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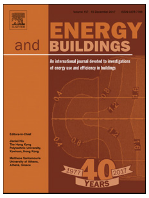

A performance enhancement of a natural draft dry cooling tower in crosswind via inlet flow field reconstruction

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ABSTRACT

With the wide utilization of a natural draft dry cooling tower (NDDCT) in power generation in arid areas, the degradation of its performance under crosswind conditions is increasingly concerned. Based on the influencing mechanisms of the crosswind, the paper reconstructs the destructed inlet flow field with a labyrinth structure. The effect of the labyrinth structure is firstly assessed by means of a verified computational fluid dynamics (CFD) model. Then, on the basis of CFD results, the labyrinth structure is further optimised by adopting a quantification method using a flow loss factor (FLF). Numerical results revealed that the proposed flow field reconstruction approach could increase the ventilation rate of a NDDCT by ~62% under high speed crosswind condition, correspondingly reducing the overall coal consumption by 23,100–33,000 t annually for a 660 MW coal-fired unit. Moreover, the negative effect of the crosswind on the performance of a NDDCT could be reversed to a positive one. The numerical results are well validated by the modelling experiments conducted in a wind tunnel.

1. Introduction

A traditional wet cooling power plant is usually a large fresh water consumer, consuming tens of million tons of water per year in waste heat rejection [1]. Building a wet cooling power plant is unpractical in arid countries and regions [2]. Thus, indirect dry cooling technology (IDCT), which adopts surface-air-cooled heat exchangers was proposed to resolve the problem [3]. Nowadays, IDCT is increasingly used not only in coal-fired power plants, but also in concentrating solar thermal power plants [5]. In addition, IDCT equipped with a natural draft dry cooling tower (NDDCT) is prevailing in low cost of operation and maintenance and long service time [4].However, as the main facility of IDCT, the performance of a NDDCT is sensitive to the ambient crosswind [6]. High-speed crosswind may degrade the ventilation rate of a NDDCT by ~36%, resulting an increment of ~7.5 °C in the air temperature inside the tower [7], or an increment of ~7 °C in cycling water [4], or a decrement of more than 25% in the heat transfer efficiency [8].

Generally, a NDDCT is consisted of a heat exchanger bundle (radiators), a plenum chamber, and an effective plume part [9]. Previous studies found that, the crosswind forms an unfavourable pressure distribution at the tower inlet [7], causing a horizontal air flow, or even a cross ventilation in the tower [10]. The inlet air flow streams from the leading and rear radiators converge and then produce complex vortices [11]. These vortices disturb the hot plume from the cooling tower. In addition, a back flow could be induced by the separation vortex at the leading edge of the tower outlet [12]. Crosswind may also squeeze the plume flow, leading to a smaller cross section of the plume and a higher flow resistance along the path line [13–15].

Along with the continuous pursuing of high efficiency, high reliability and low cost in power industry [16], a few approaches, including windbreaks [17], enclosure [18,19], and newly proposed wind collecting ducts [20], are proposed to overcome the cooling performance degrade of a NDDCT under the crosswind condition. However, there is still no distinguished approach which satisfies both the performance improvement and the construction feasibility.

Recently, our study found the crosswind changes the inlet flow field, inducing mainstream vortices inside the tower, and thereby degrades the ventilation. In addition, a high speed crosswind can generate low pressure area at the NDDCT outlet to reduce the ventilation [20].

This paper presents a flow field reconstruction to the inlet flow field when the crosswind present, to overcome the performance degradation for a NDDCT. On the ground of a thorough analysis of the non-uniform flow field around a NDDCT, two labyrinth structures equipped outside the posterolateral radiators are proposed,

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Nomenclature

d	difference
ITD	initial temperature 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	wind tunnel
total	the overall streamline field

to reconstruct the flow field of the NDDCT and facilitate the overall ventilation.

To comprehensively assess the effect of labyrinth structures, numerical and experimental studies are conducted. By using a recently proposed flow loss factor (FLF) to quantifies the effect local flow field change, the labyrinth dimensions are optimised via a developed computational fluid dynamics (CFD) model. A hot state test rig simultaneously meeting the scaling laws of Froude and Euler numbers is also adopted to verify the simulation results [20].

2. Methods

2.1. Problem descriptions

A schematic diagram of a typical NDDCT is shown in Fig. 1, where thousands of radiators are equipped evenly around the tower inlet under the expansion platform. The investigated NDDCT in this study is installed in a 660 MW coal-fired power plant in China. The basic dimensions are listed in Table 1. Under wind free condition, drafted by the pressure difference between the inside and outside, the cooling air enters the tower uniformly through the vertically arranged radiators. Then the air flow is heated by the cycling water inside the radiators, maintaining a natural draft status.

Table 1
Dimensions of the investigated NDDCT.

Items	Values (m)
Total height	170
Thickness of the expansion platform	1.5
Height of the radiators	24
Height of the radiator support	2
Diameter of the outlet	84.47
Diameter of the throat	82
Diameter of the radiator bundle base	146.17

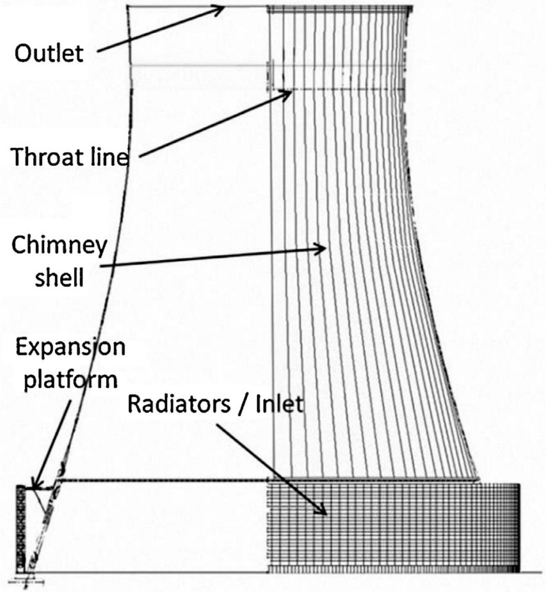

Fig. 1. Schematic diagram of a typical NDDCT.

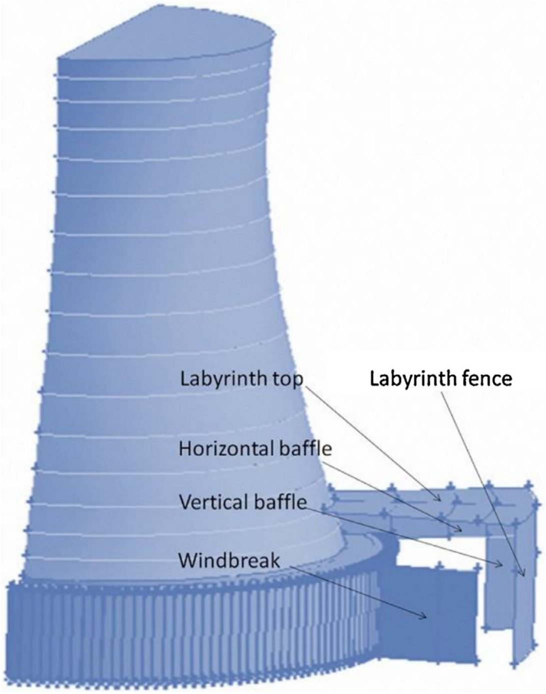

Fig. 2. A CFD model of NDDCT with labyrinth structure.

As the crosswind stagnates at the windward sections, it accelerates at the side sections, and converges at rearward sections [19]. A labyrinth is proposed to reconstruct the flow field outside the NDDCT inlet as shown in Fig. 2. It includes a windbreak, a labyrinth top with a certain circumferential width set above the windbreak, a labyrinth fence set vertically along the outer edge of the top, a horizontal baffle and a vertical baffle set along the back side edge of labyrinth top and labyrinth fence. Thereafter, a labyrinth cavity with an inlet and an outlet is constructed, where the inlet is among the outer edges of the windbreak, the leading edges of the