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Research paper

# Effects of ambient temperature and crosswind on thermo-flow performance of the tower under energy balance of the indirect dry cooling system

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## HIGHLIGHTS

- Simulation model coupling the dry cooling tower and condenser is established.
- The coupled method is based on energy balance of the indirect dry cooling system.
- Outlet water temperature of the tower is nonlinear with crosswind speed.
- Outlet water temperature of the tower is nearly linear with ambient temperature.
- The coupled method is reliable for predictions under various working conditions.

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## ABSTRACT

The indirect dry cooling system, consisting mainly of the dry cooling tower and condenser, keeps energy balance under stable state. However dry cooling tower is easily influenced by the variation of ambient condition, like ambient temperature and crosswind, and theses unfavorable effects will affect the operation of the condenser directly and further impact unit efficiency. Therefore it is necessary to study the effects of ambient temperature and crosswind on thermo-flow performance of the tower under energy balance of the indirect dry cooling system. Taking a 600 MW indirect dry cooling system as an example, numerical simulation model of the dry cooling tower and thermal calculation model of the condenser are established respectively. With the method coupling the two models, the pressure, temperature fields and streamlines are presented. The indirect dry cooling system regains equilibrium after ambient condition varies, and parameters of the system under this stable state are obtained. These parameters reflect the effects of ambient conditions on the thermo-flow performance of the tower under energy balance of the system rather than under the condition that the tower is viewed as isolated. When the power unit is steady running with a certain load, outlet water temperature of the tower is approximately linear with ambient temperature, whereas nonlinear with crosswind speed. In addition, the computational models and coupled method mentioned in this paper are proved reliable enough for the performance prediction of the tower under energy balance of the indirect dry cooling system, which is beneficial to the economic and safe operation of the unit.



## 1. Introduction

Compared with wet cooling system, indirect dry cooling system can reduce the loss of steam and water caused by evaporation and blow-down and has been widely applied in the area with rich coal and lack of water [1]. Indirect dry cooling system is essentially cooled down by ambient air. Ambient cold air flows across the air-cooled heat exchanger bundles, which are arranged vertically or

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horizontally at the bottom of the dry cooling tower, and absorbs heat emitted from the hot circulating water inside the heat exchanger bundles by indirect contact [2]. The buoyancy originating from the density difference between entering cold air and internal warm air drives upwelling flows inside the tower [3]. As a consequence, thermo-flow performance of the dry cooling tower is easily influenced by environmental factors, such as air temperature and crosswind velocity. That is cooling efficiency of circulating water will be affected by the crosswind velocity and ambient temperature, especially by the large temperature difference between day and night in windy area. These unfavorable effects will further reduce the unit efficiency [4]. Therefore, it is necessary to figure out the variation of thermo-flow performance of the dry cooling tower with ambient condition by coupling the tower and condenser.

There have been a number of studies focusing on the dry cooling tower, which is a typical large-scale object involving fluid and heat flows. Wei et al. [5] experimentally investigated the unfavorable effects of wind on the performance of dry cooling towers and explained that the deterioration of cooling efficiency reduced by wind is because of three reasons, i.e., an unfavorable pressure distribution at the tower entrance, breaking of the plume rising at the tower exit, and cold inflow of cool air induced by leading edge separation. Su et al. [6] obtained fluid flow and temperature distribution in and around a dry cooling tower through numerical simulation with FVM (finite volume method), explained the main reason for deterioration of thermo-flow performance of the dry cooling tower under crosswind. Hooman [7] simplified heat exchanger as porous media, presented scaling laws for the dry cooling tower, and studied the turbulent free convection through the heat exchanger bundles and along the cooling tower, showing a good agreement with numerical simulation. Yang et al. [8] studied the performance of a dry cooling power plant at various wind speeds and in various wind directions by means of numerical simulations. The local hot air penetration at rear or side finned tube bundles was observed at high wind speeds, but the thermo-flow performance of the indirect dry cooling system got improved compared with those at some low wind speeds. Zhai and Fu [9] investigated the influence of wind-break walls arranged inside or around the tower on the performance of a tower in windy condition, showing that wind-break walls at the lateral sides of the tower perpendicular to crosswind can recover about 50% of the reduced cooling capacity. Goodarzi [10] proposed a new oval exit for tower stack by the research of tower shape, showing that an improved tower export plane can reduce the air penetration from the lateral or back sides of the tower and increase the cooling efficiency up to 9% at wind speed of 10 m/s.

In the aforementioned studies, more attentions have been drawn to the effects of crosswind on thermo-flow performance of the dry cooling tower. However, effects of ambient temperature cannot be ignored especially in the area of high latitudes with large temperature difference between day and night. Moreover, indirect dry cooling system consisting of the condenser, dry cooling tower, pump and water pipelines is a closed-loop system where cooling water flows circularly. In different ambient conditions, the inlet water temperature of the tower is obtained by the coupling of the condenser and dry cooling tower rather than set to be constant in the aforementioned studies. Observing the temperature of cooling water, which flows circularly inside the dry cooling system, can help to know the operating state of the system and provide guidance for further operation decision.

In this paper, numerical simulation model of the dry cooling tower and thermal calculation model of the condenser are established respectively, taking a 600 MW indirect dry cooling system as the research object. The method coupling the two models, which is called coupled method in this paper, is analyzed contrastively with the method mentioned in Refs. [6–10], which is named isolated method here. With the coupled method, variations of operation parameters of the indirect dry cooling system are obtained and analyzed under the influence of ambient temperature and crosswind, the pressure, temperature fields and streamlines are presented as well. Moreover, the results calculated by coupled method are verified by practical operation data of the system.

## 2. Mathematical model

Structure schematic diagram of Harmen-type dry cooling system is shown in Fig. 1. Circulating cooling water which coagulates exhaust steam and absorbs heat in condenser is transported to dry cooling tower and cooled down by ambient air. In steady state, the quantity of heat which water absorbs from exhaust steam in condenser is equal to the amount of heat that water rejects to ambient air in the tower. Ignoring the heat loss of water pipelines, the inlet and outlet water temperature of condenser (i.e. $t_{c,wa1}$ and$t_{c,wa2}$) are equal to the outlet and inlet water temperature of tower (i.e. $t_{t,wa2}$ and $t_{t,wa1}$) respectively, and operation parameters of the system keep invariant, like circulating water temperature, condenser pressure, etc. However the fluctuation of ambient

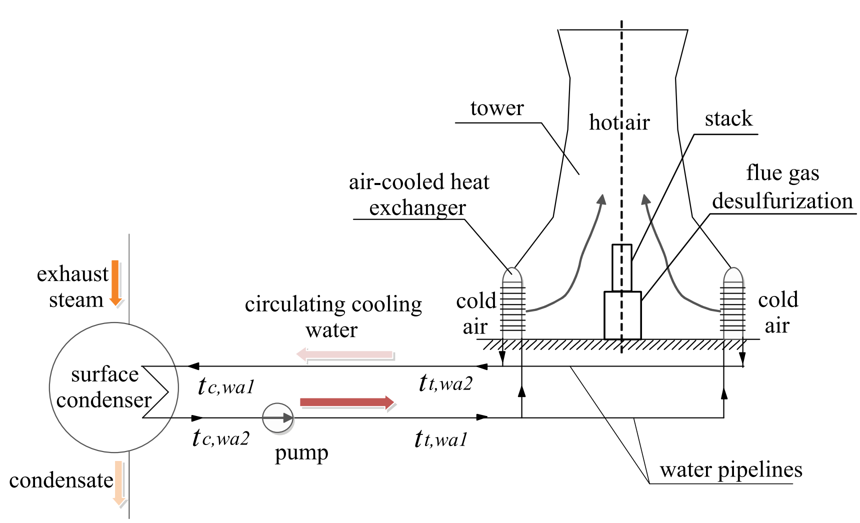


**Fig. 1.** Structure schematic diagram of Harmen-type indirect dry cooling system.