-hydraulic performance of the heat exchanger was considered in this simulation. The performance of the towers with different aspect ratios and with horizontally arranged heat exchangers were also investigated under the crosswind conditions [13,14,7,15]. Zhao et al. [16–18] studied the cooling performance of NDDCT with vertical delta radiators under the constant heat load in different crosswind conditions. The authors claimed that with increasing crosswind velocity, the cooling performance of the NDDCT under constant heat load deteriorates sharply at low velocity, but varies slightly at high velocity.

Previous research has identified a number of methods to mitigate against negative crosswind effects. Du Preez and Kroger [19] investigated the effect of the heat exchanger arrangements. They pointed out that the A-frame forms and a radial pattern heat exchanger arrangement could help defencing the negative effect of the crosswind. Zhai and Fu [20] investigated the windbreak wall methods in and around the cooling towers to enhance the cooling performance under crosswind conditions. A small-scale cooling tower model was tested in the wind tunnel. Their research indicated that the external windbreak wall can effectively reduce the adversely effect of the crosswind. Lu et al. [21–23] studied the effect of a tri-blade like windbreak wall at different wind attack angles on a small NDDCT. According to the simulation result, windbreak wall can enhance the cooling performance with the increase of the crosswind speed. Sun et al. [24] investigated the effect of the air guiding channels in both wet and dry cooling towers. Their research showed that the guiding channels can improve the thermal efficiency of the cooling tower in crosswind conditions by increasing the mass flow rate of the air stream inside the cooling tower. Goodarzi explored the influence of the shell geometry on the cooling tower performance at various crosswinds [25,26]. In his research, alternative shell geometry with elliptical cross section was proposed instead of usual shell geometry with circular cross section. At crosswind speed of 10 m/s, the cooling tower with this special shell geometry could have the same thermal performance as the cooling tower with windbreak walls. Wang et al. simulated a NDDCT of a 660 MW power plant [27]. An enclosure outside the radiators was proposed to increase the performance of the cooling tower under the windy condition. By improve the circumferential no-uniformity and the complexity of the air flow inside the tower, the air mass flow rate through the cooling tower can be increased by 36% when the crosswind speed is 20 m/s. Chen et al. [28] proposed a novel vertical arrangement of air-cooled heat exchanger to improve the thermos-flow performance of the heat exchangers by utilize the wind power.

On the other hand, in wet cooling towers, non-uniform water distribution method was proposed to increase the performance of the wet cooling tower. As reported in Smreka's experimental research [29], the temperature and velocity fields in a cooling tower are not homogeneous. The general idea of this method is to adjust the amount of water to suit the air flow conditions. It turns out that the outlet temperature of the cooling tower was decreased and the efficiency of the whole power plant was increased by applying this technology. Gao et al. [30] investigated the cooling tower with non-uniform layout fillings. By optimizing the water evaporation in certain area of the cooling tower, the performance of the cooling tower can be enhanced by 30%.

According to the above literature review, most of the previous solutions to deal with the crosswind issue on NDDCTs were to increase the air mass flow rate through the cooling tower. The water side optimization was however ignored. Based on the working mechanism of the air-cooled heat exchanger, this paper proposed a new method to enhance the cooling performance of NDDCTs under crosswind conditions. A 3D CFD model of a 20 m