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# Flow deflectors to release the negative defect of natural wind on large scale dry cooling tower

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ABSTRACT

In order to reduce the unfavorable impacts of natural wind, the arc curved air flow deflectors were proposed to be settled around the natural draft dry cooling tower. Based on 2 × 600 MW indirect air cooling power generating units, the thermo-fluid models of the natural draft dry cooling tower coupled with condenser of turbine are developed, by which the cooling performances are investigated at natural wind speed ranged from 0 to 20 m/s. The numerical results with experimental validations illustrate the thermo-fluid performance distributions of different cooling sectors around the dry cooling tower. It can be obtained that in the presence of ambient natural wind, the proposed deflectors could extend the positive effects of natural wind, leading to the decrease of outlet temperature of circulating water and back pressure of turbine. Compared to the case without deflectors, the total air mass flow rate could be increases by 50.26%, the outlet temperature of circulating water could be decreased by 10.73 °C and the back pressure of turbine could be decreases by 7.33 kPa when the wind speed is 20 m/s. In the absence of wind, the changes of air mass flow rate, heat rejection, outlet water temperature and back pressure are all no more than 0.5% compared with that without the deflectors, implying almost no negative impacts of the proposed deflectors under various operating conditions. The natural wind direction has little influence on the performance of natural draft dry cooling tower with deflectors.

## 1. Introduction

In the arid regions, natural draft dry cooling systems have been widely used to save water consumption [1]. The dry cooling tower is one of the most important parts in a natural draft dry cooling system. With heat exchanger bundles arranged vertically around the circumference of the tower or horizontally inside the tower, cooling air actuated by buoyancy force flows through the heat exchanger bundles, taking away the heat rejected by circulating cooling water inside the finned bundles. The thermo-flow performances of a natural draft dry cooling system are susceptible to ambient conditions, especially the cross natural wind.

Du Preez and Kröger [2] performed measurements on a full scale natural draft dry cooling tower and found that the wind effect on such towers increases with a reduction in the heat dissipation rate of the tower. In addition, towers where the heat exchangers were arranged horizontally in the inlet cross-section were found to be less sensitive to cross winds than those where the heat exchangers were installed vertically around the circumference of the tower. According to Su's [3] research, under the cross wind condition, the fluid flow around the tower was similar to the flow around a circular cylinder. The tangential velocity is very large and the pressure is low at the side part of the radiator, almost no air flows through the radiator, which led to the reduction of heat diffusion of cooling towers. In following researches conducted by Yang and Zhao, mechanism analysis found that the natural wind effect could be explained as that the performances of the system were deteriorated due to the changes of flow fields in and around the tower [4,5].

In order to reduce the unfavorable effect of cross winds, numerous researches have been performed. Du Preez and Kröger [6] firstly investigated the effect of wind-break walls on the performance of natural draft dry cooling towers with horizontal heat exchanger arrangements using numerical procedure. Al-Waked and Behnia [7,8] conducted a three-dimensional simulation and found that windbreak walls around the inlet of the cooling tower was an optimistic method of reducing the thermal performance losses due to crosswind. The best thermal performance was achieved by installing the windbreak walls both inside and outside the dry cooling tower.

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## Nomenclature

| | |
|---|---|
| $A$ | heat transfer surface area ($m^2$) |
| $C_r$ | the ratio of air and water heat capacity rate |
| $c_p$ | specific heat ($J\ g^{-1}\ K^{-1}$) |
| $D$ | tube outside diameter (mm) |
| $d$ | diameter (m) |
| $e$ | exponent in the power-law equation of wind speed |
| $F$ | fin pitch (mm) |
| $G_k$ | turbulence kinetic energy generation due to mean velocity gradients ($m^2\ s^{-2}$) |
| $G_b$ | turbulence kinetic energy generation due to buoyancy ($m^2\ s^{-2}$) |
| $g$ | gravitational acceleration ($m\ s^{-2}$) |
| $H$ | height (m) |
| $h$ | convection heat transfer rate ($W\ m^{-2}\ K^{-1}$) |
| $h_n$ | polynomial coefficient for the convection heat transfer coefficient |
| $I$ | turbulence intensity |
| $K$ | overall heat transfer coefficient ($W\ m^{-2}\ K^{-1}$) |
| $k$ | turbulent kinetic energy ($m^2\ s^{-2}$) |
| $k_L$ | flow loss coefficient |
| $L$ | length (m) |
| $m$ | mass flow rate ($kg\ s^{-1}$) |
| $N$ | tube row number |
| NTU | number of heat transfer unit |
| $n$ | number |
| $P$ | tube pitch (mm) |
| $p$ | pressure (Pa) |
| $Q$ | heat rejection (W) |
| $r_n$ | polynomial coefficient of non-dimensional loss coefficient |
| $S_\varphi$ | source term |
| $t$ | temperature (°C) |
| $u$ | wind velocity (m/s) |
| $u_j$ | component of velocity (m/s) |
| $v$ | frontal velocity (m/s) |
| $x_j$ | Cartesian coordinate (m) |
| $z$ | height above the ground (m) |
| $\Delta i$ | difference of enthalpy ($J\ kg^{-1}$) |

*Greek symbols*

| | |
|---|---|
| $\Gamma$ | diffusion coefficient ($kg\ m^{-1}\ s^{-1}$) |
| $\delta_1$ | thickness of tube wall (mm) |
| $\delta_2$ | thickness of fin (mm) |
| $\varepsilon$ | turbulence dissipation rate ($m^2\ s^{-3}$) |
| $\varepsilon_{he}$ | heat exchanger effectiveness |
| $\lambda$ | thermal conductivity ($W\ m^{-1}\ K^{-1}$) |
| $\mu$ | dynamic viscosity ($kg\ m^{-1}\ s^{-1}$) |
| $\mu_t$ | turbulent viscosity ($kg\ m^{-1}\ s^{-1}$) |
| $\rho$ | density ($kg\ m^{-3}$) |
| $\sigma$ | turbulent Prandtl number |
| $\varphi$ | scalar variable |

*Subscripts*

| | |
|---|---|
| a | air |
| b | base |
| B | back |
| c | condenser |
| cd | cooling deltas |
| he | air-cooled heat exchangers |
| hes | heat exchanger sectors |
| i | inlet |
| l | longitudinal direction |
| min | minimum |
| o | outlet |
| ohe | outlet of heat exchangers |
| s | exhausted steam |
| t | tower |
| tr | transverse direction |
| tt | tower throat |
| w | water |

Zhai and Fu [9] investigated the airflow and thermal performance of cooling towers under wind conditions with experimental and numerical approaches. The results indicated that placement of windbreak walls at lateral sides of towers could significantly recover the cooling efficiency by effectively hindering the cross-airflow and forcing the air flowing into the towers. Goodarzi et al. [10] proposed radiator type windbreakers, according to the numerical calculation, radiator type windbreakers improved the cooling efficiency more than solid windbreakers do, because the radiator type windbreakers could use the cooling potential of the blowing wind.

Lu et al. [11–13] studied the performance of small size natural draft dry cooling towers under cross wind condition. The numerical calculation showed that the total transferred heat could decreased by 37% compared with no-crosswind condition. To turn this negative effect into positive, the researchers proposed a tri-blade-like windbreak wall. The experimental and simulation study of the windbreak wall indicated that the cooling tower performance varied with wind speeds was highly sensitive to the wind attack angles. At attack angles of 0° and 60° the cooling performance was improved by the windbreak wall over the entire crosswind speed range investigated, while other attack angles led to unfavorable effects at certain wind speeds.

Zhao et al. [14,15] illustrated the mechanism of performance reduction by means of the air inflow deviation angle. It was found that the flow deflectors improved the cooling performance mainly through increasing the air mass flow rate and decreasing the air inflow deviation degree. According to Ma's [16] research, compared to previous radial walls, windbreak walls could be optimized to be extremely effective by adjusting the settings angles equal to air inflow deviation angles. Chen et al. [17] investigated the impacts of interior and exterior windbreaker configurations and found the exterior windbreakers were superior to the interior ones. Wang et al. [18] recommended an enclosure with an opening at the windward side. It was found that the enclosure could increase the ventilation rate by 36% and decrease the cycling water temperature by 7 °C at wind speed of 20 m/s. Wang's [19] further study showed that the approaches of windbreaks and enclosure could effectively prevent the degradation of the cooling performance for the natural draft dry cooling towers in a wide crosswind velocity range, and their combination could almost eliminate the negative effect of the crosswind.

According to the previous investigations, the windbreak walls and deflectors could improve the performance of cooling towers to some extent, but due to their plate structure [7–10,17], they could have some block effect on the airflows and cause vortexes around them especially for the windbreak walls arranged at lateral sides of cooling towers. Thus, this study recommends a novel air flow deflector with arc curved structure which could further enhance the performance of cooling towers compared with the