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RESEARCH NOTE

Study of Degradation of Dry Cooling Tower Performance under Wind Conditions and Method for Tower Efficiency Enhancement

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ABSTRACT

Wind can adversely affect the thermal performance of a dry cooling tower. In this field study, performance of Heller cooling tower and the use of guide vanes cascade at the intakes of the periphery cooling sectors, which are parallel to the wind direction and have inadequate thermal performance, for enhancement of the cooling tower performance under wind conditions were investigated. Wind velocity around the cooling tower and water flow rates and temperatures at the cooling tower inlet and outlet were measured. It was observed that the air suction through the tower prevented the flow separation at the radiators locations on the tower periphery. Moreover, with increase in wind velocity, the performance of sectors parallel to the wind direction on the tower periphery and those at the back of the tower deteriorated. However, the better airflow distribution over the wind facing cooling sectors resulted in about 20% increase in the thermal efficiency of these sectors with increased wind velocity. Results further showed that the installation of guide vanes cascade caused more uniform temperatures on the surface of the tower radiators and reduced their temperature by 2 ºC, which was translated into 7% enhancement in the thermal performance of the cooling tower.

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NOMENCLATURE

A	Heat transfer area (m^2)	W	Heat capacity (J/K)
C_p	Specific heat (J/kg K)	**Greek Symbols**	
ITD	Initial temperature difference (K)	ε	Effectiveness coefficient
$m^\bullet$	Flow rate (kg/s)	**Subscripts**	
T	Temperature (K)	a	Air
U	Overall heat transfer coefficient (W/m^{2}K)	in	Inlet
Q	Heat transfer (kW)	ref	Reference
V	Wind velocity (m/s)	w	Water

1. INTRODUCTION

Air is the cooling medium in a dry cooling tower such as Heller cooling tower. The thermal performance of such cooling towers is sensitive to variations in environmental conditions such as wind velocity and direction, which can have detrimental effects on the cooling tower performance. Hence, the study of such factors is of great importance, both for the improvement of the existing cooling towers, and the design of new cooling towers with enhanced thermal performance.

Su and Tang [1] used numerical method to investigate the thermal behavior of a dry cooling tower under blowing wind conditions. Their results showed a reduction of about 30% in heat transfer in the cooling tower.

A more realistic scenario was investigated by Fu and Zhai [2], who used numerical method to study the effect of cross-wind on two in-line dry cooling towers. The two-in-line tower configuration exhibited different airflow and heat transfer patterns than the single configuration, especially, when the wind velocity was larger than 10 m/s. However, the latter study verified

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that the wind-induced around-flow destroys the radial inflow into the cooling towers, and thus, significantly deteriorates the heat transfer performance at lateral sides. Fu and Zhai proposed use of wind-break walls to break the around-airflow at both sides of towers and force the surrounding air to enter the towers, resulting in improvement in the performance of cooling towers. Using a wind tunnel, Bender et al. [3] investigated the application of wind-break walls for balancing the rate of airflow into the cooling tower intakes with the aim of preventing the formation of ice caused by cold and windy weather. In another study, Al-Waked and Behnia [4] applied numerical method and three- dimensional analysis to investigate the use of internal and external wind-break walls and the effect of perforations in the wind-break walls on the thermal performance and cooling efficiency of dry Heller cooling tower. Their results showed that for wind velocities exceeding 10 m/s, the use of wind-break wall would increase the thermal performance of the cooling tower by 30%. Additionally, the location of the wind-break walls plays an important role in the improvement of thermal performance of the cooling tower. At low wind velocities, installation of an external wind-break wall would be more effective than using an internal wind-break wall. However, at high wind velocities, an internal wind-break wall would be a better choice. Al-Waked and Behnia concluded that the best thermal performance for a dry cooling tower would be achieved with the simultaneous use of internal and external wind-break walls. Wei et al. [5] investigated the effect of wind conditions on the thermal performance of dry cooling towers at Shanxi Power Plant (China). Their results showed that an increase in wind velocity to 6 m/s produced about 20% reduction in the air speed inside the cooling tower. They attributed the reduced cooling performance to the formation of unfavorable pressure turbulence at the tower entrance, chocking due to momentum difference between the air exiting the tower and flow over the tower, and finally flow separation around and inside the cooling tower.

Amur et al. [6] used field and experimental (wind tunnel) investigations to show the positive effect of buildings, acting as wind barriers in a power plant premises, on the performance of the cooling towers. Moreover, they applied numerical method to model the wind effects on cooling towers. They noticed that the tower thermal performance was reduced when the wind was obstructed by another cooling tower.

Ardekani and Ranjbar [7] showed that under cross wind conditions, acceleration of wind at the tower periphery and the inadequate flow pattern through the peripheral cooling sectors due to the semi vortex flow conditions reduce the airflow rate through the sectors, which deteriorates the thermal performance of peripheral cooling sectors. In another study, Ardekani et al. [8] showed that the rate of heat transfer in the deltas in sectors facing the wind is about 20% higher than the deltas in peripheral sectors. Kumar and Pant [9] studies the behavior of steady flow of visco-elastic fluid between two porous coaxial circular cylinders, which is similar to the flow between the cooling towers. Also, the investigation deals with high order suction parameter. Higher Reynolds numbers, visco-elastic parameters and suction parameter have also been considered in the study. A numerical approach has been used to demonstrate out the results and present them graphically. Moreover, the wake flow behind a circular cylinder and heat transfer in that previously been investigated by Heidarnejad and Delfani [10] and Mirzaee et al. [11]. Different methods and remedies such as change in cooling tower geometry, use of wind breaker walls, and smoke injection have been recommended for performance improvement of cooling towers. Madadnia et al. [12] studied the effect of wind breaker walls on the performance of cooling towers using wind tunnel experiments. Their results showed that wind breaker walls can enhance cooling tower efficiency by about 33%.

Eldredge et al. [13] used finite element method to study the effect of gas injection on the efficiency of cooling towers. They studied five factors, namely gas flow rate, gas temperature, position and injection angle, and the type of injected gas. They observed that the temperature of the injected gas, which greatly increases the bouncy effect in the tower, is the most influencing factor in the cooling tower efficiency.

Wang et al. [14] constructed an experimental model, consisting of plates arranged at various angles around the model, to investigate the effect of guide channels on the thermal performance of cooling towers under lateral wind conditions. Their results showed that air mass flow rate increased significantly, resulting in improved tower efficiency. The first objective of the present investigation was to carry out a comprehensive field study to evaluate the effects of wind on the thermal performance of a natural draft dry cooling tower (NDDCT) in a power plant. The second objective was to investigate the use of a guide vanes cascade as a means of improvement of the performance of periphery cooling sectors. In this study, wind velocities around the cooling tower and water flow rates and temperatures at the cooling tower inlet and outlet were measured. Based on these measurements, the thermal performance of the cooling sectors, before and after the installation of the guide vanes cascade, was determined under wind conditions.

2. FULL SCALE MEASUREMENT

The present study was carried out at the site of

Montazer Ghaem Power Plant (Karaj, Iran), which uses three Heller dry cooling towers for its operation. Accordingly, cooling tower No. 1 (C.T.No.1) was selected for this investigation.

Figure 1 shows the schematic of the cooling tower No. 1 and the arrangement of the cooling sectors (No. 1 to 6). The wind velocity was measured at a reference point, located at a height of 15 m far from the cooling tower. The field measurements were performed during the 2012 to 2014 summers, mostly in the morning hours. Wind velocity was measured using blade and cup types of digital anemometers (TERMINATOR TAM 618, LUTRON AM-4220, respectively), and wind direction around the cooling tower was visualized using tufts. Measurement errors associated with the anemometers is about 0.1 m/s.

A four-vane cascade of 3 m height, 1 m radius with 0.5 m distance between the vanes was fabricated, as shown in Figure 2. The vanes cascade was installed at the center of Sector 2 (one of the periphery sectors). Performance of radiators was evaluated using thermal image photography and measurement of water temperatures at the sectors inlets and outlets. One of the difficulties encountered during the field measurements pertained to the large and uncontrolled variations in the wind velocity and direction.

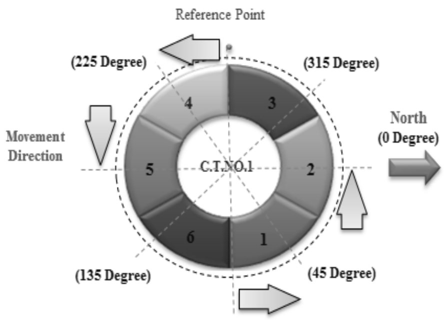

Figure 1. Position of the reference point, angles measured (clockwise) from the North direction and the cooling tower sectors (No. 1 to 6)

Figure 2. The guide vanes cascade installed in the cooling tower at Montazer Ghaem Power Plant

Increasing the number of measurement data was considered to be a practical way to alleviate this difficulty and enhance measurements accuracy. Consequently, Gauss distribution function was used to normalize and analyze the possible measurement errors due to the uncontrollable wind conditions. For each set of data, average, mean, variance, standard deviation and skewness were calculated [15]. Based on the skewness data, the erroneous data was omitted to obtain a confidence interval of 95%.

3. RESULTS AND DISCUSSIONS

The amount of transferred heat in the heat exchangers of a cooling tower is obtained as [16]:

$$Q = W_a \, (ITD) \, \varepsilon \tag{1}$$

where, W_a is the heat capacity of air, ITD is the initial temperature difference, which is the difference between the inlet temperature of the hot water and the cooling air temperature, and ε is the effectiveness coefficient. The effectiveness coefficient is function of the overall heat transfer coefficient, U, heat transfer area, A, and water pipes configuration and 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 air and water.

The effectiveness coefficient for cross flow non-mixing heat exchangers, which are identical to the arrangement of heat exchangers in the Heller dry cooling tower, is given by [16]:

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

$$W_a \neq W_w \rightarrow \; \varepsilon = \frac{1-\exp[((W_a/W_w)-1)(UA/W_a)]}{1-(W_a/W_w)\exp[((W_a/W_w)-1)(UA/W_a)]} \tag{3.b}$$

These equations show that the rate of heat transfer in the cooling tower heat exchangers depends on the ambient and water temperatures and flow rates of the cooling air and the inlet water to the cooling tower. In the present study, during the course of the experiments, temperature and flow rate of the cooling tower inlet water remained almost constant $(T_{w,in} \approx 333\text{K}, \dot{m}_w \approx 4\text{kg/s})$. Therefore, the main parameters that affected the rate of heat transfer in the cooling tower were the ambient temperature and the flow rate of the air entering the cooling tower. Under wind conditions, flow of air around the cooling tower changes and the tangential velocity increases at the peripheral sectors, parallel to the wind direction. This reduces the pressure, resulting in reduced air suction at that location. Therefore, it is necessary to measure wind distribution around the cooling tower.

Figure 3 shows variations around the sectors at 0.5m and 5m from cooling tower No. 1 (wind direction 300º). Accordingly, the tangential wind direction has been indicated by a (+), if counterclockwise, and by (-), if clockwise. As shown in this figure, in front of Sector No. 1, the tangential velocity is four times the velocity at the reference point.

The tangential velocity in front of Sector No. 4 is indicated by a (+) and is more than four times the velocity at the reference point. Also, the tangential velocity in front of Sectors No. 3, which is the wind facing sector, is very low; the dimensionless velocity at this point being approximately unity. Additionally, in case of the sectors situated at the back of the cooling tower, namely Sectors No. 5 and No. 6, the dimensionless velocity is quite low compared to the other sectors.

As shown in Figure 3, the dimensionless velocities at 0.5m and 5m from the cooling tower are almost identical. Therefore, it can be concluded that no flow separation occurs around the tower, which is due to the suction of air through the cooling tower.

Figure 4 shows the non-dimensional heat transfer ($Q/Q_{still\ air}$) in different sectors for reference velocities 1, 3.2 and 5.5 m/s and still air condition (no-wind condition). As expected, the thermal performance of wind facing sectors improves with increased wind velocity at the reference point: for example at 5.5 m/s, the thermal performance improves by 25% compared to the still air conditions. On the contrary, for peripheral sectors, thermal performance decreases significantly with increase in wind velocity at the reference point: for example at 5.5 m/s the thermal performance of peripheral sector 1 decreases by about 50%.

Although thermal performance of the wind facing sectors improves with increased wind velocity at the reference point, the significant reduction in the thermal performance of the peripheral sectors by far outweighs this improvement.

Therefore, it may be concluded that the effect of wind conditions on the cooling tower is to degrade its overall thermal performance. The effect of wind conditions on the overall thermal performance of the cooling tower is depicted in Figure 5. As shown, at wind velocity of 5.5 m/s the overall thermal performance decreases by 25%, which is very significant.

Under wind conditions, as the result of the inadequate flow pattern through the peripheral cooling sectors, some sections of the radiators remain practically deprived of any air flow. Moreover, semi vortex currents are formed in these sections. These adverse effects cause an unwanted degradation in the overall efficiency of the cooling tower.

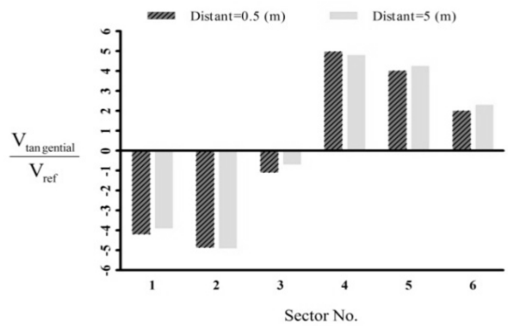

Figure 3. Variations in the dimensionless tangential velocity, measured at 0.5m and 5m from C.T.No.1

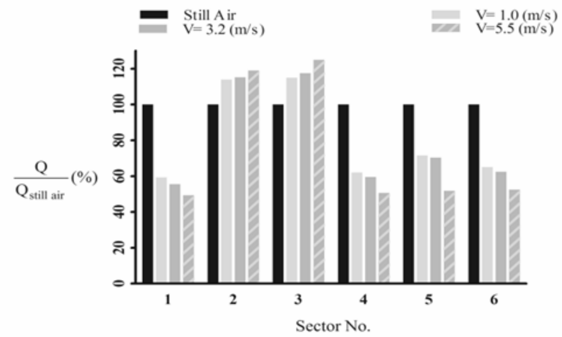

Figure 4. Non-dimensional heat transfer in different sectors, various reference velocitys, still air condition

Consequently, to reduce the wind conditions effects, a guide vanes cascade was installed at the intakes of the periphery cooling sectors, which are parallel to the wind direction (see Figure 2). The use of guide vanes cascade resulted in the turning of the airflow in a direction perpendicular to the radiators in the periphery sectors, which increased the airflow rate through these sectors and improved the performance of these sectors. In other words, the guide vanes were used to enhance the thermal performance of the peripheral sectors under wind conditions, at par with the more efficient wind facing cooling sectors.

In order to evaluate the effect of the guide vanes cascade on the thermal performance of cooling tower, a thermal imaging camera (TESTO 882) was used to obtain thermal images of the radiators in the specific delta, before and after the installation of guide vanes cascade. Temperatures of the radiator surfaces were then determined. As shown in Figure 6, compared to the temperature distribution on the radiators before the installation of the guide vanes cascade, the guide vanes cascade resulted in a more uniform temperature distribution on the radiators, reducing the mean value by about 2 ºC, equivalent to the reduction in the water temperature leaving the radiators. Therefore, it may be concluded that the use of the guide vanes cascade has resulted in an improved flow pattern through the radiators, which improves their thermal performance.

A comparison of non-dimensional heat transfer in radiators delta in the critical peripheral cooling sectors, with and without guide vanes, at different wind velocities at the reference point is shown in Figure 7.

Assuming that the guide vanes were installed at the entrance of the deltas in all the peripheral sectors, comparison of the results for the still air and wind conditions showed that the use of the guide vanes enhanced the thermal performance of the radiators under increased wind velocity, the improvement being about 20% at 5.5 m/s. On the other hand, results for the wind conditions showed that with the increase in wind velocity, the guide vanes became more effective in improving the thermal performance of the radiators. For example, performance improvement at 3.2 m/s was about 55.7%, while at 5.5 m/s this improvement was about 69.5%, which is very significant (with and without guide vanes).

Figure 8 shows the cooling tower overall non-dimensional heat transfer with and without guide vanes. As shown, when guide vanes were used, the heat transfer was increase in wind velocity at the reference point to 5.5 m/s, significantly. The heat transfer was about 7% more than the still air condition, which results in increased efficiency of the cooling tower, and hence, the steam section of the power plant.

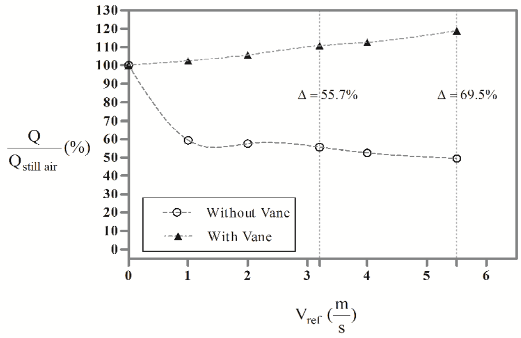

Figure 7. Non-dimensional heat transfer in radiators delta in the peripheral sectors, with and without guide vanes

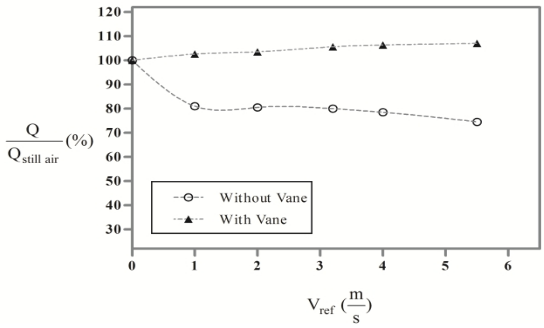

Figure 8. The cooling tower overall non-dimensional heat transfer with and without guide vanes

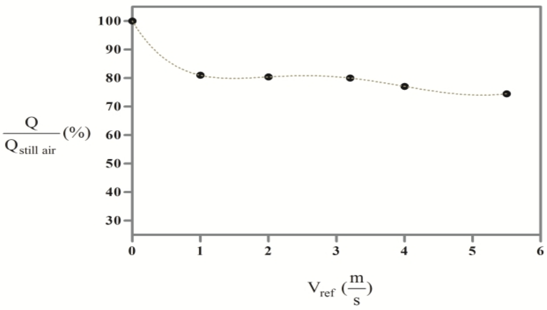

Figure 5. Effect of wind conditions on the overall thermal performance of the cooling tower

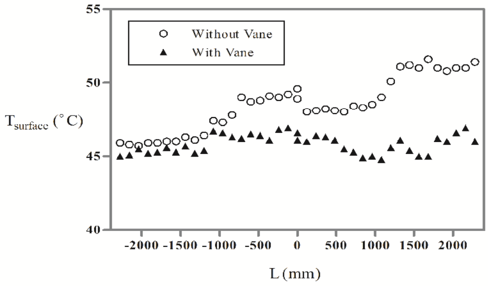

Figure 6. Temperatures at various points on the radiators delta in the peripheral sectors, with and without guide vanes

6. CONCLUSIONS

Conclusions of this field study are as follows:

1- Study of the airflow pattern around the cooling tower at different distances from the tower shows that the wind tangential velocity at the corner sectors is more than four times the wind velocity at the reference point. The increased tangential velocity reduces the air pressure, resulting in the degradation of the air suction at this section.

2- Measurement of tangential velocity at different distances from the cooling tower (at 0.5m and 5m) showed that flow separation does not occur at the periphery of the cooling tower.

3- Under wind conditions, consideration of the difference between the inlet and outlet water temperatures in wind facing sectors and the peripheral sectors showed that the temperature difference for the wind facing sector was about twice that of the peripheral sectors. However, for still-air conditions, symmetry prevailed for all the sectors in the cooling tower.

4- The difference between the inlet and outlet water temperatures in the peripheral sectors decreased with increase in the velocity at the reference point, while for the wind facing sector, this difference was increased. However, to ascertain this observation further, it is necessary to carry out more studies to obtain the actual flow pattern inside the deltas.

5- In general, the use of a guide vanes cascade resulted in considerable improvement in the performance of a delta in a critical sector of the cooling tower, approaching the performance of the wind facing sectors.

6- When using guide vanes cascade, temperature distribution on the radiators surface in the critical delta was uniform and its average value decreased. For example, the average temperature distribution reduced by 1.9 ºC for the reference point wind velocity of 3 m/s.

7- Using the guide vanes cascade, as a practical means, resulted in enhancement of the thermal performance of the cooling tower. The installed guide vanes produced a more uniform temperature distribution on the radiators in the peripheral sectors, reducing the temperature of the radiators by about 2 ºC.

8- The 2 ºC reduction in the temperature of the radiators resulted in 20% improvement in the performance of the peripheral sectors, and about 7% enhancement in the overall performance of the cooling tower compared to the still air condition.

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چکید

وزش باد تاثیر نامطلوبی بر عملکرد حرارتی برجهای خنک کن خشک دارد. در این تحقیق، یک مطالعه میدانی بر روی عملکرد حرارتی برجهای خنک کن خشک هلر و تاثیر بکارگیری پره های راهنما در ورودی رادیاتورهای سکتورهای مماس با باد تحت شرایط مختلف وزش باد انجام گرفته است. سرعت وزش باد در اطراف برج خنک کن و دبی و دمای آب ورودی و خروجی از برج اندازه گیری شده است. نتایج بدست آمده نشان می دهد که مکش هوا توسط برج مانع از وقوع پدیده جدایش در اطراف برج در قسمت قرارگرفتن رادیاتورها می گردد. بعلاوه، نتایج نشان می دهد که راندمان رادیاتورهای قرار گرفته در سمت رو به باد، با افزایش سرعت باد افزایشی حدود ۲۰٪ را تجربه می کنند، حال آنکه راندمان رادیاتورهای قرار گرفته در کناره های برج، که مماس بر جهت وزش باد هستند و همچنین رادیاتورهای پشت به باد که در قسمت پشت برج قرار گرفته اند، کاهش می یابد. نتایج همچنین نشان می دهد که پره های نصب شده دمای سطح رادیاتورها را یکنواخت تر نموده و سبب کاهش ۲ درجه سلسیوس در دمای آنها شده اند که باعث افزایش ۷ درصدی در عملکرد حرارتی برج می شود.

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