International Journal of Thermal Sciences 102 (2016) 168–184

Contents lists available at ScienceDirect

International Journal of Thermal Sciences

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

Impacts of tower spacing on thermo-flow characteristics of natural draft dry cooling system

H.T. Liao [a], L.J. Yang [a, *], X.P. Wu [b], X.Z. Du [a], Y.P. Yang [a]

[a] Key Laboratory of Condition Monitoring and Control for Power Plant Equipments of Ministry of Education, School of Energy Power and Mechanical Engineering, North China Electric Power University, Beijing 102206, China
[b] Central Southern China Electric Power Design Institute, Wuhan 430071, China

ARTICLE INFO

Article history:
Received 21 March 2015
Received in revised form
1 October 2015
Accepted 17 November 2015
Available online 2 January 2016

Keywords:
Natural draft dry cooling system
Air-cooled heat exchanger
Dry-cooling tower
Flow and heat transfer characteristics
Tower spacing

ABSTRACT

Multi-towers are widely introduced to the natural draft dry cooling system in power plants, and the geometrical layout of dry-cooling towers is a key issue to the thermo-flow characteristics of natural draft dry cooling system. Based on a representative two-tower design with vertically arranged heat exchanger bundles around the circumference, the air-side flow and heat transfer models of natural draft dry cooling system at the tower spacing to diameter ratios from 0.1 to 3 are developed and the velocity, pressure and temperature fields of cooling air in the absence and presence of ambient winds are presented. The mass flow rate and heat rejection of the two air-cooled heat exchangers at various wind speeds and in various wind directions are calculated. The correlations between the heat rejection of each tower and the tower spacing, wind speed and angle are obtained. The results show that the impacts of tower spacing on thermo-flow characteristics of natural draft dry cooling system depend on the wind speed and the arrangement of towers. The towers arranged in line are superior to those arranged in other patterns. When the tower spacing to diameter ratio is lower than unity, the conspicuous interaction between two towers will deteriorate the thermo-flow performances of natural draft dry cooling system. The results can contribute to the dry-cooling tower layout of natural draft dry cooling system in power plants.

1. Introduction

Natural draft dry cooling system, comprising natural draft dry-cooling tower and air-cooled heat exchanger, is receiving more and more attentions in recent decade due to its water conservation advantage and lower auxiliary power consumption compared with the air-cooled condenser. In practical engineering, multi-towers are widely introduced to the natural draft dry cooling system in power plants to meet the heat rejection demands. The thermo-flow characteristics of each cooling tower in group may be quite different from those of an isolated one.

For most of the research works, the emphases have been placed on the flow and heat transfer performances of the natural draft dry cooling system with only one isolated cooling tower incorporating finned tube bundles under crosswinds. Hooman [1] investigated the flow and heat transfer through the air-cooled heat exchanger and dry-cooling tower by using the dimensional analysis in combination with numerical simulations, the numerical results are in a good agreement with those from dimensional analysis. Su et al. [2] numerically simulated the thermo-dynamical performances of dry-cooling tower, making the performance deterioration at the cross winds clear. Wei et al. [3] clarified the adverse wind effects on the cooling efficiency of dry-cooling towers by means of full scale measurements and wind tunnel modeling, finding that the cross winds result in an unfavorable pressure distribution at the tower entrance, break the hot plume rising through the cooling tower and induce the cool air invasion at the tower exit. For the dry-cooling tower with vertically arranged finned tube bundles around the circumference, Yang et al. [4] found that there exists a critical wind speed at which the performance of natural draft dry cooling system is worst. Based on the thermo-flow characteristics of natural draft dry cooling system at ambient winds, some measures against the unfavorable impacts of winds were proposed, such as the wind-break wall configuration, tower exit change, tower height reduction and tower elliptical cross section design. du Preez and Kröger [5] suggested the wind-break wall on the central line of the tower, which can increase the air flow rate through the tower. Lu et al. [6,7] introduced the tri-blade-like windbreak walls at the bottom of

* Corresponding author. Tel.: +86 10 61773373; fax: +86 10 61773877.
E-mail address: yanglj@ncepu.edu.cn (L.J. Yang).

http://dx.doi.org/10.1016/j.ijthermalsci.2015.11.019
1290-0729/

Nomenclature

C	constant in turbulence model
c_p	specific heat (J kg^{-1} K^{-1})
d	diameter (m)
e	exponent of the wind speed in the power–law equation
f_n	polynomial coefficient for the pressure rise of the fan
g	gravitational acceleration (m s^{-2})
G_k	turbulence kinetic energy generation due to mean velocity gradients (m^2 s^{-2})
G_b	turbulence kinetic energy generation due to buoyancy (m^2 s^{-2})
H	air-side convection heat transfer coefficient (W m^{-2} K^{-1})
h_n	polynomial coefficient for the convection heat transfer coefficient
H	height (m)
I	turbulence intensity
k	turbulent kinetic energy (m^2 s^{-2})
k_L	flow loss coefficient
m	mass flow rate (kg s^{-1})
n	number
p	pressure (Pa)
q	heat flux (W m^{-2})
r_n	polynomial coefficient of non-dimensional loss coefficient
s	tower spacing (m)
s_h	heat source (W m^{-3})
S	source term
t	temperature (K)
v_j	component of velocity (m s^{-1})
v	velocity magnitude (m s^{-1})
x_j	Cartesian coordinate (m)
z	height above the ground (m)

Greek symbols

ε	turbulence dissipation rate (m^2 s^{-3})
μ	dynamic viscosity (kg m^{-1} s^{-1})
ν	kinetic viscosity (m^2 s^{-1})
ρ	density (kg m^{-3})
σ	turbulent Prandtl number
Γ	diffusion coefficient (kg m^{-1} s^{-1})
Φ	heat rejection (W)
φ	scalar variable

Subscripts

1	inlet
2	outlet
a	air
avg	average
b	base
cd	cooling delta
d	downstream
e	effective
he	heat exchanger
o	outer
t	tower
tt	tower throat
T	turbulence
w	wind
wa	water

the tower, finding that the total heat transfer rate increases by 30% at the wind speed of 5 m/s, and the windbreak wall orientation plays important roles in the performance of small natural draft dry cooling tower. Both Al-Waked et al. [8] and Zhao et al. [9] recommended the windbreak wall installation around the tower inlet circumferentially and uniformly to redirect the tangential flow to radial one for the cooling air. Goodarzi et al. [10] replaced usual solid windbreakers positioned at the lateral side of the cooling tower by radiator-type ones, finding that radiator-type windbreakers can substantially improve the cooling efficiency. With a purpose of reducing the throttling effect of the deflected plume under crosswinds, Goodarzi et al. [11] presented a cooling tower exit configuration, by which the cooling efficiency can improve 9% at the wind speed of 10 m/s. Furthermore, Goodarzi [12,13] proposed the tower with a reduced height to enhance the thermal performance at high wind speeds, and the alternative tower with an elliptical cross section to improve the cooling efficiency.

The natural draft dry cooling system with two or more dry-cooling towers was also studied about its thermo-flow performances at ambient winds in the past decades. Sun et al. [14] used the full-scale measurement and wind-tunnel testing to investigate the wind load effects, and obtained the pressures at the surfaces of two hyperbolic cooling towers with different gaps in various wind directions. Based on two cooling towers in the in-line pattern, Zhai and Fu [15] proposed a wind-break solution at the lateral sides of cooling towers perpendicular to the cross-winds, recovering about 50% cooling capacity. For a representative two-tower design with the flue gas desulfurization and stack inside, Yang et al. [16] obtained the natural draft dry cooling system performance in various wind directions and observed the hot plume penetration at the rear or side finned tube bundles at high wind speeds. In 1965, there was a massive collapse of three natural draft towers at the Ferry Bridge Station in the UK, which was attributed to too close tower space or very near location from other main buildings in the power station [17].

From the aforementioned literatures can be seen that, though multi-towers for natural draft dry cooling system have been involved, the impacts of tower spacing on thermo-flow performances of natural draft dry cooling system were rarely mentioned. When the tower spacing is big enough, its impact will become negligible, but a big tower spacing may result in a great land occupation for power plants and bring on a rising capitalized cost. From the economic point of view, the tower spacing should be as small as possible, but too close towers may influence each other, so result in deteriorated thermo-flow performances of natural draft dry cooling system. In this work, the impacts of tower spacing on the flow and heat transfer of air-cooled heat exchanger and dry-cooling tower will be thoroughly investigated at various wind speeds and in various wind directions on the basis of the representative two-tower design, and the optimal tower spacing will be provided, which is of benefit to the geometrical layout of natural draft dry cooling system in power plants.

2. Physical and mathematical models

Based on 2 × 200 MW power generating units, the physical models of two identical dry-cooling towers with vertically arranged heat exchanger bundles are developed. Fig. 1(a) is the schematic of the dry-cooling tower, and Fig. 1(b) shows the sector specification of the two air-cooled heat exchangers and the wind directions. In