ARTICLE IN PRESS

Applied Energy xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

The cooling performance of a natural draft dry cooling tower under crosswind and an enclosure approach to cooling efficiency enhancement

Weiliang Wang [a,b], Hai Zhang [a], Pei Liu [a,*], Zheng Li [a], Junfu Lv [a], Weidou Ni [a]

[a] State Key Laboratory of Power System, Department of Thermal Engineering, Tsinghua-BP Clean Energy Center, Tsinghua University, Beijing 100084, PR China

[b] Guodian Science and Technology Research Institute, Nanjing 210046, PR China

HIGHLIGHTS

- The cooling performance of a NDDCT under crosswind condition was investigated.
- The resistance of radiators was simulated using a viscous force based equation.
- A gentle breeze or stronger wind may influence the cooling performance of a NDDCT.
- Vortices and circumferential non-uniformity are the main degrading factors.
- An enclosure approach to cooling efficiency enhancement is found to be effective.

ARTICLE INFO

Article history:
Received 14 September 2015
Received in revised form 30 January 2016
Accepted 2 February 2016
Available online xxxx

Keywords:
NDDCT
CFD
Indirect dry cooling
Crosswind
Enclosure
Performance enhancement

ABSTRACT

Cooling performance of a natural draft dry cooling tower degrades in presence of crosswind. Upon an in service natural draft dry cooling tower of a 660 MW unit in China, a computational fluid dynamics approach with validation is adopted to investigate the cooling performance at various wind speeds. The first order viscous force based resistance mechanism is used in simulating the air flow resistance for the radiators. Numerical results confirm previous findings that the cooling performance of the natural draft dry cooling tower degrades with the increment of wind velocity when wind velocity is higher than 4 m/s, but the performance reduction is relatively less. The circumferential non-uniform ventilation and the vortices inside the tower contribute the most to the degrading of the cooling performance when crosswind is present. To enhance the overall cooling performance, an enclosure with an opening at the windward side is proposed to increase the pressure level outside the side and back radiators. Numerical results show that such an enclosure could enhance the cooling performance at all investigated wind speeds, with 36% increase of the ventilation rate and about 7 °C decrement of the cycling water temperature at 20 m/s.

1. Introduction

The power plants consume approximately half the global industrial water withdrawal [1]. As an effective water saving technology, indirect dry cooling technology has been increasingly used in the recent years for the power generation in arid countries and regions, for its merits of low noise, long service life, simple maintenance and high energy saving [2,3]. However, it was found the efficiency of dry cooling is sensitive to the ambient crosswind and weather fluctuation, which could introduce a maximum output variation in the range of 5–10% of the nominal capacity in intraday operation [4]. It is of great significance if the ambient crosswind could be positively used rather than negatively affecting the power generation efficiency.

Nowadays, some studies on ambient crosswind utilization have been conducted on the natural draft dry cooling tower (NDDCT), the primary structure of indirect dry cooling system. Through experimental research, Wei et al. [5] found that crosswind at speed of 6 m/s reduce the mean velocity rate along the annular radiators about 20%; Cui and Lu [6] reported that the influences of crosswind at speed of 5 m/s and 15 m/s equal to those of about 2 °C and 14 °C rises of the environmental temperature; Lu et al. [7] argued that the total heat transfer rate of a NDDCT is a combination of natural convective heat transfer and forced convective one, and depending on their ratio, a turnabout point wind speed exists, below which the heat transfer decreases with increasing crosswind speed and

* Corresponding author. Tel.: +86 (010) 627 957 34; fax: +86 (010) 627 957 36.
E-mail address: liu_pei@tsinghua.edu.cn (P. Liu).

http://dx.doi.org/10.1016/j.apenergy.2016.02.007
0306-2619/

Nomenclature

error	the error between simulation results and reference data (°C)
$\vec{g}$	gravity acceleration vector (m/s^2)
h	heat transfer coefficient (W m^{-2} K^{-1})
ITD	initial temperature difference between the cycling water and environment (K)
k	turbulent kinetic energy (J)
$\vec{M}$	momentum source term (kg m^{-1} s^{-1})
NDDCT	natural draft dry cooling tower
P	pressure (kPa)
Q	the overall heat released from the radiators (MW)
q	constant energy source term (W m^{-3})
R	equivalent resistance coefficient (%)
S_{ij}	the tensor of strain rate
T	temperature (K)
u	velocity scalar (m s^{-1})
$\vec{V}$	velocity vector (m s^{-1})

Greek letters

∇	Hamiltonian
μ	dynamic viscosity (N s m^{-2})
α	permeability (m s^{-1})
β	air compressibility coefficient
ε	turbulent dissipation
ρ	air density (kg m^{-3})

Subscripts

a	environmental air parameter
bottom	bottom part of the tower
chamber	tower chamber part
h	high terminal value
l	low terminal value
radiator	radiators section value
ref	reference data
s	source term
Sim	simulation results
t	turbulent parameters
total	total value of the tower

above which it does the reverse. More recently, more computational fluid dynamics (CFD) simulation were carried out. Zhao et al. [8] found that crosswind at speed of 5 m/s and 10 m/s raises the cycling water outlet temperature by 1 °C and 5 °C respectively. Zhang and Wang [9] found that crosswind at speed of 4 m/s, 6.6 m/s and 8.5 m/s degrades the cooling capacity by 5%, 10% and 25% respectively. Al-Waked and Behnia [10] found that crosswind speed at higher than 10 m/s degrades the thermal effectiveness by more than 30% (at constant ejected temperature). Goudarzi [11] found that the reduction of cooling efficiency could be up to 35% at the crosswind speed of around 18 m/s. Yang et al. [12] found that reduction of mass flow rate of the cooling air reaches its peak at around 40% at crosswind speed of 12 m/s. Zhao et al. [13] confirmed the findings and revealed that the reduction of cooling air could be up to 45%, and further found that the turnabout point is postponed to 16 m/s under constant heat load condition (while the previous study is under set water temperature condition) [14]. Based on the existing researches, we can see that crosswind effect becomes obvious from 4 m/s and the cooling capacity may decline 30–45%.

Typically, a NDDCT has three parts of effective chimney: heat exchanger bundle, plenum chamber, and the effective plume part [15,16]. As found by Wei et al. [5], crosswind affects the cooling efficiency of a NDDCT by three ways: (a) The wind forms an unfavourable pressure distribution at the tower inlet (heat exchanger part); (b) The wind disturbs the hot plume rising from the cooling tower (plume part); (c) The wind causes the back flow induced by the separation vortex at the leading edge of the tower outlet (plenum chamber part). Tang et al. [17] found that crosswind lead to a horizontal air flow in the tower to degrade the upward flow, even a cross ventilation at a high wind speed, which might degrade the heat transfer in side and rear (plenum chamber and heat exchanger parts). Zhai et al. [18,19] found that inlet air flow from the leading and rear radiators converge to produce complex vortices, hindering the upward flow and side/rear air inlet (plenum chamber and heat exchanger parts). Zhang et al. [20] and Goodarzi [21] both reported that crosswind squeezes the plume flow, leading to smaller outlet cross section and higher flow resistance along the path line (plume part). Besides, Bergles [22], Zhai and Fu [23] also reported that the suck-back of cold air at the outlet of the tower would also affect the flow field in the tower. Fisher and Torrance [24] found that the such-back of cold air at the outlet of small heat exchangers might degrade the thermal efficiency by 4%.

In order to reduce the negative crosswind effect on NDDCT, many ideas were reported in 1970 s and 1980 s, including dry/wet associated cooling, plastic tower shell, periodic dry cooling, etc. [25,26], but rather rare afterward. In 1993, wind-breaks was first proposed by Du Preez and Kroger [27], and then verified by Al-Waked and Behnia [10,28] and Zhai and Fu [23] through numerical investigation. Dai et al. [29] and Wang [30] revealed that guiding channel could promote the cooling performance of a natural draft wet cooling tower (NDWCT), by 5–10%. Later, Zhao et al. [31] and Chen et al. [32] found that the cross-wall could enhance the cooling efficiency of a NDWCT at lower crosswind speeds, but sensitive to wind direction at higher speeds, through numerical and experimental study respectively. Goodarzi [21] proposed a new inclined exit configuration to improve the cooling efficiency by 9% at 10 m/s crosswind. More recently, Lu et al. [33] found that in-tower windbreaks could reverse the negative crosswind effect to positive in a small NDDCT, at certain wind attack angles. Goodarzi et al. [34,35] reported that windbreaks constructed as radiators could even promote the cooling efficiency in NDDCT, and an elliptical cross section type cylinder could improve the cooling efficiency by 17% at 10 m/s crosswind speed.

Crosswind is generally regarded as a power source commonly used in architecture field, like wind tower [2] and wind catches [36], even to achieve nearly net zero energy buildings [37]. These applications imply that crosswind could also be used to improve the thermal performance of cooling towers. Thus, this paper presents an enclosure structure with an opening at the windward side located outside the heat exchanger bundle, to assess the flexibility to use the wind potential for the cooling efficiency improvement. Given the influence on cooling efficiency of a NDDCT by the crosswind is mainly attributed to the change of the ventilation rate, the study focuses on the assessment of the ventilation of the tower and the fluid dynamics in the air side, and then evaluate the overall performance with empirical data.

Please cite this article in press as: Wang W et al. The cooling performance of a natural draft dry cooling tower under crosswind and an enclosure approach to cooling efficiency enhancement. Appl Energy (2016), http://dx.doi.org/10.1016/j.apenergy.2016.02.007