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Effect of Wind on Thermal Performance of Heller Dry Cooling Tower

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Abstract

In a steam power plant, the temperature of the cooling water leaving the condenser for recycling should decrease. This is achieved in a cooling tower. The Heller cooling tower does not require water for operation, thus, it is a suitable system for use in thermal power plants throughout Iran. Wind is an environmental factor that unfavorably affects the performance of a cooling tower. Previous studies have not considered real prevailing conditions appropriately; their conclusions are incomplete and, at times, contradictory. The present field study of the cooling tower at Montazer-Ghaem Power Plant in the city of Karaj in Iran investigated the effect of wind on the thermal performance of the cooling tower. Wind velocity was measured using blade-and-cup type digital anemometers. The direction of the wind around the cooling tower was determined using tufts. Ultrasonic flow meters and resistance thermometers were used to measure the flow rates and temperatures of the water at the inlet and outlet, respectively. Results show that, despite air suction, no separation occurred at the periphery of the cooling tower. The front cooling sectors that face the wind and the back sectors that do not directly face the wind were more thermally efficient. They transferred about 60% more heat than did the cooling sectors parallel to the wind direction at the periphery of the cooling tower. The results also showed that thermal performance in the front and back cooling sectors increased as the wind velocity increased and that in the peripheral sectors decreased.

Keywords: *cooling tower, field measurements, heat transfer, power plant, wind velocity.*

1. Introduction

The water cycle in a steam power plant is closed. The pressure of the steam leaving the turbine must increase before entering the boiler, although increasing the pressure of two-phase flow is difficult and expensive. A better approach is to condense the steam leaving the turbine in a condenser and increase the water pressure using water pumps directed towards the boiler. The function of the cooling tower is to cool the cooling medium (water). Power plant cooling systems can be classified as

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being one-pass cooling, wet cooling or dry cooling systems.

The Heller dry cooling tower does not require water; it is low maintenance and easy to construct, making it suitable for power plant cooling systems. The evaluation of performance of these cooling towers and the parameters affecting their thermal performance is of great importance. Variation in the velocity and direction of wind can either improve or degrade the normal operation of a Heller cooling tower. It is important to determine the extent to which the ambient conditions affect its operation.

Numerical and experimental studies on the thermal performance of Heller cooling towers in the field and in wind tunnels have been reported. Su and Tang [1] used a numerical method to study the thermal behavior of a dry cooling tower under different wind conditions. Their results showed an approximate 30% decrease in heat transfer in the cooling tower.

Mekanic et al. [2] studied the effect of changes in ambient temperature, wind, and the presence of other cooling towers on each Heller cooling tower at Rajaee Power Plant in Qazvin, Iran. The results showed that increasing the ambient temperature decreased the difference in density between the air around the radiators and that at the outlet section of the cooling tower and, consequently, decreased suction. By contrast, decreasing the temperature difference between the ambient air and the air flowing through the radiators decreased heat transfer in the radiators. They observed that wind disturbed the static pressure distribution at the base and outlet section of the cooling tower and decreased the volume of the fluid entering the tower. The presence of other cooling towers facing the wind had a positive effect on the performance of the tower under study.

Ghafari et al. [3] applied a three-dimensional (3D) numerical solution to evaluate the thermal performance of three aligned cooling towers under different wind conditions. Their results indicate that, when the towers were aligned in the direction of the wind, the performance of the cooling towers was better than the performance of an individual cooling tower. This is because each cooling tower falls in line with the next tower, allowing the front cooling tower to act as a windbreak for the succeeding cooling towers. This aligned pattern is most suitable when a low velocity wind blows in line with the towers.

Al-Waked and Behnia [4] used a numerical model and 3D analysis to study the use of internal and external windbreaks and the effect of perforations in the windbreaks on the thermal performance and cooling efficiency of a dry Heller cooling tower. They found that, at wind velocities exceeding 10 m/s, windbreaks increased the thermal performance of the cooling tower by 30%. In addition, the placement of the windbreak was critical to increasing the thermal effectiveness of the cooling tower. At low wind velocities, an external windbreak was more effective than an internal windbreak. At high velocities, an internal windbreak was more effective than an external windbreak. The best thermal performance for a dry cooling tower was achieved with the use of both internal and external windbreaks.

Jahangiri and Golneshan [5] numerically studied Heller dry cooling towers. In their model, exhaust from a combined steam generating system was injected into the tower. The results showed that injection of exhaust into the cooling tower increased heat transfer in a cooling tower operating in winds of about 10 MW. The effects of wind and injection of exhaust into the dry cooling tower was studied and the optimal location for injection of exhaust into the cooling tower for maximum effectiveness was identified.

Wei et al. [6] experimentally investigated the effect of wind on the performance of dry cooling towers at Shanxi Power Plant in China. They found that the cooling efficiency of the towers decreased in response to inadequate pressure distribution at the entrance of the tower radiators and the diminishing stream of exiting hot air. Their field study showed that an increase in wind velocity to 6 m/s produced about a 20% decrease in the internal air velocity of the cooling tower. They also found a 25% increase in temperature behind the radiator at a wind velocity of 6 m/s compared with the no-wind condition. They emphasized that the reason for the decrease in cooling efficiency of the towers at normal wind velocities was the formation of unfavorable pressure turbulence at the tower entrance, choking caused by the difference in momentum between the air exiting the tower and air flow passing over the tower, and flow separation around and inside the cooling tower.

Amur et al. [7] carried out field and experimental (wind tunnel) investigations at Sydney University in Australia and found a positive effect for buildings acting as wind barriers on the power plant premises on the performance of cooling towers. Du Preez and Kröger [8] used field measurements and numerical evaluation to study the effect of wind on the performance of a cooling tower at Kendal Power Plant in South Africa. Their results showed the effect of a change in wind velocity at the tower outlet section on approach, difference between the temperature of cold water leaving the radiators and the wet bulb temperature of air entering the cooling tower for various heat transfer rates in the tower. They observed that an increase in wind velocity significantly increased the approach (the difference in temperature between the cooled-water temperature and the entering-air wet bulb temperature).

Some studies have focused on the adverse effects of wind on the performance of Heller cooling towers; however, no comprehensive solution to alleviate these effects has been proposed. Most studies are numerical and, in many cases, the results seem contradictory. This may be the result of over-simplification and/or erroneous boundary conditions. Some results lack proper validation, which adds to the existing difficulties. The present investigation is a field study of the effect of wind on natural draft dry cooling towers. The results of the investigation can provide a deeper understanding of this natural phenomenon and its adverse effects on the thermal performance of cooling towers, especially for numerical studies.

2. Field Study

The field study was carried out on cooling tower 1 (CT1) at Montazer-Ghaem Power Plant in the city of Karaj in Iran. The power plant has three Heller dry cooling towers. The base diameter of each tower is 72 m and the top diameter is 48 m and the towers are 92 m high (Fig. 1). The volume of water circulating in each cooling tower is 17000 m^3 and there are 12 peak coolers for each cooling tower.

The field measurements were performed during the summer of 2012, primarily in the morning hours. Wind velocity and direction, cooling water inlet and outlet flow rates and temperatures, and air wet bulb and dry bulb temperatures were recorded. Wind velocity was measured using blade-and-cup type digital anemometers and the wind direction around the cooling tower was determined using tufts. Ultrasonic flow meters measured flow rate and resistance thermometers measured temperature. Measurement error in the anemometers was about 0.1 m/s. The wind direction differed daily and ranged from 135º to 225º and 270º to 360º (Fig. 2).

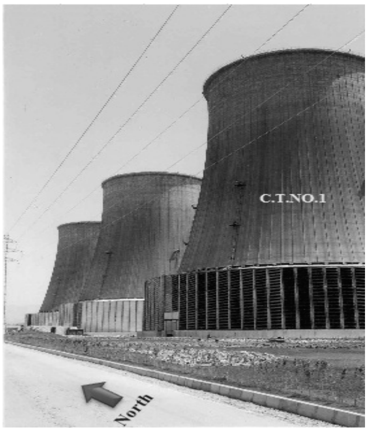


Fig. 1. Cooling towers of Montazer-Ghaem Power Plant

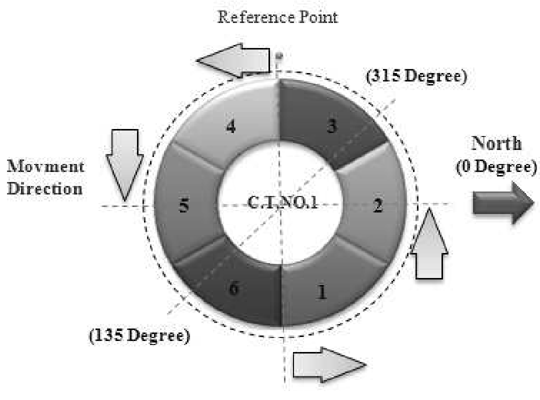


Fig. 2. Positions of reference point, angles moving north (clockwise), and other cooling towers

Figure 2 is a schematic of the cooling tower and the arrangement of the cooling sectors. The total number of deltas was 96, the angle of each delta was 49º, and every 16 deltas form a sector. The total number of cooling sectors in the tower is 6 and every sector occupies 60º of the tower periphery. The effect of wind on the temperature of the cooling water leaving the tower was obtained in these sectors. The movement northward and the reference point, angles and the direction of data measurement around the tower are shown. The reference point for the measurement of wind velocity and direction is 250 m from CT1.

One difficulty in this field study was the large and uncontrolled variation in wind velocity and direction encountered during measurement. This difficulty was alleviated by increasing the number of measurements to enhance measurement accuracy. The tests were carried out over 12 days. Each day had 3 sessions and every session had 12 batches of readings, resulting in a satisfactory overall number of measurements. The uncontrollable nature of the wind velocity increased the possibility of error in the measurements; thus, a Gaussian distribution function was used to normalize and analyze possible error. The averages, means, variance, standard deviations and skewness of the data sets were calculated [9]. The out-of-norm data identified as skewed was omitted to obtain an uncertainty of less than 90%.

3. Results and Discussion

Heat transfer in the heat exchangers of a cooling tower is obtained as [10]:

$$Q = W_a . ITD. \varepsilon \tag{1}$$

where $W_a = \dot{m} \times C_p$ is the heat capacity of air, $\dot{m}$ is the air flow rate, C_p is the specific heat of the air, ITD is the initial temperature difference and is equal to the difference between the hot water and cold air temperatures upon entrance, and ε is the effectiveness coefficient. The effectiveness factor is a function of overall heat transfer coefficient U, heat transfer area A, and pipe arrangement:

$$\varepsilon = f(W_a / W_w, UA/W_a) \tag{2}$$

where W_a / W_w is the ratio of the heat capacities of the air and water.

The effectiveness coefficients for cross-flow non-mixing heat exchangers are identical to the arrangement of the heat exchangers in the Heller dry cooling tower and are calculated as [10]:

$$W_a = W_w \rightarrow \qquad \varepsilon = 1/(1+(\frac{W_a}{UA}) \tag{3a}$$

$$W_a \neq W_w \rightarrow$$

$$\varepsilon = \frac{1 - exp\left[((\frac{W_a}{W_w})-1)(\frac{UA}{W_a})\right]}{1-(\frac{W_a}{W_{w\,w}})\,exp\left[((\frac{W_a}{W_w})-1)(\frac{UA}{W_a})\right]} \tag{3b}$$

These equations show that the rate of heat transfer in the heat exchangers of a cooling tower depend on the ambient and cooling water temperatures and flow rates of the air and cooling water entering the tower. Since the temperature and flow rate of the inlet water to the cooling tower are almost constant, the main parameters that affect the rate of heat transfer are ambient air temperature and flow rate of the air entering the cooling tower.

When the wind blows, air flow around the cooling tower changes and the tangential velocity increases at the corner sectors perpendicular to the wind direction. This decreases air pressure, which consequently decreases air suction at that location. This made it necessary to measure the wind distribution around the cooling tower. Figure 3 shows the changes in tangential velocity measured at a distance of 5 m from sector 1 versus the changes in velocity at the reference point. As shown, the tangential velocity increased significantly as wind velocity increased at the measurement point.

The slope of the curve in Figure 3 shows that the dimensionless velocity, i.e., the ratio of the tangential velocity to the velocity at the reference point, was about 4. Since the wind direction was 330º during measurement, sector 1 can be considered to be a corner sector of the cooling tower, thus, the tangential wind velocity was high in this sector. At low wind velocities and in still air at the reference point, the tangential velocity and suction in this sector was low, as expected, indicating radial velocity in sector 1. Figure 3 was used to obtain Figure 4, which shows variation in the dimensionless tangential velocity around the sectors at distances of 0.5 m and 5 m from CT1.

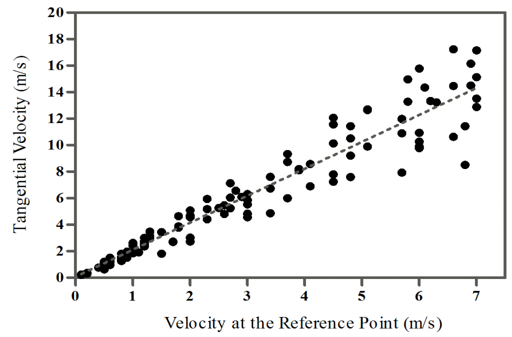


Fig. 3. Tangential velocity at 5 m from sector 1 vs. velocity at the reference point (wind direction: 330º)

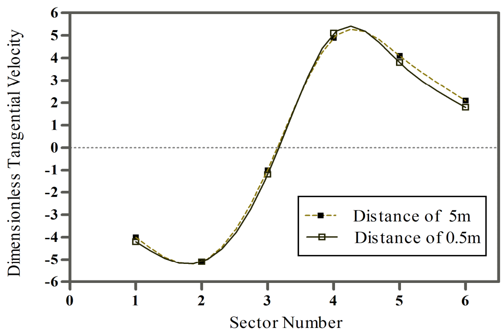


Fig. 4. Dimensionless tangential velocity (tangential velocity/velocity at reference point) at 0.5 m and 5 m from sector 1 (wind direction: 330º)

During measurement, wind direction was visualized using tufts. In Figure 4, the wind direction is denoted by a (-) when clockwise and by (+) when counter-clockwise. It can be seen that air flow was negative in front of sectors 1 and 2 and the tangential velocity is more than four times the reference velocity. In addition, the tangential velocity in front of sectors 4 and 5 was positive and was more than 4 times the reference velocity. The tangential velocity in front of sector 3, which is the sector facing the wind, was very low; the dimensionless velocity at this point was 1. Sector 6 is the sector situated at the back of the cooling tower and recorded lower dimensionless velocity than the other sectors.

Figure 4 indicates that differences in dimensionless velocity at 0.5 m and 5 m from the cooling tower were similar and not large. It can be concluded that no flow separation exists around the tower in response to the air suction caused by the cooling tower. Because conditions were not favorable for flow separation in the boundary layer, the numerical results from previous studies that assumed flow separation should be reconsidered. For wind tunnel testing, a test model constructed without suction will produce erroneous results in response to flow separation.

It is known that air flow rate passing through the cooling tower heat exchangers influences heat transfer. Figure 5 shows the variation in dimensionless air velocity at the back of the radiators. For a wind direction of 330º, the radial velocity at the back of radiators in sector 3 that faces the wind was three times the reference velocity.

Sector 6 lies at the back of the cooling tower (not facing the wind directly), where the radial velocity is high and more than 2.5 times the reference velocity. Sectors 2 and 4 lie perpendicular to the wind direction and are considered to be corner sectors. The tangential air velocity was the highest and the radial velocity at the back of the radiators was the lowest at about 50% of the flow rate of the air entering the cooling tower. These results show that the temperature of the water leaving these sectors was the highest of all cooling sectors in the tower.

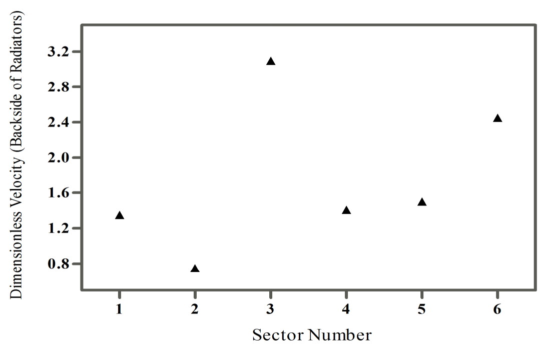


Fig. 5. Dimensionless velocity in back of radiators (wind direction: 330º)

Figures 6 and 7 show the difference in the inlet and outlet temperatures of the cooling water for sectors 1 and 3 of CT1 at reference wind velocities exceeding and lower than 1 m/s, respectively, and constant ambient temperature. As shown, sector 3 facing the wind showed the highest temperature difference and better thermal performance. The worst thermal performance (the lowest temperature difference) was recorded for sector 1. Figure 6 shows that the thermal performance of sector 1 deteriorated as the reference wind velocity exceeded 1 m/s, resulting in a decrease in the temperature difference.

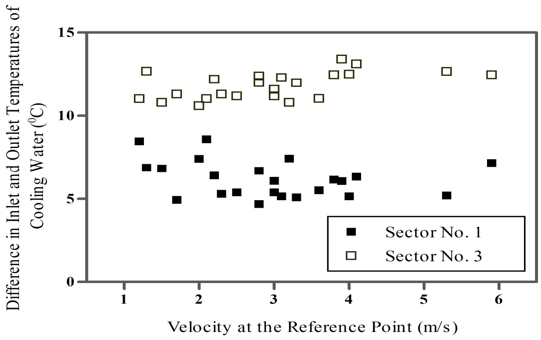


Fig. 6. Difference in inlet and outlet temperatures of cooling water for sectors 1 and 3 (CT1), for wind velocities exceeding 1 m/s at the reference point (wind direction: 330º)

Sector 3, which faces the wind direction, showed an increased rate of flow for entering air. Thermal performance increased as the reference wind velocity increased. At velocities of <1 m/s, a nearly symmetrical air flow condition prevailed around the cooling tower and there was no significant temperature difference between sectors 1 and 3.

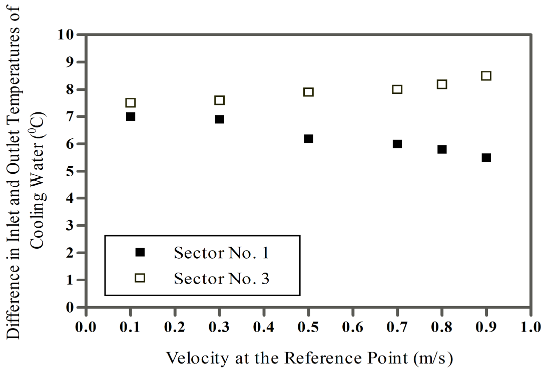
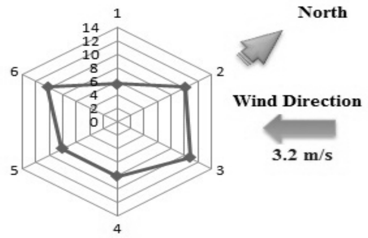
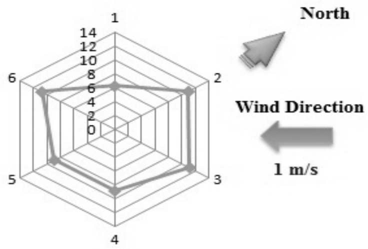


Fig. 7. Difference in inlet and outlet temperatures of cooling water for sectors 1 and 3 at wind velocities <1 m/s at the reference point (wind direction: 330º)

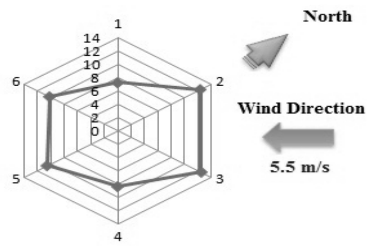
Figure 8 shows wind velocities exceeding 1 m/s and the effect of wind on the inlet and outlet temperatures of each sector assuming constant ambient temperature. The sectors directly facing the wind and situated at the back of the cooling tower showed better thermal performance with a sizeable difference in temperature. The corner sectors showed lower thermal performance and a smaller difference in temperature. The temperature difference for the sector facing the wind increased as the wind velocity increased; the temperature difference of the corner sectors decreased as the wind velocity increased.



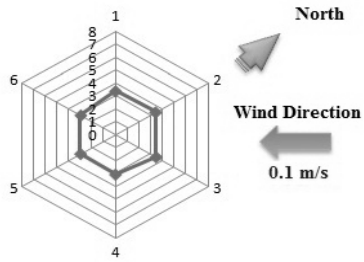
(a)



(b)



(c)



(d)

Fig. 8. Difference in inlet and outlet temperatures for all sectors at wind velocities of (a) 3.2 m/s; (b) 1 m/s; (c) 5.5 m/s; and (d) still air (wind direction: 330º)

The thermal performance of the sector at the back of the cooling tower fell between that of the sector facing the wind and the other sectors. Figure 8 shows that maximum heat transfer occurred in sector 3, the sector facing the wind at a wind velocity of 5.5 m/s.

Figure 8(d) shows the difference in inlet and outlet temperatures for each sector in still air (wind velocity ≤1 m/s). Symmetrical air flow exists around the tower and the temperature difference in each sector is lower than that for the same sector under windy conditions. Figure 8 shows that the maximum heat transfer in both windy conditions (330º wind direction) and still conditions occurs in sector 3.

Figure 9 depicts heat transfer in various sectors expressed as percentage of heat transfer in sector 3 for still air and at a wind velocity of 5.5 m/s (wind direction: 330º). As shown, the heat transfer in sector 1 is 60% lower than that of sector 3 under the same wind conditions, which is significant and affects the thermal performance of the cooling tower. In still air, heat transfer decreased by about 50% compared to heat transfer at a wind velocity of 5.5 m/s, which indicates a significant decrease in the performance of the tower in still air.

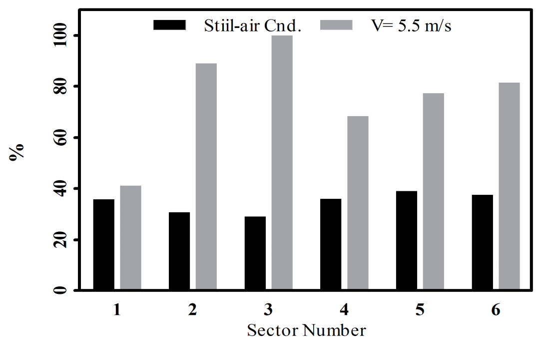


Fig. 9. Heat transfer by sector expressed as percentage of heat transfer in sector 3 for still air and at a wind velocity of 5.5 m/s (wind direction: 330º)

4. Conclusions

The following conclusions can be drawn from this field study:

- Large uncontrollable variations in environmental conditions made the field study difficult. The large dimensions of the cooling tower made measurements difficult and increased the likelihood of error. The best method to decrease error and increase measurement accuracy is to increase the number of measurements (i.e., data points) and perform statistical analysis of the data.
- The study of the air flow pattern around the cooling tower at different distances from it indicated that the tangential velocity of the air in the corner sectors (perpendicular to the direction of wind) was more than four times the wind velocity at the reference point. This increase in the wind velocity decreased air pressure and the air suction in this section.
- The tangential velocity was measured at 0.5 and 5 m. It showed that no flow separation occurred for air flow on the periphery of the tower. Results of previous numerical and experimental studies that have reported the occurrence of flow separation should be reexamined in light of this finding. To ensure correct results from wind tunnel studies, a suction fan should be included in the test model.
- Measurement of air flow velocity at the radiator outlets showed that sections with maximum tangential velocity experienced the lowest exit velocity at the back of the radiators. Maximum wind velocity occurred at the back of the radiators in sectors that directly faced the wind; this was about three times the wind velocity at the reference point.
- Under windy conditions at reference velocities exceeding 2 m/s, the difference between the temperatures of the inlet and outlet cooling water showed that the sector directly facing the wind was about twice that of the corner sectors. For still air conditions, symmetry prevailed for all the sectors.
- The difference between the temperatures of the inlet and outlet cooling water from the corner sectors decreased as the velocity at the reference point increased. For the sector directly facing the wind, this difference increased. Further observation of this phenomenon is necessary to obtain the actual flow pattern inside the deltas.

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