Applied Thermal Engineering 137 (2018) 93–100

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

Research Paper

Ventilation enhancement for a natural draft dry cooling tower in crosswind via windbox installation

Weiliang Wang*, Hai Zhang, Junfu Lyu, Qing Liu, Guangxi Yue, Weidou Ni

Key Laboratory for Thermal Science and Power Engineering of Ministry of Education, Department of Energy and Power Engineering, Tsinghua University, Beijing 100084, China

HIGHLIGHTS

- A windbox consists of windbreaks, an enclosure, a top and a barricade is proposed.
- A CFD modelling was conducted for the effect of windbox on the flow field of a NDDCT.
- FLF is adopted to quantify the affecting process of the windbox on NDDCT flow field.
- The suggested windbox configuration is effective in enhance the NDDCT performance.
- A reduction of annual unit coal consumption of 30,000–45,000 tons is estimated.

ARTICLE INFO

Keywords:
NDDCT
Crosswind
Windbox
Windbreaks
Flow loss factor

ABSTRACT

A natural draft dry cooling tower (NDDCT) is demanded to save water for power generation in arid area, but its performance could be degraded greatly by the crosswind. To overcome the degradation, this paper proposes the installation of a windbox, which consists of windbreaks, an enclosure, a back barricade and a wind top to improve the pressure distribution outside the heat exchanger bundle of a NDDCT, so as to increase the ventilation rate under crosswind condition. Full dimensional computational fluid dynamics (CFD) modelling was conducted for the windbox installed around the NDDCT of a large scale coal-fired power plant. Different configurations of the windbox were studied. The flow characteristics along the streamline in the NDDCT were analyzed and quantified by adopting the concept of flow loss factor (FLF). Based on simulation and experiments, the installation of the windbox is shown to be effective. The windbox with a 120 m radius enclosure and a full size louver-type top could improve the ventilation rate of a NDDCT by ∼60% in gale crosswind condition, and keep high performance in breeze crosswind condition. Consequently, an annual reduction of coal consumption of 30,000–45,000 tons could be achieved on a 1000 MW unit, which is ∼3000,000–4500,000 $/a.

1. Introduction

A large scale thermal power plant equipped with wet cooling towers consumes 10–20 M tons of water per year [1–3]. Such amount of water is often unacceptable for arid countries and regions [4,5]. Thus, indirect dry cooling technology, with its merits of water saving, low operation and maintenance cost, and long service time, has being increasingly used [6]. However, the performance of the main component of the indirect dry cooling system, namely the natural draft dry cooling tower (NDDCT) is found to be sensitive to ambient crosswind [7].

Previous studies found that a crosswind at 20 m/s could decrease the ventilation rate of a NDDCT by 36%. Besides, crosswind could increase the air temperature inside the tower up to 7.5 °C [8], and thereby decrease the heat transfer efficiency by more than 25% [9]. In another word, the crosswind could significantly reduce the efficiency, reliability and increase the operation cost of a power plant [10].

To prevent the performance degradation caused by the crosswind, a few measures were suggested to take [11–13]. Among them, installation of windbreaks is a common one due to its competent effectiveness [9,14–16], which was validated through numerical studies and wind tunnel experiments [17,18]. Besides, computational fluid dynamics (CFD) simulations showed the arrangement of [16]an enclosure around the radiators bundle was an effective way [19,20]. Straightforwardly, the combination windbreaks and enclosure was also suggested [21]. However, the size of the enclosure introduced in previous studies is too large to install.

* Corresponding author.
E-mail address: wang_wl@tsinghua.edu.cn (W. Wang).

https://doi.org/10.1016/j.applthermaleng.2018.03.059
Received 12 February 2018; Received in revised form 18 March 2018; Accepted 19 March 2018
Available online 20 March 2018

Nomenclature

D	difference
NDDCT	natural draft dry cooling tower
P	pressure kPa
q	mass flow rate kg/s
T	temperature K
U	potential flow kg/(s·m^2)
v	average velocity m/s
z	the vertical height m

Greek letters

Δ	differential error
ρ	air density kg/m
ξ	local resistance coefficient
Ω	flow resistance 1/m^2

Superscripts

*	total value

Subscripts

0	the baseline value
bottom	the area inside the radiator
chimney	the area right inside the tower chamber
f	flow
inlet	the area prior to the inlet of the NDDCT
m	mass
outlet	the area above the outlet of the NDDCT
r	reference value
radiator	the area between the radiator fins
t	total value
total	the overall streamline field

This paper proposes a more compact and effective approach by optimizing the structure based on the combination of an enclosure and windbreaks. The flow fields around the NDDCT under crosswind condition were obtained using CFD simulation. The concept of flow loss factor (FLF) [22] was adopted to quantify the effect of the local flow field on the overall performance of a NDDCT. Besides, a set of hot state experiments were carried out in a wind tunnel with a NDDCT model to validate the simulation results [22].

2. Numerical and experimental approaches

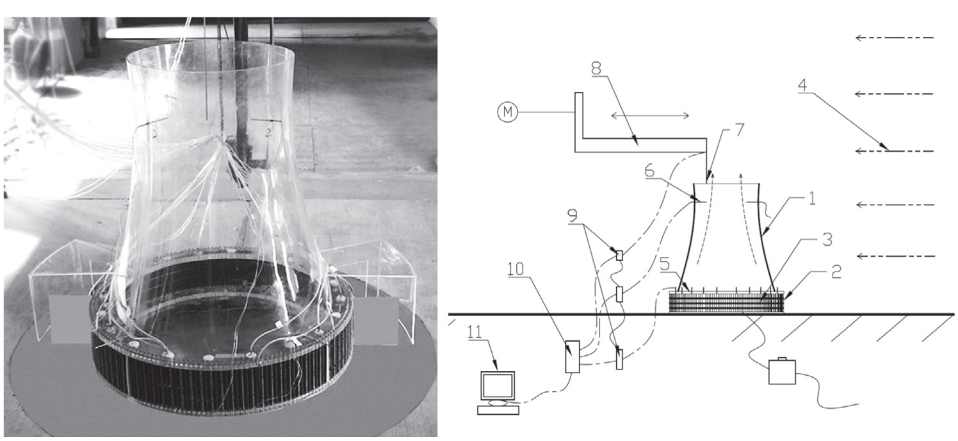
2.1. Numerical approach

The NDDCT investigated in this paper is the one installed in a large scale coal-fired power plant in China. It is 170 m tall. The heights of the extension platform and radiators are 27.5 m and 24 m respectively, and the length of radiator support is 2 m. The outlet, throat and base radiator diameters of the tower are 84.466 m, 82 m and 146.17 respectively.

Provided the power load is constant, the steam rate per unit power generation increases slightly when back pressure increases in a certain range, and the latent heat of the saturated vapour decreases slightly [23–25]. As a result, the variation of heat rejection could be negligible. Indeed, it was found that a 5 kPa increment of back pressure resulted in only ~2% increment of the exhaust heat. Hence, in this study, the heat release in NDDCT radiators is approximated as constant under different crosswind conditions. Namely, the heat release of the radiator bundle is simplified as a constant heat source in numerical modelling, and mimicked by evenly assembled heating rods in the experiments.

Due to symmetric characteristics of the flow field, the CFD model is developed in a half-cylinder configuration, with a dimension of 1200 m (in diameter) × 1700 m (in height), ~10 times of the tower. The large space allows the crosswind to develop a reasonable velocity profile from a constant one at the inlet. The surfaces including the side walls, the ground, the inside/outside cooling tower shells and the support and joint faces between adjacent radiators are all set as adiabatic walls with no slip condition. The pressure-based solver built in FLUENT with pressure-velocity coupling SIMPLEC method is used. The governing equations of the momentum, energy, turbulent kinetic energy and dissipation rate are discretized using the second-order upwind differencing scheme.

The air flow is assumed to be in fully developed turbulent regime, with negligible air density variation. Boussinesq approximation is used in the vertical momentum equation to consider the buoyancy force [26]. Governing equations for steady, buoyant, and turbulent flow including heat transfer are continuity, momentum, energy, and turbulence modelling equations and use standard $k-\varepsilon$ model to describe the turbulent flow [27]. Based on grid checking, the model of hexahedral meshing with a grid number of 13.8 M was adopted. More detailed descriptions about the CFD model can be referred to our previous study [20].



(a) Photo of the actual NDDCT model (b) System diagram of test rig

Fig. 1. Experimental system. (a) Photo of the actual NDDCT model; (b) System diagram of test rig.